California Environmental Protection Agency

AIR RESOURCES BOARD

A REPORT TO THE CALIFORNIA LEGISLATURE ON THE POTENTIAL HEALTH AND ENVIRONMENTAL IMPACTS OF LEAF BLOWERS

Mobile Source Control Division

February 2000

State of California
AIR RESOURCES BOARD

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Public Hearing: January 27, 2000
Date of Revision: February 29, 2000

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

Background and Overview

California Senate Concurrent Resolution No. 19 (SCR 19) requests the Air Resources Board (ARB) to prepare and submit a report to the Legislature on or before January 1, 2000, summarizing the potential health and environmental impacts of leaf blowers and including recommendations for alternatives to the use of leaf blowers and alternative leaf blower technology, if the ARB determines that alternatives are necessary. The goal of this report is to summarize for the California Legislature existing data on health and environmental impacts of leaf blowers, to identify relevant questions not answered in the literature, and suggest areas for future research.

The leaf blower was invented in the early 1970s and introduced to the United States as a lawn and garden maintenance tool. Drought conditions in California facilitated acceptance of the leaf blower as the use of water for many garden clean-up tasks was prohibited. By 1990, annual sales were over 800,000 nationwide, and the tool had become a ubiquitous gardening implement. In 1998, industry shipments of gasoline-powered handheld and backpack leaf blowers increased 30% over 1997 shipments, to 1,868,160 units nationwide.

Soon after the leaf blower was introduced into the U.S., its use was banned as a noise nuisance in two California cities, Carmel-by-the-Sea in 1975 and Beverly Hills in 1978. By 1990, the number of California cities that had banned the use of leaf blowers was up to five. There are currently twenty California cities that have banned leaf blowers, sometimes only within residential neighborhoods and usually targeting gasoline-powered equipment. Another 80 cities have ordinances on the books restricting either usage or noise level or both. Other cities have considered and rejected leaf blower bans. Nationwide, two states, Arizona and New Jersey, have considered laws at the state level, and five other states have at least one city with a leaf blower ordinance.

The issues usually mentioned by those who object to leaf blowers are health impacts from noise, air pollution, and dust. Municipalities regulate leaf blowers most often as public nuisances in response to citizen complaints. Two reports were located that address environmental concerns: the Orange County Grand Jury Report, and a series of reports from the City of Palo Alto City Manager's office. The City of Palo Alto reports were produced in order to make recommendations to the City Council on amending their existing ordinance. The Orange County Grand Jury took action to make recommendations to improve the quality of life in Orange County, and recommended that cities, school districts, community college districts, and the County stop using gasoline-powered leaf blowers in their maintenance and clean-up operations. The major findings of each are similar: leaf blowers produce exhaust emissions, resuspend dust, and generate high noise levels.

As per SCR 19, this report includes a comprehensive review of existing studies of the impacts of leaf blowers on leaf blower operators and on the public at large, and of the availability and actual use

of protective equipment for leaf blowers. The receptors identified by the resolution are humans and the environment; sources of impacts are exhaust, noise, and dust. Because the Legislature specified that ARB use existing information, staff conducted no new studies. In order to locate existing data, staff searched the published literature, contacted potential resources and experts, and requested data from the public via mail and through a web page devoted to the leaf blower report. Two public workshops were held in El Monte, California, to facilitate further discussions with interested parties.

The methodology followed for this report depends on both the objectives of SCR 19 and available data. As staff discovered, in some areas, such as exhaust emissions, much is known; in other areas, such as fugitive dust emissions, we know very little. For both fugitive dust and noise, there are few or no data specifically on leaf blower impacts. For all hazards, there have been no dose-response studies related to emissions from leaf blowers, we do not know how many people are affected by those emissions, and no studies were located that address potential health impacts from leaf blowers. Therefore, staff determined to provide the Legislature with a report that has elements of both impact and risk assessments.

The body of the report comprises three components, following the introduction: hazard identification, review of health effects, and a characterization of the potential impacts of leaf blowers on operators and bystanders. In Section II, the emissions are quantified as to specific hazardous constituents, the number of people potentially exposed to emissions is discussed, and laws that seek to control emissions are summarized. Section III reviews health effects, identifying the range of potential negative health outcomes of exposure to the identified hazards. Section IV is a synthesis of hazard identification and health effects, characterizing potential health impacts that may be experienced by those exposed to the exhaust emissions, fugitive dust, and noise from leaf blowers in both occupational and non-occupational setting. Section V discusses recommendations. Additional information, including a discussion of research needs to make progress toward answering some of the questions raised by this report, a description of engine technologies that could reduce exhaust emissions and alternatives to leaf blowers, and a complete bibliography of materials received and consulted but not cited in the report, is found in the appendices.

Description of the Hazards

Hazard identification is the first step in an impact or risk assessment. Each of the three identified hazards are examined in turn, exhaust emissions, dust emissions, and noise. For each, the hazard is described and quantified, to the extent possible, and the number of people potentially exposed to the hazard is discussed. For exhaust emissions, the number of people potentially impacted is as high as the population of the state, differing within air basins. Fugitive dust emissions impact a varying number of people, depending on one?s proximity to the source, the size of the particles, and the amount of time since the source resuspended the particles. Finally, we also discuss laws that control the particular hazard.

Exhaust emissions from leaf blowers consist of the following specific pollutants of concern: hydrocarbons from both burned and unburned fuel, and which combine with other gases in the

atmosphere to form ozone; carbon monoxide; fine particulate matter; and other toxic air contaminants in the unburned fuel, including benzene, 1,3-butadiene, acetaldehyde, and formaldehyde. Exhaust emissions from these engines, while high compared to on-road mobile sources on a per engine basis, are a small part of the overall emission inventory. Emissions have only been controlled since 1995, with more stringent standards taking effect in 2000. The exhaust emissions from leaf blowers are consistent with the exhaust emissions of other, similar off-road equipment powered by small, two-stroke engines, such as string trimmers. Manufacturers have developed several different methods to comply with the standards and have done an acceptable job certifying and producing engines that are below the regulated limits. Electric-powered models that are exhaust-free are also available.

Data on fugitive dust indicate that the PM10 emissions impacts from dust suspended by leaf blowers are small, but probably significant. Previous emission estimates range from less than 1% to 5% of the statewide PM10 inventory. The ARB previously estimated statewide fugitive dust emissions to be about 5 percent of the total, the Sacramento Metropolitan AQMD estimated leaf blower fugitive dust emissions to be about 2 percent of the Sacramento county PM10 air burden, and AeroVironment estimated dust attributable to leaf blowers in the South Coast Air Basin to be less than 1% of all fugitive dust sources. Dust emissions attributable to leaf blowers are not part of the inventory of fugitive dust sources. ARB, therefore, does not have official data on the quantity of fugitive dust resuspended by leaf blowers. A more definitive estimate of leaf blower fugitive dust emissions will require verification of appropriate calculation parameters and representative silt loadings, measurement of actual fugitive dust emissions through source testing, and identification of the composition of leaf blower-generated fugitive dust.

Noise is the general term for any loud, unmusical, disagreeable, or unwanted sound, which has the potential of causing hearing loss and other adverse health impacts. While millions of Californians are likely exposed to noise from leaf blowers as bystanders, given the ubiquity of their use and the increasing density of California cities and towns, there is presently no way of knowing for certain how many are actually exposed, because of the lack of studies. In contrast, it is likely that at least 60,000 lawn and garden workers are daily exposed to the noise from leaf blowers. Many gardeners and landscapers in southern California are aware that noise is an issue and apparently would prefer quieter leaf blowers. Purchases of quieter leaf blowers, based on manufacturer data, are increasing. While little data exist on the noise dose received on an 8-hr time-weighted-average by operators of leaf blowers, data indicate that some operators may be exposed above the OSHA permissible exposure limit. It is unlikely that more than 10% of leaf blower operators and members of the gardening crew, and probably a much lower percentage, regularly wear hearing protection, thus exposing them to an increased risk of hearing loss. The sound quality of gasoline-powered leaf blowers may account for the high level of annoyance reported by bystanders.

Review of Health Effects

Potential health effects from exhaust emissions, fugitive dust, and noise range from mild to serious. Fugitive dust is not a single pollutant, but rather is a mixture of many subclasses of pollutants,

each containing many different chemical species. Many epidemiological studies have shown statistically significant associations of ambient particulate matter levels with a variety of negative health endpoints, including mortality, hospital admissions, respiratory symptoms and illness, and changes in lung function. Carbon monoxide is a component of exhaust emissions which causes health effects ranging from subtle changes to death. At low exposures, CO causes headaches, dizziness, weakness, and nausea. Children and people with heart disease are particularly at risk from CO exposure. Some toxic compounds in gasoline exhaust, in particular benzene, 1,3-butadiene, acetaldehyde, and formaldehyde, are carcinogens. Ozone, formed in the presence of sunlight from chemical reactions of exhaust emissions, primarily hydrocarbons and nitrogen dioxide, is a strong irritant and exposures can cause airway constriction, coughing, sore throat, and shortness of breath. Finally, noise exposures can damage hearing, and cause other adverse health impacts, including interference with communication, rest and sleep disturbance, changes in performance and behavior, annoyance, and other psychological and physiological changes that may lead to poor health.

Potential Health and Environmental Impacts of Leaf Blowers

Health effects from hazards identified as being generated by leaf blowers range from mild to serious, but the appearance of those effects depends on exposures: the dose, or how much of the hazard is received by a person, and the exposure time. Without reasonable estimates of exposures, ARB cannot conclusively determine the health impacts from leaf blowers; the discussion herein clearly is about potential health impacts. The goal is to direct the discussion and raise questions about the nature of potential health impacts for those exposed to the exhaust emissions, fugitive dust, and noise from leaf blowers in both occupational and non-occupational settings.

For the worker, the analysis suggests concern. Bearing in mind that the worker population is most likely young and healthy, and that these workers may not work in this business for all of their working lives, we nonetheless are cautioned by our research. Leaf blower operators may be exposed to potentially hazardous concentrations of CO and PM intermittently throughout their work day, and noise exposures may be high enough that operators are at increased risk of developing hearing loss. While exposures to CO, PM, and noise may not have immediate, acute effects, the potential health impacts are greater for long term exposures leading to chronic effects. In addition, evidence of significantly elevated concentrations of benzene and 1,3-butadiene in the breathing zone of operators leads to concern about exposures to these toxic air contaminants.

Potential noise and PM health impacts should be reduced by the use of appropriate breathing and hearing protective equipment. Employers should be more vigilant in requiring and ensuring their employees wear breathing and hearing protection. Regulatory agencies should conduct educational and enforcement campaigns, in addition to exploring the extent of the use of protective gear. Exposures to CO and other air toxics are more problematic because there is no effective air filter. More study of CO and other air toxics exposures experienced by leaf blower operators is warranted to determine whether the potential health effects discussed herein are actual effects or not.

Describing the impacts on the public at large is more difficult than for workers because people?s exposures and reactions to those exposures are much more variable. Bystanders are clearly annoyed and stressed by the noise and dust from leaf blowers. They can be interrupted, awakened, and may feel harassed, to the point of taking the time to contact public officials, complain, write letters and set up web sites, form associations, and attend city council meetings. These are actions taken by highly annoyed individuals who believe their health is being negatively impacted. In addition, some sensitive individuals may experience extreme physical reactions, mostly respiratory symptoms, from exposure to the kicked up dust.

On the other hand, others voluntarily purchase and use leaf blowers in their own homes, seemingly immune to the effects that cause other people such problems. While these owner-operators are likely not concerned about the noise and dust, they should still wear protective equipment, for example, eye protection, dust masks, and ear plugs, and their exposures to CO are a potential problem and warrant more study.

Recommendations

The Legislature asked ARB to include recommendations for alternatives in the report, if ARB determines alternatives are necessary. This report makes no recommendations for alternatives. Based on the lack of available data, such conclusions are premature at this time. Exhaust standards already in place have reduced exhaust emissions from the engines used on leaf blowers, and manufacturers have significantly reduced CO emissions further than required by the standards. Ultra-low or zero exhaust emitting leaf blowers could further reduce public and worker exposures. At the January 27, 2000, public hearing, the Air Resources Board directed staff to explore the potential for technological advancement in this area.

For noise, the ARB has no Legislative mandate to control noise emissions, but the evidence seems clear that quieter leaf blowers would reduce worker exposures and protect hearing, and reduce negative impacts on bystanders. In connection with this report, the Air Resources Board received several letters urging that the ARB or another state agency set health-based standards for noise and control noise pollution.

A more complete understanding of the noise and the amount and nature of dust resuspended by leaf blower use and alternative cleaning equipment is suggested to guide decision-making. Costs and benefits of cleaning methods have not been adequately quantified. Staff estimates that a study of fugitive dust generation and exposures to exhaust emissions and dust could cost $1.1 million, require two additional staff, and take two to three years. Adding a study of noise exposures and a comparison of leaf blowers to other cleaning equipment could increase study costs to $1.5 million or more (Appendix H).

Fugitive dust emissions are problematic. The leaf blower is designed to move relatively large materials, which requires enough force to also blow up dust particles. Banning or restricting the use of

leaf blowers would reduce fugitive dust emissions, but there are no data on fugitive dust emissions from alternatives, such as vacuums, brooms, and rakes. In addition, without a more complete analysis of potential health impacts, costs and benefits of leaf blower use, and potential health impacts of alternatives, such a recommendation is not warranted.

Some have suggested that part of the problem lies in how leaf blower operators use the tool, that leaf blower operators need to show more courtesy to passersby, shutting off the blower when people are walking by. Often, operators blow dust and debris into the streets, leaving the dust to be resuspended by passing vehicles. Interested stakeholders, including those opposed to leaf blower use, could join together to propose methods for leaf blower use that reduce noise and dust generation, and develop and promote codes of conduct by workers who operate leaf blowers. Those who use leaf blowers professionally would then need to be trained in methods of use that reduce pollution and potential health impacts both for others and for themselves.

I. INTRODUCTION

A. Background

California Senate Concurrent Resolution No. 19 (SCR 19) was introduced by Senator John Burton February 23, 1999, and chaptered May 21, 1999 (Appendix A). The resolution requests the Air Resources Board (ARB) to prepare and submit a report to the Legislature on or before January 1, 2000, "summarizing the potential health and environmental impacts of leaf blowers and including recommendations for alternatives to the use of leaf blowers and alternative leaf blower technology if the state board determines that alternatives are necessary." The Legislature, via SCR 19, raises questions and concerns about potential health and environmental impacts from leaf blowers, and requests that ARB write the report to help to answer these questions and clarify the debate. The goal of this report, then, is to summarize for the California Legislature existing data on health and environmental impacts of leaf blowers, to identify relevant questions not answered in the literature, and suggest areas for future research.

As per SCR 19, this report includes a comprehensive review of existing studies of the impacts of leaf blowers on leaf blower operators and on the public at large, and of the availability and actual use of protective equipment for leaf blowers. The receptors identified by the resolution are humans and the environment; sources of impacts are exhaust, noise, and dust. Because the Legislature specified that ARB use existing information, staff conducted no new studies. In order to locate existing data, staff searched the published literature, contacted potential resources and experts, and requested data from the public via mail and through a web page devoted to the leaf blower report.

B. History of the Leaf Blower and Local Ordinances

The leaf blower was invented by Japanese engineers in the early 1970s and introduced to the United States as a lawn and garden maintenance tool. Drought conditions in California facilitated acceptance of the leaf blower as the use of water for many garden clean-up tasks was prohibited. By 1990, annual sales were over 800,000 nationwide, and the tool had become a ubiquitous gardening implement (CQS 1999a). In 1998, industry shipments of gasoline-powered handheld and backpack leaf blowers increased 30% over 1997 shipments, to 1,868,160 units nationwide (PPEMA 1999).

Soon after the leaf blower was introduced into the U.S., its use was banned in two California cities, Carmel-by-the-Sea in 1975 and Beverly Hills in 1978, as a noise nuisance (CQS 1999a, Allen 1999b). By 1990, the number of California cities that had banned the use of leaf blowers was up to five. There are currently twenty California cities that have banned leaf blowers, sometimes only within residential neighborhoods and usually targeting gasoline-powered equipment. Another 80 cities have ordinances on the books restricting either usage or noise level or both. Other cities have considered and

rejected leaf blower bans. Nationwide, two states, Arizona and New Jersey, have considered laws at the state level, and five other states have at least one city with a leaf blower ordinance (IME 1999).

Many owners of professional landscaping companies and professional gardeners believe that the leaf blower is an essential, time- and water-saving tool that has enabled them to offer services at a much lower cost than if they had to use rakes, brooms, and water to clean up the landscape (CLCA 1999). A professional landscaper argues that the customer demands a certain level of garden clean-up, regardless of the tool used (Nakamura 1999). The issues continue to be debated in various public forums, with each side making claims for the efficiency or esthetics of leaf blower use versus rakes and brooms. Leaf blower sales continue to be strong, however, despite the increase in usage restrictions by cities.

C. Environmental Concerns

The issues usually mentioned by those who object to leaf blowers are health impacts from noise, air pollution, and dust (Orange County Grand Jury 1999). The Los Angeles Times Garden Editor, Robert Smaus (1997), argues against using a leaf blower to remove dead plant material, asserting that it should be left in place to contribute to soil health through decomposition. Municipalities regulate leaf blowers most often as public nuisances in response to citizen complaints (for example, City of Los Angeles 1999). Two reports were located that address environmental concerns: an Orange County Grand Jury report (1999), and a series of reports written by the City Manager of Palo Alto (1999a, 1998a, 1998b). The purpose of the City of Palo Alto reports is to develop recommendations to the City Council on amending its existing ordinance. The Orange County Grand Jury took action to make recommendations that would ? improve the quality of life in Orange County,? and recommended that cities, school districts, community college districts, and the County stop using gasoline-powered leaf blowers in their maintenance and clean-up operations. The major findings of each are similar (Table 1).

Table 1. Major Findings of the Orange County Grand Jury and City of Palo Alto

Orange County Grand Jury Report (1999)	**City of Palo Alto City Manager? s Report (1999a)**
(1) Toxic exhaust fumes and emissions are created by gas-powered leaf blowers.	(1) Gasoline-powered leaf blowers produce fuel emissions that add to air pollution.
(2) The high-velocity air jets used in blowing leaves whip up dust and pollutants. The particulate matter (PM) swept into the air by blowing leaves is composed of dust, fecal matter, pesticides, fungi, chemicals, fertilizers, spores, and street dirt which consists of lead and organic and elemental carbon.	(2) Leaf blowers (gasoline and electric) blow pollutants including dust, animal droppings, and pesticides into the air adding to pollutant problems.

(3) Blower engines generate high noise levels. Gasoline-powered leaf blower noise is a danger to the health of the blower operator and an annoyance to the non-consenting citizens in the area of usage.	(3) Leaf blowers (gasoline and electric) do produce noise levels that are offensive and bothersome to some individuals.

As will be discussed in more detail later in this report, the findings in these two reports about exhaust emissions and noise are substantiated in the scientific literature. The report?s findings regarding dust emissions, however, were not documented or based on scientific analysis of actual emissions, but were based on common sense knowledge. The City of Palo Alto continued to examine the issue, at the behest of council members, and reported revised recommendations for the use of leaf blowers in Palo Alto in September (City of Palo Alto 1999b) and January 2000 (City of Palo Alto 2000). The City of Palo Alto subsequently voted to ban the use of fuel-powered leaf blowers throughout the city as of July 1, 2001 (Zinko 2000).

D. Health and Environmental Impacts

SCR 19 asks ARB to summarize potential health and environmental impacts of leaf blowers, and thus our first task is to determine what information and analysis would comprise a summary of health and environmental impacts. The methodology followed for this report is dependent both on the objectives of SCR 19 and on the available data. As staff discovered, in some areas, such as exhaust emissions, we know much; in other areas, such as fugitive dust emissions, we know very little. For both fugitive dust and noise, there are few or no data specifically on leaf blower impacts. For all hazards, there have been no dose-response studies related to emissions from leaf blowers and we do not know how many people are affected by those emissions. Therefore, staff determined to provide the Legislature with a report that has elements of both impact and risk assessments, each of which is described below.

1. Life-cycle Impact Assessment

Life-cycle impact assessment is the examination of potential and actual environmental and human health effects related to the use of resources and environmental releases (Fava et al. 1993). A product?s life-cycle is divided into the stages of raw materials acquisition, manufacturing, distribution/transportation, use/maintenance, recycling, and waste management (Fava et al. 1991). In this case, the relevant stage of the life-cycle is use/maintenance. Life-cycle impact assessment tends to focus on relative emission loadings and resources use and does not directly or quantitatively measure or predict potential effects or identify a causal association with any effect. Identification of the significance and uncertainty of data and analyses are important (Barnthouse 1997).

2. Risk Assessment

A traditional risk assessment, on the other hand, seeks to directly and quantitatively measure or predict causal effects. A risk assessment evaluates the toxic properties of a chemical or other hazard, and the conditions of human exposure, in order to characterize the nature of effects and determine the likelihood of adverse impacts (NRC 1983). The four components of a risk assessment are:

Hazard identification: Determine the identities and quantities of chemicals present, the types of hazards they may produce, and the conditions under which exposure occurs.
Dose-response assessment: Describe the quantitative relationship between the amount of exposure to a substance (dose) and the incidence of adverse effects (response).
Exposure assessment: Identify the nature and size of the population exposed to the substance and the magnitude and duration of their exposure.
Risk characterization: Integrate the data and analyses of the first three components to determine the likelihood that humans (or other species) will experience any of the various adverse effects associated with the substance.

The goal of risk assessment is the quantitative characterization of the risk, i.e., the likelihood that a certain number of individuals will die or experience another adverse endpoint, such as injury or disease. A risk assessment is ideally followed up by risk management, which is the process of identifying, evaluating, selecting, and implementing actions to reduce risk to human health and ecosystems (Omenn et al. 1997). While a risk assessment appears to be preferable because it allows us to assign an absolute value to the adverse impacts, a quantitative assessment is difficult, if not impossible, to perform when data are limited.

E. Public Involvement

To facilitate public involvement in the process of preparing the leaf blower report, staff mailed notices using existing mailing lists for small off-road engines and other interested parties, posted a leaf blower report website, met with interested parties, and held two public workshops, in June and September, 1999. In addition to face-to-face meetings and workshops, staff contacted interested parties through numerous telephone calls and e-mails. A list of persons contacted for this report is found in Appendix B. Letters and documents submitted to the Air Resources Board as of December 15, 1999, are listed in Appendix K. The vast majority of those contacted were very helpful, opening their files and spending time answering questions. ARB staff were provided with manufacturer brochures; unpublished data; old, hard-to-find reports and letters; and given briefings and demonstrations. Many reports have been posted on the Internet, for downloading at no cost, which considerably simplified the task of tracking down significant works and greatly reduced the cost of obtaining the reports.

F. Overview of this Report

The main body of this report comprises four additional sections, followed by the references cited and appendices. Section II describes the hazards, as identified in SCR 19, from leaf blowers. Hazardous components of exhaust emissions, fugitive dust emissions, and noise are covered in turn, along with who is exposed to each hazard and how society has sought to control exposure to those hazards through laws. Section III reviews health effects of each of the hazards, with exhaust emissions subdivided into particulate matter, carbon monoxide, ozone, and toxic constituents of burned and unburned fuel. Health effects from fugitive dust are covered in the subsection on particulate matter. Section IV discusses the potential health and environmental impacts of leaf blowers, synthesizing the information presented in Sections II and III. Section V discusses recommendations. Additional information, including a discussion of research needs to make progress toward answering some of the questions raised by this report, a description of engine technologies that could reduce exhaust emissions and alternatives to gasoline-powered leaf blowers, and a complete bibliography of materials received and consulted but not cited in the report, is found in the appendix.

II. DESCRIPTION OF THE HAZARDS

This section of the report describes the three potential hazards identified by SCR 19 as resulting from leaf blowers. This report examines the three hazards that have been of most concern of the public and the Legislature. Hazard identification is the first step in an impact or risk assessment. In this section, then, each of the three identified hazards are examined in turn, exhaust emissions, dust emissions, and noise. For each, the hazard is described and quantified, and the number of people potentially exposed to the hazard is discussed. For exhaust emissions, the number of people potentially impacted is as high as the population of the state, differing within air basins. Fugitive dust emissions impact a varying number of people, depending on one?s proximity to the source, the size of the particles, and the amount of time since the source resuspended the particles. Finally, in this section we also discuss laws that control the particular hazard.

A. Exhaust Emissions

Exhaust emissions are those emissions generated from the incomplete combustion of fuel in an engine. The engines that power leaf blower equipment are predominantly two-stroke, less than 25 horsepower (hp) engines. This section describes the two-stroke engine technology prevalent in leaf blower equipment and associated emissions, reviews the leaf blower population and emission inventory data approved by the Board in 1998, and describes federal, state, and local controls on small off-road engines.

1. Characterization of Technology

Small, two-stroke gasoline engines have traditionally powered leaf blowers, and most still are today.[1] The two-stroke engine has several attributes that are advantageous for applications such as leaf blowers. Two-stroke engines are lightweight in comparison to the power they generate, and operate in any position, allowing for great flexibility in equipment applications. Multi-positional operation is made possible by mixing the lubricating oil with the fuel; the engine is, thus, properly lubricated when operated at a steep angle or even upside down.

A major disadvantage of two-stroke engines is high exhaust emissions. Typical two-stroke designs feed more of the fuel/oil mixture than is necessary into the combustion chamber. Through a process known as scavenging, the incoming fuel enters the combustion chamber as the exhaust is leaving. This timing overlap of intake and exhaust port opening can result in as much as 30% of the fuel/oil mixture being exhausted unburned. Thus, exhaust emissions consist of both unburned fuel and products of incomplete combustion. The major pollutants from a two-stroke engine are, therefore, oil-based particulates, a mixture of hydrocarbons, and carbon monoxide. A two-stroke engine forms

[1]Unless otherwise referenced, this section makes use of material in the ARB's Small Off Road Engine staff report and attachments, identified as MSC 98-02; 1998a.

relatively little oxides of nitrogen emissions, because the extra fuel absorbs the heat and keeps peak combustion temperatures low.

Hydrocarbon emissions, in general, combine with nitrogen oxide emissions from other combustion sources to produce ozone in the atmosphere. Thus ozone, although not directly emitted, is an additional hazard from leaf blower exhaust. In addition, some of the hydrocarbons in fuel and combustion by-products are themselves toxic air contaminants, such as benzene, 1,3-butadiene, acetaldehyde, and formaldehyde (ARB 1997). The major sources of benzene emissions are gasoline fugitive emissions and motor vehicle exhaust; about 25% of benzene emissions are attributed to off-road mobile sources. Most 1,3-butadiene emissions are from incomplete combustion of gasoline and diesel fuels from mobile sources (about 96%). Sources of acetaldehyde include emissions from combustion processes and photochemical oxidation. The ARB has estimated that acetaldehyde emissions from off-road motor vehicles comprise about 27% of the total emissions. Finally, formaldehyde is a product of incomplete combustion and is also formed by photochemical oxidation; mobile sources appear to contribute a relatively small percentage of the total direct emissions of formaldehyde. Data do not exist to allow reliable estimation of toxic air contaminant emissions from small, two-stroke engine exhaust.

A small percentage of blowers utilize four-stroke engines. These blowers are typically "walk-behind" models, used to clean large parking lots and industrial facilities, rather than lawns and driveways. Overall, the engines used in these blowers emit significantly lower emissions than their two-stroke counterparts, with significantly lower levels of hydrocarbons and particulate matter. These four-stroke blower engines have a significantly lower population than the traditional two-stroke blowers and only peripherally fit the definition or commonly-accepted meaning of the term "leaf blower." They are mentioned here only for completeness, but are not otherwise separately addressed in this report.

2. Exhaust Emissions

a. Leaf Blower Population

The best estimates available indicate that there are approximately 410,000 gasoline-powered blowers in use in the state today. Less than 5,000 of those use four-stroke engines; the remainder (99%) utilize two-stroke engines. These data have been developed from information gathered through the development and implementation of ARB's small off-road engine regulation. Since the small off-road engine regulation does not apply to blowers powered by electric motors, data regarding the number of electric blowers are not as extensive. However, information shared by the handheld power equipment industry indicates that approximately 60 percent of blowers sold are electric. This would indicate that there are approximately 600,000 electric blowers in California. It must be stressed that the majority of the blower population being electric does not imply that the majority of usage accrues to electric blowers. In fact, electric blowers are more likely to be used by homeowners for occasional use, whereas virtually all professional gardeners use engine-powered blowers.

b. Emission Inventory

California?s emission inventory is an estimate of the amount and types of criteria pollutants and ozone precursors emitted by all sources of air pollution. The emission inventory method and inputs for small off-road engines, with power ratings of less than 25 hp, were approved by the Board in 1998 (ARB 1998b) (Table 2). Exhaust emissions from leaf blowers contribute from one to nine percent of the small-off road emissions, depending on the type of pollutant, based on the 2000 emissions data. Exhaust emission standards for small off-road engines, which will be implemented beginning in 2000, will result in lower emissions in the future. By 2010, for example, hydrocarbon emissions are expected to shrink by 40% statewide, while CO declines by 35% and PM10 drops 90%. The reductions reflect the replacement of today's blowers with cleaner blowers meeting the 2000 standards.

Table 2. Statewide Inventory of Leaf Blower Exhaust Emissions (tons per day)

	Leaf blowers 2000	**Leaf blowers 2010**	**All Lawn & Garden, 2000**	**All Small Off-Road, 2000**
Hydrocarbons, reactive	7.1	4.2	50.24	80.07
Carbon Monoxide (CO)	16.6	9.8	434.99	1046.19
Fine Particulate Matter (PM10)	0.2	0.02	1.05	3.17

3. Regulating Exhaust Emissions

a. State Regulations

The California Clean Air Act, codified in the Health and Safety Code Sections 43013 and 43018, was passed in 1988 and grants the ARB authority to regulate off-road mobile source categories, including leaf blowers. The federal Clean Air Act requires states to meet national ambient air quality standards (Appendix C) under a schedule established in the Clean Air Act Amendments of 1990. Because many air basins in California do not meet some of these standards, the State regularly prepares and submits to the U.S. EPA a plan that specifies measures it will adopt into law to meet the national standards. Other feasible measures not specified in the state implementation plan may also be adopted as needed.

In December 1990, the Board approved emission control regulations for new small off-road engines used in leaf blowers and other applications. The regulations took effect in 1995, and include exhaust emission standards, emissions test procedures, and provisions for warranty and production

compliance programs. In March of 1998, the ARB amended the standards to be implemented with the 2000 model year (ARB 1998a). Table 3 illustrates how the standards compare with uncontrolled engines for leaf blower engines. Note that there was no particulate matter standard for 1995-1999 model year leaf blowers, but that a standard will be imposed beginning with the 2000 model year.

Among other features of the small off-road engine regulations is a requirement that production engines be tested to ensure compliance. Examination of the certification data confirms that manufacturers have been complying with the emissions regulations; in fact, engines that have been identified as being used in blowers tend to emit hydrocarbons at levels that are 10 to 40 percent below the existing limits. This performance is consistent with engines used in string trimmers, edgers, and other handheld-type equipment, which are, in many cases, the same engine models used in leaf blowers.

Table 3
Exhaust Emissions Per Engine for Leaf Blowers
(grams per brake-horsepower-hour, g/bhp-hr)

	Uncontrolled Emissions	**1995-1999 Standards[2]**	**2000 and later Standards**
HC+NOx	283 + 1.0	180 + 4.0	54[3]
CO	908	600	400
PM	3.6	---[4]	1.5

b. Federal Regulations

Although the federal regulations for mobile sources have traditionally followed the ARB's efforts, the U.S. EPA has taken advantage of some recent developments in two-stroke engine technology. Specifically, compression wave technology has been applied to two-stroke engines, making possible much lower engine emissions. Bolstered by this information, the U.S. EPA (1999a) has proposed standards for blowers and other similar equipment that would be more stringent than the ARB standards. ARB plans a general review of off-road engine technology by 2001, and will consider the implications of this new technology in more detail then. A short description is included in Appendix I.

[2]Applicable to engines of 20-50 cc displacement, used by the vast majority of leaf blowers.

[3]For yr 2000, the HC + NOx standards have been combined.

[4]There was no particulate standard for this time period.

c. South Coast AQMD Emissions Credit Program

The South Coast Air Quality Management District (SCAQMD), an extreme non-attainment area for ozone, has promulgated Rule 1623 - Credits for Clean Lawn and Garden Equipment. Rule 1623 provides mobile source emission reduction credits for those who voluntarily replace old high-polluting lawn and garden equipment with new low- or zero-emission equipment or who sell new low- or zero-emission equipment without replacement. The intent of the rule is to accelerate the retirement of old high-polluting equipment and increase the use of new low- or zero-emission equipment. In 1990, volatile organic carbon emissions from lawn and garden equipment in the South Coast Air Basin were 22 tons per day (SCAQMD 1996). To date, no entity has applied for or received credits under Rule 1623 (V. Yardemian, pers. com.)

4. Summary

Exhaust emissions from leaf blowers consist of the following specific pollutants of concern: hydrocarbons from both burned and unburned fuel, and which combine with other gases in the atmosphere to form ozone; carbon monoxide; fine particulate matter; and other toxic air contaminants, including benzene, 1,3-butadiene, acetaldehyde, and formaldehyde. Exhaust emissions from these engines, while high compared to on-road mobile sources on a per engine basis, are a small part of the overall emission inventory. Emissions have only been controlled since 1995, with more stringent standards taking effect in 2000. The exhaust emissions from leaf blowers are consistent with the exhaust emissions of other, similar off-road equipment powered by small, two-stroke engines, such as string trimmers. Manufacturers have developed several different methods to comply with the standards and have done an acceptable job certifying and producing engines that are below the regulated limits. Electric-powered models that are exhaust-free are also available.

B. Fugitive Dust Emissions

? Blown dust? is the second of the hazards from leaf blowers specified in SCR 19. For the purposes of this report, we will use the term ? fugitive dust,? which is consistent with the terminology used by the ARB. This section, in addition to defining fugitive dust emissions, characterizes fugitive dust resuspended by leaf blowers by comparing previous estimates of emission factors (amount emitted per hour per leaf blower) and emissions inventory (amount resuspended per day by all leaf blowers statewide) to a current estimate, developed for this report. In addition, the potential composition of leaf blower dust and fugitive dust controls at the state and local levels are described.

1. Definition of Fugitive Dust Emissions

From the Glossary of Air Pollution Terms, available on the ARB?s website,[5] the following definitions are useful:

Fugitive Dust: Dust particles that are introduced into the air through certain activities such as soil cultivation, or vehicles operating on open fields or dirt roadways; a subset of fugitive emissions.

Fugitive Emissions: Emissions not caught by a capture system (often due to equipment leaks, evaporative processes, and windblown disturbances).

Particulate Matter (PM): Any material, except uncombined water, that exists in the solid or liquid state in the atmosphere. The size of particulate matter can vary from coarse, wind-blown dust particles to fine particle combustion products.

Fugitive dust is a subset of particulate matter, which is a complex mixture of large to small particles that are directly emitted or formed in the air. Current control efforts focus on PM small enough to be inhaled, generally those particles smaller than 10 micrometers (? m). So-called coarse particles are those larger than 2.5 ? m in diameter, and are directly emitted from activities that disturb the soil, including construction, mining, agriculture, travel on roads, and landfill operations, plus windblown dust, pollen, spores, sea salts, and rubber from brake and tire wear. Those with diameters smaller than 2.5 ? m are called fine particles. Fine particles remain suspended in the air for long periods and can travel great distances. They are formed mostly from combustion sources, such as vehicles, boilers, furnaces, and fires, with a small dust component. Fine particles can be directly emitted as soot or formed in the atmosphere as combustion products react with gases from other sources (Finlayson-Pitts & Pitts 1986).

Dust emissions from leaf blowers are not part of the inventory of fugitive dust sources. ARB, therefore, does not have official data on the quantity of fugitive dust resuspended by leaf blowers. No data on the amount and size distributions of resuspended dust from leaf blower activities have been collected, although estimates have been made. ARB evaluated three previous estimates (McGuire 1991, Botsford et al. 1996, Covell 1998) and developed a proposed methodology for estimating fugitive dust emissions from leaf blowers. The estimate presented below begins with the assumptions and calculations contained in the study conducted for the SCAQMD by AeroVironment (Botsford et al. 1996). Additional methodologies and data have been reviewed and derived from the U.S. EPA document commonly termed AP-42, and reports by the Midwest Research Institute; University of California, Riverside; and the Desert Research Institute.

[5]http://arbis.arb.ca.gov/html/gloss.htm

2. Calculating Leaf Blower Emissions

There are more than 400,000 gasoline-powered leaf blowers, plus approximately 600,000 electric leaf blowers, that are operated an estimated 114,000 hours per day in California. The fundamental premise in the calculations below is that leaf blowers are designed to move relatively large materials such as leaves and other debris, and hence can also be expected to entrain into the air much smaller particles, especially those below 30 ? m diameter, which are termed total suspended particulate (PMtsp). Subsets of PMtsp include PM10, particulates with diameters less than or equal to 10 ? m, and PM2.5, particulates with diameters less than or equal to 2.5 ? m. Particles below 30 ? m are not visible to the naked eye. Note that PM10 includes PM2.5 particles, and PMtsp includes PM10 and PM2.5 particles.

a. Generation of Fugitive Dust by Leaf Blowers

The leaf blower moves debris such as leaves by pushing relatively large volumes of air, typically between 300-700 cubic feet per minute, at a high wind speed, typically 150 to 280 miles per hour (hurricane wind speed is >117 mph). A typical surface is covered with a layer of dust that is spread, probably non-uniformly, along the surface being cleaned. While the intent of a leaf blower operator may not be to move dust, the high wind speed and volume result in small particles being blown into the air. In order to calculate how much fugitive dust is generated by the action of a blower, we assume that this layer of dust can be represented by a single average number, the silt loading. This silt loading value, when combined with the amount of ground cleaned per unit time and the estimated PM weight fractions, produces estimates of fugitive dust emissions from leaf blowers.

Staff have located no fugitive dust measurement studies on leaf blowers, but have found previous calculations of fugitive dust estimates from leaf blowers. Based on a review of those estimates, staff applied the latest knowledge and research in related fields in order to derive a second-order approximation. This section presents the best estimates using existing data, while recognizing that estimates are only approximations. Variables that would affect fugitive dust emissions, and for which ARB has little or no empirical data, include, for example:

(1) the specific surface types on which leaf blowers are used;
(2) the percentage of use on each specific surface type;
(3) effects of moisture, humidity, and temperature;
(4) silt loading values for surfaces other than paved roadways, shoulders, curbs, and gutters and in different areas of the state; and
(5) measurements of the amount of surface cleaned per unit time by the average operator.

Other variables are not expected to greatly influence fugitive dust emissions; the hurricane-force winds generated by leaf blowers are expected to overcome such influences, for example, as the roughness of relatively flat surfaces and the effect of particle static charge.

b. Size Segregation of Particulate Matter

PM emissions can be subdivided into the following three categories, operator emissions, local emissions, and regional emissions. They are differentiated as follows:

1) Operator emissions. PMtsp emissions approximate emissions to which the operator is exposed. The larger of these particles, between approximately 10 and 30 ? m, have relatively short settling times, on the order of minutes to a couple of hours, maximum (Finlayson-Pitts & Pitts 1986, Gillies et al. 1996, Seinfeld & Pandis 1998). These would be emissions to which both the leaf blower operator and passersby would be exposed.

2) Local emissions. PM10 emissions will be used to estimate "local" PM emissions. PM10, which includes particles at or below 10 ? m, may remain suspended for hours to days in the atmosphere (Finlayson-Pitts & Pitts 1986, Gillies et al. 1996, Seinfeld & Pandis 1998). These are emissions to which persons in the near-downwind-vicinity would be exposed, for example, residents whose lawns are being serviced and their neighbors, persons in commercial buildings whose landscapes are being maintained or serviced, and persons within a few blocks of the source.

3) Regional emissions. PM2.5 emissions may remain suspended for as long as a week or more (Finlayson-Pitts & Pitts 1986, Gillies, et al. 1996, Seinfeld & Pandis 1998). These particles are sized at or below 2.5 ? m, and hence can be considered as contributors to regional PM emissions over a county or air basin because of their long residence time.

c. Calculation Assumptions and Limitations

The method presented uses the following assumptions.

1) Methods used for estimating wind blown dust for paved roads can be applied to estimating fugitive dust emissions from leaf blowers. That is, one can use an "AP-42" type (U.S. EPA 1997) of approach that calculates dust emissions based on the silt loading of the surfaces in question.

2) The typical leaf blower generates sufficient wind speed to cause sidewalk/roadway dust, in particular, particles 30 µm or less in aerodynamic diameter, to become airborne. The AeroVironment study (Botsford et al. 1996) assumed that nozzle air velocities ranged from 120 to 180 mph, and calculated that wind speed at the ground would range from 24 mph to 90 mph, sufficient to raise dust and equivalent, at the middle to high end speeds, to gale-force winds.

3) Currently available paved road, roadside shoulder, and gutter silt loadings (Venkatram & Fitz 1998) can be used to calculate emissions from leaf blowers, as there are no data on silt loadings on other surfaces. Observations and communications with landscapers indicate that leaf blowers are most commonly used to clean hardscape surfaces, such as sidewalks, after lawns and flower beds have been

trimmed and cuttings left on hardscapes. Debris is then frequently blown into the roadway before being collected for disposal.

4) The size fractions for particles for paved road dust can be used to calculate emissions from leaf blowers (G. Muleski, pers. comm.). The ratios of particle size multipliers, or ? k? factors, are used to estimate the weight fraction of windblown dust for leaf blower usage. The ? k? factor is a dimensionless value that represents the percentage of the total dust loading that is of a certain size fraction (MRI 1997).

5) Silt loading values and usage are assumed to be the same for residential and commercial leaf blower use. In an earlier draft, ARB staff had proposed different silt loading values for residential and commercial leaf blowers; comments were received that indicated that heavier-duty commercial leaf blowers were used in the same way in both residential and commercial settings. In addition, data on nozzle air speeds indicate that most electric leaf blowers, targeted at homeowners, have air speeds at or above 120 mph, the lowest air speed considered in the AeroVironment report (Botsford et al. 1996) as capable of raising dust.

6) The weight of total suspended particulates is equivalent to 100% of the silt loading, the weight fraction that comprises PM10 is 19% of the total, and the weight fraction comprising PM2.5 is 9% of the total (U.S. EPA 1997, MRI 1997, G. Muleski, pers. com). A recent study, however, found that 50-70% of the mass of PMtsp of paved road dust at three southern California locations is present in the PM10 fraction (Miguel et al. 1999), so more data would be helpful.

A final limitation is the recognition that emissions inventories are estimates of the unknown and unknowable actual emissions inventory. An earlier draft of this report was criticized as providing only estimates of emissions, and not actual emissions, when in fact all emissions inventories are based on models developed through scientific research on how the chemicals behave in the atmosphere, limited testing to determine emission factors, and industry-provided data on the population and usage of each particular source of air pollution. Each generation of emission inventories is an improvement over the one previous as assumptions are examined, tested, and modified. As discussed earlier, the estimate in this report builds on previous estimates.

d. Calculation Methodology

The proposed emissions estimation methodology uses measured silt loadings (Venkatram & Fitz 1998) and size fraction multipliers for PM10 and PM2.5 (U.S. EPA 1997, MRI 1997, G. Muleski, pers. com.).

$EF_{size} = (sL)\ (Q)\ (f_{size})$
where:
EF_{size} = PM30, or PM10, or PM2.5 emission factors;
sL = silt loading fraction, from ARB (1998b);

Q = amount of ground cleaned per unit time, estimated to be 1,600 m^2/hr, corresponding to a forward speed of 1 mph, with the operator sweeping the blower in a one meter arc;
f_{size}= fraction of PMtsp dust loading that comprises PM10 (0.19) or PM2.5 (0.09).

Silt loading values are the critical parameter in the calculation. ARB has chosen, for this emissions estimate, to use recent data from a study conducted for the ARB by a team at the University of California, Riverside (Venkatram & Fitz 1998) (Table 4). As data were collected only in Riverside County, it is not known how representative they are of other areas of the state or of substrates cleaned by leaf blowers. The data are, however, the most complete we have to date. Because the data are not normally distributed, the median and 95% percentile samples for silt loading are used to represent the data set in calculations.

Table 4
Silt Loading Values, Riverside County
(grams per square meter, g/m^2)

Roadway Type	Material Loading, Median	Silt Loading, Median (95%)	Range of Silt Loading Values
Paved Road	108.44	0.16 (6.34)	0.003-107.596
Roadway Shoulders	481.08	3.33 (15.73)	0.107-23.804
Curbs and Gutters	144.92	3.39 (132.94)	0.97-556.65

3. Characterization of Fugitive Dust Emissions

This section includes results from this present analysis, as well as results from previous estimates prepared by the ARB and others for comparison.

a. Emission Factors - This Study

Possible emission factors have been calculated for leaf blower use on paved roadways, roadway shoulders, and curbs and gutters (Table 5). Two emission factors are presented for each surface and particle size, based on the median and 95th percentile of the empirical silt loading data. The resulting range for PM10 is from 48.6 to 1030.6 g/hr for PM10, for example, depending on the surface cleaned. Cleaning of curbs and gutters generates the highest emission factors, whereas paved roadways

and shoulders are lower. As discussed before, staff have no data on which to base emission factors for sidewalks, driveways, lawns, or flower beds.

Table 5. Leaf Blower Estimated Emission Factors, This Study
(grams per hour, g/hr)

Emission Factor	Paved Roadway, Median (95%)	Shoulders, Median (95%)	Curbs/Gutters, Median (95%)
Total Suspended Particulate	256.0 (10,144.0)	5,328 (25,168)	5,424 (212,704)
PM10	48.6 (1,927.4)	1,012.3 (4,781.9)	1,030.6 (40,413.8)
PM2.5	23.0 (913.0)	479.5 (2,265.0)	488.2 (19,143.4)

b. Statewide Emissions Inventory - This Study

Three potential statewide emissions inventory values (Table 6), in tons per day (tpd), have been calculated by multiplying the median emissions factors, shown above, by the hours of operation for each of three different substrates: paved roadways, paved shoulders, and paved curbs/gutters, based on the Riverside data. From the statewide emissions inventory, the total number of hours of operation in the year 2000 are estimated to be 113,740 hr/day, or 97,302 hr/day for gasoline-powered leaf blowers plus 16,438 hr/day for electric leaf blowers.[6]

Table 6. Leaf Blower Emissions,
Possible Statewide Values, This Study
(tons per day, tpd)

Emissions Inventory	Paved Roadway, Median	Shoulders, Median	Curbs/Gutters, Median
Total Suspended Particulates	32.1	667.4	679.4
PM10	6.1	126.8	129.1
PM2.5	2.9	60.1	61.2

[6]On a per-unit basis, electric blowers are assumed to be used 10 hr/yr.

The goal in developing an emissions inventory is to derive one statewide emissions inventory number for each category of particulate sizes, which can then be subdivided by air basin or air district. Ideally, ARB would have developed emissions factors for each surface cleaned by leaf blowers, and apportioned the emissions based on the percentage of hours spent cleaning each surface annually. Table 6, however, presents an array of values because staff have no data on the percentage of time spent cleaning various surfaces. For comparison, the 1996 statewide PM10 estimated emission inventory was 2,400 tpd; estimates for paved road dust, unpaved road dust, and fugitive windblown dust were 400, 610, and 310 tpd, respectively. Based on the estimates in Table 6, then, PM10 emissions impacts from leaf blower use could range from insignificant (0.25%) to significant (5.4%), on a statewide basis. Additional study is required to refine the analysis and develop a statewide emission inventory.

c. Previous Emissions Estimates: ARB, 1991

The ARB's Technical Support Division, in a July 9, 1991 response to a request from Richard G. Johnson, Chief of the Air Quality Management Division at the Sacramento Metropolitan Air Quality Management District, prepared a leaf blower emissions estimate in grams per hour of dust (McGuire 1991). PM10 emissions were reported as being 1,180 g/hr, or 2.6 lb/hr, which is the same order of magnitude as the present study's calculated emission factors for roadway shoulders and curbs/gutters (Table 5). If this emission factor is combined with current statewide hours-of-operation data of 113,740 hr/day of leaf blower usage, this would produce an emission inventory of 147.8 tpd of PM10, similar to the present study's inventory for shoulders and curbs/gutters (Table 6).

d. Previous Emissions Estimates: SMAQMD

Sacramento Metropolitan Air Quality Metropolitan District (SMAQMD) staff (Covell 1998) estimated that "Dust Emissions (leaf blowers only)" are 3.2 tpd in Sacramento County. The memo included commercial and residential leaf blower populations (1,750 commercial and 15,750 residential), and hours of use (275 hr/yr for commercial and 10 hr/yr for residential). Using these values one can calculate the assumed g/hr emission factor for particulate matter. The resulting emission factor is 1,680 g/hr, or 3.7 lb/hr. The resulting statewide emission inventory is 210.4 tpd, higher than this study's estimates (Tables 5 & 6).

e. Previous Emissions Estimates: AeroVironment

The South Coast AQMD commissioned AeroVironment to determine emission factors and preliminary emission inventories for sources of fugitive dust previously uninventoried; leaf blowers were one of the categories examined (Botsford et al. 1996). The study focused on PM10, and did not include field measurements. The study assumed that each leaf blower was used, at most, one day per week to clean 92.9 m^2 (1000 ft^2) of ground. Silt loading was assumed to be 1.42 g/m^2. Combining these two values yields an emission factor of 5.5 g/hr. With an estimated 60,000 leaf blowers in the South Coast Air Basin, AeroVironment calculated an emission inventory of 8.6 tpd, just for the South Coast AQMD, more than double the basin-wide inventory calculated for the Sacramento Metropolitan

AQMD (above). The obvious difference between this estimate and the others summarized herein is the assumption that each leaf blower is used for no more than one day per week and is used to clean an area equivalent to only one front yard (20 ft by 50 ft); as commercial gardeners could not make a living cleaning one front yard once per week, this figure is obviously much too low. It is, however, coincidentally similar to the present study? s estimate for paved roadways (Table 6).

4. Particulate Composition

Substances such as fecal material, fertilizers, fungal spores, pesticides, herbicides, pollen, and other biological substances have been alleged to make up the dust resuspended by leaf blower usage (Orange County Grand Jury 1999), and thus staff looked for data on the composition of particulate matter. Little information is available. Suspended paved road dust is a major contributor to airborne particulate matter in Los Angeles and other cities (Miguel et al. 1999). Staff considered, therefore, size-segregated chemical speciation profiles for paved road dust to chemically characterize leaf blower PM emissions. The chemical speciation profiles for paved road dust show small percentages of the toxic metals arsenic, chromium, lead, and mercury. In addition to soil particles, paved road dust emissions may contain contributions from tire and brake wear particles. Paved road dust chemical speciation, however, characterizes the dust by elemental composition, and was not useful in estimating health impacts for this assessment. ARB's chemical speciation profile for paved road dust is presented in Appendix D for information.

Recently, however, researchers published a study on allergans in paved road dust and airborne particles (Miguel et al. 1999). The authors found that biologic materials from at least 20 different source materials known to be capable of causing or exacerbating allergenic disease in humans are found in paved road dust, including pollens and pollen fragments, animal dander, and molds. Allergen concentrations in the air are increased above the levels that would otherwise occur in the absence of suspension by passing traffic. The authors conclude that paved road dust is a ubiquitous mixed source of allergenic material, resuspended by passing traffic, and to which virtually the entire population is exposed. The applicability of this study to particulate matter resuspension by leaf blower usage is unknown, but it is likely that leaf blowers would be as effective at resuspending paved road dust as automobiles. Information on the characteristics of other sources of resuspended particulates, for example lawns and gardens, is unfortunately lacking.

5. Regulating Fugitive Dust Emissions

Fugitive dust emissions are generally regulated as a nuisance, although PM10 and PM2.5 are specifically addressed through the state planning process as criteria air pollutants. There are no explicit federal, state, or local regulations governing leaf blower fugitive dust emissions.

a. State and Federal PM10 and PM2.5 Standards

The California and Federal ambient air quality standards for PM10 and PM2.5 are located in Appendix C. Any state that has air basins not in attainment with the standards must submit a plan to U.S. EPA on how they will achieve compliance. For California, most of the state violates the PM10 standard; attainment status has not yet been determined for the new PM2.5 standard (promulgated July 18, 1997 and under challenge in the courts). California, and its air districts, is therefore required to control sources of PM10, including fugitive dust.

b. Local District Regulations

Many air districts have a fugitive dust control rule that prohibits activities that generate dust beyond the property line of an operation. For example, the SCAQMD Rule 403 states: ? A person shall not cause or allow the emissions of fugitive dust from any active operation, open storage pile, or undisturbed surface area such that the presence of such dust remains visible in the atmosphere beyond the property line of the emission source.? In addition, rules may place limits on the amount of PM10 that can be detected downwind of an operation that generates fugitive dust; for SCAQMD that limit is 50 ? g/m^3 [SCAQMD Rule 403]. The Mojave AQMD limits PM emissions to 100 ? g/m^3 [Mojave AQMD Rule 403]. Others, such as the San Joaquin Unified APCD, define and limit visible emissions (40% opacity) from activities that generate fugitive dust emissions [SJUAPCD Rule 8020]. Finally, another approach is to simply request individuals take reasonable precautions to prevent visible particulate matter emissions from moving beyond the property from which the emissions originate [Great Basin Unified APCD Rule 401].

6. Summary

Data on fugitive dust indicate that the PM10 emissions impacts from dust suspended by leaf blowers are small, but probably significant. Previous emission estimates range from less than 1% to 5% of the statewide PM10 inventory. The ARB previously estimated statewide fugitive dust emissions to be about 5 percent of the total, the Sacramento Metropolitan AQMD estimated leaf blower fugitive dust emissions to be about 2 percent of the Sacramento county PM10 air burden, and AeroVironment estimated dust attributed to leaf blowers in the South Coast Air Basin to be less than 1% of all fugitive dust sources. Dust emissions attributable to leaf blowers are not part of the inventory of fugitive dust sources. ARB, therefore, does not have official data on the quantity of fugitive dust resuspended by leaf blowers. A more definitive estimate of leaf blower fugitive dust emissions will require research to verify appropriate calculation parameters, determine representative silt loadings, measure actual fugitive dust emissions through source testing, and identify the chemical composition of leaf blower-generated fugitive dust.

C. Noise Emissions

The third of the hazards from leaf blowers identified in SCR 19 is noise. This section defines noise, describes the physical properties of sound and how sound loudness is measured, discusses noise sources, the numbers of Californians potentially exposed to noise, and how noise is regulated at the federal, state, and local levels, and addresses specific sound loudness and quality from leaf blowers. In addition, the incidence of the use of hearing protection, and other personal protective equipment, by leaf blower operators is described.

1. Defining Noise

Noise is the general term for any loud, unmusical, disagreeable, or unwanted sound. In addition to damaging hearing, noise causes other adverse health impacts, including interference with communication, rest and sleep disturbance, changes in performance and behavior, annoyance, and other psychological and physiological changes that may lead to poor health (Berglund & Lindvall 1995). In this report, noise will be used to refer both to unwanted sounds and sounds that damage hearing. The two characteristics, although related, do not always occur together.

The effects of sound on the ear are determined by its quality, which consists of the duration, intensity, frequency, and overtone structure, and the psychoacoustic variables of pitch, loudness, and tone quality or timbre, of the sound. Long duration, high intensity sounds are the most damaging and usually perceived as the most annoying. High frequency sounds, up to the limit of hearing, tend to be more annoying and potentially more hazardous than low frequency sounds. Intermittent sounds appear to be less damaging than continuous noise because the ear appears to be able to recover, or heal, during intervening quiet periods. Random, intermittent sounds, however, may be more annoying, although not necessarily hazardous, because of their unpredictability (Suter 1991).

The context of the sound is also important. While certain sounds may be desirable to some people, for example, music at an outdoor party, others may consider them noise, for example, those trying to sleep. Even desirable sounds, such as loud music, may cause damage to hearing and would be considered noise in this context. Thus, not only do loudness, pitch, and impulsiveness of sound determine whether the sound is noise, but also the time of day, duration, control (or lack thereof), and even one?s personality determine whether sounds are unwanted or not.

The physical and psychoacoustic characteristics of sound, and thus noise, are described in more detail in Appendix E. The discussion is focused on information necessary for the reader to understand how sound is measured, and clarify measures of leaf blower sound. The interested reader is referred for more information to any physics or acoustic reference book, or the works referred to herein.

2. Measuring the Loudness of Sound

The weakest intensity of sound a health human ear can detect has an amplitude of 20 millionths of a Pascal[7] (20 ?Pa). The loudest sound the human ear can tolerate, the threshold of pain, has an amplitude ten million times larger, or 200,000,000 ?Pa. The range of sound intensity between the faintest and the loudest audible sounds is so large that sound pressures are expressed using a logarithmically compressed scale, termed the decibel (dB) scale. The decibel is simply a unit of comparison between two sound pressures. In most cases, the reference sound pressure is the acoustical zero, or the lower limit of hearing. The decibel scale converts sound pressure levels (SPL) to a logarithmic scale, relative to 20 ? Pa (Figure 1).

$$SPL, dB = 10 \log_{10} (P^2/P_o^2)$$

Where P is the pressure fluctuation in Pascals,
P_o is the reference pressure; usually 20 ? Pa.

Thus, from this relationship, each doubling of sound pressure levels results in an increase of 6 dB. From the relationship between sound intensity and distance (Appendix E), we find also that doubling the distance between the speaker (source) and listener (receiver), drops the level of the sound by approximately 6 dB. Sound pressure levels are not directly additive, however, but must first be expressed as mean square pressures before adding (Berglund & Lindvall 1995). The equation is as follows:

$$SPL = 10 \log_{10} [10^{SPL_1/10} + 10^{SPL_2/10} + ... + 10^{SPL_x/10}]$$

For example, if two sound sources have SPLs of 80 dB and 90 dB, then the resulting sound pressure is 90.4 dB. Adding two sounds with the same SPL, for example 90 dB, increases the total SPL by 3 dB, to 93 dB.

a. Loudness Description

Sound pressure level, however, does not completely describe loudness, which is a subjective perception of sound intensity. Loudness increases with intensity, but is also dependent on frequency. Thus the human ear may not perceive a six dB increase as twice as loud. In general, people are more sensitive to sounds in the middle of the range of hearing, from around 200 Hz to 5000 Hz. Fletcher and Munson (1933) first established the 1000-Hz tone as the standard sound against which other tones would be judged for loudness. Later, Stevens (1955) proposed that the unit of loudness be termed the

[7]Other units used to represent an equivalent sound pressure include 0.0002 ? bar, 0.0002 dyne/cm^2, and 20 ? N/m^2.

sone, and that one sone be ascribed to a 1000-Hz tone set at a SPL of 40 dB under specified listening conditions. On the sone scale, a sound twice as loud as one sone would be two sones, four times as loud would be four sones, and so on.

Equal loudness contours, identified in units of phons, demonstrate how the SPL, in dB, of a tone must be varied to maintain the perception of constant loudness. Ideally, sound measurement meters would give a reading equal to loudness in phons, but because phons are based on human perception, and perception process will vary from individual to individual, this has not been practical until recently (Berglund & Lindvall 1995). Loudness is still measured in decibels, however, following past practices. Various filters have been devised to approximate the frequency characteristics of the human ear, by weighting sound pressure level measurements as a function of frequency. Several weighting systems have been developed, but the one in most common use is the A-weighted filter, with sound pressure levels commonly expressed as dBA. Loudness levels range from about 20 dB (24-hr average) in very quiet rural areas, to between 50 and 70 dB during the daytime in cities. Additional examples of typical loudness measures are illustrated in Figure 1.

Perceived Sound Level	Sound Level dB	Sound Level μPa	Examples	Leaf Blower Reference
PAINFULLY LOUD	160	$2x10^9$	fireworks at 3 feet	
	150		jet at takeoff	
	140	$2x10^8$	threshold of pain	OSHA limit for impulse noise
UNCOMFORTABLY LOUD	130		power drill	
	120	$2x10^7$	thunder	
	110		auto horn at 1 meter	90-105 dB leaf blower at operators ear
	100	$2x10^6$	snowmobile	
VERY LOUD	90		diesel truck, food blender	90 dB OSHA permissible exposure limit
	80	$2x10^5$	garbage disposal	
MODERATELY LOUD	70		vacuum cleaner	62-75 dB Leaf blower at 50 feet
	60	$2x10^4$	ordinary conversation	
	50		average home	
QUIET	40	$2x10^3$	library	
	30		quiet conversation	
VERY QUIET	20	$2x10^2$	soft whisper	
	10		rustling leaves	
BARELY AUDIBLE	0	$2x10^1$	threshold of hearing	dB= decibels μPa= micro Pascals

Fig. I. Comparison of sound levels in the environment

b. Sound Level Measurement

The ANSI B175 Accredited Standard Committee, a group that includes government officials, Underwriters Laboratories, leaf blower manufacturers, and trade associations, and which is accredited by the American National Standards Institute, Inc. (ANSI), developed a method for measuring the sound levels from leaf blowers (Appendix F). The purpose of the standard method is to establish sound level labeling requirements for leaf blowers applicable to noise received by bystanders. The standard also includes requirements for safety precautions to be included in manuals for use by operators. The ANSI standard specifies a test area in a field in which natural ground cover does not exceed three inches in height and which is free of any large reflecting surfaces for a minimum of 100 ft from the blower. The sound level meter must be set for slow response and the A-weighting network. Once the blower is adjusted and running properly, the receiver (microphone) is set up 50 ft from the operator and 4 ft above ground. Sound level readings are taken in a circle every 45 degrees for a total of eight readings, as either the operator rotates or the microphone is moved. The eight readings are then averaged and reported to the nearest decibel.

In wide use, the method has been criticized as sometimes generating unreproducible results. Typical comments expressed in meetings with ARB staff were to the effect that the manufacturer-reported sound levels for leaf blowers can be significantly different than those obtained by some third party testers. The standard has been revised (Dunaway 1999) and approved February 11, 2000, which may address the issue of reproducibility. Other comments about the method criticize the fundamental requirements for testing in an open field, with no reflecting surface for 100 ft, and the receiver 50 ft away, as being unrealistic and unrepresentative of real-world use on residential properties (Allen 1999a). A standardized method, however, usually does not reflect real-world conditions, but rather is useful for comparing sound levels from different blowers tested under the same conditions. The complexity and precision required by the method does appear to render it unsuitable as a field enforcement standard (Zwerling 1999).

While the ANSI method yields sound level exposures for a bystander, the noise level exposure for the operator is measured using an audiodosimeter. For occupational exposures, a dosimeter can report the noise dose as a percentage relative to the permissible exposure level of 90 dBA (8 CCR General Industry Safety Orders, Article 105, Appendix A; 29 CFR ? 1910.25). The eight-hour time-weighted-average sound level experienced by the worker is then calculated from the dose, using a formula specified in regulations. Additional details can be found in the OSHA and Cal/OSHA Technical Manuals.[8]

[8]OSHA?s Technical Manual is available on their website (www.osha.gov) and noise measurement is in Section III, Chapter 5. Cal/OSHA?s manual is available from Cal/OSHA.

3. Noise in California

a. Noise Sources

By all accounts, noise exposure is increasing both as the number of sources increases and as existing sources get noisier (Berglund & Lindvall 1995). We drive our cars more and take more airplane trips, increasing noise from what have been the two major sources of noise for at least the last two decades; sales of engine-powered lawn and garden equipment continue to increase; and movie theaters and video arcades use noise to increase excitement (Consumer Reports 1999, PPEMA 1999, U.S. EPA 1981). The major sources of noise are transportation, from road, air, and rail traffic, which impact the most people of all noise sources; industrial machinery and facilities; construction; building services and maintenance activities; domestic noise from one?s neighbors; and self-inflicted noise from leisure activities, which may quality as domestic noise to one?s neighbors (Berglund & Lindvall 1995).

b. Numbers of People Potentially Exposed: the Public

It is not possible to state with any certainty how many people in California are exposed to noise from leaf blowers. Indeed, the most recent nationwide estimate of the number of people exposed to noise from various sources dates from 1981. In that study, the U.S. EPA estimated that 730,000 people were exposed to noise from leaf blowers above the day-night average sound level of 45 dBA (U.S. EPA 1981). The use of leaf blowers has grown tremendously since 1980, however, and thus these numbers cannot be reliably scaled for an estimate of the number of Californians exposed to leaf blower noise today.

As California?s population has grown almost 41% since 1970 (CDF 1998, CDF 1999), population density, and thus noise exposure, has increased. California classifies counties as being metropolitan or non-metropolitan, based on the Bureau of the Census categorization of standard metropolitan statistical areas as containing or being close to a large city. As of January 1, 1999, the thirty-four metropolitan counties comprise 96.7% of California?s population, or about 32.67 million people. The population of Californians who live in non-metropolitan counties, while small at 3.3% of the total, or 1.11 million people, has increased faster than the population in metropolitan counties (47.1% increase versus 40.5% increase, 1970-1999) and thus even noise exposures in the lowest populated counties have likely increased over the past thirty years.

Unfortunately, without a comprehensive and current survey of noise exposures in California, it is not possible to determine, from available data, how many Californians are exposed to noise, and in particular exposed to noise from leaf blowers. The only conclusion is that the number of people affected by noise is likely increasing as population density increases even in non-metropolitan areas of the state. How many people are exposed to, and annoyed by, noise from leaf blowers is a question for future research.

c. Numbers of People Potentially Exposed: the Operator

In southern California, about 80% of lawn and landscape contracting firms use leaf blowers (Anon 1999), thus one can assume that most gardeners are exposed to the noise from leaf blowers, either as an operator or from working in close proximity to the operator. From the California database of employees covered by unemployment insurance, in the fourth quarter of 1998 there were 59,489 workers reported by 6790 firms, in the SIC Code 0782, Lawn and Garden Services (M. Rippey, pers. com). This number is assumed to be the lower bound of those exposed, as there are an unknown number of self-employed gardeners, who may not report their earnings or be covered by unemployment insurance. Future research could test the hypothesis that all lawn and garden service workers are exposed, as operators or from working in close proximity, to the noise from leaf blowers.

4. Regulating Noise

a. Federal Law

The Noise Control Act of 1972 established a statutory mandated national policy ? to promote an environment for all Americans free from noise that jeopardizes their public health and welfare.? The Office of Noise Abatement and Control was established within the U.S. EPA to carry out the mandates of the Noise Control Act. The Office of Noise Abatement and Control published public health and welfare criteria; sponsored an international conference; examined dose-response relationships for noise and its effects; identified safe levels of noise; promulgated noise regulations; funded research; and assisted state and local offices of noise control; until funding for the office was removed in 1981-1982 (Suter 1991; Shapiro 1991). In its almost ten years of operation, U.S. EPA produced several documents that are still relevant and were consulted from this report.

The hearing of workers is protected by regulations promulgated under the Occupational Safety and Health Act of 1970. As California employers fall under California?s equivalent program, hearing protection law will be covered below under state law.

b. State Law

California enacted the Noise Control Act of 1973 to ? establish a means for effective coordination of state activities in noise control and to take such action as will be necessary...? [HSC ?46000(g)]; the office was established within the California Department of Health Services. One of the primary functions of the office was to provide assistance to local governmental entities that develop and implement noise abatement procedures, and several guidelines were written. Funding for the office, however, ended beginning in the 1993-1994 fiscal year; no relevant reports or guidelines were located for this report.

California?s counterpart to OSHA, the Cal/OSHA, has a General Industry Safety Order [8 CCR Article 105 ? 5095-5100] for the control of noise exposure that is very similar to the federal

OSHA regulations. When sound level exposure exceeds 85 dBA for an 8-hour time-weighted average, employers are required to provide a hearing conservation program at no cost to employees. The hearing conservation program includes audiometric testing of hearing, provision of hearing protectors, training, and record keeping. Employers are required to provide employees with hearing protection when noise exposure exceeds 90 dBA in an eight-hour work day; as noise levels increase, the allowable exposure duration also decreases. The permitted duration for an employee exposed to 103 dBA, for example, is one hour and nineteen minutes in a work day [8 CCR ? 5096 (a)(b)]. Employers are allowed to use personal protective equipment to reduce sound level exposures if administrative or engineering controls are not feasible or fail to reduce sound levels within permissible levels.

c. Local Ordinances

In contrast to the low level of activity on noise control at the federal and state levels, local California cities and counties have been very active in regulating and enforcing noise standards. About twenty cities have banned the use of gasoline-powered, or gasoline- and electric-powered leaf blowers, from use within their city limits (City of Palo Alto 1999a). Including the recent Los Angeles ban on use within 500 ft of residences, about 13% of Californians live in cities that ban the use of leaf blowers, and six of the ten largest California cities have ordinances that restrict or ban leaf blowers. All together, about one hundred California cities have ordinances that restrict either leaf blowers specifically or all gardening equipment generally, including the cities with bans on leaf blower use (IME 1999).

The restrictions on leaf blowers fall into four basic categories, with many cities employing a combination of approaches: time of day/day of week, noise levels, specific areas, and educational (City of Palo Alto 1999a). Time of day/day of week ordinances are the most common and are used to control when leaf blowers can be operated. Typically, hours of use are restricted to times between 7:00 a.m. and 7:00 p.m., and days of use are either Monday through Friday or Monday through Saturday, and sometimes including Sunday, with shorter hours on the weekend, based on the assumption that leaf blower noise is most offensive during the evening and night time hours, and on the weekend. There may be exceptions for homeowners doing their own yard work and for work in commercial areas. Time of day/day of week ordinances are relatively easy to enforce. A problem with these ordinances, however, is that they ignore the needs for quiet during the day of babies, young children, and their caretakers; day-sleepers; the ill; the retired; and a growing population of those who work in a home office.

Some cities regulate leaf blower use based on noise levels recorded at a specified distance from the operator. Palos Verdes Estates and Davis, for example, set the noise level at 70 dBA at 50 ft, and Newport Beach and San Diego have a 65 dBA at 50 ft restriction. Davis allows single-family homeowners to avoid the restriction if the leaf blower is operated for less than ten minutes. Palos Verdes Estates requires blowers to be tested and certified by the city. Otherwise, a noise level restriction is very difficult to enforce as the enforcement officer must be trained in the use of sound level meters, carry the meter, and record the sound level before the operator turns off the leaf blower or moves on. These rules target the control of noise from blowers, and could protect those who are home during the day, if they could be effectively enforced.

Recognizing that leaf blowers are often perceived as most offensive when used in residential areas, many cities stipulate usage restrictions only in residential areas, or within a certain distance of residential areas. The residential use distance restrictions prohibiting the use of leaf blowers range from 100 ft, in Foster City, to 500 ft, in Los Angeles. This type of ordinance protects those who are at home and in need of quiet during the day, but does not address issues of those who work and recreate in commercial or other non-residential areas.

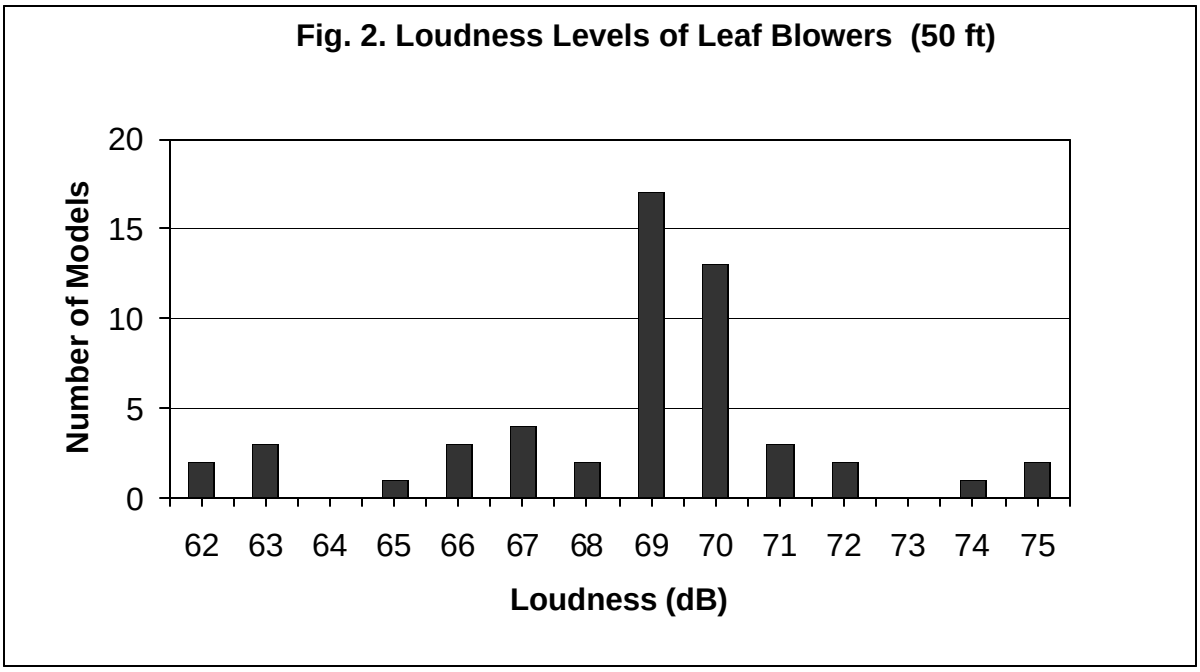
Cities sometimes couple area restrictions with user guidelines, such as prohibitions on blowing debris onto adjacent properties, and require operators be educated on the proper use of leaf blowers so as to minimize noise levels and environmental issues. These educational approaches are generally not oriented towards enforcement, but seek to change operator behavior. Educational approaches are often endorsed by landscapers and manufacturers, who believe that much of the discord over leaf blower usage originates with the few gardeners who use them incorrectly or inconsiderately. For example, an organization calling itself LINK, or Landscapers Involved With Neighborhoods and Kids, promotes educating operators to use their leaf blowers at half-throttle within 150 ft of homes (LINK 1999).

5. Noise From Leaf Blowers

In a survey of Southern Californian gardeners by a consumer products manufacturer (Anon 1999), the top two ranked attributes of a desirable leaf blower were, in order, ? powerful? and ? quiet.? Important features were identified as ? backpack mounted,? ? noise below legal limits,? and ? variable speed.? When asked what they dislike about their leaf blowers, the most commonly cited problem was ? noise.? Taken together, these answers suggest that loud noise from leaf blowers is not only an issue for the public, but is also a major issue of concern for the gardeners who use them, at least in Southern California. On the other hand, a major manufacturer has indicated that low noise does not even show up in their survey of desirable leaf blower features (Will 1999b), so perhaps low noise is only a concern of California gardeners.

a. Bystander noise exposure

Manufacturer-reported noise levels from leaf blowers are summarized in Appendix G; all reported noise levels are assumed to represent bystander exposure, with the receiver 50 ft from the blower, unless otherwise noted. The reported levels are based on statements in promotional literature or personal communications with manufacturers; some manufacturers did not report the sound levels of most of their models in materials available to the ARB. For backpack and hand held blowers, sound levels range from 62 dBA to 75 dBA, with more than half registering between 69 and 70 dBA (Figure 2). Bearing in mind the logarithmic decibel scale, the difference in a leaf blower at 62 dBA and one at 75 dBA, a 13 dBA range, represents more than a quadrupling of the sound pressure level, and would be perceived by a listener as two to three times as loud. The rule of thumb is that when a sound level increases by ten dB, the subjective perception is that loudness has doubled (MPCA 1987).



There are presently two gasoline-powered backpack and three hand held electric leaf blowers that are reported by their manufacturers to be very quiet. Maruyama and Toro have the two quietest backpack blowers, and Poulan/Weedeater, Stihl, and Toro have produced the quietest hand held blowers. Echo, Inc., which sells slightly under one-third of the total number of backpack blowers, has a model rated at 65 dB, the PB-46LN. In 1996, the most popular Echo backpack leaf blower, based on sales, was the Echo PB-400E, which is also one of the noisiest at 74 dBA. By 1999, however, the quieter PB-46LN had surpassed the PB-400E in sales (Will, L., pers. com.).

b. Operator Noise Exposure

Data on noise levels at the leaf blower operator's ear are limited. The League for the Hard of Hearing (1999) publishes a fact sheet in which the noise level of a leaf blower is listed as 110 dBA. Clark (1991) reported that one model by Weedeater emitted a maximum level of 110-112 dBA and an equivalent A-weighted sound level (L_{eq}) of 103.6 dBA. This leaf blower model, however, is no longer available and these data may not be comparable to today?s leaf blowers. Other than Clark?s report, no other published report could be located, but unpublished data were found.

Schulze and Lucchesi (1997), in an unpublished conference presentation, reported the range and average sound pressure level from four leaf blowers. The four leaf blowers were unidentified models from Craftsman, Weedeater, and Shop Vac.[9] The authors reported that 3 ft from the leaf

[9]ARB was not able to obtain the specific models tested or actual SPLs for each model leaf blower.

blower the sound pressure levels ranged from 80 to 96 dBA, with an average value of 88 dBA, and concluded that leaf blower noise did not violate the OSHA permissible noise exposure limit. Sound pressure levels, however, were not measured at the operator? s ear, and thus usefulness of the data is limited. In addition, whether or not the OSHA noise exposure limits are violated depends on the amount of time the listener is exposed, as the action level is an eight-hour time-weighted average. At least one of the leaf blowers had an SPL above the Permissible Exposure Limit of 90; at 96 dBA, the operator would be restricted to a 3 hr, 29 minute daily exposure without hearing protection.

The Portable Power Equipment Manufacturers Association (Hall 1999) conveyed limited, blinded data to the ARB on operator exposures. With no information as to data collection methods (some pages were marked ? ISO 7182"), manufacturers, models, or maximum and minimum sound levels, these data are of limited quality. Reported operator sound levels, some of which were identified as ? full open throttle? or ? full load,? ranged from 91.5 dBA to 106 dBA.

A consultant with James, Anderson & Associates, Inc. (Hager 1999), provided ARB with data collected as a part of comprehensive noise exposure studies by the firm (Table 7). As with the PPEMA data, ARB was not given the make or models of leaf blowers tested. Sound levels were recorded in the hearing zone of groundskeepers while they were operating leaf blowers, along with the amount of time the groundskeeper operated the leaf blower in an 8-hr day. Sound levels were measured in dBA per federal OSHA requirements. As shown, duration of use ranged from 15 minutes to 7.6 hours (average 2.1 hr) during the day. Operator exposure ranged from 88.6 to 101.3 dBA. In this data set, only one of the six individuals monitored would have exceeded the protective levels, based on leaf blower use for 7.6 hrs.

Table 7. Leaf Blower Operator Noise Exposures and Duration of Use (Hagar 1999)

Average SPL, dBA	Minimum SPL, dBA	Maximum SPL, dBA	Duration of Leaf Blower use (hr)
99.5	96.4	101.3	0.75
92.0	N/R	N/R	1.0
101.2	N/R	101.9	2.3
101.3	98.3	105.7	7.6
95.9	92.0	97.0	0.25
88.6	85.0	90.4	0.5

N/R = not reported

Eric Zwerling of the Rutgers Noise Technical Assistance Center, along with Les Blomberg, Executive Director of the Noise Pollution Clearinghouse, recently conducted studies of operator exposure and the sound quality of leaf blowers (Zwerling 1999). While the data are still being analyzed, preliminary results were made available to the ARB. Three backpack and one handheld leaf blowers were tested using ANSI B175.2-1996 test method for the bystander exposure and using personal dosimetry for operator exposures (Table 8). All equipment used for tests was certified and calibrated. Zwerling and Blomberg used a 3 dB exchange rate for the operator dosimetry, as recommended by NIOSH, but noted that the data can be reasonably compared to data derived with the OSHA mandated 5 dB exchange rate because of the steady sound emissions of the leaf blowers. Because of this, the OSHA permissible exposure durations, which are based on the 5 dB exchange rate, are noted in Table 8. The difference is most important for the worker, who is allowed, for example, a 1 hr exposure (unprotected) at 105 dB by OSHA, but only 4 min, 43 sec exposure (unprotected) under the more conservative NIOSH-recommended 3 dB exchange rate.

Table 8. Sound Levels of Some Leaf Blowers,
E. Zwerling & L. Blomberg

Make/Model	Type	Condition	Bystander Exposure, dB	Operator Exposure,* Leq	OSHA Permissible Exposure Duration (approx)
Stihl BR 400	Backpack	New	73.89	105.7, 105.8, 105.5	52 min
Stihl BR 400	Backpack	Used	74.5, 74.63	103.3, 102.9	1 hr, 19 min
Kioritz DM9	Backpack	Used	76.0	102.0	1 hr, 31 min
Stihl BR 75	Handheld	New	68.4	98.4, 97.9	2 hr, 38 min

*Samples ranged from 5-10 minutes; each reported value is a distinct sample. The microphone was attached to the cap above the operator?s ear.

Finally, the Echo *Power Blower Operator?s Manual* advises operators to wear hearing protection whenever the unit is used. The user is instructed that ? OSHA requires the use of hearing protection if this unit is used 2 hours per day or more.? This statement indicates that the operator may be exposed to an SPL of 100 dBA or more during use.

6. Use of Hearing Protectors and Other Personal Protection Gear

When this study was initiated, there were no studies found that documented the incidence of personal protective equipment usage among operators of leaf blowers. Hearing protectors are widely available, and some manufacturers provide an inexpensive foam ear plug set with the purchase. More expensive custom molded ear plugs and ear muffs provide better protection than the moldable foam ear plugs, but again no data were available on usage. Two studies did examine the incidence of usage of hearing protection in other industries. In one study of 524 industrial workers, although 80.5% were provided with hearing protection devices, only 5.1% wore them regularly (Maisarah & Said 1993). In another study of metal assembly workers who worked in a plant where the average noise level was 89 dBA, only 39% of the men reported wearing hearing protection always or almost always (Talbott et al. 1990).

By the end of September 1999, however, three studies were delivered to the ARB that included information on the use of hearing protection by leaf blower operators. Two of the studies consisted of

direct observations of operators; the third was a survey that asked people who hire gardeners to recall the use of personal protection gear by their gardeners. Following are summaries of each of the studies.

a. Zero Air Pollution Study (1999)

The goal of this study was to ? observe 100 yard maintenance workers to determine the percentage of workers who followed the safety instruction while operating gas powered leaf blowers.? Workers were observed from August to October, 1997 in the western portions of the City of Los Angeles, including the San Fernando Valley. Of 100 leaf blower operators observed, none wore hearing protection, one (1%) wore breathing protection (dust mask), and 22 (22%) wore eye protection of some kind. Of the workers observed, 27 (27%) were interviewed; seven of those claimed hearing impairment as a result of using leaf blowers and two claimed to have breathing problems which they attributed to using leaf blowers. Ten of those interviewed (37%) said they were aware of manufacturers? safety instruction but did not feel it was necessary to follow the instructions. The remaining 17 (63%) were unaware of manufacturers? safety instructions.

b. Citizens for a Quieter Sacramento Study (1999b)

The goal of this study, as for the Zero Air Pollution study, was to determine the percentage of leaf blower operators who wear personal protective equipment when using blowers. A total of 64 observations were made during August and September 1999; 12 in Sacramento, 47 in the Los Angeles area, and 5 in other cities. Most (88%) of the observations were of blowers being used on residential properties. Of the 64 observations, there were four (6%) individuals observed wearing hearing protection, 41 (64%) were not wearing hearing protection, and in the remaining cases the observer could not tell whether or not hearing protection was used. Eye protection use was lower, only 3 (5%) operators were wearing glasses, but breathing protection incidence was higher, seven (11%) wore dusk masks. Observations were also made of the incidence of personal protection of other workers, when the crew was larger than one person. Of the 38 observations of other workers, two (5%) were using hearing protection, two (5%) were using eye protection, and two (5%) wore dusk masks.

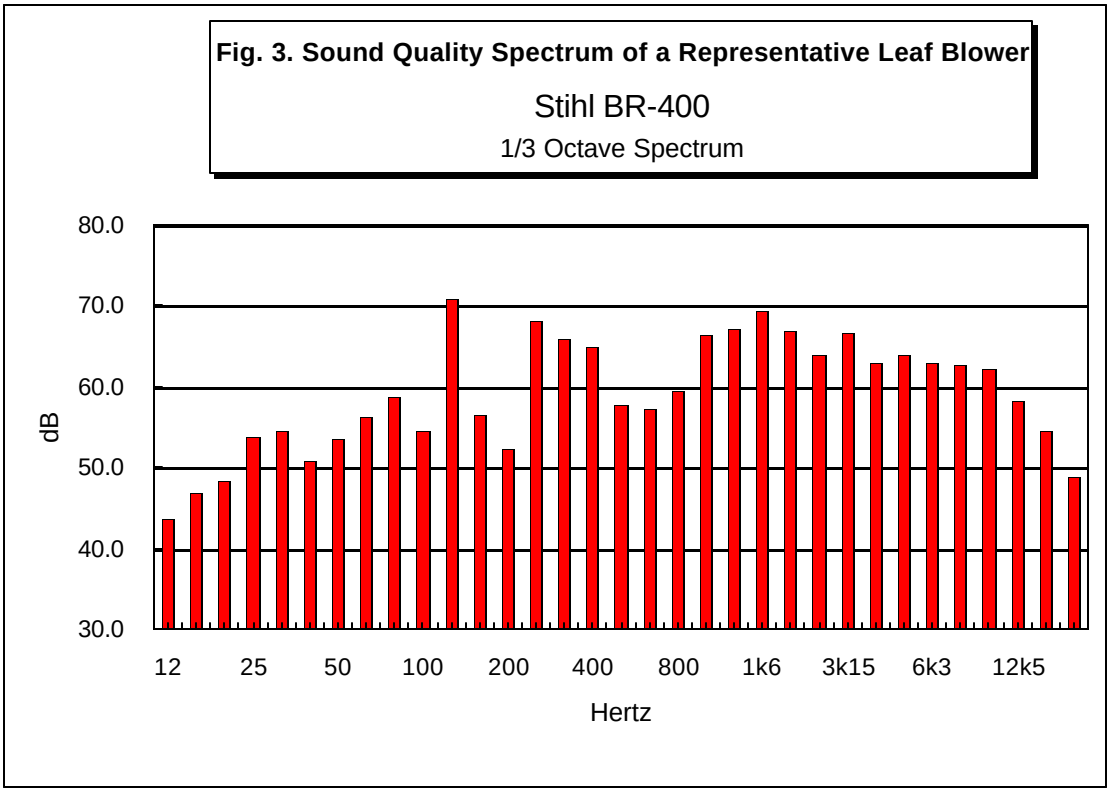
c. Survey99 Report (Wolfberg 1999)

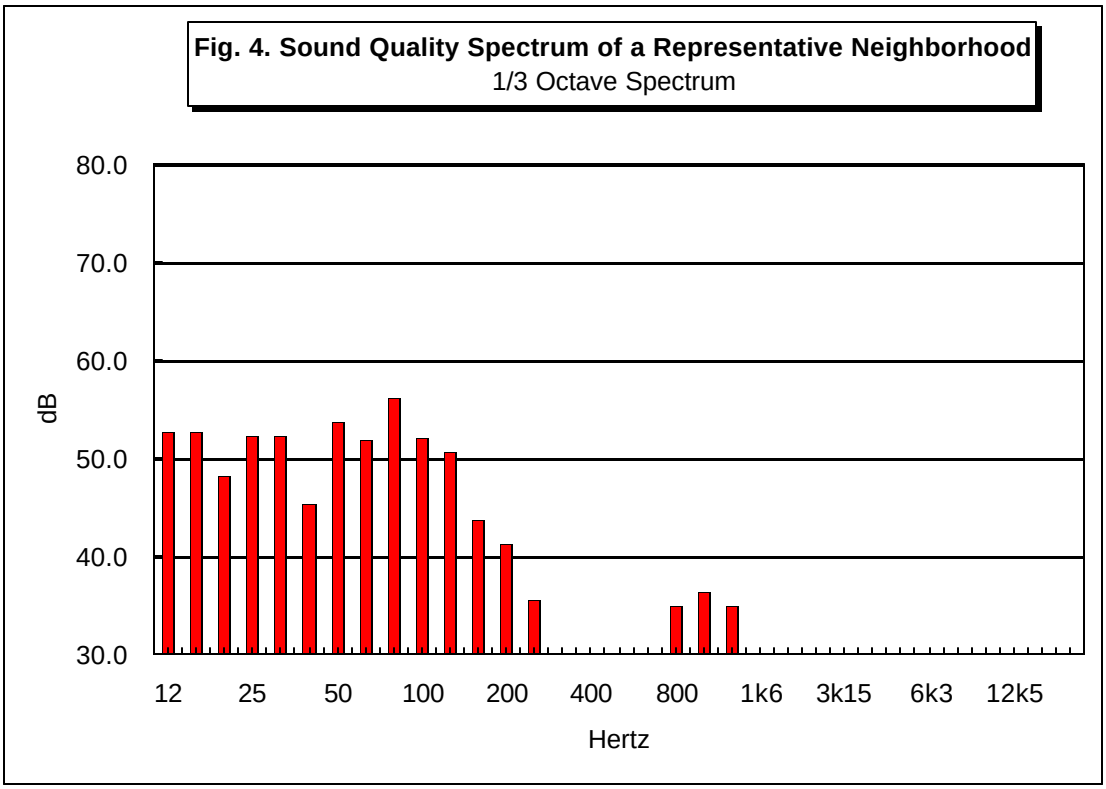
The third study provided to the ARB was authored by Mrs. Diane Wolfberg, Chair of the Zero Air Pollution Education Committee and Mr. George Wolfberg. Although the authors are members of Zero Air Pollution, the study was distinct from the 1997 study summarized above. The goal of this study was to determine ? opinions and perceptions of California residents regarding the use of leaf blowers . . . for residential landscape maintenance.? Mainly residents of Los Angeles were surveyed. Survey takers asked residents a variety of questions related to the use of leaf blowers on residential properties; in addition, respondents were asked about the incidence of personal protective equipment use by leaf blower operators. Because the data are based on recall rather than direct observations, their usefulness is limited. Data are summarized here, nevertheless, for completeness.

Of respondents who have had leaf blowers used on their properties in the previous 12 months, 53% reported that leaf blower operators never use a face mask, 62% never use eye protection, and 69% never wear hearing protection. On the positive side, however, respondents reported that 13% of operators always wear a face mask, 19% always wear eye protection, and 9% always wear hearing protection. These percentages are much higher than found in the two direct observation studies.

7. Sound Quality

As discussed earlier, the perceived loudness of noise is dependent on both sound pressure level and frequency, which is termed the sound quality. One study examined sound quality from leaf blowers (Zwerling 1999). While this study is unpublished and data are still being analyzed, the authors have made data and preliminary findings available to the ARB. Figures 3 and 4 illustrate sample sound spectra from a leaf blower and ambient sound, respectively. As shown in Figure 3, the sound spectrum of the gasoline-powered leaf blower contains a significant amount of high intensity and high frequency emissions. In a quiet residential neighborhood (Figure 4), there are few or no natural sources of sound at these high frequencies. Therefore, the sound emissions of gasoline-powered leaf blowers are not only more intense than the ambient sound levels, their spectra are noticeably different than the spectrum for ambient sounds. The high frequency emissions are, therefore, not masked by other sounds and are more noticeable, perhaps accounting for the high level of annoyance reported by bystanders. These data and their implications for annoyance should be confirmed by further study.





8. Summary

Noise is the general term for any loud, unmusical, disagreeable, or unwanted sound, which has the potential of causing hearing loss and other adverse health impacts. While millions of Californians are likely exposed to noise from leaf blowers as bystanders, given the ubiquity of their use and the increasing density of California cities and towns, there is presently no way of knowing for certain how many are actually exposed, because of the lack of studies. In contrast, it is likely that at least 60,000 lawn and garden workers are daily exposed to the noise from leaf blowers. Many gardeners and landscapers in southern California are aware that noise is an issue and apparently would prefer quieter leaf blowers. Purchases of quieter leaf blowers, based on manufacturer data, are increasing. While little data exist on the noise dose received on an 8-hr time-weighted-average by operators of leaf blowers, data indicate that some operators may be exposed above the OSHA permissible exposure limit. It is unlikely that more than 10% of leaf blower operators, and probably a much lower percentage, regularly wear hearing protective gear, thus exposing them to an increased risk of hearing loss. The sound quality of gasoline-powered leaf blowers may account for the high level of annoyance reported by bystanders.

III. REVIEW OF HEALTH EFFECTS

Leaf blower noise, exhaust and fugitive dust emissions, as discussed in previous sections of this report, are health concerns. The goal of this section is to present information on health effects of identified hazards from leaf blowers; this section does not present exposure information or data tying identified hazards to specific health effects in leaf blower operators or bystanders. The following discussion addresses the health effects of particulate matter, carbon monoxide, unburned fuel, and noise. Particulate matter, carbon monoxide, and unburned fuel are components of exhaust emissions; particulate matter is also the major constituent of fugitive dust. Ozone is a pollutant that is formed in the atmosphere through chemical reactions of hydrocarbons (unburned fuel) and nitrogen oxides in the presence of ultraviolet light. Although not directly emitted, ozone is a pollutant of concern because leaf blowers emit hydrocarbons, which react to form ozone. The health effects of nitrogen oxides are not discussed as these emissions from leaf blowers are relatively low, and any health effects would be negligible.

National Ambient Air Quality Standards have been set by the federal government to protect public health and welfare. In addition, California has State ambient air quality standards. These standards include a margin of safety to protect the population from adverse effects of chronic pollutant exposure. The National Ambient Air Quality Standards and California standards are intended to protect certain sensitive and probable risk groups of the general population (Appendix C).

A. Particulate Matter

Fugitive dust is not a single pollutant, but rather is a mixture of many subclasses of pollutants, collectively termed particulate matter (PM), each containing many different chemical species (U.S. EPA 1996). Particles of 10 ? m and smaller are inhalable and able to deposit and remain on airway surfaces. The smaller particles (2.5 ? m or less) are able to penetrate deep into the lungs and move into intercellular spaces. The respirable particles owe their negative health impacts, in part, to their long residence time in the lung, which allows chemicals time to interact with body tissues. ARB staff could not locate data on the specific chemical and physical make-up of leaf blower dust, although some data are available on paved road dust, thus only generic effects from the respirable fraction (particles 10 ? m and smaller) are addressed.

Many epidemiological studies have shown statistically significant associations of ambient PM levels with a variety of negative human health endpoints, including mortality, hospital admissions, respiratory symptoms and illness measured in community surveys, and changes in pulmonary mechanical function. Associations of both short-term, usually days, and long-term, usually years, PM exposure with most of these endpoints have been consistently observed. Thus, the public health community has a great deal of confidence that PM is significantly associated with negative health outcomes, based on the findings of many studies.

There remains uncertainty, however, regarding the magnitude and variability of risk estimates for PM. Additional areas of uncertainty include the ability to attribute observed health effects to specific PM constituents, the time intervals over which PM health effects are manifested, the extent to which findings in one location can be generalized to other locations, and the nature and magnitude of the overall public health risk imposed by ambient PM exposure. While the existing epidemiology data provide support for the associations mentioned above, understanding of underlying biologic mechanisms is incomplete (U.S. EPA 1996).

B. Carbon Monoxide

A component of exhaust, carbon monoxide (CO) is a colorless, tasteless, odorless, and nonirritating gas that is a product of incomplete combustion of carbon-containing fuels. With exposure to CO, subtle health effects can begin to occur, and exposure to very high levels can result in death. The public health significance of CO in the air largely results from CO being absorbed readily from the lungs into the bloodstream, forming a slowly reversible complex with hemoglobin, known as carboxyhemoglobin. The presence of significant levels of carboxyhemoglobin in the blood reduces availability of oxygen to body tissues (U.S. EPA 1999b).

Symptoms of acute CO poisoning cover a wide range depending on severity of exposure, from headache, dizziness, weakness, and nausea, to vomiting, disorientation, confusion, collapse, coma, and at very high concentrations, death. At lower doses, central nervous system effects, such as decreases in hand-eye coordination and in attention or vigilance in healthy individuals, have been noted (Horvath et al. 1971, Fodor and Winneki 1972, Putz et al. 1976, 1979, as cited in U.S. EPA 1999b). These neurological effects can develop up to three weeks after exposure and can be especially serious in children.

National Ambient Air Quality Standards have been set to protect public health and welfare and are intended to protect certain sensitive and probable risk groups of the general population. The sensitive and probable risk groups for CO include anemics, the elderly, pregnant women, fetuses, young infants, and those suffering from certain blood, cardiovascular, or respiratory diseases. People currently thought to be at greatest risk from exposure to ambient CO levels are those with ischemic heart disease who have stable exercise-induced angina pectoris (cardiac chest pain) (ARB 1992, U.S. EPA 1999b). In one study, high short-term exposures to CO were found in people operating small gas-powered garden equipment (ARB 1992).

C. Unburned Fuel

Some toxic compounds are present in gasoline and are emitted to the air when gasoline evaporates or passes through the engine as unburned fuel (ARB 1997). Benzene, for example, is a component of gasoline. Benzene is a human carcinogen and central nervous system depressant. The major sources of benzene emissions in the atmosphere are from both unburned and burned gasoline.

The amount of benzene in gasoline has been reduced in recent years through the mandated use of California Reformulated Gasoline (ARB undated fact sheet[10]). Other toxic compounds that are emitted from vehicle exhaust include formaldehyde, acetaldehyde, and 1,3-butadiene. Acetaldehyde is a probable human carcinogen (Group B2) and acute exposures lead to eye, skin, and respiratory tract irritation. 1,3-Butadiene is classified as a probable human carcinogen, is mildly irritating to the eyes and mucous membranes, and can cause neurological effects at very high levels. Formaldehyde is highly irritating to the eyes and respiratory tract and can induce or exacerbate asthma. It is classified as a probable human carcinogen (Group B1).

D. Ozone

Ozone is a colorless, odorless gas and is the chief component of urban smog. It is by far the state?s most persistent and widespread air quality problem. Ozone is formed from the chemical reactions of hydrocarbons and nitrogen dioxide in the presence of sunlight. Leaf blowers emit substantial quantities of hydrocarbons, primarily from unburned fuel, which can react to form ozone. Ozone is a strong irritant and short-term exposures over an hour or two can cause constriction of the airways, coughing, sore throat, and shortness of breath. Ozone exposure may aggravate or worsen existing respiratory diseases, such as emphysema, bronchitis, and asthma. Chronic exposure to ozone can damage deep portions of the lung even after symptoms, such as coughing, disappear. Over time, permanent damage can occur in the lung, leading to reduced lung capacity.

E. Noise

The literature on health effects of noise is extensive. Exposure of adults to excessive noise results in noise-induced hearing loss that shows a dose-response relationship between its incidence, the intensity of exposure, and duration of exposure. Noise-induced stimulation of the autonomic nervous system reportedly results in high blood pressure and cardiovascular disease (AAP 1997). In addition there are psychological effects. The following subsections will first discuss noise-induced hearing loss and physiological stress-related effects. Adverse impacts on sleep and communication, effects of performance and behavior, annoyance, and effects on wildlife and farm animals are also described. These are not perfect divisions between discreet affects: nighttime noises can cause sleep-deprivation, for example, which can lead to stress, elevated blood pressure, and behavioral changes, especially if the effect is repeated and uncontrollable. But first, before discussing effects, the reader should have an understanding of how the ear functions.

[10]http://arbis.arb.ca.gov/cbg/pub/cbgbkgr1.htm

1. Hearing and the Ear

A detailed discussion of the ear?s anatomy and the mechanism by which we hear is beyond the scope of this report, but a basic level of understanding is necessary so that later discussions of damage to hearing will be better understood. For further information, the reader is referred to any basic acoustics or biology text.

The ears are paired sensory organs that serve two functions, to detect sound and to maintain equilibrium; only sound detection will be addressed in this report. The ears are composed of the external ear, middle ear, and the inner ear. With the assistance of the external ear in collecting and focusing sound, vibrations are transmitted to the middle ear via the ear canal and the eardrum. The vibrations of the eardrum are transmitted by the bones of the middle ear to the fluid-filled sensory organ of the inner ear, the cochlea. As the fluid of the inner ear vibrates, the hair cells located in the cochlea bend, stimulating sensory receptors, and leading to nerve impulses being transmitted to the brain via the auditory nerve. The greater the hair cell displacement, the more sensory receptors and neurons are stimulated, resulting in the perception of an increase in sound intensity.

Hearing loss can result from damage or growths in any portion of the ear and the part of the brain that processes the nerve impulses. Damage to the outer and middle ear result in conductive hearing loss, in which case the vibrations can still be perceived and processed if they can be transmitted by another means to the inner ear. Damage to the inner ear and auditory nerve result in sensorineural hearing loss. Sensorineural hearing loss can be temporary, if the body?s mechanisms can repair the damage, but cumulative inner ear damage will result in permanent hearing loss. Aging, diseases, certain medications, and noise cause the majority of sensorineural hearing loss, which is not reversible by surgery or medication, and is only partially restored by hearing aids.

2. Noise-Induced Hearing Loss

Roughly 25% of all Americans aged 65 and older suffer from hearing loss. Contrary to common belief, hearing loss is not part of the natural aging process, but is caused by preventable, noise-induced wear and tear on the auditory system (Clark & Bohne 1999). Noise-induced hearing loss develops gradually over years and results from damage to the inner ear. Sensory cells within the cochlea are killed by exposure to excessive noise. These cells do not regenerate but are replaced with scar tissue. After weeks to years of excessive noise, the damage progresses to the point where hearing loss occurs in the high-frequency range and is detectable audiometrically; speech comprehension is not usually affected and so at this level hearing loss is goes unnoticed by the individual. Eventually, with continued exposure, the hearing loss spreads to the lower pitches necessary to understand speech. At this point, the impairment has proceeded to the level of a handicap and is quite noticeable. The damage is not reversible and is only poorly compensated for by hearing aids.

There is considerable variability among individuals in susceptibility to hearing loss. Based on major field studies conducted in the late 1960s and early 1970s, the U.S. EPA suggested that a 24-hour

equivalent sound level of 70 dBA would protect 96% of the population, with a slight margin of safety, from a hearing loss of less than five dBA at 4000 Hz (U.S. EPA 1974). This 24-hour, year-round equivalent sound level is based on a forty-year work-place noise level exposure (250 working days per year) of 73 dBA for eight hours and 60 dBA for the remaining 16 hours.

The National Institute for Occupational Safety and Health reviewed the recommended occupational noise standard recently (NIOSH 1996) and reaffirmed its recommended exposure limit of 85 dBA for occupational noise exposure. The report concluded that the excess risk of developing occupational noise-induced hearing loss for a 40-hr lifetime exposure at 85 dBA is 8%. In comparison, the OSHA regulation [29 CFR ? 1910.95] allowing a 90 dBA permissible exposure limit results in a 25% excess risk of developing hearing loss. The OSHA regulation, however, has not been changed to reflect the recommendation of the National Institute for Occupational Safety and Health.

NIOSH also recommended changing the exchange rate, which is the increment of decibels that requires the halving or doubling of exposure time, from the OSHA mandated 5 dBA to 3 dBA. This would mean that if the worker was permitted to be exposed to 85 dBA unprotected for 8 hr, then a noise exposure level of 88 dBA would be limited to 4 hr per day. The 3-dBA exchange rate is supported by acoustics theory, and by national and international consensus. OSHA, however, continues to mandate a 5 dBA exchange rate in its regulations. In addition, the American Academy of Pediatrics (1997) has asked the National Institute of Occupational Safety and Health to conduct research on exposure of the fetus to noise during pregnancy and recommends that the OSHA consider effects on the fetus when setting occupational noise standards.

3. Non-Auditory Physiological Response

In addition to hearing loss, other physiologic and psychological responses resulting from noise have been noted and are termed non-auditory effects. Noise is assumed to act as a non-specific biological stressor, eliciting a ? fight or flight? response that prepares the body for action (Suter 1991). Research has focused on effects of noise on blood pressure and changes in blood chemistry indicative of stress. Despite decades of research, however, the data on effects are inconclusive. While many studies have shown a positive correlation between hearing loss, as a surrogate for noise exposure, and high blood pressure, others have shown no correlation (Suter 1991; Kryter 1994). The National Institutes of Occupational Safety and Health (1996) has called for further research to define a dose-response relationship between noise and non-auditory effects, such as hypertension and psychological stress.

4. Interference with Communication

The inability to communicate can degrade the quality of living directly, by disturbing social and work-related activities, and indirectly, by causing annoyance and stress. The U.S. EPA (1974), in developing its environmental noise levels, determined that prolonged interference with speech was inconsistent with public health and welfare. Noise that interferes with speech can cause effects ranging from slight irritation to a serious safety hazard (Suter 1991), and has been shown to reduce academic performance in children in noisy schools, as reviewed by Kryter (1994). The U.S. EPA, therefore, developed recommended noise levels that are aimed at preventing interference with speech and reduced academic performance. An outdoor yearly average day-night sound level of 55 dBA permits adequate speech communication at about 9-10 ft, and also assures that outdoor noise levels will not cause indoor levels to exceed the recommended level of 45 dBA.

5. Interference with Sleep

It is common experience that sound rouses sleepers. Noise that occurs when one is trying to sleep not only results in repeated awakenings and an inadequate amount of sleep, but is also annoying and can increase stress. Noise that is below the level that awakens, however, also changes the sleep cycle, reduces the amount of "rapid eye movement" sleep, increases body movements, causes cardiovascular responses, and can cause mood changes and performance decreases the next day (Suter 1991). The U.S. EPA recommended an indoor average yearly day-night level of 45 dBA, which translates into a night time average sound level of 35 dBA, to protect most people from sleep disturbance.

An average sound level, however, does not adequately account for peak sound events that can awaken and disturb sleep. Continuous noise has a significantly smaller sleep disturbance effect than intermittent noise. Research has found that subjects in sleep laboratory experiments will gradually reduce the number of awakenings throughout the night in response to noise, but other physiological changes, including a momentary increase in heart rate, indicative of arousal do not change. The question is whether physiological arousal, short of awakening, has a negative health effect. While study results are inconclusive on this issue, it is clear that noise above a certain level, about 55 dBA L_{eq} according to Kryter (1994), will awaken people, even after long periods of repeated exposures. Repeated awakenings reduce feelings of restedness and cause feelings of annoyance, leading to stress responses and associated health disorders.

6. Effects on Performance and Behavior

The working hypothesis in this area has been that noise can cause adverse effects on task performance and behavior at work, in both occupational and non-occupational settings. Results of studies, however, have not always been as predicted. Sometimes noise actually improves performance, and sometimes there are no measurable differences in performance between noisy and quiet conditions

(Suter 1991). Kryter (1994) concluded that masking by noise of other auditory signals is the only inherent auditory variable responsible for observed effects of noise on mental and psychomotor tasks.

The effect of noise on "helping behavior" in the presence and absence of noise is more clear. Mathews and Canon (1975) tested the hypothesis that high noise levels may lead to inattention to the social cues that structure and guide interpersonal behavior. In a laboratory study in which subjects did not know they were being studied, they found that fewer persons were willing to help someone who had ? accidentally? dropped materials when background noise levels were 85 dB than when they were 65 dB or 48 dB. In a subsequent field study, similar results were demonstrated with background noise from a lawn mower. Initially, subjects were tested as to their willingness to help a man who had dropped books and papers while walking from his car to a house; in this test, helping behavior was low both in ambient (50 dB) and high (87 dB) noise conditions. When the test was repeated with a cast on the arm of the man who dropped the books, helping behavior was high under ambient noise (80%) and low under high noise (15%) conditions. These and other studies lead to the conclusion (Suter 1991) that even moderate noise levels can increase anxiety, decrease the incidence of helping behavior, and increase the likelihood of hostile behavior.

7. Annoyance and Community Response

Annoyance is a response to noise that has been extensively studied for years. Various U.S. government agencies began investigating the relationships between aircraft noise and its effect on people in the early 1950's. Annoyance is measured as an individual response to survey questions on various environmental factors, including as noise (Suter 1991). The consequences of noise-induced annoyance are privately held dissatisfaction, publicly expressed complaints, and possibly adverse health effects. Fidell et al. (1991) reviewed and synthesized the relationship between transportation noise and the prevalence of annoyance in communities based on over 30 studies. The relationship is an exponentially increasing function, with less than 10% of respondents reporting themselves to be highly annoyed at noises under an average day-night sound level of 56 dB. Fifty percent responded they were highly annoyed at sound levels approaching 79 dB, and nearly every person was highly annoyed at sound levels above 90 dB.

Suter (1991) concluded that throughout decades of study, community annoyance has been positively correlated with noise exposure level, and that although variables such as ambient noise level, time of day, time of year, location, and socioeconomic status are important, the most important variable is the attitude of the affected residents. Kryter (1994) further elaborates that interference by noise, and the associated annoyance, depends on the activity of an individual when the noise event occurs, and the intensity and duration of the noise. People have different beliefs about noise, which are also important. Those most annoyed share similar beliefs that the noise may be dangerous, is probably preventable, are aware that non-auditory effects are associated with the noise source, state they are sensitive to noise, and believe that the economic benefit represented by the source is not important for the community (Fields 1990).

8. Effects of Noise on Animals

Kryter (1994) reviewed studies on the effects of noise both on wildlife and farm animals. None of these studies examine noise-induced hearing loss, but rather looked at effects of noise on litter size, prevalence of wildlife, and milk production. Most of the studies were conducted to examine the effects of airport noise, including noise from landings and takeoffs and sonic booms near commercial and military airports, and noise from construction activities during laying of pipelines across wilderness areas. Negative impacts on wildlife and farm animals, due to noise, were not supported by the studies. In the airport studies, the absence of human activities in the areas surrounding the high noise exposure zones appeared to be more important than noise, resulting in abundant wildlife. Farm animals exposed to frequent sonic booms showed little or no negative effects, again using such criteria as reproduction, milk production, and growth rate. No study, however, has examined the effects of leaf blower noise on animals.

IV. POTENTIAL HEALTH AND ENVIRONMENTAL IMPACTS OF LEAF BLOWERS

This section of the report synthesizes the information presented in the two previous sections, hazard identification and health effects, and characterizes the potential health impacts of leaf blowers on operators and bystanders. As discussed previously, there are no studies of the health impacts of leaf blowers, and essential information is missing that prevents ARB from preparing a quantitative risk characterization. There is, for example, no information on the quantitative relationship between exposure to hazards from leaf blowers and adverse effects. The size of the exposed population and the magnitude and duration of exposures are also unknown. The goal of this section, then, is to point the discussion in directions dictated by the findings of the two previous sections, and to raise questions about the nature of health impacts that may be experienced by those exposed to the exhaust emissions, fugitive dust, and noise from leaf blowers in both occupational and non-occupational settings.

Leaf-blower operators and bystanders have two different types of exposures to exhaust and fugitive dust emissions: exposures that occur on a regional basis and exposures that occur when one is within a short distance of the leaf blower. Regional exposures are those exposures to air pollution that occur as a result of leaf blowers contributing to the basin-wide inventory of ozone, carbon monoxide, particulates, and toxic air pollutants. While leaf blowers contribute a small percentage to the basin-wide air pollution, they are nonetheless a source of air pollution that can be, and is, controlled through exhaust emission standards.

The second type of exposure is of greater concern. Lawn and landscape contractors, homeowners using a leaf blower, and those in the immediate vicinity of a leaf blower during and shortly after operation, are exposed to potentially high exhaust, fugitive dust, and noise emissions from leaf blowers on a routine basis. While ARB staff have not located conclusive data on how often, how long, and at what concentrations exposures occur, the ARB off-road model assumes that each commercial leaf blower is used for 275 hr/yr, and each residential leaf blower is used for 10 hr/yr. These figures do not tell us, however, how long each leaf blower operator is exposed.

Because of the highly speculative nature of the data on operator and bystander exposure time, staff have been unable to develop estimates of the quantities of chemicals individuals could be exposed to per amount of time. Instead, impacts are presented somewhat qualitatively, with recommendations for appropriate personal protection or controls from hazards that staff have found to be significant.

A. The Leaf Blower Operator

In this section, data are presented that apply to the commercial leaf blower operator, a person who regularly uses the leaf blower in the course of a landscaping or gardening job. Staff assume that a commercial leaf blower operator will use equipment with a higher horsepower than a residential, or homeowner, operator.

1. Exhaust Emissions

The typical leaf blower owned and operated by commercial lawn and landscape contractors, with an average horsepower of three and a load factor of 50% based on the ARB off-road emissions model, produces the estimated average emissions for a one hour usage as shown in Table 9. Actual operator usage apparently ranges from 15 minutes to a full work day (Table 7). To illustrate the magnitude of potential exhaust and fugitive dust emissions, staff have compared the estimated leaf blower emissions to the emissions from one hour of operation of two different types of light duty vehicles, one new and one old. A comparison of emissions from leaf blowers to vehicle engines is relevant to provide some sense of the relative quantities of pollutants.

Table 9. Commercial Leaf Blower Emissions Compared to Light Duty Vehicle Emissions
3 hp average, 50% load factor, 1999 emissions data

	Exhaust Emissions, g/hr	**Exhaust Emissions, new light duty vehicle,* g/hr**	**Exhaust Emissions, older light duty vehicle,** g/hr**
Hydrocarbons	199.26	0.39	201.9
Carbon Monoxide	423.53	15.97	1310
Particulate Matter	6.43	0.13	0.78
Fugitive Dust	48.6-1031	N/A	N/A

*New light duty vehicle represents vehicles one year old, 1999 or 2000 model year, driven for one hour at 30 mph.
**Older light duty vehicle represents vehicles 1975 model year and older, pre-catalytic vehicle, driven for one hour at 30 mph.

For CO (Table 9), the estimated 423 g emitted by one hour of leaf blower use is approximately 26 times the amount emitted by a new vehicle, but approximately one-third of the CO emissions of an older vehicle. While not implying that the operator will inhale this amount of CO, these data do suggest concern about the relatively large amount of CO emitted directly into the air space surrounding the operator. For particulate matter exhaust emissions, the leaf blower emits eight to 49 times the particulates of a light duty vehicle, primarily because of the large amount of unburned fuel directly released by the two-stroke engine.

Another way to visualize the data is to compare emissions for a given amount of leaf blower operation to miles traveled by car. The Air Resources Board regularly publishes such emissions benchmarks. Thus, for the average 1999 leaf blower and car data presented in Table 9, we calculate that hydrocarbon emissions from one-half hour of leaf blower operation equal about 7,700 miles of

driving, at 30 miles per hour average speed. The carbon monoxide emission benchmark is signficantly different. For carbon monoxide, one-half hour of leaf blower useage (Table 9) would be equivalent to about 440 miles of automobile travel at 30 miles per hour average speed.

Exposure data are necessary to determine potential health impacts of the pollutants. Since few exposure data exist, staff have developed a model that estimates potential exposures based on 10 minutes of leaf blower operation and compares those emissions to the amount of still air in which emissions would need to be mixed to avoid a transitory, local exceedance of the ambient air quality standards, which are health-based standards. Details of the model and results are presented in Appendix J.

The exposure scenario suggests that 10 minutes of leaf blower usage could expose the operator to a significant, potentially harmful dose of CO, assuming a worst case exposure, in which there is no dispersion of pollutants out of the immediate area. In this case, the operator could be exposed to potentially harmful amounts of carbon monoxide. The best case would be that all emissions and fugitive dust from the leaf blower would be blown out of the immediate area, resulting in little or no exposure to the operator. Actual exposures would most likely be somewhere in between these two assumptions and would vary greatly with weather conditions, wind, use or nonuse of protective gear, walking speed of the operator, and type of machine used. In addition, for carbon monoxide exposures, whether or not the operator has heart disease would be important in determining potential risk. Exposure studies would need to be conducted to obtain more reliable estimates of operator exposure, and staff recommend further research.

On December 27, 1999, ARB was mailed a redacted copy of a 1995 report on operator exposure levels for several chemicals that are present in handheld gasoline-powere equipment exhaust emissions. The report summarized breathing zone measurements during operation of chain saws, a string trimmer, and a leaf blower, but all data pertaining to equipment other than the leaf blower was blacked-out. The study and its limitations are discussed in some detail in Appendix H, but it is relevant to note here that ARB has received two measurements from one leaf blower of breathing zone concentrations of carbon monoxide, toluene, benzene, 1,3-butadiene, acetaldehyde, and formaldehyde. As reported in the study, concentrations of carbon monoxide, benzene, and 1,3-butadiene were high enough as to reinforce concern over operator exosures for the commercial leaf blower operator.

2. Fugitive Dust

Estimated fugitive dust emissions cannot be compared to light duty vehicle exhaust. The worst case exposure scenario, however, suggests that ten minutes of use of a commercial blower would exposure the operator to significant amounts of PM (Appendix J). While leaf blower operators would not be expected to spend significant amounts of time within such a particulate cloud, the day-in-day-out exposure to this much PM10 could result in serious, chronic health consequences in the long-term. Short-term exposures of one to two days to high levels of PM can lead to coughing and minor throat irritation. Long-term exposures have shown statistically significant associations of ambient PM levels

with a variety of negative human health outcomes, as discussed previously. These data strongly suggest that professional leaf blowers operators, and those regularly working within the envelope described above, should wear a face mask effective at filtering PM from the air, and further research is warranted.

3. Noise

The potential health impacts of leaf blowers on workers from noise center on noise-induced hearing loss. Two factors contribute to an increased risk of hearing loss in typical career gardeners: the high sound pressure levels emitted by leaf blowers at the level of the operator?s ear, and the infrequent use of hearing protection. While we cannot estimate the percentage of workers who will experience noise-induced hearing loss without additional data, these two factors are likely to be responsible for hearing loss in an unknown percentage of workers, although individuals may not notice any hearing loss until many years have passed. In order to reduce potential hearing loss, employers should ensure that employees use hearing protection. State and local health and enforcement agencies should promote hearing protection in campaigns targeted at professional landscapers and gardeners. Hearing loss is gradual, and may become obvious only years after the exposure has ceased.

B. The Public-at-Large

Those who are not working in landscaping and gardening fall into two categories: homeowners doing their own gardening and bystanders. Homeowners who chose to use a leaf blower likely experience relatively low-level exposures which they control. Bystanders may experience low or high exposures, depending on the nature of the exposure. Bystanders, however, almost never have chosen to be exposed to the exhaust, dust, and noise emissions of the leaf blower. Thus their attitude toward the leaf blower is likely very negative and they may be highly annoyed by the exposure.

In addition, staff have received letters, and read testimonials on Internet web-sites, concerning acute symptoms, such as asthma and allergies, exhibited by sensitive individuals to relatively limited exposures. These symptoms have not been evaluated in this report as they are anecdotal and unable to be substantiated. The recent study by Miguel et al. (1999), however, lends support to those who claim that exposure to leaf blower-generated dust causes allergic and asthmatic symptoms. It is also important to acknowledge that some individuals may be very sensitive to the emissions from leaf blowers and unable to tolerate exposures that do not seem to bother other individuals.

In addition to homeowner-leaf blower operators and bystanders who are in the vicinity of leaf blower operation, everyone is exposed to a small degree to air pollution that results from exhaust and dust emissions from leaf blowers. This report does not quantify those exposures, but the ARB does regulate exhaust emissions from leaf blowers, as from most other sources of air pollution. All sources of air pollution need to be reduced in order that Californians can breathe clean air.

1. Exhaust Emissions

The typical leaf blower owned and operated by a homeowner for private residential use is assumed to have an average horsepower of 0.8 and a load factor of 50%, based on the ARB off-road emissions model. Emissions from one hour of operation are compared to exhaust emissions from two different age light duty vehicles (Table 10). There are few data available on the length of time a homeowner runs a leaf blower, but it is likely that the homeowner uses a leaf blower for less than one hour, which would reduce the potential exposures and impacts.

Table 10. Homeowner Leaf Blower Emissions Compared to Light Duty Vehicle Emissions 0.8 hp average, 50% load factor, 1999 emissions data

	Exhaust Emissions, g/hr	Exhaust Emissions, new light duty vehicle,* g/hr	Exhaust Emissions, older light duty vehicle,** g/hr
Hydrocarbons	56.73	0.39	201.9
Carbon Monoxide	119.2	15.97	1310
Particulate Matter	1.44	0.13	0.78
Fugitive Dust	48.6-1031	N/A	N/A

*New light duty vehicle represents vehicles one year old, 1999 or 2000 model year, driven for one hour at 30 mph.
**Older light duty vehicle represents vehicles 1975 model year and older, pre-catalytic vehicle, driven for one hour at 30 mph.

As with the heavier-duty commercial leaf blower, CO and particulate matter emissions from the lighter-duty leaf blower are many times higher than emissions of the same pollutants from vehicles (Table 10). CO emissions from a leaf blower that might be used by a typical homeowner are significantly lower than those from a commercial leaf blower (Table 9) and it is likely that homeowners use leaf blowers for much less than one hour at a time. The exposure scenario for homeowner usage (Appendix J) estimates a correspondingly lower potential exposure. The homeowner is, therefore, less likely to be exposed to potentially harmful amounts of carbon monoxide, although sensitive individuals should be cautioned. For all exhaust emissions, exposures are considerably lower in a residential setting than in a commercial setting. In the best case, all emissions and fugitive dust from the leaf blower would be blown out of the operator?s immediate area, resulting in little or no exposure. Actual exposures would most likely be somewhere in between these two assumptions and would vary greatly with weather conditions, wind, use or nonuse of protective gear, walking speed of the operator, and type of machine used. Exposure

studies would need to be conducted to obtain more reliable estimates of operator exposure, and staff recommend further research.

As discussed in Section IV. A. 1., another way to visualize the data is to compare emissions for a given amount of leaf blower operation to miles traveled by car. The Air Resources Board regularly publishes such emissions benchmarks. Thus, for the average 1999 homeowner-type leaf blower and car data presented in Table 10, we calculate that hydrocarbon emissions from one-half hour of leaf blower operation equal about 2,200 miles of driving, at 30 miles per hour average speed. The carbon monoxide emission benchmark is signficantly different. For carbon monoxide, one-half hour of a homeowner-type leaf blower useage (Table 10) would be equivalent to about 110 miles of automobile travel at 30 miles per hour average speed.

2. Fugitive Dust Emissions

For fugitive dust, because the homeowner is likely using leaf blowers for a very short time each week, the potential risk from exposure is much lower than for commercial gardeners. Still, based on estimates in the exposure scenario (Appendix J), staff recommends that even homeowners wear a dust filtering mask when using a leaf blower.

3. Noise

The homeowner who uses a leaf blower for a brief amount of time each week or two is unlikely to experience noise-induced hearing loss. The cumulative exposure to many recreational sources of noise, such as recreational power tool use, lawn care, shooting, boating, concert-going, and other activities that expose one to loud noises, however, is likely to be great enough to impact hearing (Clark 1991). Those who regularly use noisy power equipment should be in the habit of using hearing protection to reduce their overall exposure to potentially damaging noise.

The likelihood of a bystander exposed to leaf blower noise on an irregular basis experiencing hearing loss is low. The potential health impacts from leaf blowers on bystanders that are likely more important include interference with communication, sleep interruption, and annoyance. Each of these impacts may in turn lead to stress responses, although research has not conclusively tied chronic exposures with any particular adverse health outcome. Although interference with communication, sleep interruption, and annoyance may not seem to be serious impacts, they are important health and quality of life issues for many people. At least 100 municipalities in California have restricted or banned the use of leaf blowers within city limits in response to people who object to the loud noise of leaf blowers interrupting their lives.

C. Summary of Potential Health Impacts

Health effects from hazards identified as being generated by leaf blowers ranging from mild to serious, but the appearance of those effects depends on exposures: the dose, or how much of the hazard is received by a person, and the exposure time. Without reasonable estimates of exposures, ARB cannot conclusively determine the health impacts from leaf blowers; the discussion herein clearly is about potential health impacts. The goal is to direct the discussion and raise questions about the nature of potential health impacts for those exposed to the exhaust emissions, fugitive dust, and noise from leaf blowers in both occupational and non-occupational settings.

For the worker, the analysis suggests concern. Bearing in mind that the worker population is most likely young and healthy, and that these workers may not work in this business for all of their working lives, we nonetheless are cautioned by our research. Leaf blower operators may be exposed to potentially hazardous concentrations of CO and PM intermittently throughout their work day, and noise exposures may be high enough that operators are at increased risk of developing hearing loss. While exposures to CO, PM, and noise may not have immediate, acute effects, the potential health impacts are potentially greater for chronic effects. In addition, evidence of significantly elevated concentrations of benzene and 1,3-butadiene in the breathing zone of workers leads to concern about exposures to these two toxic air contaminants.

Potential noise and PM effects should be reduced by the use of appropriate breathing and hearing protective equipment. Employers should be more vigilant in requiring and ensuring their employees wear breathing and hearing protection. Regulatory agencies should conduct educational and enforcement campaigns, in addition to exploring the extent of the use of protective gear. Exposures to CO and other air toxics are more problematic because there is no effective air filter for these air pollutants. More study of CO and other air toxics exposures to leaf blower operators is warranted to determine whether the potential health effects discussed herein are actual effects or not.

Describing the impacts on the public-at-large is more difficult than for workers because people?s exposures, and reactions to those exposures, are much more variable. Bystanders are clearly annoyed and stressed by the noise and dust from leaf blowers. They can be interrupted, awakened, and may feel harassed, to the point of taking the time to contact public officials, complain, write letters and set up web sites, form associations, and attend city council meetings. These are actions taken by highly annoyed individuals who believe their health is being negatively impacted. In addition, some sensitive individuals may experience extreme physical reactions, mostly respiratory symptoms, from exposure to the kicked up dust.

On the other hand, others voluntarily purchase and use leaf blowers in their own homes, seemingly immune to the effects that cause other people such problems. While these owner-operators are likely not concerned about the noise and dust, they are should still wear protective equipment, for example, eye protection, dust masks, and ear plugs, and their exposures to CO are a potential problem and warrant more study.

V. RECOMMENDATIONS

The Legislature asked ARB to include recommendations for alternatives in the report, if ARB determines alternatives are necessary. This report makes no recommendations for alternatives. Based on the lack of available data, such conclusions are premature at this time. Exhaust standards already in place have significantly reduced exhaust emissions from the engines used on leaf blowers, and manufacturers have reduced CO emissions further than required by the standards. Ultra-low or zero exhaust emitting leaf blowers could further reduce public and worker exposures. At its January 27, 2000, public hearing, the Air Resources Board directed its staff to explore the potential for technological advancement in this area.

For noise, the ARB has no Legislative mandate to control noise emissions, but the evidence seems clear that quieter leaf blowers would reduce worker exposures and protect hearing, and reduce negative impacts on bystanders. In connection with this report, the Air Resources Board received several letters urging that ARB or another state agency set health-based standards for noise and control noise pollution.

A more complete understanding of the noise and the amount and nature of dust resuspended by leaf blower use and alternative cleaning equipment is suggested to guide decision-making. Costs and benefits of cleaning methods have not been adequately quantified. Staff estimates that a study of fugitive dust generation and exposures to exhaust emissions and dust could cost $1.1 million, require two additional staff, and take two to three years. Adding a study of noise exposures and a comparison of leaf blowers to other cleaning equipment could increase study costs to $1.5 million or more (Appendix H).

Fugitive dust emissions are problematic. The leaf blower is designed to move relatively large materials, which requires enough force to also blow up dust particles. Banning or restricting the use of leaf blowers would reduce fugitive dust emissions, but there are no data on fugitive dust emissions from alternatives, such as vacuums, brooms, and rakes. In addition, without a more complete analysis of potential health impacts, costs and benefits of leaf blower use, and potential health impacts of alternatives, such a recommendation is not warranted.

Some have suggested that part of the problem lies in how leaf blower operators use the tool, that leaf blower operators need to show more courtesy to passersby, shutting off the blower when people are walking by. Often, operators blow dust and debris into the streets, leaving the dust to be resuspended by passing vehicles. Interested stakeholders, including those opposed to leaf blower use, could join together to propose methods for leaf blower use that reduce noise and dust generation, and develop and promote codes of conduct by workers who operate leaf blowers. Those who use leaf blowers professionally would then need to be trained in methods of use that reduce pollution and potential health impacts both for others and for themselves.

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