State of California
AIR RESOURCES BOARD

# STAFF REPORT

# PUBLIC HEARING TO CONSIDER ADOPTION OF EMISSION STANDARDS AND TEST PROCEDURES FOR NEW 2001 AND LATER OFF-ROAD LARGE SPARK-IGNITION ENGINES

Date of Release: September 4, 1998
Scheduled for Consideration: October 22, 1998
Agenda Item No.: 98- -

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## I. INTRODUCTION

The California Clean Air Act (CCAA) as codified in the Health and Safety Code Sections 43013 and 43018 grants the Air Resources Board (ARB) authority to regulate off-road mobile sources of emissions. These mobile sources include, but are not limited to marine vessels, locomotives, utility engines, off-road motorcycles, and off-highway vehicles. Off-road large spark-ignition engines are a subcategory of off-road engines subject to ARB regulation.

Typical applications for off-road large spark-ignition engines include specialty vehicles, forklifts, portable generators, large turf care equipment, irrigation pumps, welders, air compressors, scrubber/sweepers, airport service vehicles, and a wide array of other agricultural, construction and general industrial equipment. The engines used in these equipment often are derived from automobile engines, though they tend to use less sophisticated fuel and emission control systems. Most commonly, engines in this category are fueled by gasoline or liquefied petroleum gas (LPG). They are typically liquid-cooled engines, but some air-cooled engines remain in use. Similarly, most engines, particularly those derived from automobile engines, tend to use overhead-valve designs, although some use the mechanically simpler side-valve design.

ARB staff believes that emissions from these engines can be reduced significantly, through use of common automotive emissions control technologies such as exhaust gas recirculation (EGR), closed-loop fuel control systems, and three-way catalytic converters. The proposal described herein establishes emission standards for new off-road large spark-ignition engines (over 25 hp) and accompanying compliance procedures, which are based on the use of these or other effective emission control technologies.

## II. BACKGROUND

In November 1994, the ARB approved the State Implementation Plan (SIP) for ozone which outlines the measures to be taken to bring the state’s air quality into attainment with federal ambient air quality standards for ozone. During the SIP’s development, it became clear that reducing emissions of oxides of nitrogen (NOx) and reactive organic gases (ROG) from off-road engines and equipment operating within the state is imperative for cleaning California's air. The SIP identified several categories of off-road equipment where significant emissions reduction opportunities exist, including spark-ignition engines of 25 through 175 horsepower used in industrial equipment. The lower limit of 25 horsepower is defined by the upper boundary of the small off-road engine category; hence, no engine would be subject to multiple requirements. The 175 horsepower rating was originally noted because the greater part of off-road spark-ignition engines, and the emissions therefrom, is below that rating. However, the staff's proposal includes engines greater than 175 horsepower because those engines and equipment are very similar in design and use to those in the 25 to 175 horsepower range and they are not currently covered by other regulatory requirements.

The federal Clean Air Act Amendments of 1990 preempt California control of emissions from farm and construction equipment under 175 horsepower. Because of this preemption, significant emissions from the subject engine category are beyond ARB's authority to regulate. Thus, since only the United States Environmental Protection Agency (U.S. EPA) has authority to establish emission standards for these preempt engines, the ARB staff has worked closely with U.S. EPA toward the development of a nationwide federal rule to cover all engines in this category. This federal rule would then serve to regulate emissions from farm and construction equipment in California in the absence of ARB's authority to do so. The federal rule and California's regulations, if adopted, will be harmonized as much as possible to minimize any confusion and expenses that could result from significantly different state and federal requirements for non-preempt engines. Thus, the staff proposal contained herein will address the state's obligations under SIP measure M11, while the corresponding federal action, when finalized will address the obligations of M12.

Since the adoption of the 1994 SIP, the emissions inventory for large, spark-ignited engines has been updated. It was originally estimated that preempt engines were responsible for contributing approximately half of the category's combined hydrocarbon (HC) and oxides of nitrogen (NOx) emissions. Based on current information, it is now estimated that preempt engines are responsible for contributing approximately 12 percent of the HC+NOx emissions. The 1994 SIP inventory also underestimated the number of LPG-fueled equipment compared to the updated population. Finally, new test data show the relative proportions of HC and NOx emissions has changed. While the previous estimate had been that HC comprised 60 percent of the total ozone precursor emissions and NOx 40 percent, the latest data indicate that only 20 percent of the total ozone precursors are HC; the remaining 80 percent are NOx.

The proposal contained herein addresses the California (M11) portion of the SIP. However, it represents the collective effort of the ARB and the U.S. EPA working together to develop a harmonized national program. The U.S. EPA is expected to promulgate its portion, M12, shortly. The U.S. EPA expects to publish an Advance Notice of Proposed Rulemaking by early 1999, with a Notice of Proposed Rulemaking to follow in late 1999. The final rule is expected to be published within a year of that.

SIP Measures M11 and M12 were developed in 1994 from the assumption that manufacturers would be able to use closed-loop, three-way catalysts that would result in reducing the large spark-ignition engine HC inventory by 75 percent, and the large spark-ignition engine NOx inventory by 50 percent. Significant work has been done to approach those levels, and the staff believes that those levels are achievable. However, M11 and M12 as presented in the SIP did not address the issue of emissions deterioration. Deterioration of these engines over their useful life can lead to significant emissions increases; therefore, the staff has included a provision to ensure that engines are "emissions durable," i.e., controlled throughout their useful life.

## III. SUMMARY OF STAFF RECOMMENDATION

The ARB staff has met with various entities regarding the large spark-ignition engine proposal. The staff, with the U.S. EPA, held industry meetings in November 1997, March 1998, and July 1998. A general public workshop took place on May 19, 1998. The staff also met with engine manufacturers, trade associations, emission control manufacturers and developers, fuel system suppliers, environmental organizations and other interested parties in numerous individual meetings and conference calls. Staff's meetings with manufacturers have indicated that the technological foundation of SIP measures M11 and M12 is sound; the staff therefore has developed emission standards that will reflect the implementation of closed-loop, three-way catalyst systems on large spark-ignition engines.

The regulatory text of the staff proposal is contained in Attachment A, and the emissions test procedures (Parts I and II) are contained in Attachment B. The proposal is intended to achieve significant emissions reductions while providing industry with flexibility in compliance. The effect of the proposal and the improved emissions inventory on the SIP obligations is discussed in detail in Section IV of this report. The proposed regulations are described below.

A. Applicability

The proposal would apply to off-road spark-ignition engines 25 horsepower or above, with some exceptions. For example, the proposal would exclude construction and farm equipment engines below 175 horsepower, consistent with the 1990 Clean Air Act Amendments' preemption of state authority, and the U.S. EPA's subsequent implementation of that provision. Staff has updated the preemption list to exclude forklifts greater than 50 horsepower. The basis for the change is discussed in Section IV of this report. (Attachment C has a list of preempted equipment.) Note that the preempted equipment would be subject to the national regulation which the U.S. EPA is developing concurrently with this proposal.

The other exceptions consist of a number of sub-categories that have been or will be regulated separately: off-road motorcycles, all-terrain vehicles, snowmobiles, and engines used to propel marine vessels or personal watercraft. These applications are sufficiently different in use and purpose to warrant separate consideration.

B. Emissions Standards

ARB staff has developed numerical standards (shown in Table 1) for NMHC+NOx emissions based primarily on what is achievable with automotive-derived technologies. The staff proposes to institute new or "zero-hour" engine emissions standards beginning with the 2001 model year. Staff anticipates that manufacturers will use three-way catalysts with closed-loop controls to meet those standards. The proposal would result in a reduction of up to 90 percent from current uncontrolled levels. The proposed combination of NMHC plus NOx standards provides industry with flexibility regarding the technology used for compliance. Staff has based the proposed CO standard on current levels for on-road heavy-duty trucks powered by gasoline.

Beginning with 2004 models, the same numerical emission standards would apply throughout the engine's useful life. The delay in applying the useful life standards until 2004 models allows engine manufacturers ample lead time to stabilize their engine and emission control technology designs.

Table 1

Proposed
Emissions Standards

| Year | Engine Size | Standards (g/bhp-hr) | | Useful Life |
|---|---|---|---|---|
| | | NMHC+NOx | CO | |
| Tier 1 2001-2003 (Phase-in) | < 1.0 liter | 5.0 | 37 | N/A |
| | 1.0 liter and greater | 3.0 | 37 | N/A |
| Tier 2 2004 and later | < 1.0 liter | 5.0 | 37 | 3000 hours or 5 years |
| | 1.0 liter and greater | 3.0 | 37 | 5000 hours or 7 years |

Note that separate NMHC+NOx emissions standards are proposed, based on engine displacement. Specifically, a division is proposed between small and large engines at 1.0 liter. This division is intended to separate those engines that are typically derived from automotive engines from those that are not.

1. Engines Below One Liter

Many of the engines below one liter in displacement share many characteristics with the larger of the small off-road engines below 25 horsepower, as opposed to the engines greater than one liter, which tend to be derived from automotive engines. Thus, the technology that is most appropriate, and the ease of installation and adaptation may differ somewhat from the options available for the larger engines.

2. Engines One Liter or Greater

Engines one liter or greater are typically derived from automotive engines. These engines tend to be de-featured versions of current or past automobile engines. They are most often liquid-cooled and multi-cylinder (usually four or more cylinders). As derivatives of automobile engines, the engines one liter and greater are well-suited for the use of automotive emission controls. In many of the cases, exhaust aftertreatment systems, as well as fuel and electronic control systems, already exist for these engines.

3. Phase-in

The Tier 1 emission standards would be phased in over three years, as shown in Table 2. The phase-in, based on the manufacturer's large spark-ignition engines sales into California, will provide industry with flexibility to develop controlled engines over a period of years instead of developing all their controlled engines by 2001.

Table 2

Tier 1
Phase-In Schedule

| Year | Percentage of Complying Production |
|---|---|
| 2001 | 40 |
| 2002 | 60 |
| 2003 | 80 |

4. Small-Volume Manufacturer Allowance

The proposal would provide relief to manufacturers that produce a total of less than 2000 large spark-ignition engines annually for the United States. Small-volume manufacturers would not be required to comply until 2004, at which time, like all other manufacturers, 100 percent of production would have to comply. The small-volume represent approximately 4 percent of the total engines (1994-1996 annual average nationwide sells) in this category.

5. Closed Crankcase

The proposal would require that all engines produced in model year 2001 or later have closed crankcases. This requirement is already met by the large majority of the engines in the category.

## C. 2001 (Tier 1) Compliance Programs

1. Certification

A certification process similar to that used for small off-road engines and heavy-duty off-road engines is proposed. The process is most similar to the streamlined small off-road engine certification process recently developed by ARB, U.S. EPA, and industry.

2. Test Cycles

ARB and the affected industry agree the most appropriate test cycle for most large spark-ignition engines is the steady-state ISO 8178 C2 cycle, developed by the International Organization for Standardization (ISO). The C2 cycle was developed to reflect typical activity of engines used in forklifts and other industrial equipment. The staff is also proposing the adoption of the ISO 8178 D2 cycle for those engines used in generators or other constant-speed applications. Additionally, the proposal would allow manufacturers the option of using the ISO 8178 G1 test cycle for engines below one liter, because the G1 cycle better represents operation of equipment, such as sweepers or turf care equipment, using these engines.

3. Production Line Testing

Compliance of production engines would be determined through the Cumulative Sum procedure used by both ARB and the U.S. EPA for small off-road engines. The Cumulative Sum procedure replicates the statistical foundation of the federal Selective Enforcement Audit program, while providing greater opportunity for a quick decision, thus minimizing the manufacturer's possible testing burden, particularly for those engine families that consistently meet the standards by a wide margin. The staff proposes the adoption of a modified Cumulative Sum procedure to ensure year-round sampling, as was approved for small off-road engines. Testing at least two engines per production quarter should ensure compliance throughout the model year.

4. Compliance Testing

In addition to the Cumulative Sum production line testing described above, the initial stage of regulation will include new engine compliance testing similar to other on- and off-road programs. Since Tier 1 does not require manufacturers to meet an emissions durability standard, there will not be an in-use component for Tier 1.

5. Defects Warranty

For 2001 through 2003 model year engines, the manufacturers would provide a two year emissions defects warranty to the ultimate purchaser, consistent with current practice. The warranty would help to ensure that emissions-related parts are free of defects.

D. <u>2004 (Tier 2) Compliance Programs</u>

1. Deterioration

Manufacturers would be required to demonstrate that their emission controlled engine complies with the emission standards for its useful life period. To demonstrate compliance, manufacturers may choose to operate an engine for its useful life period over a test cycle that represents typical engine/application usage, perform periodic emission tests, and calculate the engine’s deterioration rate. Staff also proposes to allow manufacturers to develop their own procedures to determine the deterioration rate of their engines over the useful life period. This is consistent with the current approach for determining emission deterioration for other on-road and off-road engine certified products.

2. Useful Life and Emissions Warranty Periods

The proposed useful life period for engines below one liter is 3000 hours or five years; for engines one liter and greater, it is 5000 hours or seven years. These periods represent typical "half-lives" (the point at which one-half of the original engines have left the fleet) of these engines.

The emissions defects warranty period would be 80 percent of the useful life period. Thus, the warranty period for engines below one liter would be 2400 hours or four years, while the warranty period for engines one liter or greater would be 4000 hours or five years. This is a longer warranty period than required during Tier 1 (2001-2003).

### 3. In-Use Testing

An in-use testing program would ensure that certified engines meet the standards throughout their useful lives. For each engine family selected by the ARB, engine manufacturers must perform emission testing of an appropriate sample of in-use engines and submit the resulting data to ARB. The ARB would limit its request for a manufacturer in-use testing to no more than 25 percent of that manufacturer's total certified engine families per model year. This proposal is very similar to current on-road medium-duty vehicle in-use testing requirements using engine-certification protocols. For manufacturers producing fewer than four engine families in a model year, the ARB could choose one engine family per model year for manufacturer in-use testing. The program would also include a means to reduce the testing burden on small-volume manufacturers, consistent with the Tier 1 provisions described above.

## E. Technology Review

Manufacturers of large spark-ignition engines, although likely to have experience with certifying engines through participation in the on-road market or in other off-road markets, may encounter unforeseen issues when developing complying engines for the large spark-ignition engine market. In addition, many of the equipment manufacturers are less familiar than the engine manufacturers with the emission control technologies that will be used to comply. For these reasons, the staff proposes to hold a technology review of the Tier 2 standards in 2001. The review will enable industry and ARB to determine how the application of technology is progressing, identify any unforeseen challenges, and recommend regulatory changes to the Tier 2 standards, if warranted.

Staff believes that three-way catalyst, closed-loop controls provide excellent emission reduction capability and that those reductions can be maintained over the life of large spark-ignition engine applications. Nevertheless, staff agrees with industry that additional emissions durability testing would be beneficial to support the staff's assertion that the 2004 emission standards are technologically feasible in-use. Staff believes that this can best be accomplished through co-funded demonstrations to show that the emission standards can be met in-use with the technology of choice. A successful project must involve both regulatory agencies (ARB and U.S. EPA), the engine and equipment industry, and the emission control manufacturers. A consortium of these parties would work together to develop the test program, determine the technology to be used, choose the specific applications to examine, and conduct the in-use testing.

The results of this multi-government/industry effort would be presented to the Board as part of the 2001 technology review.

## IV. DISCUSSION

### A. Emissions Standards

Compliance with the proposed Tier 1 emissions standard is based on new engine or "zero-hour" emissions, rather than deteriorated emissions. However, the staff is proposing that the emission levels for 2001 be based on the same numerical standards developed for 2004 and subsequent model years (Tier 2). The expectation is that the implementation of the Tier 1 standards will allow industry the opportunity to fine tune their engine technology and performance before implementing emissions durability requirements in 2004. California will benefit from the Tier 1 program because, although some emissions deterioration is expected, staff is confident that it will not be excessive. The proposed production line testing and emissions warranty requirements (discussed later) will help provide this assurance.

The Tier 2 standards would go into effect in 2004. The 2001-2003, and 2004 and subsequent emission standards are numerically the same. The 2001-2003 emission standards are based on “zero-hour” emission compliance testing, while the 2004 and subsequent model year emission standards require manufacturers to demonstrate compliance over the engine’s useful life period. The staff considers the two tiers of emission standards to be more of a multi-year phase-in rather than two distinctly different emission standards. The experience gained by observing and testing engine-catalyst based control systems in the field in 2001-2003 will provide the manufacturers with valuable knowledge on the deterioration and performance of their designs. That knowledge will be used to validate their designs or encourage redesign for 2004.

As shown in Table 1, separate NMHC+NOx emission standards are proposed based on engine displacement. Staff proposes a division between small and large engines at 1.0 liter. This division will separate those engines that are typically derived from automotive engines from those that are not. The development of the emission standards is discussed below, separately for each displacement class.

#### 1. Engines Below One Liter

Staff searched for available emissions data for large spark-ignition engines under 1.0 liter. No specific baseline or controlled emission test data for this class of engines was found. As a result, staff relied on emission test data from similar engines for its assessment of the achievable controlled emission levels. The data serve as the basis for staff's proposed 5.0 g/bhp-hr HC+NOx emission standard for large spark-ignited engines under 1.0 liter.

Southwest Research Institute, under two ARB-sponsored contracts, tested spark-ignition engines to measure the baseline (uncontrolled) emission levels and determine the controlled emission levels achievable using current automotive control technology. As part of the contracts, engines similar in design to the under 1.0 liter large spark-ignition engines were tested. These engines are primarily air cooled and carbureted, and some engines utilize older side valve, as opposed to overhead valve, engine design. Three engines were tested that cover these characteristics. The emission results of the baseline (uncontrolled) and controlled engine tests are shown in Tables 3, 4, and 5.

The Southwest Research Institute's large spark-ignition engine contract included one engine, Engine E, that is larger (2.5 liter engine) than this subcategory of engines, however, it is representative of the side valve, air-cooled engines below one liter and their potential emission reductions. Engine E was modified to include a closed-loop fuel injection system and three-way catalyst. The engine was allowed to run rich during the high-load test modes to reduce cylinder temperatures and ensure engine and catalyst durability. Thus, the resulting emissions were higher than expected, as shown in Table 3, the engine emissions were reduced from 12 to 2 g/bhp-hr HC+NOx (83 percent HC+NOx emission reduction).

Table 3

Summary of Emission Test Results of Engine E
Side Valve 2.5 liter Engine

| Test | Emissions, g/hp-hr | | | |
|---|---|---|---|---|
| | HC | CO | NOx | HC+NOx |
| Baseline Results | 10.7 | 479 | 1.70 | 12.4 |
| Controlled Results | 0.25 | 26 | 1.83 | 2.1 |
| Reduction From Baseline, % | 97.7 | 94.6 | -7.6 | 83.2 |

Source: Southwest Research Institute, ARB Contract No. 95-340.

Under the second contract, Southwest Research Institute was given the task to show that current small off-road engines under 25 hp could be brought into compliance with the then existing 1999 3.2 g/bhp-hr HC+NOx emission standard. The two engines tested, a 5.5 horsepower Honda overhead-valve engine (163 cc) and a 2.8 horsepower Briggs & Stratton side-valve engine (148 cc), exhibited controlled HC+NOx emission levels of about 3 g/bhp-hr (Tables 4 and 5). Southwest Research Institute used carburetor enleanment of the existing engines with the addition of a catalyst system to achieve the controlled emission results. As was done with the 2.5 liter engine testing, the engines were allowed to run rich during the high-load test modes to reduce cylinder temperatures and ensure engine durability.

Table 4

Summary of Emission Test Results of
Honda Overhead Valve 163 cc Engine

| Test | Emissions, g/hp-hr | | | |
|---|---|---|---|---|
| | HC | CO | NOx | HC+NOx |
| Baseline Results | 6 | 200 | 1.5 | 7.5 |
| Controlled Results | 2.8 | 65.6 | 0.2 | 3 |
| Reduction From Baseline, % | 54 | 67 | 84 | 60 |

Source: Southwest Research Institute, ARB Contract No. 95-340.

Table 5

Summary of Emission Test Results of
Briggs and Stratton Side Valve 148 cc Engine

| Test | Emissions, g/hp-hr | | | |
|---|---|---|---|---|
| | HC | CO | NOx | HC+NOx |
| Baseline Results | 10.3 | 357 | 1.7 | 12 |
| Controlled Results | 2.2 | 64.2 | 0.9 | 3.1 |
| Reduction From Baseline, % | 78 | 82 | 49 | 74 |

Source: Southwest Research Institute, ARB Contract No. 95-340.

Staff assumed that the data presented in Tables 3, 4, and 5, which represent similar engines that are larger and smaller than the under one liter engines subject to this proposal, would provide a range of the baseline and achievable controlled emission levels. Thus, baseline (uncontrolled) zero-hour emission levels of these engines should range from about 7 to 12 g/bhp-hr HC+NOx, while controlled levels should range from about 2 to 3 g/bhp-hr HC+NOx. Staff acknowledges that although these engine tests show that technology exists to comply with these emission levels on a zero-hour emission test basis, engines and catalyst systems deteriorate over time. Therefore, the emissions are expected to deteriorate over time, and future emission control development over the next five years may be needed to account for this.

Staff relied upon on-road light-duty truck engine emission deterioration rates to represent these off-road large spark-ignition engines with similar emission control technology because light-duty truck engines are similar in size and horsepower as large spark-ignition engines and their control technology is expected to be analogous to that used for the large spark-ignition engines. The deterioration rates available for on-road light-duty trucks from the early 1990's were used because they include currently available catalysts able to withstand higher temperatures and poisoning of active cells. Also, California fuels have improved with the elimination of leaded fuel and the introduction of cleaner burning gasoline which should improve these deterioration rates. Applying the deterioration factor of 1.6 used for controlled engines (the average of gasoline and LPG engine deterioration factors) to the range of zero-hour controlled emission levels between 2 and 3 g/bhp-hr HC+NOx, yields a useful life emission level between 3.2 and 4.8 g/bhp-hr. The proposed standard of 5.0 g/bhp-hr HC+NOx allows some additional compliance margin for manufacturers, by being at the high end of the range.

Some members of industry have indicated that they believe these smaller engines should, in fact, be subject to the same requirements as the small off-road (below 25 horsepower) engines. Staff disagrees; the 25 horsepower division was chosen because it provided a demarcation between differing types of technology and applications. Most engines below 25 horsepower are single-cylinder, air-cooled engines. The majority are side-valve, although some are overhead-valve. Furthermore, the engines tend to be extremely inexpensive; $50 to $100 is not an uncommon wholesale price. In contrast, engines above 25 horsepower are mostly multi-cylinder, liquid-cooled engines. Most are overhead valve, and prices are typically more than $1000.

Some manufacturers of small off-road engines, currently not in the above-25-horsepower market, have indicated that they are currently considering such a venture. Those manufacturers have asked that ARB consider emissions standards that were originally developed for engines as small as 5.5 horsepower. For the reasons stated above, the staff believes that those standards would not be appropriate for engines 25 horsepower and above. By expanding the "domain" of the small off-road engine regulations, it would provide a greater incentive to use a relatively dirty technology that is not representative of the above-25-horsepower market as it has evolved in the absence of regulation. For instance, Ford Power Products, which is currently in the market, produces a 1.0 liter large spark-ignited engine (about 45 horsepower). Based on testing they have performed, Ford believes it can achieve an emission level of 3.0 g/hp-hr HC+NOx when new. However, Ford has not yet tested the 1.0 liter engine to confirm that it can meet that level over the engine's useful life period. Nonetheless, Ford believes its emissions will remain low over the useful life of the engine and supports the staff's proposal of a 5.0 g/bhp-hr useful life standard.

### 2. Engines One Liter or Greater

Engines one liter or greater are typically derived from automotive engines. Specifically, these engines tend to be de-featured versions of current or past automobile engines and are thus most often liquid-cooled and multi-cylinder (usually four cylinders). As derivatives of automobile engines, the engines one liter and greater are well-suited for the use of automotive controls. In the majority of cases, there already exist compatible exhaust aftertreatment systems and electronic control systems. Staff relied on the emission reduction capability of this technology (closed-loop, three-way catalyst) and the emission data available to develop the proposed emission standard of 3.0 g/bhp-hr HC+NOx for the large spark-ignition engines 1.0 liter and greater. A summary of data used by staff is provided below.

The Southwest Research Institute test program provided staff with baseline emissions data from eight uncontrolled large spark-ignition engines (all engine data included multiple tests, fuels and cycles). The emission tests resulted in an average uncontrolled emissions level of 13.5 g/bhp-hr HC+NOx. Uncontrolled HC+NOx emissions levels ranged from 19.8 to 7.8 g/bhp-hr.

As part of the Southwest Research Institute test program, two engines were outfitted with closed-loop, three-way catalyst systems. The baseline data of a 2.5 liter, 4-cylinder LPG engine was 12.6 g/bhp-hr HC+NOx, as shown in Table 6. With a closed-loop, off-the-shelf automotive three-way catalyst, the engine’s emissions were reduced to 0.10 g/bhp-hr HC+NOx, a 99 percent emission reduction. Additional testing of the engine with a different control system configuration and a different catalyst, resulted in a controlled emission level of 0.49 g/bhp-hr HC+NOx, well below the proposed 3.0 g/bhp-hr HC+NOx standards.

Table 6

Three-way Catalyst Demonstration
Zero-Hour Test Results for LPG Engine

| Test | Emissions, g/hp-hr | | | |
|---|---|---|---|---|
| | HC | CO | NOx | HC+NOx |
| Baseline Results | 0.94 | 7.37 | 11.7 | 12.64 |
| Controlled Results | 0.09 | 2.1 | 0.01 | 0.1 |
| Reduction From Baseline, % | 90.4 | 71.5 | 99.9 | 99.2 |

The second engine, considered a “worst case” engine, was a 2.5 liter gasoline engine. It was considered worst case because it uses a side valve, air cooled engine design which is typically found in small off-road engines used in lawnmowers. Generally this engine design can not meet emission levels as stringent as overhead valve, liquid-cooled engines can meet. This is because these engines tend to run very rich to protect the valves and pistons from excessive heat and minimize distortion of engine components (due to uneven heat distribution inherent with air-cooled, side-valve engines). Thus, as would be expected (and as shown below in Table 7), the engine’s baseline emissions level was about 12 g/bhp-hr HC+NOx. With the addition of closed-loop fuel injection and catalyst technology, the emissions dropped to 2.1 g/bhp-hr HC+NOx.

Table 7

Summary of Emission Test Results of Engine E
Side Valve 2.5 liter Engine

| Test | Emissions, g/hp-hr | | | |
|---|---|---|---|---|
| | HC | CO | NOx | HC+NOx |
| Baseline Results | 10.7 | 479 | 1.70 | 12.4 |
| Controlled Results | 0.25 | 26 | 1.83 | 2.1 |
| Reduction From Baseline, % | 97.7 | 94.6 | -7.6 | 83.2 |

In discussions with manufacturers, additional data were presented to support the proposed emission levels. One engine manufacturer provided data on its primary 40-60 horsepower forklift engine with three-way catalyst, closed-loop technology; the data are summarized in Table 8, below.

Table 8

Zero-Hour HC+NOx Emissions Results
(g/bhp-hr)

| Fuel | Baseline configuration | Closed-Loop Three-Way Catalyst |
|---|---|---|
| Gasoline | 16.8 | 0.9 |
| LPG | 7.6 | 0.4 |

Staff used the engine test data from tables 6, 7, and 8 to represent the range of emission levels achievable for large spark-ignition engines greater than one liter; from 2.1 to 0.1 g/bhp-hr HC+NOx. As discussed above, these emission levels are zero-hour levels and staff recognizes that engines, control technology, and emissions will deteriorate over time.

As was done with the smaller engines, staff relied on the deterioration rates associated with current model on-road light- and heavy-duty trucks with closed-loop three-way catalyst control technology to develop the appropriate in-use emission standards. Typical deterioration factors are about 2.1 for these trucks. Applying this DF to the controlled emission data range of 2.1 to 0.1 presented in Tables 6, 7, and 8 would yield a useful life emission level of between 4.4 and 0.21 g/bhp-hr HC+NOx. The staff's proposed level of 3.0 g/bhp-hr HC+NOx provides manufacturers with some additional compliance margin to reflect in-use variability.

In discussions with manufacturers, staff has received support for its proposed HC+NOx standard. Some manufacturers have stated that they believe the staff’s proposal may be met in 2001. They still have some concerns about compliance to the 2004 useful life requirements, but have indicated that compliance is probable. In particular, Ford Power Products and IMPCO Technologies have publicly supported the staff’s proposed emission standards. Ford has already developed the control technology and is currently testing its controlled configurations. It plans to continue production of several of its current engine lines and introduce new engines into

California for a variety of industrial applications and forklifts that can meet the staff's proposed 2001 emission standards. Ford and IMPCO have raised concerns similar to other manufacturers regarding compliance with the 2004 useful life requirements due to their current lack of large spark-ignition engine durability test data.

### 3. Phase-in

The Tier 1 emission standards would phase-in over three years based on a manufacturers California engine sales, as shown in Table 2. In meetings with manufacturers, staff suggested a more stringent phase-in approach with 60 percent of the engines required to comply in 2001, 80 percent in 2002 and 100 percent in 2003. Because of the inclusion of forklifts greater than 50 horsepower into the non-preempt category and therefore under California's authority to regulate, staff revised its phase-in to provide these manufacturers with additional flexibility and lead time to comply.

The phase-in schedule will provide manufacturers with the flexibility to develop the technology and incorporate it on the engine lines that are most easily controlled or that represent the greatest volume of their sales. The phase-in reduces the burden on manufacturers to develop and incorporate the technology on their engines over a period of years instead of all in one year. Some manufacturers have a single engine family that accounts for a majority of its sales volume; the phase-in will allow an engine manufacturer to concentrate solely on that high volume engine family for the first, and possibly the second, year of the phase-in.

Although the phase-in is directed toward engine manufacturers, it may provide flexibility to equipment manufacturers as well. The engine manufacturers have the option of directing their uncontrolled engine models, during the phase-in years, to the small volume equipment manufacturers, thereby providing them additional time to reconfigure equipment, if necessary.

### 4. Small-Volume Manufacturer Allowance

The proposal would provide relief to manufacturers that produce a total of less than 2000 engines annually for the United States. The staff recognizes that small volume manufacturers may require special consideration to continue to serve their markets. To ensure continued product availability, the staff proposes to delay compliance for small volume manufacturers until 2004, when 100 percent of production would need to comply with the Tier 2 standards. The staff also proposes to allow the small-volume manufacturers to use an assigned deterioration factor, and to reduce the in-use testing requirements.

The staff arrived at a 2000 engines per year definition following examination of average annual U.S. sales figures for 1994-1996. Those figures indicted a natural break at between 900 and 1600 engines per year. A modest allowance for continued growth suggests that 2000 engines per year is an appropriate choice. The affected small-volume manufacturers represents approximately 4 percent of the total number of engines sold in this category. Thus, staff's proposal provides relief to truly small-volume manufacturers.

5. Closed Crankcase

Another source of HC emissions is the release of crankcase gases to the atmosphere. These gases result primarily from cylinder intake and combustion gases passing the piston ring assemblies into the crankcase (blowby) on the compression and power strokes. The primary control approach is the use of positive crankcase ventilation (PCV). PCV requires the sealing of the crankcase from the ambient air except for a filtered air inlet, and an exit to the carburetor or intake manifold below the throttle plate. When the engine is running, the crankcase gases are drawn into the intake system and then into the engine to be burned. Fresh outside air is drawn into the crankcase through the filtered inlet.

The closed crankcase requirement is already met by a majority of the engines in the category. Reduction of crankcase emissions was one of the earliest automotive emission controls used in production, and virtually all engines in other regulated categories have a closed crankcase requirement, so compliance should not be technically challenging for these engines. Although the proposal is prescriptive, it would be less onerous than developing a test procedure and requiring manufacturers to conduct additional tests on their engines, which would most likely result in the same physical changes to the engine.

B. <u>2001 Compliance</u>

1. Certification

Engine certification would follow a process similar to that used for the small off-road engine and Heavy-Duty Off-Road categories. The certification process has been streamlined to allow ARB to receive the most useful and pertinent information on a timely basis, while minimizing the paperwork and administrative burden on manufacturers. Features of streamlined certification include annual electronic submittal of the certification information. Information such as the description of test facilities, warranty, engine and equipment labels, and tamper resistance provisions need only be submitted once with the manufacturer's initial engine certification, in the absence of manufacturer modifications to those items, rather than including such information with each engine family application, as has been the practice in the past.

2. Maintenance Schedules

Since the majority of the engines and technology found in this category are similar to existing automotive engines, the staff proposes that the allowable maintenance schedule for this category should be similar to existing automotive and small off-road engine maintenance schedules, for the one liter and greater and less than one liter categories, respectively.

3. Test Cycles

The staff is proposing to use test cycles that have previously been developed by the ISO. ISO is an international group that includes representatives from industry; use of the ISO test cycle will allow the greatest harmonization, not just with U.S. EPA, but worldwide.

The staff has determined that the most appropriate test cycle for most of the large spark-ignition engines at this time is the steady-state ISO 8178 C2 cycle. The C2 cycle was developed to reflect typical activity of engines used in forklifts and other industrial equipment. The staff is also proposing the adoption of the D2 cycle, which will be used to test engines used in generators or other constant-speed applications. In addition, the staff proposes to give manufacturers the option of using the G1 test cycle for engines below one liter, because the G1 cycle better represents operation of equipment such as sweepers or turf care equipment, which typically use engines below one liter. See the Technical Support Document (Attachment E) for further information regarding the test cycles.

4. Test Fuel Specifications

The proposal would allow service accumulation using commercially available fuel (gasoline or alternative fuel), but would require that fuel meeting the California on-road fuel specifications be used for emissions testing to eliminate the variability of commercial fuels. The California fuel specifications are contained in the California Code of Regulations, Title 13, Chapter 5, Article 1, Sections 2260-2272, and Article 3, Sections 2290-2293.5.

In discussions with industry and the U.S. EPA, LPG fuel specifications have been raised as an issue both in terms of the need for ARB and U.S. EPA harmonization and a concern about the inconsistent quality of fuel across the country. In terms of harmonization, ARB has begun working with U.S. EPA and believes that a fuel policy similar to that used for other mobile sources can be developed for the large spark-ignition engine category to prevent manufacturers from having to test engines on separate fuels for California and the other 49 states. A correction factor may be applied to the emission results to simulate the impact of federal commercially available fuel. California has LPG fuel limits that should provide for consistent fuel quality throughout the state.

5. Production Line Testing

As noted earlier, compliance of production engines would be determined through the Cumulative Sum procedure used for the small off-road engine category. The Cumulative Sum procedure replicates the statistical foundation of the federal Selective Enforcement Audit program, while providing greater opportunity for a quick decision, thus minimizing the manufacturer's possible testing burden, particularly for those engine families that consistently meet the standards by a wide margin. The adoption of a modified Cumulative Sum procedure would ensure year-round sampling, as was approved for small off-road engines; staff opted to retain year-round sampling because of its experience with the small off-road engine quality-audit test program. Staff has noted that some engine families that demonstrate good performance in the first or second quarters of production may then encounter serious difficulties complying in later quarters. Testing at least two engines per production quarter should ensure compliance throughout the model year. Therefore, based on four quarters per production year, the minimum number of tests required is only eight; the maximum, as determined by the need to match Selective Enforcement Audit's confidence level, is only thirty. This is a low number of tests compared to other programs where manufacturers are required to test one percent of all off-road engine production and two percent of on-road vehicle production. Overall, the Cumulative Sum procedure will minimize the testing burden on manufacturers. A complete description of the Cumulative Sum program and the staff's proposed modifications are in Attachment D.

### 6. Compliance Testing

In addition to the Cumulative Sum production line testing described above, the staff's proposal includes new engine compliance testing requirements similar to other on- and off-road programs. Unlike production line testing, which would be automatically conducted by the engine manufacturer, new engine compliance testing would be conducted only when ordered by the ARB. New engine compliance testing is typically ordered only when there is evidence to indicate a possibility of noncompliance. The testing would then be carried out by ARB, the engine manufacturer, or a third party, at the ARB's discretion. Compliance testing would be performed according to the certification test procedures.

### 7. Labeling

Manufacturers would be required to install on all new 2001 and subsequent model year large spark-ignition engines labels that identify the engine as being certified for sale in California. The label clearly identifies an engines as one that has complied with the ARB regulations and is legal for sale in the state. The use of the label is a simple enforcement tool for the regulations. If an engines has no label, it is not legal for sale. Additionally, when performing new engine testing, testing the label provides the information to identify the engine family, test cycle, and engine settings. The label would include the engine family identification number, the date produced, and any specific exhaust emission control devices utilized on the engine. The specific fuels, engine lubricant, and the engine displacement must also be shown on the label.

### 8. Defects Warranty

For 2001 through 2003 model year engines, the manufacturers would provide a two year emissions defects warranty to the ultimate purchaser, similar to the basic mechanical warranties offered by many manufacturers now. The requirement is similar to the small off-road engine two-year emissions defects warranty and the five-year or 3000-hour Heavy-Duty Off-Road emissions defects warranty, and would ensure that emissions-related parts are free of defects.

The warranty would not cover the basic engine with respect to normal wear or failure, but only specific, listed emissions-related parts. Manufacturers would provide, free of charge to the purchaser, repair and replacement of any parts included on the warranty parts list that are defective.

## C. 2004 Compliance

As noted, the Tier 2 emission standards (i.e, the addition of the durability requirement) would go into effect in 2004.

### 1. Deterioration

Manufacturers would use a deterioration factor (DF) to represent the deterioration expected of an engine at the end of its emissions durability period. To establish a DF the manufacturer would test an engine at zero hours, at the middle of the durability period and at the end of the durability period. The manufacturer would be allowed, but not required, to test at additional points at equal intervals between zero hours and the end of the durability period. The manufacturer may also choose to replicate tests for greater certainty. The manufacturer would fit a line to those points, and determine the DF by calculating the value for the end of the emissions durability period and dividing that value by the value at zero hours. The DF would be multiplied by the zero-hour emissions whenever an engine was tested for the production-line testing or new engine compliance programs, alleviating the need to perform costly engine aging on each test engine.

Manufacturers may choose to use the durability demonstration noted above or an alternative. The proposal would allow manufacturers to develop their own procedure to demonstrate the deterioration of their engine over its useful life. Manufacturers have a variety of data available to them, such as performance test results and warranty information from previous years, to establish deterioration rates. Manufacturers using alternative methods of durability demonstration would still be responsible for engine compliance during in-use testing.

### 2. Useful Life and Emissions Warranty Periods

The proposed useful life period for engines below one liter is 3000 hours or five years; for engines one liter and greater, it is 5000 hours or seven years. As noted above, these periods represent typical "half-lives" (the point at which one-half of the original engines have left the fleet) of these engines.

The emissions defects warranty period would be 80 percent of the useful life period. Thus, the warranty period for engines below one liter would be 2400 hours or four years, while the warranty period for engines one liter or greater would be 4000 hours or five years.

### 3. In-Use Testing

To ensure that certified engines are meeting the emission standards throughout their useful lives, the staff also proposes an in-use testing program. Each year, the ARB would identify the engine families to be tested for the in-use testing program. For each engine family selected, engine manufacturers would have to perform emission testing of an appropriate sample of in-use engines and submit the resulting data to ARB. Upon notification that an engine family has been selected, a manufacturer would have 12 months to provide a plan for ARB approval. Testing would begin when the engines had accumulated sufficient hours of service; testing must be completed within two years of notification.

For each model year, the ARB would be limited to selecting no more than 25 percent of the manufacturer's total number of engine families. For manufacturers producing fewer than four engine families in a model year, the ARB could choose one engine family per model year for in-use testing. Staff has agreed to work cooperatively with the U.S. EPA in choosing families in order to minimize the burden on manufacturers. The expectation is that the combined ARB and U.S. EPA testing will be below the 25 percent cap in most instances.

Engines to be tested must have accumulated a minimum of 75 percent of the family's useful life. A minimum of four engines per family must be tested, provided that no engine fails any emission standard. For each failing engine, two more engines must be tested until the total number of engines equals ten. In recognition of the special concerns of low-volume engine manufacturers, the minimum for engine families with nationwide sales of less than 500 units or for engine manufacturers whose total national production for that model year is 2,000 engines or less, would be of two engines per family, provided that no engine fails any standard. At the discretion of the Executive Officer, an engine manufacturer may test more engines than the minimum or may concede failure before testing a total of ten engines.

To further accommodate low-volume engine families, the Executive Officer may approve an alternative to manufacturer in-use testing. Such alternatives must be designed to determine whether the engine family is in compliance in-use, and would be limited to cases where:

(A) National production of the engine family is 200 per year or less;

(B) Engines cannot be obtained for testing because they are used substantially in vehicles or equipment that are not conducive to engine removal such as large vehicles or equipment from which the engine cannot be removed without dismantling either the engine, vehicle, or equipment; or

(C) Other compelling circumstances associated with the structure of the industry and uniqueness of engine applications.

If a selected in-use engine fails to comply with any applicable emission standards, the manufacturer must determine the reason for noncompliance and report all such reasons within fifteen days of the end of testing. The manufacturer must electronically submit to the Executive Officer all emission testing results generated from the in-use testing program within three months of completion of testing.

The Executive Officer will consider failure rates, average emission levels and the existence of any defects, among other factors, in determining whether to pursue remedial action. The Executive Officer could order a recall pursuant to Section 2439 before testing reaches the tenth engine. However, prior to an ARB-ordered recall, the manufacturer may perform a voluntary emissions recall. Such manufacturer would remain subject to the reporting requirements. Once ARB determines that a substantial number of engines fail to conform with the requirements, the manufacturer would not have the option of a voluntary emissions recall.

4. Credits

In general, any engine family certified to the 2004 and later model-year emission standards would be eligible to participate in the in-use credit program; however, engines that are delivered to a "point of first retail sale" outside of California would not be eligible.

An engine family with a compliance level, as determined by in-use testing, below the emission standards to which it is certified would be able to generate emission credits for averaging, banking, or trading. Positive credits generated in a given model year could be used in that model year or in any subsequent model year. Additionally, in-use credits could be used to remedy an emissions exceedance. Since some manufacturers may wish to build a credit reserve, the proposal would allow a manufacturer to voluntarily perform additional in-use testing to generate credits.

Credit Calculation - For each participating engine family, emission credits (positive or negative) would be calculated according to the following equation and rounded to the nearest gram.

$$\text{Credits}_{\text{(grams)}} = \text{SALES} \times (\text{STD} - \text{CL}) \times \text{POWER} \times \text{AF} \times \text{LF} \times \text{UL}$$

Where:

**SALES** = the number of eligible sales tracked to the point of first retail sale in California for the given engine family during the model year.

**STD** = the emission standard in g/bhp-hr

**CL** = compliance level of the in-use testing in g/bhp-hr.

**Power** = the sales-weighted average power of an engine family in bhp. The power of each configuration is the rated output in kilowatts as determined by SAE J1228.

**AF** = adjustment factor for the number of tests conducted. The adjustment factor is based on the degree of confidence level that the results of the number of engines tested represent the engine family's performance. The adjustment factors are shown in Table 9, below, with the exception that when a manufacturer concedes failure before completion of testing, the adjustment factor shall be 1.0:

**LF =** Load factor, which is the fraction of rated engine power utilized in-use (0.32 for engines with displacement of 1.0 liter or greater; 0.47 for engines with displacement less than 1.0 liter).

**UL**= useful life in hours (5000 hours for engines with displacement of 1.0 liter or greater; 3000 hours for engine with displacement less than 1.0 liter).

Table 9

In-Use Credit Adjustment Factors

| Number of Engines Tested | Adjustment Factor |
|---|---|
| 2*, 4 | 0.5 |
| 6 | 0.75 |
| 8 | 0.9 |
| 10 | 1.0 |

*Small volume manufacturer

A manufacturer who participates in the in-use credit program would be required to submit an end of the model year in-use testing credit report. The report would contain the calculated credits from all the in-use testing conducted by the manufacturer for that model year. Manufacturers must demonstrate a zero or positive credit balance for a particular model year within 90 days of the end of the in-use testing of that model year's engine families, or at the same time as the final certification averaging, banking and trading report, whichever is later. To ensure a benefit to air quality, the credits used to demonstrate a zero or positive credit balance would have to be used at a rate of 1.1 gram to 1 gram.

A manufacturer of an engine family with an in-use compliance level exceeding the emission standards to which the engine family is certified, may, prior to the date of the report, use credits to remedy the exceedance. The manufacturer could do this by using previously banked credits, purchasing credits from another manufacturer, or performing in-use testing of additional engine families to generate credits. A manufacturer would have to notify the Executive Officer of plans to test additional engine families beyond the 25 percent engine family limit for the required in-use testing program. If the additional testing indicated a manufacturer-selected engine family was in noncompliance with the emission standards, the testing would be treated as if it were a failure of the normal in-use testing requirement of an engine family.

In the event of a negative credit balance resulting from a transaction of emissions credits, both the buyer and the seller would be liable, except in cases involving fraud. Engine families participating in a negative trade may be subject to recall.

### D. Inclusion of Forklifts in the Non-preempt Category

In 1992 and 1993, staff worked with the Industrial Truck Association (ITA) and other industry groups to clarify terminology and determine whether a piece of equipment was construction or farm equipment when considered in the context of the U.S. EPA's 1991 proposed primary-use test (final rule promulgated by the U.S. EPA in July, 1994). In a letter from ARB to U.S. EPA, dated July 20, 1993, staff presented a list of preempt and non-preempt equipment agreed upon by ARB and the various industry groups. The agreement regarding forklifts was based on data presented to staff from ITA. The data indicated that "a very significant quantity" of forklifts over 50 horsepower were used on construction or farm sites.

Since then, staff has obtained data that has called into question the basis for listing forklifts over 50 horsepower as preempt. It now appears that only a small percentage of the forklifts are used in construction or farm activities, well under the 51 percent primary use determination. Thus, the staff has adjusted the scope of the large spark-ignition engine proposal and the emissions inventory to reflect the inclusion of all spark-ignition engine forklifts, except rough terrain forklifts, into the non-preempt category.

The data used to reach the conclusion was obtained from two sources: 1996 report by the National Propane Gas Association (NPGA) on the role of propane in the forklift market, and the ARB large spark-ignition engine emissions inventory. The NPGA report provided general information and statistics on the 1995 U.S. forklift population. In the report, class 4, 5, and 6 forklifts (internal combustion engine forklifts, not rough terrain) as a group were divided into the following industrial sectors: construction, manufacturing, transportation/utility, retail, wholesale, services, and "other." The report indicated that the construction and "other" sectors comprised only 11 percent of the group (manufacturing was the largest group with 36 percent). Additionally, 80 percent of the forklifts were estimated to use spark-ignition engines with the remainder being compression-ignition engines. Based on these splits and using the percentage of engines by horsepower splits in the ARB's inventory, the conclusion was that no more than 18 percent of forklifts 50-175 horsepower would be in construction and farm applications.

## E. Other Regulatory Requirements

### 1. Underwriters Laboratories

Underwriters Laboratories (UL) is a not-for-profit corporation whose reputation for certifying the safety of machinery, equipment and consumer products is known worldwide. UL certification of a product signifies that it has been tested and determined to meet UL standards for safeguarding operators against exposure to such hazards as electrical shock, fire, excessively high surface temperatures, etc.

Several equipment manufacturers have informed staff that their customers expect the equipment they purchase to be UL approved. These manufacturers express concern that the presence of catalytic converters could make it difficult to meet UL requirements for fire safety and safety from exposure to high temperature surfaces. They also express concern about the expense of conducting the tests required by UL.

Staff has discussed this issue with UL personnel, who have indicated that they do certify catalysts. The UL catalytic converter requirements limit the temperatures of surfaces located adjacent to a muffler or catalytic converter, while maintaining the converter's structural capability to contain backfire pressures, etc. Certification can be conducted directly through testing of the complete converter/equipment configuration, or, alternatively, through testing of the converter as a component in a reference installation. The reference installation usually represents a worst-case scenario in terms of engine size, converter proximity to sensitive surfaces, etc. The component evaluation ensures that all requirements (temperature, etc.) are met in that reference installation. The equipment manufacturer would then need to show UL, through engineering evaluation, that its application is similar to or inherently safer than the reference installation. This process minimizes the actual testing for UL approval and shares the costs and responsibility for the approval between the equipment manufacturer and the catalytic converter manufacturer. Catalyst manufacturers have stated that this process will minimize the costs of UL approval.

2. CalOSHA

The Federal Occupational Safety and Health Act of 1970 contains provisions allowing California to administer its own workplace safety and health program. California's program is called CalOSHA and is administered by the state's Department of Industrial Relations (DIR). Of particular interest are the requirements and regulations CalOSHA has established to safeguard workers from harmful exposure to engine exhaust and its components. A primary regulation of concern regards worker exposure to several airborne contaminants, including CO and $NO_2$ (Title 8, California Code of Regulations, Section 5155). CalOSHA also has standards placing limits on engine exhaust emission concentrations of CO, and the test procedure to be used for its measurement (Title 8, California Code of Regulations, Section 5146). DIR does not routinely test engines to determine whether they meet the CalOSHA CO emission requirements.

Staff has discussed the proposed large spark-ignition engine regulations with DIR personnel in order to coordinate and avoid conflicts with existing CalOSHA requirements. At present, ARB and DIR agree that no conflict exists between the agencies' emission requirements, since the ARB's requirements will either cap or reduce CO emission levels.

## V. TECHNOLOGY

As noted earlier, SIP Measure M11 was developed in 1994 from the assumption that manufacturers would be able to use closed-loop three-way catalysts that would result in a 75 percent reduction in the HC inventory and a 50 percent reduction in the NOx inventory. The proposed exhaust emission standards remain performance-based; manufacturers will be able to use any technology that accomplishes the ultimate goals. The staff's proposal would, in the near-term, require manufacturers to accelerate the introduction of proven control technology and, in the mid-term, require minimization of emissions deterioration.

The following discussion is a general overview of technology likely to be used. A more detailed analysis is contained in the Technical Support Document.

### A. Catalytic Converters

The catalytic converter is the primary technology responsible for the remarkable improvements in automotive emission control over the past two to three decades. Indeed, due largely to the catalytic converter, ozone-forming emissions from a modern automobile are less than ten percent of the levels of an uncontrolled vehicle of the 1960s, with improved operability and fuel economy as an added bonus. The typical modern automotive catalytic converter consists of an active catalytic material (usually one or more noble metals such as platinum, palladium or rhodium) applied as a washcoat to a substrate (usually ceramic or metal), surrounded by a mat and placed in a housing ("can") which also acts to direct the exhaust flow over the active material so as to maximize surface exposure. The two major types of converters are described in detail in the Technical Support Document. Staff expects that three-way catalyst technology will be the approach used to meet the proposed large spark-ignition engine emission standards.

Catalysts have long been used to reduce emissions from large spark-ignition engines in special operating environments such as mines and indoor warehousing applications. As explained below, the design and operation of most large spark-ignition engines and automobile engines are similar; thus direct application of current automotive catalyst technology to large spark-ignition engines is both likely and expected.

Several engine manufacturers have expressed concerns regarding durability of a catalytic converter and the technical challenges regarding use that differ from automobile applications. These include heat management, deactivation by poisoning from lubricating oil, space available for the catalyst, and the physical location of the converter relative to the engine.

### 1. Heat Management

Some engine manufacturers have raised concerns about the catalytic converter's external temperature. Because the converter for most engines' applications is in close proximity to both the engine and the equipment, for some applications, the converter could be exposed to ignitable adjacent materials. However, the Manufacturers of Emissions Controls Association (MECA) and individual catalytic converter/muffler manufacturers indicate that properly designed external shielding and insulation material around the converter eliminate this concern.

Several engine manufacturers expressed concerns regarding the thermal durability of the catalyst. Historically, thermal deactivation of catalysts has been known to occur when temperatures exceeded 2100€ F (1050€ C); at the deactivation temperature of a catalyst, sintering causes a loss in active area, dependent on the time spent at that temperature. However, in recent years, because of the need to close-couple catalysts in automotive applications and in anticipation of the US06[1] driving cycle, catalyst manufacturers have developed catalyst technology which is thermally stable well in excess of the aforementioned temperatures. One catalyst manufacturer has indicated that there are current catalyst designs that can handle limited temperature excursions into the 1200 $^{0}$C temperature range without significant thermal degradation of the catalyst. Also, employing electronic fuel-injection technology will eliminate the extremely rich excursions currently experienced with these engines which will serve to minimize catalyst bed temperatures. Furthermore, the typical engine-out temperatures from gasoline-fueled engines are approximately 500€ C to 650€ C, while LPG engine-out temperatures are only slightly higher. In short, existing catalytic converter technology has demonstrated thermal durability in automotive applications; thus, there is no reason to believe the thermal durability would not also be demonstrated on large spark-ignition engines.

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[1] The US06 driving cycle is a high speed vehicle chassis-based emission test cycle to be required by ARB beginning with the 2000 model year passenger cars and light-duty trucks. The US06 driving cycle's anticipated engine-out temperature exceeds today's chassis-based emission test cycle.

### 2. Packaging Issues

An additional technical issue faced when using catalysts is the additional space needed by some equipment applications. A single large spark-ignition engine family may be used in a wide variety of applications. If a catalyst is to be added to a large spark-ignition engine, it is imperative that it adhere to the existing space envelope. Further, it is not practical to design unique exhaust systems and catalytic converters for a variety of applications. Thus, any catalyst will have to work across broad equipment applications.

Packaging issues are particularly relevant for forklifts. The size of forklifts is critical (over-all height, turning radius, wheel base, sitting position of operator on hood), which results in limited space for additional exhaust components. Increasing the physical size of the forklifts is not considered an option, as warehouse and yard space is critical with many of the current facilities designed around the size and capabilities of the forklifts.

As one major catalyst manufacturer pointed out, one appropriate solution is to employ an integrated catalyst and muffler assembly. Forklift manufacturers already have experience with this approach, which has often been used for indoor applications. MECA has also provided confirmation that converter mufflers can simply replace the original equipment muffler and hence occupy the same space.

Another solution is to bolt a close-coupled catalyst directly to the manifold, as is the case for some automotive catalyst systems. Again, MECA has submitted information demonstrating that close-coupled catalysts have also been used within the physical constraints of forklifts. Additionally, MECA indicated that the Underwriters Laboratory has approved a number of catalyst/mufflers designed for forklifts.

### 3. Poisoning

Catalyst poisoning is another possible cause of catalyst deactivation. Poisoning is primarily related to engine oil passing the engine's piston rings and valve guide seals and entering the exhaust stream. Additives in the oil, such as phosphorus and zinc, then coat the catalyst, reducing its activity. The higher throughput or "space velocity" under which a large spark-ignition engine catalyst operates could aggravate the condition. This is because a given concentration of contaminant in the exhaust will result in a greater quantity of the contaminant passing through a given volume of the catalyst.

The extent of the problem depends upon overall oil consumption. One of the major contributors to oil consumption is cylinder bore distortion when the engine is hot. This problem is more severe with side-valve engines than with overhead-valve engines because a side-valve's exhaust port is adjacent to the cylinder and more difficult to cool. The industry trend to overhead-valve engines is the obvious solution to oil consumption problems. Other approaches include tighter manufacturing tolerances and the use of improved seals which limit the oil available to the valve guides.

Catalyst manufacturers are aware of the effects of lubrication oil contamination and have designed catalysts which resist it for other applications. A good example of this is in Taiwan where approximately 3,000,000 two-stroke motorcycles have been successfully equipped with catalysts since 1992. These two-stroke motorcycles burn lubricating oil which has been mixed with the fuel; hence, the concentration of oil contaminants in the exhaust are significantly higher than typical automotive exhaust. MECA has additional data showing catalytic mufflers on forklifts to be effective after 6,000 to over 10,000 hours of operation.

Finally, even oil composition today helps work against the possibility of catalyst poisoning. Today's commercially available engine oils frequently contain calcium- and manganese-based oil additives; those additives reduce the amount of phosphorus which adheres to the catalyst.

4. Engine Design Constraints

Existing large spark-ignition engines typically run at rich air to fuel ratios, and so have high concentrations of exhaust gas constituents requiring conversion. On average, current engines have in-use HC+NOx emissions of between 12 to 14 g/bhp-hr. The high specific throughput and the high concentration of pollutants result in heat generation in the catalyst. The thermal energy from the exothermic catalytic reaction must be dissipated within the space available for the current engine and exhaust system. However, this should not be a concern based on data submitted by MECA which show that current catalyst technology used on these engines is capable of reducing HC+NOx levels from approximately 20.5 g/bhp-hr to 1.14 g/bhp-hr even with the higher space velocities associated with these systems as compared to automotive applications.

The need for a compact, self-contained exhaust system on smaller large spark-ignition engines may require mounting of the exhaust system and catalyst directly to the engine. The close proximity of the engine to the catalyst aggravates the mechanical loads to which the catalyst is subjected, as engine vibration is directly transmitted to the catalyst. Long term exposure to thermal excursions, and the significant engine vibration will increase the susceptibility of the converter and associated exhaust system components to mechanical failure. However, the need for close couple catalysts to meet the Low-Emission Vehicle requirements and anticipation of US06 requirements have led to recent advances in catalyst and canning materials that alleviate these concerns.

B. Closed-Loop Fuel Delivery

The most direct way to reduce HC emissions from large spark-ignition engines would be through the use of more precise and consistent fuel-air ratio control. Especially in smaller displacements, the carburetors and mixers used on many large spark-ignition engines, both gasoline and LPG, are quite rudimentary. They are adequate in terms of allowing the engine to operate and provide power satisfactorily, but they cannot provide the constant and precise fuel-air ratio control needed under all operating conditions to avoid periods of excessively rich mixtures. This can result in high HC and CO emissions. Automotive-type closed-loop controls, utilizing an exhaust gas oxygen sensor and an electronic control unit (ECU) to control a LPG fuel regulator, special carburetor or fuel injection system, can eliminate rich mixture excursions under most operating conditions. Engine hardware for closed-loop control systems was developed and used starting in the early 1980's for automotive applications; it is therefore readily available for use in large spark-ignition engines.

As discussed in the Technical Support Document, precise fuel-air control is needed to maintain the near-stoichiometric mixture necessary for proper three-way catalyst operation. Indeed, in automotive use, closed-loop control is an emission control strategy in and of itself, but its main purpose is to allow the major emission reductions possible with advanced catalysts.

C. Timing Retard

NOx can be reduced by retarding the ignition timing. Retarding the timing means that more of the combustion occurs later in the expansion portion of the power stroke. This results in lower temperatures and pressures and therefore lower NOx formation in the combustion chamber. Unfortunately, retarded timing also results in reduced power and reduced thermal efficiency. The impact on performance and fuel economy can be severe and places a practical limit on how much NOx reduction can be achieved through this method, but properly managed, modest timing retard is an effective and inexpensive NOx control strategy.

D. Exhaust Gas Recirculation

Exhaust gas recirculation (EGR) involves the redirection of a portion of the exhaust gases into the engine intake and thus into the combustion chamber. This dilutes the incoming fuel-air charge and provides thermal mass to absorb heat and slow reaction rates, reducing combustion chamber temperatures, and thus NOx formation. Proper calibration is necessary since excessive EGR leads to reduced combustion stability. But, if carefully applied, EGR can provide significant NOx reductions with minimal impact on performance, fuel economy or other emissions.

E. Electric Vehicles and Equipment

Many types of equipment that are included in the large spark-ignition category have electrically-powered counterparts. Electrically-powered equipment, having zero emission levels, is typically used in indoor materials handling applications, e.g., forklifts used in warehouse type building supply stores. Electric forklifts with lift capacities of up to 12,000 pounds are available from several forklift manufacturers, such as Toyota, Nissan, NACCO, Clark, Crown, and others. As another example, Taylor-Dunn Manufacturing Company makes and sells burden carriers and utility vehicles to the U.S. Postal Service, among other customers. Additionally, because of air quality concerns, many airlines utilize electric ground support equipment (for luggage handling, etc.) at various airports.

Electrically-powered vehicles and equipment utilize large battery packs, typically of deep discharge lead-acid design, to provide the power for equipment operation. The batteries must be recharged periodically and, unless they are of the maintenance-free variety, water levels need to be monitored and maintained. Charging facilities must also be provided with proper ventilation to avoid explosive hydrogen gas buildup. Battery packs can weigh as much as one to three thousand pounds depending on application, and require special equipment for handling. (Usually a major problem in vehicular applications, such heavy weights can actually be advantageous for equipment like counterbalanced forklifts.) For most working applications, battery packs generally are sized to allow operation for a complete eight-hour shift on one charge. Endurance in some applications may be less, depending on duty cycle and other factors.

Upon battery exhaustion, and depending on the equipment and its design, the equipment can either be removed from service during the recharge period or the battery pack can be exchanged for a fully-charged pack. In this way, the equipment can be kept operating continually, in use with one battery pack while another is being charged back to full capacity. Proper design minimizes the exchange time to just a few minutes, utilizing quick-disconnect connectors, sliding/rolling battery holders and other specialized accessories. Battery pack costs can amount to about 10 to 15 percent of the total equipment cost, and most operators obtain at least one additional pack to allow multi-shift operation.

The Electric Power Research Institute (EPRI) is currently developing a fast charger system that can greatly reduce the time required for battery charging. For example, the typical forklift battery pack requires approximately eight hours to recharge with conventional chargers. The new EPRI fast charger can bring the same pack to full charge in about one half hour, though it would periodically require a one to two hour equalization charge. The projected cost of the fast charger is about $25,000, but for a large enough fleet this could be more than offset by eliminating the need to procure extra battery packs to extend vehicle operation time.

A major advantage of electrically-powered equipment is that they typically require far less maintenance than comparable equipment powered by large spark-ignition engines since they do not require oil changes, spark plug replacement, etc. In addition, electric equipment powertrain components are inherently more reliable, and fuel (power) costs may be drastically reduced, depending upon utility rates for commercial customers. These factors generally result in reduced total life cycle costs. Electric equipment is also invariably quieter than its engine powered counterpart.

Disadvantages of electric-powered equipment include reduced work capacity. For example, most electric forklift manufacturers only make their products available with lift capacities of up to 12,000 pounds, while spark-ignition engine-powered models with capacities of three times that are available. Electric equipment is also typically slower, has slower lift speeds and does not operate as well on steep ramps and slopes. However, further development work continues to extend the capabilities of electrically-powered industrial equipment.

Population data for 1995 indicate that there were over 41,000 ride-on type electric-powered forklifts in operation in California in that year. At the same time there were over 50,000 gasoline- and LPG-fueled forklifts in use in the state. This information indicates that electric forklifts are commonly accepted as having adequate performance, and that a significant portion of the state's forklift population can already be considered zero-emission; thus, the potential to further reduce the impact of this category of equipment on air quality is available.

## VI. AIR QUALITY, ENVIRONMENTAL AND ECONOMIC IMPACTS

### A. Air Quality and Environmental Impacts

#### 1. Benefit of the Proposal

Table 10 shows the significant statewide emissions benefit of the staff's proposal in 2010 as compared to the uncontrolled emissions inventory; it also shows the benefit from equivalent federal control. The data reflect the latest information on engines in the category affected by the staff proposal and their emissions. Additionally, the emission inventory includes the emissions from engines used in forklifts greater than 50 horsepower in the "Staff Proposal" measure (non-preempt engines) as discussed in section IV.D. above. Note that discrepancies may occur due to rounding of the numbers to one decimal point.

Table 10

2010 Statewide Benefit of the Proposal
tons per day

| Measure | Pollutant | Emissions Inventory | | Reductions |
|---|---|---|---|---|
| | | Uncontrolled | Controlled | |
| Staff Proposal (Non-Preempt Engines) | HC+NOx | 82.3 | 27.2 | 55.1 |
| | CO | 266.2 | 199.2 | 67.0 |
| Assumed Federal Action (Preempt Engines) | HC+NOx | 11.2 | 5.3 | 5.9 |
| | CO | 42.8 | 30.5 | 12.3 |
| **TOTAL** | **HC+NOx** | **93.5** | **32.5** | **61.0** |
| | **CO** | **308.9** | **229.7** | **79.2** |

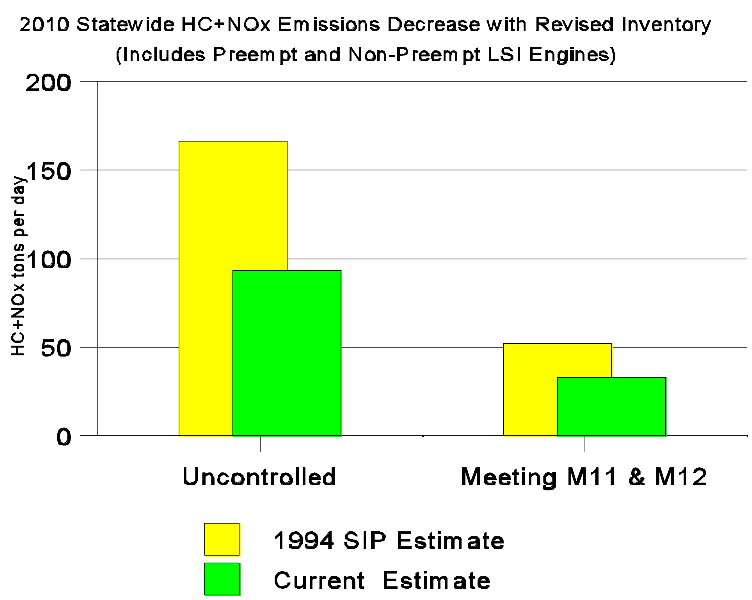
2. Impacts on the 1994 Ozone SIP and Inventory

The 1994 State Implementation plan (SIP) for Ozone is California's master plan for achieving the federal ozone standard in all areas of the state by the federally required date. The 1994 Ozone SIP includes state measures to control motor vehicles and pesticides, local measures for stationary and area sources, and federal measures for sources under exclusive or practical federal control. The 1994 Ozone SIP was approved by the U.S. EPA in September 1996. California’s SIPs for carbon monoxide and inhalable particulate matter (PM10) also rely on mobile source controls.

a. Inventory Updates - Since 1994, substantial improvements have been made to the emissions inventory for large spark-ignition engines. Updated data on activity, growth, population, emission rates (including emissions deterioration), and which engine applications are exclusively under the jurisdiction of the U.S. EPA (i.e., are preempted), have been incorporated into the revised inventory.

The inventory revisions show that the projected HC+NOx emissions in 2010 from uncontrolled engines is approximately 40 percent lower than anticipated in 1994. Much of this decrease results from new information showing a lower population, slower growth, and lower operational load factors. The HC/NOx split was also updated to show a shift toward a higher proportion of NOx emissions than was assumed in 1994. Figure 1 illustrates the impact of the revised estimates of large spark-ignition engine emissions. The 1994 SIP estimate shows the uncontrolled and controlled emissions assumed in the SIP. The current estimate uses the most current inventory and the staff's proposed controls.

Figure 1




b. Review of SIP Measure M11 - SIP Measure M11 requires existing technology to be applied in new ways. For regulations that require future phase-in of significant new standards, equipment, or processes, the ARB staff must periodically evaluate the technological, economic, and market feasibility of the regulations prior to implementation.

According to Volume II of the SIP, M11 and M12 are "based on [the] use of closed-loop three-way catalyst systems," which are "expected to reduce ROG by 75 percent, and NOx by at least 50 percent" (page B-14). As substantiated by the attached Technical Support Document (Attachment E), the staff has determined that the technological foundation of measure M11 is sound, although the specifics of the 1994 analysis have changed somewhat as more information has been gathered, particularly with regards to the emissions inventory and the percentage reductions achievable by 2010. These specifics are discussed below.

c. Assessing the SIP Commitment - Attainment of the national ozone ambient air quality standard is premised on reducing emissions to a specified level within an urban area. The maximum allowable emissions level is called the carrying capacity. Attainment of the federal ambient air quality standards requires that the carrying capacity not be exceeded. The 1994 SIP established this level for each nonattainment area, and the Board approved the emission reduction measures needed to achieve this level.

As noted earlier, the SIP goal for large spark-ignition engines is a 75 percent reduction of HC and 50 percent reduction of NOx, based on the introduction of closed-loop three-way catalyst systems. The combined ROG and NOx commitment in the SIP is a 68 percent reduction. Although the staff proposal is based on the use of closed-loop three-way catalyst systems, because the SIP did not fully account for the effects of deterioration on catalyst technology, the staff proposal would not achieve the required HC reduction. The proposal would, however, achieve more than the mandated NOx reduction. As Table 11 shows, the staff proposal would provide an HC reduction of 67 percent, while the NOx reduction would also be 67 percent. The combined ROG and NOx reduction of 67 percent meets the SIP performance standard commitment. The emissions reductions shown for M12 are based on the assumption that U.S. EPA will adopt the same standards and implement the regulation in the same timeframe as California. The discrepancies in the percentage reductions between the state and federal proposals are due to the different equipment types contained in the preempt and non-preempt categories (e.g., the preempt category contains agricultural equipment, which is typically long-lived, so the effects of any federal action would take longer to be reflected in the emissions inventory).

Table 11

2010 Statewide Benefit of the Proposal
Percentage Reductions from Uncontrolled

| Measure | Pollutant | Emissions Inventory | | Reduction | |
|---|---|---|---|---|---|
| | | Uncontrolled | Controlled | Percent | tons per day |
| **Staff Proposal (Non-Preempt Engines)** | HC+NOx | 82.3 | 27.2 | 67% | 55.1 |
| | HC | 18.2 | 6.0 | 67% | 12.2 |
| | NOx | 64.1 | 21.1 | 67% | 43.0 |
| | CO | 266.2 | 199.2 | 25% | 67.0 |
| Assumed Federal Action (Preempt Engines) | HC+NOx | 11.2 | 5.3 | 52% | 5.9 |
| | HC | 2.4 | 1.2 | 50% | 1.2 |
| | NOx | 8.8 | 4.1 | 53% | 4.7 |
| | CO | 42.8 | 30.5 | 29% | 12.3 |

d. Assessing the SIP Impacts of the Proposal - Because of the shift in the emissions inventory with respect to the allocation of preempt and non-preempt emissions, M11 and M12 measures should be considered jointly when evaluating their effect on the emissions inventory.

Table 12 summarizes how the revised inventory in the South Coast Air Basin would be affected by adoption of the M11 proposal and federal adoption of the M12 proposal, and how it compares with the SIP's emissions inventory estimate. The net result is that the remaining, or controlled emissions, under the proposal (along with M12) differ from the SIP emissions inventory projections by approximately 16 tons per day of HC+NOx. The difference is in part due to the changes described in the discussion of the emissions inventory model.

Table 12

Remaining Emissions From Large Spark-Ignition Engines Compared to the SIP Target for the South Coast Air Basin in 2010
HC+NOx (tons per day)

| Category | Emissions Inventory | | Difference |
|---|---|---|---|
| | Target based on SIP | Resulting from Staff Proposal* | |
| M11 (Non-Preempted) | 22 | 14 | -8 |
| M12 (Preempted) | 10 | 2 | -8 |
| Total | 32 | 16 | -16 |

* Reflects the assumption that the U.S. EPA will propose and adopt equivalent standards for preempt engines.

Tables 13 and 14 describe the tons per day reduction commitments in “SIP currency” for the Ventura, Sacramento, and South Coast air basins which relied upon reductions from M11 and M12. Tables 13 and 14 also show the emissions reductions expected from the proposed regulations in SIP currency. Although the commitment for the South Coast is the greatest, Ventura and Sacramento need to achieve their benefits five years earlier.

Because the 1994 SIP inventory did not include deterioration, the SIP currency benefits do not reflect the proposed regulation’s focus on in-use standards. The SIP currency estimate is a conservative estimate, assuming that engines emit at the in-use standard throughout their useful life, even though engines will certify (and operate) with lower emissions to allow for deterioration to the in-use standard.

Table 13

1994 SIP Commitments and Expected Emission Reductions for M11
(SIP Currency in tons per day)

| SIP Area | Attainment Year | Uncontrolled Inventory | | SIP Reduction Commitment | | Proposed Regulation Reductions | |
|---|---|---|---|---|---|---|---|
| | | ROG | NOx | ROG | NOx | ROG | NOx |
| Ventura | 2005 | 0.5 | 0.3 | 0.1 | 0.06 | 0.2 | 0.04 |
| Sacramento | 2005 | 0.9 | 0.6 | 0.2 | 0.1 | 0.3 | 0.09 |
| South Coast | 2010 | 35.5 | 24.2 | 23.0 | 11.6 | 25.4[2] | 7.3 |

Table 14

1994 SIP Commitments and Expected Emission Reductions for M12
(SIP Currency in tons per day)

| SIP Area | Attainment Year | Uncontrolled Inventory | | SIP Reduction Commitment | | Assumed Federal Action Reductions | |
|---|---|---|---|---|---|---|---|
| | | ROG | NOx | ROG | NOx | ROG | NOx |
| Ventura | 2005 | 0.4 | 0.2 | 0.2 | 0.1 | 0.1 | 0.05 |
| Sacramento | 2005 | 0.6 | 0.4 | 0.3 | 0.2 | 0.2 | 0.08 |
| South Coast | 2010 | 27.9 | 17.8 | 25.1 | 12.6 | 20.2 | 6.8 |

[2]Although it appears that the proposal would achieve greater ROG reductions that the SIP commitment, and equivalent federal action would achieve less, this is not the case. The SIP inadvertently attributed approximately 2 tons per day of ROG reductions under M12 that should have been attributed to M11. The proposed ROG reductions for both the proposal and the assumed federal action are virtually equivalent to the intended reductions in the SIP.

Although the staff's proposal meets the performance standard commitment in the SIP, using SIP currency, the proposal does not entirely achieve the tons per day reductions shown in the SIP. As noted earlier, the mix of equipment in the preempt category differs from that in the non-preempt category. The particular mix of equipment in the non-preempt category enable the staff proposal to essentially achieve the ROG tonnage reductions shown in the SIP. However, the proposal would not achieve the M11 NOx tons and the M12 NOx tons, in part due to the gasoline/LPG equipment mix, but largely due to the SIP currency not reflecting the durability aspects of the proposal. Although the SIP currency must be used to provide consistency with the legal obligations of the SIP, the SIP inventory does not reflect the significant improvements to the inventory since 1994.

Table 15 shows the emission benefits of the proposal, using the updated inventory model which enables full modeling of the effects of engine deterioration. It includes estimates for selected ozone SIP areas in the corresponding attainment years, and also the South Coast Air Basin and the San Joaquin Air Basin in 2006, the PM10 attainment date for those areas. The table shows that the staff proposal achieves significantly more NOx reductions than anticipated in the 1994 SIP, which will aid attainment of both the ozone and PM10 standards.

Table 15

Emission Reductions of Staff Proposal
Using Revised Emissions Inventory
(Preempt and Non-Preempt Engines)

| SIP Area | Attainment Year | ROG | NOx | CO | PM |
|---|---|---|---|---|---|
| Ventura | 2005 | 0.07 | 0.3 | 0.4 | 0 |
| Sacramento | 2005 | 0.1 | 0.5 | 1.7 | 0 |
| San Joaquin Valley | 2006 (particulate) | 0.4 | 1.5 | 2.5 | 0 |
| South Coast | 2006 (particulate) | 3.2 | 13.9 | 16.8 | 0 |
| South Coast | 2010 (Ozone) | 6.4 | 23.1 | 31.6 | 0 |

e. Summary of SIP Assessment – The staff's proposal meets the 1994 SIP commitment to achieve a 68 percent reduction in emissions of ROG and NOx from off-road spark-ignition engines. The proposal does not fully achieve the tons of reductions shown in the SIP, largely because the updated inventory is 40 percent lower than assumed in 1994. However, the staff's proposal responds to two major improvements to the inventory. More stringent NOx control than anticipated in the SIP addresses a shift in the inventory from ROG to NOx. In addition, the in-use standards will reduce emissions from deterioration which were not accounted for in the 1994 SIP.

## B. Economic Impacts

### 1. Cost and Cost-Effectiveness

In the May 1998 workshop, the various industry meetings, and Mail Out # 98-06, the staff requested that industry provide specific cost information so that the economic impact of the proposed regulations could be determined. As part of the testing and demonstration program being conducted for ARB, Southwest Research Institute also conducted an economic analysis. Staff evaluated the industry responses, along with cost information from its contractors, MECA, and other companies. The Southwest report is the basis for the methodology of the following presentation of incremental cost and cost effectiveness, with some modifications and additions based on other information made available to staff in response to staff's requests. Two basic cases, one utilizing cost data supplied in the Southwest report and the other using data made available by MECA, are presented.

The Southwest methodology combines all large spark-ignition engines into a typical engine with typical emission control equipment, mostly disregarding size or fuel choice (although a cost benefit for the elimination of the carburetor from gasoline engines is included). The typical equipment consists of the three-way catalyst, the closed-loop fuel control system and an EGR system. The EGR system was included in the cost analysis to provide a conservative result, even though most engines are expected to be able to meet the proposed standards without the need for EGR. Hardware cost data for each of the two cases are presented in Table 16.

Table 16

Variable Cost to Manufacturers
($/engine)

| Item | Southwest Research Institute data | MECA data |
|---|---|---|
| Closed-Loop Fuel Control | $300 | $550 |
| Three-Way Catalyst | $75 | (incl. above) |
| EGR Components | $40 | $40* |
| Removal of Carburetor | -$50 | -$50* |
| Manufacturing and Assembly Labor | $28 | $28* |
| Total | $393 | $568 |

* In the absence of specific data from MECA for these components, the staff has used the Southwest Research Institute data.

These costs are called variable because their impact on a manufacturer's total costs varies with the total number of engines sold. Note the modest savings since a carburetor is no longer needed. The manufacturing and assembly labor cost to install the new emissions control equipment is based on one half hour at $40 per hour with a 40 percent overhead.

Fixed costs are those costs to the manufacturer which remain constant regardless of the number of engines eventually produced. Their impact on individual engine retail price decreases with increasing production numbers. In this analysis, the fixed costs are considered the same for each of the two cases. Therefore, the more units a manufacturer sells, the lower the per-unit fixed costs. Table 17 shows a summary of the fixed costs, as taken from the Southwest analysis. They are based on a total of eight major engine manufacturers, a two year design and development (D&D) period, and then amortizing the total over ten years at 10 percent annual interest.

Table 17

Fixed Costs to Manufacturers

| Item | Cost |
|---|---|
| Engineering Labor | $2,600,000 per year for two years, 8 mfrs |
| Test Costs | $2,700,000 per year for two years, 8 mfrs |
| Technical Support | $80,000 per year for two years, 8 mfrs |
| Other Engineering Costs | $1,000,000 per year for two years, 8 mfrs |
| Tooling Costs | $4,000,000 , 8 mfrs |
| Total D&D and Tooling | $2,727,613 per year over 10 years, 8 mfrs |

The Southwest report assumed that little or no basic research would need to be conducted since the recommended technology is the same as that used in the automotive industry for many years. However, some development would be needed to modify large spark-ignition engines and equipment to accommodate the hardware and to gather calibration data. Accordingly, Table 17 reflects such things as the 300 emission tests per manufacturer and the 2 engineer-years per manufacturer that would be required for each year of the two year D&D effort. Staff suspects that some of these values are conservative, leading to higher cost estimates, but they represent the best information readily available.

Available information on sales indicate that California annual sales can be estimated as 11 percent of the nationwide annual sales[3]. Non-preempt California equipment sales are about 75 percent of total California sales. Table 18 presents sales estimates for preempted and non-preempted equipment based on these assumptions.

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[3] Nationwide sales estimates were based on 1994-1996 annual average sales from Power Systems Research.

Table 18

Equipment Annual Average Sales Estimates

| Segment | California Annual Sales | Nationwide Annual Sales |
|---|---|---|
| Non-Preempted | ***9,312*** | 84,656 |
| Preempted | 3,008 | 27,344 |
| Total | 12,320 | ***112,000*** |

Staff believes it is important to look at two limiting subcases. The first subcase is where the costs are totally attributed to developing engines for meeting California's SIP goals, meaning the costs would be spread over just the 9,312 non-preempted engines sold in California per year. The second, and perhaps more appropriate subcase, is to spread the costs over all 112,000 engines sold nationwide every year.

The Southwest cost methodology utilizes a 25 percent manufacturer's markup and a 10 percent dealer's markup to combine the variable and fixed costs into a retail price equivalent (RPE) for the incremental cost of the anticipated emission controls. Table 19 presents the per-engine costs for each of these two cases and two subcases.

Table 19

Emission Control Incremental Costs (RPE)

| Subcase | Southwest Research Institute Data | MECA Data |
|---|---|---|
| California Non-Preempted Sales (9,312 per year) | $865 per engine | $1105 per engine |
| Nationwide Total Sales (112,000 per year) | $569 per engine | $810 per engine |

The table shows that, as expected, Southwest's lower estimates (see Table 16) for the fixed costs lead to lower per engine incremental retail prices. This table also shows that spreading the cost per engine over the larger numbers of engines nationwide reduces the cost per engine. However, this latter effect is limited since the variable costs begin to dominate the total cost calculation, approaching the point where the fixed costs become less and less significant. The worst-case cost increase, $1,105 per engine, has been used for cost-effectiveness calculations in order not to underestimate the effect of the proposal. However, because the proposal has been developed in cooperation with the U.S. EPA, actual price increases are expected to be nearer the $569-810 range for nationwide implementation.

To determine the cost effectiveness of the proposed regulations, it is necessary to divide the incremental cost per engine for the expected emission controls by the expected emission reductions per engine due to the use of those controls. Table 20 presents the anticipated lifetime emission reductions for several typical equipment types. The lifetime emissions are derived using the average horsepower, annual usage, load factor, and useful life for each equipment type. The lifetime emission reductions is the difference between the uncontrolled and controlled (2004) lifetime emissions.

Table 20

Effect of the Proposal
Expected Lifetime Emission Reductions
(pounds)

| Equipment Type | Lifetime Reductions | | |
|---|---|---|---|
| | HC | NOx | HC+NOx |
| Forklifts Gasoline 50-120 hp | 2,259 | 5,554 | 7,814 |
| Forklifts LPG 50-120 hp | 1,180 | 4,736 | 5,916 |
| Turf Care 25-50 hp | 1,810 | 1,988 | 3,798 |
| Gen Sets 50-120 hp | 592 | 2,284 | 2,876 |
| Airport Lavatory Trucks 120-175 hp | 896 | 8,453 | 9,349 |

Using the costs presented in Table 19, Table 21 presents the results of the cost-effectiveness estimate.

Table 21

Expected NOx+NMHC Cost Effectiveness
Cost per Pound Reduced

| Subcase | Southwest Research Institute Data | | MECA Data | |
|---|---|---|---|---|
| | Range | Weighted Average | Range | Weighted Average |
| California Non-Preempted Sales (9,312 per year) | \$0.02 - \$2.97 | \$0.18 | \$0.02 - \$3.79 | \$0.23 |
| Nationwide Total Sales (112,000 per year) | \$0.01 - \$1.95 | \$0.12 | \$0.02 - \$2.78 | \$0.17 |

Although the cost-effectiveness figures can range as high as \$3.79 per pound reduced, using the worst-case assumptions, the cost effectiveness weighted by the total number of pounds reduced shows that the overall cost per pound reduced would vary from \$0.12 to \$0.23, depending on the assumptions used. These cost effectiveness numbers are on the low (i.e., favorable) end of the range of commonly accepted values for past regulatory efforts. For example, they compare well with the cost effectiveness numbers for using four-stroke engines in blowers, trimmers and chain saws based on the recently-approved small off-road engine regulations (\$0.28 to \$0.75 per pound of NOx+non-methane HC (NMHC) reduced) or that of the recent heavy-duty on-road truck regulations (\$0.05 to \$0.60 per pound of NOx+NMHC reduced). The benchmark values of cost effectiveness for regulations adopted by the ARB and districts are \$5 per pound of NOx or NMHC, with an upper limit of \$11 per pound. Note that even the upper end of the range for the worst-case estimates falls below these benchmark values.

2. Economic Impacts on the Economy of the State

a. Summary of Economic Impact on the State - Overall, most manufacturers of off-road large spark-ignition engines and original equipment using such engines are able to comply with the proposed regulation with no significant impact on their financial results. These manufacturers are mostly located outside California. However, some of them may have small operations in California. These manufacturers are generally expected to pass on the compliance costs to equipment operators in California. The expected increase in the retail price of an engine is estimated to be about $1,000, but its impact on equipment operators is likely to be offset by improvement in engine technology. The cost impact of the proposed regulation to equipment users, thus, is likely to be negligible over the life of engine. As a result, staff expects the proposed regulation to impose no significant adverse impacts on California competitiveness, employment, and business status.

b. Legal Requirements - Section 11346.3 of the Government Code requires State agencies to assess the potential for adverse economic impacts on California business enterprises and individuals when proposing to adopt or amend any administrative regulation. The assessment shall include a consideration of the impact of the proposed regulation on California jobs, business expansion, elimination, or creation, and the ability of California business to compete.

Also, State agencies are required to estimate the cost or savings to any state, local agency and school district in accordance with instructions adopted by the Department of Finance. The estimate shall include any nondiscretionary cost or savings to local agencies and the cost or savings in federal funding to the state.

c. Businesses Affected - Any business involved in the production or use of large off-road spark-ignition engines would potentially be affected by the proposed regulation. These engines are used in industrial equipment such as forklifts, airport ground equipment, generator sets, mining equipment, refrigeration units, scrubber/sweepers, turf care equipment, speciality vehicles, etc. Also affected are manufacturers which supply components for engines and industrial equipment and distributors and retailers which sell those equipment. The focus of this analysis, however, will be on engine manufacturers which will be affected directly by the proposed regulation. There are about 16 engine manufacturers which may be impacted by the proposed regulation; eight are considered to be major manufacturers. None of these manufacturers is located in California, although some may have small operations in California. A few manufacturers of industrial equipment and engine components are, however, located in California although they do not account for a significant share of the market.

d. Potential Impact on Manufacturers - Engine manufacturers currently have numerous options to meet the requirements of the proposed regulation. These include the use of the best available automotive technology such as three-way catalyst with closed-loop electronic fuel injection or a combination of older technologies such as air-fuel ratio calibration, spark timing calibration, exhaust gas circulation (EGR), air injection, improved open loop carburetor, and oxidation or three-way catalyst. Although the older technology potentially costs less, staff believes that most manufacturers are likely to use a closed-loop, electronic fuel injection system with three-way catalyst to comply with the proposed regulation.

Based on the use of the best available automotive technology, staff estimates that the proposed regulation will increase average annual costs of manufacturing of off-road large spark-ignition engine by about $7.9 annually. A detailed analysis of these costs is provided in the study prepared by Southwest Research Institute for the Air Resources Board. A small number of well-diversified and large manufacturers will incur the bulk of the cost increase. These manufacturers are most likely to pass on the bulk of the cost increase to equipment operators. Low-volume engine manufactures are unlikely to spend much of their own resources on this effort, they are more likely to rely on their suppliers. As a result, the proposed regulation is expected to have no noticeable adverse impact on affected manufacturers.

e. Potential Impact on Distributors and Dealers - Most engine and equipment manufacturers sell their products through distributors and dealers, of which some are owned by manufacturers and some are independent. These distributors and dealers are not directly affected by the proposed regulation. However, the regulation may affect them indirectly in two ways. First, an increase in prices of industrial equipment could potentially reduce sales volume. Dealers' revenue would be impacted adversely if the reduction in sales volume exceed the increase in prices. Second, adequate supplies of new engines may not be available in a timely manner, thereby resulting in a loss of sales.

Staff believes these effects are unlikely to cause a significant adverse impact on distributors and dealers. First, because most distributors and dealer are expected to pass on any increase in equipment prices to operators because all competing equipment will increase in prices as a result of the proposed regulations. In addition, new engines are potentially more fuel efficient and durable. Second, the U.S. EPA is planning to adopt similar regulations in 1999. The harmonization of the state and federal regulations is likely to stabilize supplies of all new engine models.

f. Potential Impact on Equipment Operators - The potential impact of the proposed regulation on the retail prices of affected industrial equipment hinges on the ability of manufacturers to pass on the cost increases to operators of such equipment. Assuming that manufacturers are able to pass on the entire costs of compliance to operators, staff estimates the average retail price of an engine would increase by an average of about $1,000 per unit. Since an average of about 9,300 equipment are sold in California annually, total costs to California operators are estimated to be around $9.3 million. However, California operators are expected to recover the bulk of the cost increase indirectly. This is because some new engines are expected to be more fuel efficient and possibly all new engine will be durable. Given that new engines are likely to be more fuel efficient and have longer life, the life-time cost impact of the proposed regulation on California businesses and individuals is expected to be negligible

g. Potential Impact on Business Competitiveness - The proposed regulation would have no significant impact on the ability of California businesses to compete with businesses in other states. This is because all manufacturers of engines and equipment that sell their products in California are subject to the proposed regulation, regardless of their location. Furthermore, all engine manufacturers and most equipment manufacturers are located outside California. Finally, California operators of affected equipment would not be impacted significantly because the proposed regulation has a minor impact on the lifetime value of such equipment. Finally, the U.S. EPA is expected to adopt similar regulations in 1999.

h. Potential Impact on Employment - The proposed regulation is not expected to cause a noticeable change in California employment. California accounts only for small share of manufacturing employment in industrial equipment and components production. Besides, most engine and equipment manufacturers are expected to pass on the compliance costs to equipment operators. However, the lifetime cost impact of the proposed regulations on equipment operators are not expected to be significant because new engines are likely to operate more efficiently and have a better performance life than existing engines.

Some jobs may actually be created in California as a result of the proposed regulation. The regulation would possibly stimulate the demand for manufacturers of fuel system components and after-treatment devices, of which some are located in California. An expansion of production by California manufacturers to meet higher demand may in turn lead to creation of new jobs.

i. Potential Impact on Business Creation, Elimination, or Expansion - The proposed regulation would cause no significant change in the status of California businesses. The regulation would potentially increase the retail price of an engine by an average of about $1,000. The price increase is unlikely to dampen demand for industrial equipment significantly because the impact of the price increase is expected to be offset by improvement in engine technology. In addition, the regulation is likely to stimulate demand for fuel system components and after-treatment devices, resulting in an expansion of production for some California manufacturers.

C. Issues of Controversy

Although the staff has made every effort to resolve issues to the mutual benefit of the air and the industry, some issues of controversy remain.

1. Test Cycle-NACCO

NACCO Material Handling Group, a forklift manufacturer, has stated that the C2 test cycle is not appropriate for forklift engines. NACCO presented two reasons: 1) NACCO's in-house test data indicate that the engine load factor for the C2 cycle is too high, and 2) the definition for engine speeds does not address the different operating characteristics of various engine speed governors. NACCO recommends that the C2 cycle should be modified and the definition for engine speed should be revised.

The C2 emissions test cycle was developed, with extensive industry input, to represent the majority of engine operation. NACCO’s suggested modification to the test cycle may reflect NACCO’s operations, but, unlike the C2 cycle, is not generally accepted as representative of typical forklift engine operation. Thus staff does not agree with NACCO’s suggested modifications.

With regards to the definition of engine speed, NACCO contends that engine speed (intermediate and rated) should be revised to reflect the use of pneumatic, mechanical, and electric governors. In essence, all engines should be tested in each "governed" engine configuration. Modification to the speed definitions based on a manufacturer's hardware selection (governors) would limit and encroach on other manufacturer’s engine component choices. Currently, exhaust emission certification is based on the worst-case emission engine configuration within an engine family. A manufacturer using two different types of governors would test only the worst-case engine for the engine family. NACCO's suggested changes would result in each engine code being tested to certify the engine family. Therefore, staff recommends no changes to the C2 test cycle.

2. Useful Life Periods

The Engine Manufacturers Association, Industrial Truck Association, and Outdoor Power Equipment Institute, representing the engine and equipment manufacturing industries, have stated that the proposed useful life periods of 3,000 hours for engines less than one liter and 5,000 hours for engines one liter and greater are too long. They instead suggest that 1,500 hours and 3,000 hours, respectively, would be more appropriate for these engines. The manufacturers stated that the staff's use of Power Systems Research data on engine lives was inappropriate, and essentially doubled the periods in question. Despite the manufacturers assertions, Power Systems Research has verified that the staff used the data correctly. Thus the staff stands by the useful life periods as proposed.

3. Small Engines

Two engine manufacturers who currently do not produce engines greater than 25 horsepower (Kohler and Briggs & Stratton), have stated that the emission standards for large spark-ignition engines less than one liter in displacement should be the same as the small off-road engine emission standards. However, another engine manufacturer who produces large spark-ignition engines less than one liter has stated that the proposed emission standards are achievable without any difficulties. In addition, the small off-road engine regulations were premised on the capabilities of the smaller engines in that category. Staff acknowledges that the less than one liter engines are different than the larger (greater than one liter) engines and thus propose less stringent standards for them. However, staff does not believe that using the small off-road engine standards would be appropriate, and would result in a loss of emission reduction since the under 25 horsepower standards are numerically less stringent.

4. ATV Definition

Some manufacturers have asked that the definition of ATV be expanded to include all ATVs regardless of vehicle weight. The current definition of ATVs (CCR, Title 13, section 2411) has an upper weight limit of 600 pounds. Vehicles over 600 pounds are defined as specialty vehicles. Thus, specialty vehicles with engines greater than 25 horsepower would be included in this proposal. Staff has examined product literature, and determined that the ATV weight limit provides a logical cut point between an ATV commonly used for recreation and vehicles used to transport people and materials which are specialty vehicles.

5. National Specifications for LPG

Some manufacturers have argued that the lack of a national standard for LPG means that LPG equipment cannot be certified. Staff disagrees. Although national specifications would be desirable, and would increase harmonization, the existing California specifications would be used for certification and other emissions tests. Service accumulation, including accumulation for in-use testing, could be done with commercially-available fuel.

D. Alternatives considered

1. Evaluation of Alternatives Considered

The primary alternative the staff considered was the deletion of the 2001-2003 requirements and allowing the U.S. EPA to fully implement the program. The large spark-ignition engine industry strongly supported this alternative. However, the 2004 program would not, by itself, provide sufficient emissions reduction by 2005 (for Sacramento) or even by 2010 (for the South Coast). It would also be inconsistent with the SIP, which reflects earlier introduction of complying engines, and would place implementation of measures M11 and M12 fully with U.S. EPA, where ARB would be just one of many interested parties involved in establishing the effectiveness and timing of the federal regulations.

The staff also considered a performance standard in place of the prescriptive closed crankcase requirement. However, the requirement is already met by a majority of the engines in the category and virtually all engines in other regulated categories have a similar requirement. The staff concluded that the requirement would be less onerous to manufacturers than the imposition of an additional test procedure and further tests.

### 2. Conclusion

The proposal described herein would reduce HC+NOx emissions in a cost-effective manner. No alternative considered by the agency would be more effective in carrying out the purpose for which the regulation is proposed or would be as effective or less burdensome to affected private persons than the proposed regulation.

# REFERENCES


1. Southwest Research Institute, ARB Contract No. 95-340, "Three-Way Catalyst Technology for Off-Road Equipment Powered by Gasoline and LPG Engines -- Interim Report," April 1998.

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3. Manufacturers of Emissions Controls Association, Dale McKinnon, et al., 1997-1998.

4. Air Resources Board, "State Implementation Plan," November 1994.

5. ISO 8178

6. Society of Automotive Engineers, J1228