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

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State of California

AIR RESOURCES BOARD

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This report on potential health and environmental impacts of leaf blowers was developed by the following Air Resources Board staff:

Mobile Sources Control Division:
Nancy L.C. Steele, D.Env. (Lead)
Scott Rowland
Michael Carter (Branch Chief)

Research Division:
Hector Maldonado
Cindy Stover

And with the assistance of additional staff: Cresencia Gapas-Jackson, Leslie Krinsk, Jeff Long, Keith Macias, Angela Ortega, Muriel Strand, John Swanton, Maggie Wilkinson, and Walter Wong.

The many other individuals who provided information and assistance for this report are listed in Appendix B.

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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

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

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[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.

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

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. <u>State Regulations</u>

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.

c. South Coast AQMD Emissions Credit Program

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[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.

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 (μm). So-called coarse particles are those larger than 2.5 μm 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 μm 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.

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[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 μm diameter, which are termed total suspended particulate (PMtsp). Subsets of PMtsp include PM10, particulates with diameters less than or equal to 10 μm, and PM2.5, particulates with diameters less than or equal to 2.5 μm. Particles below 30 μm are not visible to the naked eye. Note that PM10 includes PM2.5 particles, and PMtsp includes PM10 and PM2.5 particles.

a. <u>Generation of Fugitive Dust by Leaf Blowers</u>

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 μm, 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 μm, 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 μm, 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 95^{th} 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

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

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

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 $\mu g/m^3$ [SCAQMD Rule 403]. The Mojave AQMD limits PM emissions to 100 $\mu g/m^3$ [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 μPa). The loudest sound the human ear can tolerate, the threshold of pain, has an amplitude ten million times larger, or 200,000,000 μPa. 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
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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	
[illegible]	20	$2x10^2$	[illegible]	

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]

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[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.

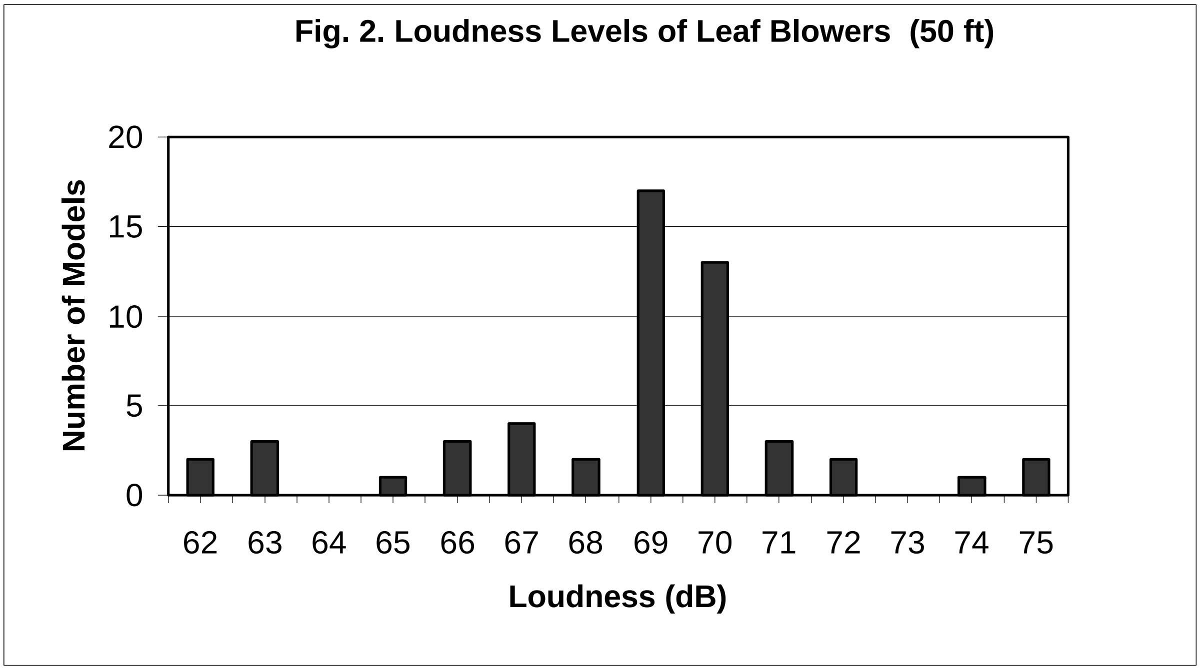
Cities sometimes couple area restrictions with user guidelines, such as prohibitions on blowing debris onto adjacent properties, and require operators be educated on the proper use of leaf blowers so as to minimize noise levels and environmental issues. These educational approaches are generally not 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 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 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.

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

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.

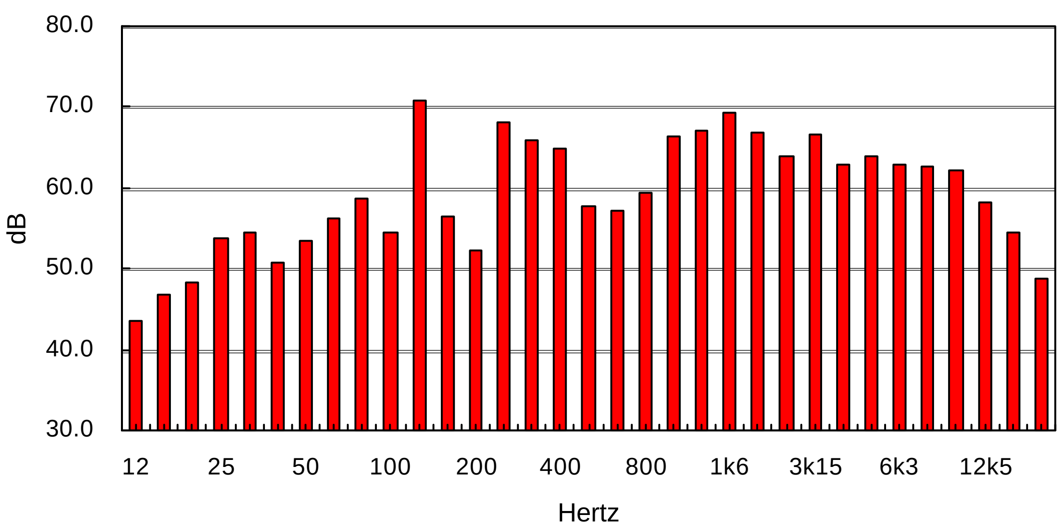
7. Sound Quality

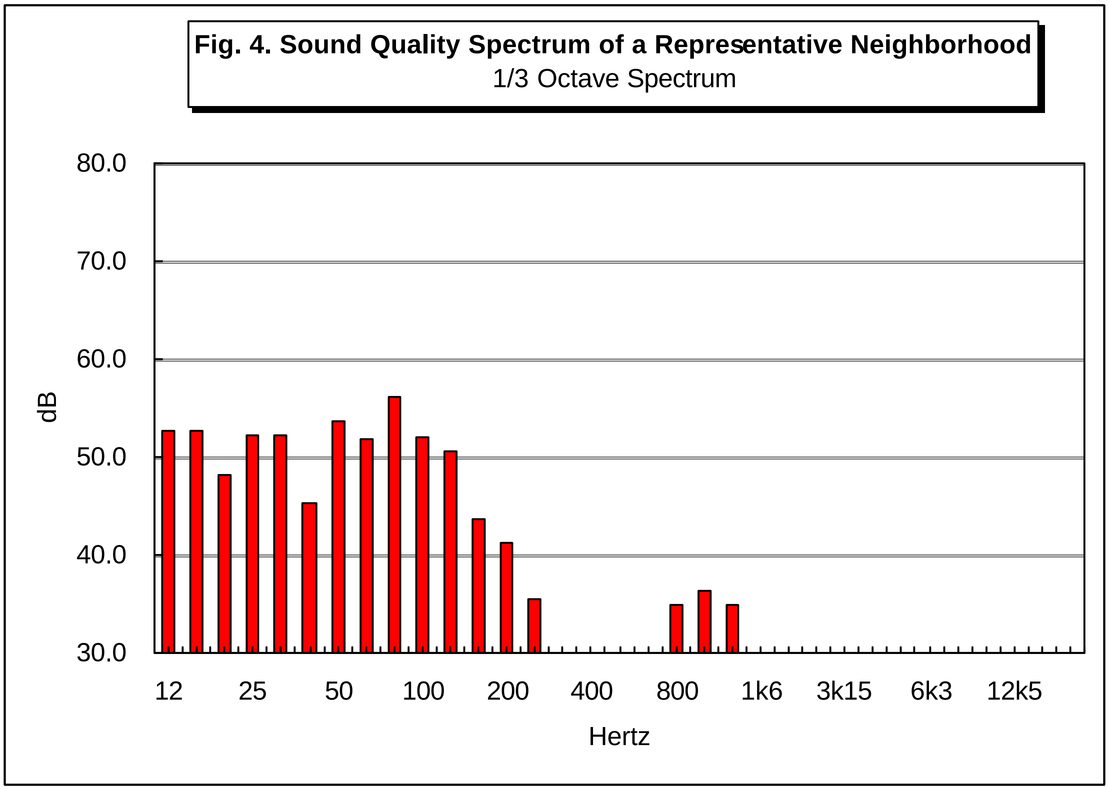
As discussed earlier, the perceived loudness of noise is dependent on both sound pressure level and frequency, which is termed the sound quality. One study examined sound quality from leaf blowers (Zwerling 1999). While this study is unpublished and data are still being analyzed, the authors have made 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.

Fig. 3. Sound Quality Spectrum of a Representative Leaf Blower

Stihl BR-400

1/3 Octave Spectrum





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 μm and smaller are inhalable and able to deposit and remain on airway surfaces. The smaller particles (2.5 μm 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 μm 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.

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[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

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,

(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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APPENDIX A

SENATE CONCURRENT RESOLUTION 19

APPENDIX B

CONTACT LIST

Leaf Blower Report Contact List

Name	Representing	Phone number	E-mail address
Jack Allen	Zero Air Pollution or Coalition to Ban Leafblowers	310/454-2062	jackjack@linkline.com
Adrian Alvarez	Association of Latin American Gardeners of Los Angeles	213/538-7296	pipila@earthlink.net
Barbara Alvarez	Golden State Landscaping, Inc. or California Landscape Contractor's Association	626/917-1614	
Mike Alvarez	Cal/OSHA Consultation, External Education & Training	916/574-2528	
Tony Ashby	Sierra Research	916/444-6666	Hashby@SierraResearch.com
Glenn Barr	Aide to Los Angeles City Councilwoman Cindy Miscikowski	213/485-3811	
Bob Barrish	Cal/OSHA Consultation	415/703-5270	
Matthew Blodgett	Self, Zero Air Pollution	310/454-2945 (fax)	
Nicholas Blonder	Self, resident of Mill Valley, CA	none	
Arline Bronzaft, PhD.	Self, League for the Hard of Hearing	212/288-7532	Albtor@aol.com
David Coel	SCAQMD	909/396-3143	
James Cone	Department of Health Services, Occupational Health Branch	510/622-4319	
Chatham Cowherd	Midwest Research Institute		
Vernita Davidson	Cal/OSHA, Information Management Unit	415/703-5116	
Don DeYoung	City of Carmichael, Parks Department		
Mac Dunaway	Portable Power Equipment Manufacturers	202/862-9700	duncross@msn.com

Name	Representing	Phone number	E-mail address
	Association (PPEMA)		
Dennis Earhardt	California Department of Industrial Relations, Division of Workers' Compensation	818/901-5030	
Margaret Easton	California Department of Industrial Relations, Division of Workers' Compensation	213/576-7422	
Dennis Fitz	University of California, Riverside; CE-CERT	909/781-5781	
John Froines, PhD	University of California, Los Angeles	310/206-6141	
Joan Graves	Zero Air Pollution	310/454-1069	
William M. Guerry, Jr.	Outdoor Power Equipment Institute	202/342-8858	wguerry@colshan.com
Kim Hagadone	Department of Health Services, Occupational Health Branch	510/622-4234	
Lee Hager	James, Anderson and Associates, Inc	517/349-8066	Lee_Hager@compuserve.com
Matthew F. Hall	Portable Power Equipment Manufacturers Association (PPEMA)	202/862-9700	mfhall@email.com
Bob Hayes	Cal/OSHA	415/703-5174	
Henry Hogo	SCAQMD	909/396-3184	hhogo@aqmd.gov
Karen Hutchinson	PPEMA	301/652-0774	
LeiLani Johnson	Los Angles Department of Water & Power	213/367-4690	ljohns@dwp.ci.la.ca.us
Lynne Johnson	City of Palo Alto, Asst. Chief of Police	650/329-2115	
Julie Kelts	Citizens for a Quieter Sacramento	916/454-5173	jvkelts@ns.net; http://www.nonoise.org/quietnet/cqs/cqs.htm

Name	Representing	Phone number	E-mail address
Steven Kramer, PhD	San Diego State University, Communications Disorders Department	619/594-6140	
Michael Laybourn	SCAQMD	909/396-3066	
Susan Leong	Office of Environmental Health Hazard Assessment (OEHHA)	916/327-3015	
John Liskey	OPEI	703/549-7600	opeistat@aol.com
Michael Lipsett	OEHHA	510/622-3153	
Jack McGurk	California Department of Health Services	916/445-0498	
James McNew	Husqvarna	704/597-5000	
Gregory Muleski	Midwest Research Institute	816/753-7600	
Douglas Nakamura	Northwest Landscape	408/298-4720	
Jerry Nakano	U.S. Department of Housing and Urban Development	213/894-8000X3009	
Tony Nash	Sierra Research	916/444-6666	
Robin Pendergrast	International Marketing Exchange, Inc.	815/363-0909	ime@imeinc.com
Margaret Petitjean	Self		mpetitjean@webtv.net
Barry Raybould	Self		BRaybould@aol.com
Mary Rippey	California Employment Development Department, Labor Market Information Division	916/262-2266	
Larry Rohlfes	California Landscape Contractor's Association	916/448-2522	
Larry Royster, PhD.	North Carolina State University		royster@eos.ncsu.edu
Ranjit (Ron) Sahu	OPEI, consultant	626/440-8931	
Alex Schneider	City of Berkeley Environmental Health	510/665-6854	
Lawrence Schulze, PhD.	University of Houston, Department of Industrial Engineering	713/743-4196	LJHS@uh.edu
Timothy Somheil	Appliance Magazine	630/990-3484	tim@appliance.com

Name	Representing	Phone number	E-mail address
Parke Terry	California Landscape Contractor's Association	916/442-1111	
Jean Wasserman	Michigan Occupational Health Division	517/322-6052	
Ed Weil	California Department of Justice, Deputy Attorney General	510/622-2149	
Larry N. Will	Echo, Inc., Vice President, Engineering	847/540-8400X138	vpengecho@aol.com
Diane Wolfberg	Zero Air Pollution		wolfberg@iramp.com
Vasken Yardemian	SCAQMD	909/396-3296	
Eric Zabon	Michigan, Occupational Health	517/322-1608	
Thomas Zambrano	AeroVironment Inc.	626/357-9983X268	zambrano@aerovironment.com
Eric Zwerling	Rutgers Noise Technical Assistance Center	732/932-8065	Ezwerling@aol.com

APPENDIX C

AMBIENT AIR QUALITY STANDARDS

APPENDIX D

CHEMICAL SPECIATION PROFILE

FOR PAVED ROAD DUST

APPENDIX E

PHYSICAL PROPERTIES OF SOUND AND LOUDNESS MEASURES

Physical Properties of Sound

Sound is defined as vibrations in a medium, such as air or water, that stimulate the auditory nerve and produce the sensation of hearing. The vibrations propagate outward from the source of the sound in the form of pressure waves, traveling in straight lines in all directions outward from the source, as with the ripples in a pond resulting when one drops a rock into the water. Sound is a form of mechanical energy and is measured in energy-related units (WHO 1980).

The speed of sound depends on the properties of the medium through which the sound wave moves. Sound travels more rapidly through air than through water, but may travel more rapidly through a solid than through air (Sataloff & Sataloff 1993). Sound waves, however, do not transmit through a vacuum. At sea level and 68^{o} F, the speed of sound through air is 770 miles per hour, or 344 meters per second. A Asonic boom≅ is heard when an object is traveling through air faster than the speed of sound, which creates an impulse of sound from the leading and trailing edges of the object (Kryter 1994).

Sounds are characterized by pitch, loudness, quality, and duration. Leaving aside duration, each of these is a psychological sensation, largely correlated to the physical attributes of frequency, intensity, and overtone structure, or timbre. Other physical factors, however, also influence the perception of sound. Sounds can be distorted by the wind, rendering them quieter or louder depending on the relative direction of the wind. Sound waves can bend around an obstacle, such as a wall, pass through the object unaffected, be reflected off the object, or be partially reflected and partially passed through or around the object. Two sound waves can also have the effect of canceling or amplifying each other at fixed distances from the source. Each of these behaviors depends on physical characteristics of the sound waves; frequency, amplitude, and wavelength; and physical characteristics of the environment (Sataloff & Sataloff 1993).

The sensation of pitch is related to the number of vibrations per second of a sound wave, which is called the sound=s frequency, and is measured in Hertz (Hz). A whistle and bird song, for example, are high frequency sound, and thunder and the bass line of a rock song are low frequency sound. The normal hearing range of a young, healthy person ranges from about 20 Hz to 20,000 Hz (20 kHz). Some animals can hear lower and higher frequencies than can humans; for example bats, moths, and dogs hear frequencies higher than the human hearing range. Loss of hearing acuity involves the inability to hear sounds of certain frequencies, usually at the upper and lower bounds of normal hearing.

A sound that is made up of only one frequency is a pure tone. Most sound is made up of more than one tone, or several frequencies, sounding together. The quality, or timbre, of a sound is related to the presence and intensity of the additional tones contained in the sound; these overtones are the result of different frequencies sounding at the same time, resulting in a complex waveform. In addition, sound timbre includes the pattern of change over time of each of the tones. The relative intensity and pattern of change of each frequency in the sound is what allows us to describe sounds of the same fundamental frequency as tinny, flute-like, or brassy. One can thus discriminate between the human voice, a flute, a violin, and a french horn, each playing the same note. Industrial noises, on the other hand, consist of a wide mixture of frequencies, known as broad band noise. A sound composed of frequencies that are evenly distributed throughout the audible range is termed white noise and sounds somewhat like rushing water (Brüel & Kjær 1984).

Sound duration can be described by the pattern of sound in time and intensity, or level, and can be described as continuous, fluctuating, impulsive, or intermittent (U.S. EPA 1979). Continuous sounds are those produced for a long period of time at a relatively constant level, such as the rushing of water in a river. Fluctuating sounds vary in level over time, such as traffic noise at an intersection. Impulse noises are those sounds with an extremely short sound pressure peak of less than a second in total duration. Impulse noises may be repetitive and occur close together, as in hammering or riveting; be spaced out in time, as in manual hammering; or occur as a single event, such as a single gun shot or explosion (Niedzielski 1991). Intermittent noises are those recurring noises lasting a relatively short period of time, such as the ringing of a phone, or aircraft take offs and landings.

The intensity, or magnitude, of sound is described by the size or amplitude of the fluctuation in sound pressure. In general, the larger the amplitude, the louder the sound, although other factors also affect the perceived loudness of a sound. Over moderate distance, sound intensity decreases at a rate inversely proportional to the square of the distance from the source (Sataloff & Sataloff 1993). Thus, halving the distance from the source of the sound quadruples the sound intensity, assuming there are no interfering surfaces to reflect the sound waves.

Measures of sound loudness

Different measures of sound loudness have been developed for the general purpose of relating, with respect to effects on people, the amount of sound energy exposures (Table 1). For a single event exposure, the descriptor is SEL or L_{ex}. For a composite measure of the sound level of a number of events over a specified time, the descriptor is L_{eq}, measured over 8-hours for occupational exposures, or 24-hours, for characterizing lifetime occupational and non-occupational exposures. A composite measure of average sound levels in residential areas throughout the day and night adds a 10-dB penalty for noise that occurs from 10:00 p.m. to 7:00 a.m (DNL or L_{dn}) (EPA 1974). Finally, California has developed a variant of the DNL that applies to aircraft and airport noise, the Community Noise Equivalent Level (CNEL) (21 CCR э5001). The CNEL adds a 3-dB penalty for noise occurring in the evening, from 7:00 p.m. to 10:00 p.m., and a 10-dB penalty for noise occurring at night, from 10:00 p.m. to 7:00 am.

Table 1. Sound Descriptors (dBA)[1]

Name of Descriptor	Notation	Nature of Descriptor	Typical Use
Sound Exposure Level, or Single Event Noise Exposure Level	SEL, SENEL, or L_{ex}	A summation of the energy of the momentary magnitudes of sounds associated with a single event to measure the total sound energy of the event.	To describe noise from a continuous noise occurring over time
Equivalent Sound Level	L_{eq}(8) or (24)	The sound level that is equivalent to an actual time varying sound level, in the sense that it has the same total energy for the duration of the sound.	To measure average environmental noise levels people are exposed to on the job (8-hrs) or all day (24-hr) for use in determining lifetime exposures
Day-Night Sound Level	DNL or L_{dn}	The equivalent sound level for a 24-hr period with 10 dB penalty for nighttime sounds from 10:00 p.m. to 7:00 am	To characterize average sound levels as perceived in residential areas throughout the day and night
Community Noise Equivalent Level	CNEL	The equivalent sound level for a 24-hr period with 3-dB penalty for evening sounds, from 7:00 p.m. to 10:00 p.m., and 10-dB penalty for nighttime sounds, from 10:00 p.m. to 7:00 am	To characterize average sound levels as perceived in residential areas impacted by aircraft/airport noise

1From EPA 1974, EPA 1979, Kryter 1994, and 21 CCR э5001.

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WHO (World Health Organization & The United Nations Environment Programme). *Noise*, World Health Org.: Geneva, **1980**.

APPENDIX F

AMERICAN NATIONAL STANDARD

FOR POWER TOOLS B

HAND-HELD AND BACKPACK,

GASOLINE-ENGINE-POWERED BLOWERS

B175.2-1996

ANSI7

APPENDIX G

MANUFACTURER-REPORTED NOISE LEVELS FROM LEAF BLOWERS

Manufacturer-Reported Noise Levels from Leaf Blowers

The data on leaf blowers in the following table were collected from manufacturer-provided brochures and from Internet web sites. Web sites were checked, when possible, to verify the information in brochures, especially when brochures were older than 1999. No attempt was made to determine which of the leaf blowers are available for sale in California. In addition to noise levels, reported for each model are also the type of blower, whether hand held, backpack, or wheeled (walk-behind); the engine displacement (cc), reported air volume; and air speed. Some manufacturers noted whether they reported maximum air volume and air speed or the average air volume and air speed, but these were not distinguished in the table. Air volume was sometimes reported as without tubes, or the air volume exiting the housing, and with tubes, or the air volume exiting the unit with the blower tubes in place. The notes column includes miscellaneous information, such as whether the unit includes a vacuum option, and model names.

Ninety-one blowers are listed in the table, 55 of which have reported sound pressure levels. Electric-powered blowers make up 21% of the total. Approximately half of all models are hand held, 41% of which are electric models. Backpack models are 42% and wheeled models are 8% of the total; there are no electric-powered backpack or wheeled leaf blowers. Of the 55 models that have manufacturer-reported noise levels, more than half (55%) reported noise levels to be 69 to 70 dBA. A slightly higher proportion of the blowers were quieter than 69 dBA (27%) than were louder than 70 dBA (18%). Manufacturers usually noted that noise levels were reported at 50 ft, implying the use of ANSI test method; even if not stated, all reported noise levels were assumed to have been recorded at 50 ft. The quietest gasoline-powered blowers, all backpack models, are the Maruyama BL4500 (62 dBA), Toro BP6900 (62 dBA), and Echo PB46LN (65 dBA). The quietest electric-powered blowers, all hand held models, are the Toro 51589 (63 dBA), the Stihl BGE60 (63 dBA), and the cordless Poulan/Weedeater VROOM (63 dBA).

Brand	Model	Type	Noise Level (dBA)	Engine Displacement (cc)	Engine Power	Air Volume (cfm)	Air Speed (mph)	notes
Billy Goat	QB883	Wheeled	*	N/R	8 hp	N/R	N/R	96 LpA (operator's ear), 89 LwA (ave of 12 readings at 4 m)
Billy Goat	QB1103	Wheeled	*	N/R	11 hp	N/R	N/R	100 LpA, 92 LwA
Billy Goat	QB553HC	Wheeled	N/R	N/R	5 hp	N/R	150	"low noise"
Black And Decker	BV1000	Hand Held	N/R	Electric	12 amp	480	195	"Vac 'N' Mulch"
Black And Decker	BV2000	Hand Held	N/R	Electric	12 amp	480	195	"Vac 'N' Mulch"
Black And Decker	BV3000	Hand Held	N/R	Electric	12 amp	480	195	"Vac 'N' Mulch"
Cifarelli	M88BL	Backpack	N/R	77	5 hp	706	280	Standard model; Italian Co.
Cifarelli	M88BL1	Backpack	N/R	77	5 hp	706	280	With gas lever & stop on frame; Italian Co.
Echo	PB-400E	Backpack	74	39.7	N/R	388 (590)	180	Air volume reported with tubes (without tubes)
Echo	PB-46HT	Backpack	70	44	N/R	370 (740)	180	Air volume reported with tubes (without tubes)
Echo	PB-46LN	Backpack	65	44	N/R	370 (740)	180	Air volume reported with tubes (without tubes)
Echo	PB-60HT	Backpack	71	58.2	N/R	405 (840)	195	Air volume reported with tubes (without tubes)
Echo	PB-2100	Hand Held	69	21.2	N/R	302 (330)	135	Air volume reported with tubes (without tubes)
Echo	PB-210E	Hand Held	69	21.2	N/R	310 (310)	150	Air volume reported with tubes (without tubes)
Echo	PB-24LN	Hand Held	67	23.6	N/R	300 (375)	150	Air volume reported with tubes (without tubes)
Fradan Power Equip.	BB-50	Backpack	67	42	N/R	590	236	
Fradan Power Equip.	see notes	Wheeled	70	N/R	N/R	N/R	N/R	Five models w/ 5hp, 8hp, 9hp, 11hp, &14 hp engines
Homelite	The Backpacker	Backpack	70	30	N/R	425	170	
Homelite	d25b	Hand Held	69	25	N/R	350	150	
Homelite	d30mhv	Hand Held	70	30	N/R	360	160	Vaccum included
Homelite	d30mha	Hand Held	70	30	N/R	360	160	Vacuum kit capable
Homelite	VacAttack	Hand Held	70	25	N/R	360	160	Blower/Vacuum/ Mulcher
Homelite	Yard Broom	Hand Held	69	25	N/R	350	150	
Homelite	Yardvark	Wheeled	69	25	N/R	385	165	
Husqvarna	145BT/BF	Backpack	N/R	40	N/R	340 (589)	175	Air volume reported with tubes (without tubes)

Brand	Model	Type	Noise Level (dBA)	Engine Displacement (cc)	Engine Power	Air Volume (cfm)	Air Speed (mph)	notes
Husqvarna	132HBV	Hand Held	N/R	32	N/R	360	170	Vacuum included
Husqvarna	225HBV	Hand Held	N/R	25.4	1.2 hp	392	128	Vacuum/mulcher attachment optional
John Deere	BH30	Hand Held	69	30	N/R	450	180	Vacuum kit optional
John Deere	BP40	Backpack	69	40.2	N/R	404 (590)	180	Air volume reported with tubes (without tubes)
John Deere	BP50	Backpack	69.5	48.6	N/R	470 (672)	185	Tube-mounted controls; Air vol. with tubes (without tubes)
Jonsered	BV 32	Hand Held	N/R	31.7	0.9 hp	N/R	170	Vacuum included
KAAZ	BA402K	Backpack	N/R	40.2	N/R	586	250	
Kawasaki	KRB400A	Backpack	68	48.6	3.2 hp	380	180	
Makita	RBL250	Hand Held	65.6	24.5	N/R	321	165	Vacuum attachment optional
Makita	RBL500	Backpack	70	48.6	N/R	447	187	
Mantis	BSV	Hand Held	N/R	N/R	N/R	350	130	Blower/Shredder/Vacuum
Maruyama	BLL2600	Hand Held	66	25.6	1.5 hp	300	150	Vacuum attachment optional
Maruyama	BL4500	Backpack	62	40.2	3.2 hp	470	170	
Maruyama	BL5400	Backpack	69	48.6	3.7 hp	520	180	
MTD	652 B	Wheeled	N/R	N/R	5 hp	N/R	200	
Poulan/Weedeater	2510	Hand Held	66	Electric	7.5 amp	280	110	"GroundSweeper"
Poulan/Weedeater	2540	Hand Held	67	Electric	8.5 amp	320	125	"GroundsKeeper"
Poulan/Weedeater	2560	Hand Held	N/R	Electric	8.5 amp	320	125	"GroundsKeeper Plus"
Poulan/Weedeater	2570	Hand Held	71	Electric	12 amp	405	195	"Barracuda Super Blower"
Poulan/Weedeater	2595	Hand Held	71	Electric	12 amp	405	195	"Barracuda Super Blower/Mulching Vac"
Poulan/Weedeater	VROOM	Hand Held	63	Electric	N/R	95	105	"Cordless Broom"
Poulan/Weedeater	GBI 20	Hand Held	N/R	22	N/R	330	140	
Poulan/Weedeater	SV 22	Hand Held	N/R	22	N/R	360	165	"Barracuda Blower/Vac"
Poulan/Weedeater	SV 30	Hand Held	70	30	N/R	375	180	"Barracuda Blower/Vac"
Poulan/Weedeater	BV 1650	Hand Held	70	22	N/R	370	165	"Blower/Vac"
Poulan/Weedeater	BV1800	Hand Held	70	24	N/R	380	180	"Barracuda Super Blower/Vac"
RedMax	EB4300	Backpack	72	41.5	N/R	565	160	"EPA certified"
RedMax	EB431	Backpack	69	41.5	N/R	565	186	"EPA certified"
RedMax	EB441	Backpack	69	41.5	N/R	565	186	"EPA certified"
RedMax	EB6200	Backpack	75	62	N/R	730	200	"EPA certified"
RedMax	EBA431	Backpack	69	41.5	N/R	565	186	"EPA certified"
RedMax	HB2300	Hand Held	68	22.5	N/R	353	150	"EPA certified"
Robin	FL500	Backpack	70	48.6	2 hp	530	260	

Brand	Model	Type	Noise Level (dBA)	Engine Displacement (cc)	Engine Power	Air Volume (cfm)	Air Speed (mph)	notes
Robin	FL 251	Hand Held	N/R	24.5	1.2 hp	272	117	
RYOBI	160r	Hand Held	N/R	electric	9 amp	N/R	120	
RYOBI	180r	Hand Held	N/R	electric	9.5 amp	N/R	130	blower/vacuum/mulcher
RYOBI	190r	Hand Held	N/R	electric	12 amp	N/R	180	blower/vacuum/mulcher
RYOBI	280r	Hand Held	N/R	31 cc.	N/R	N/R	150	
RYOBI	310BVr	Hand Held	N/R	31 cc.	N/R	N/R	150	blower/ vacuum/mulcher
RYOBI	RESV1300	Hand Held	N/R	electric	N/R	350	157	Electric Mulchinator Vacuum
Shindaiwa	EB240	Hand Held	67	24	1.2 hp	307	166	
Shindaiwa	EB480	Backpack	69	43.6	3 hp	415	188	
Shindaiwa	EB500	Backpack	72	43.6	2.3 hp	434	190	
Shindaiwa	EB630	Backpack	75	62	3.9 hp	631	201	
Solo	414	Backpack	N/R	54	3.4 hp	647	N/R	
Solo	470	Backpack	N/R	52.6	3.4 hp	706	N/R	"reduced noise emission by approx. 13 dB(A)" from the 414 model
Stihl	BGE 60	Hand Held	63	electric	1150 W	362	139	
Stihl	BG 75	Hand Held	69	25.4	N/R	377	135	Blower/Vacuum
Stihl	BR 320	Backpack	N/R	44.9	2.7 hp	435 (589)	164	Blower/Vacuum; Air vol. reported with tubes (without tubes)
Stihl	BR 320 L	Backpack	69	44.9	1.9 hp	382 (589)	143	Air volume reported with tubes (without tubes)
Stihl	BR 400	Backpack	N/R	56.5	3.4 hp	476 (624)	180	Blower/Vacuum; Air vol. reported with tubes (without tubes)
Stihl	SR 320	Backpack	N/R	44.9	2.7 hp	385 (589)	205	Blower/Sprayer; Air vol. reported with tubes (without tubes)
Stihl	SR 400	Backpack	N/R	56.5	3.4 hp	420 (624)	230	Blower/Sprayer; Air vol. reported with tubes (without tubes)
Tanaka	TBL-4600	Backpack	69	43	2.5 hp	500	200	
Tanaka	TBL-505	Backpack	69	43	2.5 hp	540	218	
Tanaka	THB-2500	Hand Held	69	24	1.3 hp	304	134	
Toro	BP6900	Backpack	62	41	N/R	370	N/R	
Toro	51539	Hand Held	N/R	electric	7.3 amp	N/R	155	"Air Rake"
Toro	51549	Hand Held	N/R	electric	7.3 amp	N/R	155	"Rake And Vac"
Toro	51586	Hand Held	N/R	electric	7 amp	170	140	"Power Sweep"
Toro	51587	Hand Held	N/R	electric	12 amp	275	210	"Super Blower Vac"
Toro	51589	Hand Held	63	electric	12 amp	260	190	"QuieTech"

APPENDIX H

RESEARCH NEEDS

RESEARCH NEEDS

Exhaust Emissions

The ARB has an active research program to determine exhaust emissions from engines that it regulates. Existing and future exhaust emission control standards will continue to require that manufacturers reduce emissions from the small off-road engines found in leaf blowers. Staff conducts periodic reviews of technology to determine whether further emission reductions are possible. For example, the ARB has recently awarded a contract to the Southwest Research Institute to conduct research entitled ΑParticulate Emissions from Marine Outboard Engines, Personal Watercraft and Small Off-Road Equipment.≅ The objectives relevant to leaf blower technology are (1) to measure the emissions from two-stroke engines used in small off-road equipment, with an emphasis on PM emissions and polycyclic aromatic hydrocarbon levels; and (2) to determine particle size distribution and mutagenic toxicity of the PM. The contractor will obtain and test five engines typically used in leaf blowers or similar off-road equipment, and staff have recommended that engines used in leaf blowers be among those chosen.

In addition to this study, staff has identified investigation into small off-road engine deterioration as an area for future research; engine deterioration causes emissions to increase with engine usage. In general, research into annual usage data, both for the leaf blower equipment and for the operator, would be helpful. The estimated annual usage in the inventory may be lower than actual usage, and may not correlate well with how long an operator, commercial or residential, uses the equipment throughout the year.

Fugitive Dust

ARB staff found a fundamental lack of information on the nature and quantity of fugitive dust blown, or resuspended, by leaf blowers. Empirical data are needed, however, as calculations only go so far. Any study would need to consider a large number of variables, such as substrate, humidity, seasonality, and type of materials being moved by the leaf blower. Ideally, as part of a future research project, one would want to first quantify the emissions in actual use by: (1) inventorying the types of surfaces cleaned by leaf blowers statewide, and by air district, (2) determining the silt loading for surfaces that are cleaned, and (3) performing source testing to determine the amount of PM30, PM10 and PM2.5 entrained in the air, and to determine the "exposure envelope" associated with leaf blower usage. This information could then be used to calculate more accurate estimates of dust associated with leaf blower usage.

In addition to quantifying emissions, it would also be important to determine what is in the dust. This information would not be applicable only to leaf blowers, but would reflect what is in dust that is resuspended by wind from any source. Presently, chemical speciation data are available for sources such as paved and unpaved roadways. For leaf blowers, we should also examine the make-up of dust from lawns, sidewalks, parking lots, and flower beds. In addition to chemical speciation, it would also be useful to analyze the dust for the presence of herbicides, pesticides, bacterial endotoxins, and other toxins.

Noise Emissions

The investigation and reduction of noise emissions is not part of the ARB's authority or mission. Traditionally, noise control and abatement has been a local function, although a state Office of Noise Control did exist for a short time; the Office was housed within the Department of Health Services. Quantifying noise exposures of landscape and gardening workers might be conducted as a part of a larger ARB effort aimed at better understanding the leaf blower population and annual hours of use. Otherwise, most noise related research would be better conducted by other state agencies.

Quantify the number of Californians affected by noise and noise exposure levels. The purposes of this study would be two-fold: First, to assess the number of workers who are exposed to leaf blower noise, the number of hours they are exposed daily, and their daily noise dose and exposures. Second, to determine the number of people exposed non-occupationally to leaf blower noise, average noise exposures, frequency of exposure (e.g., daily, weekly), and how they are affected (e.g., annoyed, interference with sleep or communication). Agencies potentially responsible for this study would include ARB; the Office of Environmental Health Hazard Assessment; and the California Department of Health Services Occupational Health Branch.

Evaluate hearing loss in gardeners, emphasizing those who use leaf blowers as a part of their work. The purpose of this study would be to evaluate, more specifically, the incidence of noise-induced hearing loss in occupationally exposed gardeners. Non-occupational exposure to noise would also need to be assessed. Agencies potentially responsible would include the California Department of Health Services Occupational Health Branch.

Exposure Data and Potential Health Impacts

Exposure data are needed to determine potential health effects, particularly from CO, particulates, and noise. On December 27, 1999, ARB was mailed a redacted copy of a 1995 report entitled “Evaluation of Chemical Emissions From White Consolidated Industries Products”[1] (WCI). The WCI report was prepared for Poulan/Weed Eater to determine operator exposure levels for several chemicals that are present in handheld gasoline-powered

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1 Batelle. Evaluation of chemical emissions from White Consolidated Industries products, final report. Prepared for Poulan/Weed Eater, Division of WCI Outdoor Products, Inc. Batelle: Columbus Operations. October 1995.

equipment exhaust emissions, specifically chemicals that are listed under California's "Proposition 65" law as either carcinogens or reproductive or developmental toxins. Batelle, which prepared the WCI report, measured breathing zone concentrations during operation of a leaf blower, three chain saws, and a string trimmer and calculated user exposures. Before sending the report to ARB, however, all data relating to the chain saws and string trimmer were blacked-out.

The WCI report presents the only data on operator exposures from leaf blowers known to ARB at this time. As noted, exposure data are crucial for determining health impacts. Although the WCI report was received too late for discussion in the body of the leaf blower report, the following summary and analysis of the results of the WCI report are included in this appendix.

The WCI study measured breathing zone exposures of operators of certain power equipment to six toxic chemicals: formaldehyde, acetaldehyde, benzene, 1,3-butadiene, toluene, and carbon monoxide. The leaf blower tested was a consumer model with an engine displacement of 32 cc and engine horsepower of 0.9; the blower was run at full throttle for 30 minutes in each of two tests. Concentrations of the six toxic chemicals were measured and user exposures were calculated based on specified assumptions. The WCI report concludes that "[m]easured concentrations and calculated user exposures are below all existing concentration standards and Prop 65 allowable exposures. . . . Consequently, operator exposures to the target chemicals from normal use of WCI power equipment do not convey significant health risks as established under Prop 65."

Study limitations include a small sample size and potential bias towards conditions that could minimize risk calculations. As only one leaf blower was tested, the results cannot be assumed to represent all leaf blowers. As only two samples were collected from the leaf blower, the results are likely not representative of breathing zone concentrations that would be experienced by a variety of operators. Conditions during the test that could minimize measured concentrations, and thus underestimate risk, include 10 mph winds, one start-up per test (emissions are higher during start-up), and the use of a new, properly tuned leaf blower. Typically, older equipment emits more pollutants. In addition, the user exposure is calculated by assuming that 30-minutes is the maximum time of exposure for all users, and Batelle represents this as a "worst case" exposure. It is more likely that this represents a "best case" scenario for exposure, however, and that 8-hours of exposure would more likely represent a "worst case" scenario. Given these limitations, the WCI report supports ARB's conclusion that additional research is needed to better understand operator exposures to hazards and provides further evidence for concern regarding operator exposures to exhaust emissions.

Table 1. WCI Report Calculated Daily Exposure Levels

Weed Eater model GBI-30V, 0.9 hp engine	Measured Conc. (μg/m^3)	Ambient Air Conc. (μg/m^3)	WCI Adjusted Conc. (μg/m^3)	WCI Calculated User Exposure (μg/day)	Standards (μg/day)
Formaldehyde	33.1, 28.1	22.6, 23.4	7.6	0.31	40*
Acetaldehyde	23.0, 22.2	12.3, 17.5	7.7	0.31	90*
Toluene	265, 144	2.0, 1.7	55.3	84	13,000+
Benzene	67.2, 45.2	0.84, 1.02	203	2.25	7*
1,3-Butadiene	0.92, <0.15	<0.15, <0.15	0.39	0.02	0.4*
Carbon Monoxide, ave.	3435, 6870	1145, <1145	4010	2005†	40000#
Carbon Monoxide, peak	29800, 43500	3435, 1145	34400	34400‡	458000**

†Assumes 30 minute exposure averaged over one-hour, in μg/m^3; an 8-hour exposure is assumed to be 250 μg/m^3, or 2005 μg/m^3 divided by 8 hours.
‡Measured peak in units of μg/m^3
*Prop 65 No Significant Risk Level
+Prop 65 Acceptable Daily Intake Level
#U.S. EPA One Hour Ambient Air Quality Standard (The California one hour standard is 23,000 μg/m^3)
**ACGIH Workplace Short Term Exposure Limit (15 min)

A draft research plan to begin assessment of potential health impacts of leaf blowers on operators and the public-at-large is included herein as a starting point to assess tasks and costs:

Assessing Potential Health Impacts of Leaf Blowers on Operators and the Public-at-Large

This draft, proposed research plan would address two issues related to leaf blower usage in California: First, what is the nature and quantity of fugitive dust resuspended by leaf blower usage; and second, what are the exposures to carbon monoxide, other exhaust emissions, and fugitive dust experienced by leaf blower operators? The proposed research does not include research into noise exposure, although the study could be expanded with outside expert assistance, as ARB does not have a mandate to study noise. The study also would not directly assess exposures experienced by bystanders in the vicinity of someone else using a leaf blower, although the data gathered could be used to make some preliminary estimates regarding these exposures. The estimated cost of the study is $1,100,000.

Task 1 - Population and activity survey. $50,000. Determine the population of leaf blowers, by type (backpack engine-powered, wheeled engine-powered, handheld engine-powered, handheld electric), by air district. Determine usage patterns, how many are used by homeowners and how often, and how many by professional gardeners and how often. Also determine the amount of time each leaf blower is used versus the amount of time each person (including non-operators on a gardening crew) are exposed to leaf blower use. This task would involve the development of a survey instrument and may involve the use of data loggers.

Task 2 - Methodology development for measuring and calculating fugitive dust (particulate matter) emissions and exposure assessment. $50,000. This task would build on previous data on measuring and calculating emissions, but would involve some new methodology as no previous studies have measured fugitive dust resuspended by leaf blowers. As leaf blowers are often used at the same time as other lawn and garden equipment, this task will include differentiating between emissions from leaf blowers and other equipment.

Task 3 - Field study to collect data on exhaust and fugitive dust generation and exposures by operators. $800,000. The study has several facets:

Task 3a - Dosimetry of operators to measure CO and other exhaust emissions exposures. Could also include audiodosimeters if noise dose is being measured. Operators participating in the study would keep journal records of activities while working with lawn and garden equipment.

Task 3b - Measure silt loadings for representative sites based on where leaf blowers are used, during different climate conditions and/or seasons, and in different regions of the state.

Task 3c - Perform fugitive dust emissions sampling and sample collection at selected sites, during selected seasons; data are to be used to estimate both personal exposures, emissions factors, and aggregate daily emission rates.

Task 4 - Sample chemical analysis. $100,000. Actual cost depends on number of samples and chemical species analyzed. Cost assumes 50 samples at $2,000/sample. Study would analyze samples for elements and ions and organic species, such as vegetative detritus, fecal matter, pollen, mold spores, and endotoxins.

Task 5 - Data analysis. $30,000. Analyze data and prepare emissions estimates. Include size-segregated PM emissions for emissions inventory and for personal exposure assessment.

Task 6 - Quality assurance. $30,000. Determine accuracy of subjects in recording leaf blower usage in daily journals, proper use of dosimetry equipment, and chemical and data analyses.

Task 7 - Reporting and final report. $30,000.

APPENDIX I

FUTURE TECHNOLOGY

AND

ALTERNATIVES

Engine Technologies That Reduce Exhaust Emissions

For the most part manufacturers have met the 1995-1999 emissions standards by calibrating their engines to use less fuel, and improving production practices to include tighter tolerances. With implementation of more stringent standards in the 2000 model year will come more advanced technologies (ARB 1998). Various manufacturers have indicated that they will meet the 2000 model-year standards with either small four-stroke engines that have been specifically designed for light-weight and multi-positional use, two-stroke engines with direct fuel injection, or two-stroke engines with stratified scavenging. Moreover, virtually all manufacturers have indicated that they will provide complying products, though not all have been specific about the technologies they plan to use. The various technologies represent a variety of ideas, but ultimately all would reduce the amount of fuel delivered to the combustion chamber. The technologies are briefly described below.

Four-Stroke Engines. Four-stroke engines possess the advantage that the exhaust stroke expels very little unburned fuel, so engine-out HC emissions are much lower than a two-stroke engine. This is because exhausting the spent gases and refilling the cylinder with a fresh air/fuel charge happens sequentially in a four-stroke engine, but simultaneously in a two-stroke engine. In the past, four-stroke engines have not been able to operate multi-positionally, because of engine lubrication problems, so four-strokes have not traditionally been used in handheld equipment. Ryobi and Honda, however, are two companies that have developed handheld four-stroke engines for the 2000 standards. Honda has indicated that it intends to use its engine in blowers and Ryobi offers attachments that can convert a string trimmer to a blower.

Fuel-Injected Two-Stroke Engines. Fuel injection provides better control of the amount and the timing of fuel entering the cylinder. By limiting the fuel admitted to the amount necessary for combustion, and timing fuel introduction to limit the fuel exiting with the exhaust gases, less unburned fuel exits the engine. The loss of unburned fuel is the primary cause of the high HC emissions from two-stroke engines; up to one third of the fuel going into a conventional two-stroke engine exits the exhaust pipe unburned. Tanaka is a company that has developed a fuel-injected two-stroke engine, partially through funding provided by the ARB's Innovative Clean Air Technologies program.

Stratified Scavenging Two-Stroke Engines. Stratified scavenging refers to a system that prevents mixing of the incoming fuel with the exhaust gas by injecting a layer ("strata") of air between the two. The result is that less of the fresh (unburned) fuel escapes, and HC emissions are dramatically reduced. Test results indicate that the technology can easily meet the 2000 standard. As put into practice by Komatsu Zenoah, manufacturer of the Red Max line of blowers, the stratified scavenging engine retains all the advantages of a conventional two-stroke: light-weight, high power output, and relatively simple design. The result is an engine that operates nearer to the chemically balanced air/fuel ratio, which also translates into improved fuel economy.

Two-Stroke Engine with Compression Wave Technology. This technology involves a compressed-air-assisted fuel injection system that eliminates the unburned fuel during the scavenging process of the exhaust portion of the two-stroke cycle. Engines utilizing this technology retain much of the conventional two-stroke design and hardware, and although the fuel metering system needs to be designed to perform with the engine's needs, it reportedly does not need to provide high precision in timing or in spray quality.

The thrust behind the technology is a compression wave, which causes the fuel and air in the cylinder to be greatly disturbed, in effect functioning as a shock wave. This atomizes the fuel and mixes it more thoroughly with the air. In addition, the compression wave helps keep fuel from sticking to the cylinder. According to the U.S. EPA regulatory impact analysis for its small engine regulatory efforts (U.S. EPA 1999), the system as developed by John Deere Consumer Products includes an "accumulator" which collects and temporarily stores compressed air scavenged from the crankcase. The piston compresses the air in the crankcase on the piston's downward stroke. The fuel injection system uses the piston head to open and close its ports. With respect to engine power, John Deere Consumer Products states that the engine power remains nearly the same as the engine without the technology. The technology is planned for production on John Deere Consumer Products equipment in California in 2000.

Two-Stroke Engines with Catalysts. In addition to the above technologies, some manufacturers currently offer equipment with catalytic converters; in fact, the presence of a catalyst is sometimes used as a marketing feature in Europe. As with an automobile, the catalyst assists the conversion of hydrocarbons and carbon monoxide to more benign compounds.

Sound Reduction Technologies

Leaf blower manufacturers are developing new designs to both reduce the amount of noise from leaf blowers and change the quality of sound to make it less irritating (L. Will, pers. com.). The methods range from quieting the engine noise by insulating the engine compartment to changing the design of the fan. Significant sound comes from the fan itself, and thus new fan designs have the potential to change both the loudness and sound quality.

Electric leaf blowers can be quieter than gasoline-powered leaf blowers because of the absence of the engine noise, but often are just as noisy as gasoline-powered leaf blowers (Appendix G). The Los Angeles City Council requested that its Department of Water and Power develop a quieter leaf blower, and a contract was awarded to AeroVironment. The firm developed a prototype electric, battery-powered blower that should be produced in small quantities for testing late in 1999 or early in 2000 (L. Johnson, LADWP, pers. com.). This blower is discussed more in below.

Methanol-Fueled Leaf Blowers

The use of methanol as a fuel for leaf blowers came about following ordinances to ban the use of "gas-powered" leaf blowers. Some parties have undertaken the development of methanol-fueled leaf blowers as an alternative. However, regulations in effect starting with the 1995 model year require manufacturers to certify that engines meet certain emission standards. The certification process involves documentation of the emissions performance of the engine running on a specific fuel. No manufacturer has yet certified a methanol blower, nor has any manufacturer indicated plans to do so in the near future, thus 1995 and new methanol-fueled leaf blowers operate in violation of California and federal law. The ARB is not currently aware of any such violations. If methanol engines were to be offered, they would need to be certified by the ARB and comply with the same emissions standards as any other engines. Modification of pre-1995 blowers would not need to be certified under the current regulations. Modification of 1995 and newer leaf blowers, however, must be made in accordance with the ARB=s aftermarket parts regulations.

The use of methanol also raises some concerns beyond those associated with a gasoline-fueled internal combustion engine. These include flame luminosity, as methanol burns with a pale flame, leading to safety issues, and toxicity. Occupational exposure to methanol through inhalation and skin contact is widespread (U.S. EPA 1998), and exposure would be expected during fueling of leaf blowers. The symptoms of methanol poisoning include nervous symptom dysfunction, damage to the visual system, and even death, and are thought to be due to build of metabolic breakdown products in the body. Most analysts believe that inhaling low concentrations of methanol is not harmful for healthy people, but may be harmful for potentially susceptible populations, such as those deficient in folic acid (Medinsky, et al. 1997).

Electric Equipment

Another technology in current use, particularly for residential applications, is powering the leaf blower with electricity. Electric equipment tends to be less expensive than the equivalent gasoline-powered equipment, with comparable performance on residential products. Staff investigated the products available at several mass market stores, and found that several corded, and one model of non-corded, electric blowers are available. Additionally, AeroVironment, working under the auspices of the Los Angeles Department of Water and Power, has developed a prototype battery-powered blower for commercial use. As many as 1500 pre-production models will be distributed to various gardeners and landscapers to verify its utility for commercial use (L. Johnson, LADWP, pers. com.).

Alternatives to Leaf Blowers

Questions have been asked about the impacts of other methods of street cleaning, such as using a broom or washing down the street with water. Data that were located generally focused on a comparison of the amount of time it would take to clean a given space with leaf blowers versus other equipment, but no controlled, scientific studies were available. For example, ARB was given a press release that quoted a cleaning contractor for the Rose Bowl in Pasadena as stating that cleaning the Rose Bowl after a game takes 1,000 to 1,500 man-hours unless they use leaf blowers, in which case the job takes about 720 man-hours (IME 1999). Other short tests have been conducted, comparing cleaning time using a broom versus a leaf blower (Wolfberg, pers. com.). Finally, a City of Whittier report includes a chart comparing cleaning efficiencies of a “giant vac,” back pack blower, broom, and “hose down,” but no information were available as to the methods used to collect or analyze the data (Hamano 1992). In short, data were not of sufficient quality to permit an evaluation of the efficiency of alternatives to leaf blowers.

Similarly, no data could be located regarding fugitive dust resuspended by alternatives, such as brooms or vacuums or the amount of water that would be used for cleaning, in lieu of leaf blowers. The Los Angeles Department of Water and Power collected very limited data on sound levels of raking. One measurement of noise from raking was about 66 dBA at 50 ft (LADWP 1998), but it is intermittent noise, as compared to the continuous noise of a leaf blower, and a direct comparison is not possible without more data. Further study would be required to fully characterize such alternatives to leaf blowers as vacuuming, sweeping, raking, and hosing.

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APPENDIX J
EXPOSURE SCENARIOS FOR
LEAF BLOWER EMISSIONS AND USAGE

Exposure Scenarios for Leaf Blower Emissions and Usage

Exposure scenarios are presented that describe potential exposures resulting from the emissions from two types of leaf blowers. Commercial-type blowers have an average power rating of 3 hp and residential-type blowers have an average power rating of 0.8 hp. Staff has estimated the amount of still air in which the emissions from 10 minutes of leaf blower operation would need to be mixed in order to prevent a local, transitory exceedance of the relevant national ambient air standards. These are worst case scenarios, which assume that all emissions from the blower in the specified time-frame remain in the breathing zone of the operator. The best case would be one in which all emissions and fugitive dust are blown out of the immediate area, resulting in no exposures to operators or bystanders. Actual exposures would vary greatly, and depend on many factors, including wind, temperature, humidity, use of protective gear, surface being cleaned, walking speed of operator, and proximity of bystanders.

Based on the estimated emissions, the amount of air that would be needed to mix with the emissions to avoid exceeding the National Ambient Air Quality Standards (see Appendix C) has been calculated. The PM standards, however, are not generally short term exposure standards, but have been selected as the best surrogate for short term exposure standards. The estimates for exhaust and fugitive dust exposures, then, have no objective significance, in and of themselves, but are presented for comparative purposes.

A. Commercial Leaf Blower Usage

Ten minutes is considered to be a reasonable estimate of the time it might take to clean an average yard by an experienced leaf blower operator (Table 1). If the actual usage time is greater or less, the data can be adjusted accordingly. Also calculated are emissions of leaf blowers complying with yr 2000 and later standards (Table 2). The difference between the data is that Table 1 presents actual exhaust emissions of a 1999 population, based on certification and test data; Table 2 uses a future regulatory level, which will not be reflected in the population of leaf blowers for several years until all leaf blowers produced prior to 2000 have been removed from use. Carbon monoxide levels are higher because the regulatory level is higher than what is being achieved in practice by current leaf blower engines. Also presented in Table 1 are fugitive dust emissions for 10 minutes, which are not repeated in other tables, as the data do not change. The data illustrate a worst case scenario, as discussed above.

Table 1. Leaf Blower Emissions and Mixing Space for the Operator, 3 hp average and 50% load factor, 1999

	Exhaust Emissions, g/bhp-hr	Exhaust Emissions, g/10 min	Amount of Mixing Space Necessary to Not Exceed the NAAQS[3]
Hydrocarbons	132.84	33.21	NA[4]
Carbon Monoxide	282.35	70.59	1765 m^3
Particulate Matter	4.29	1.07	7133 m^3
Fugitive Dust	---	8.1 - 171.8	Varies

Table 2. Leaf Blower Emissions and Mixing Space for the Operator, 3 hp average and 50% load factor, Based on 100% compliance with yr 2000 standard

	Exhaust Emissions, g/bhp-hr	Exhaust Emission, g/10 min	Mixing Space Necessary to Not Exceed the NAAQS
Hydrocarbons + NOx	54	13.5	NA
Carbon Monoxide	400	100	2500 m^3
Particulate Matter	1.5	0.375	250 m^3

For CO (Table 1), the 71 g emitted in ten minutes would require mixing in 1765 m^3 of air in order avoid exceeding the NAAQS 1 hr standard for CO of 35 ppm, assuming that all of the CO remains in the immediate area, and that the person being exposed breathes this air for 1 hour. The amount of air in 1765 m^3 is comparable to the amount of air that would fill a cube 12.1 m, or 39.6 ft, on each side. As discussed above, this estimate does not permit a determination of the health impacts of the exposure to CO. These data, however, do suggest that the relatively large amount of CO emitted directly into the air space surrounding the operator could result in the inhalation of an unhealthful dose. Staff recommends that further research is warranted to determine exposures and related health impacts from small, two-stroke engine emissions.

For the PM10 (Table 1) directly emitted from exhaust emissions, the air space necessary for

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[3] National Ambient Air Quality Standard

[4] No relevant NAAQS exists for hydrocarbons as this is a catch-all category for many chemicals.

mixing in order not to exceed the 24-hour standard for PM10 is larger than that for CO, comprising an amount of air equivalent to a cube 19.2 m, or 63.2 ft, on each side. The yr 2000 standards will result in a significant reduction in directly emitted PM10.

PM emissions from the blown dust, however, dwarf the PM emissions from exhaust. Using the low median emissions factor of 8.1 g/10 min, we find that a cube of air 37.8 m, or 124.0 ft, on each side would be equivalent to the 54,000 m^3 of air that would be needed to dilute the PM10 sufficiently to avoid exceeding the 24-hour national ambient air quality standard. The high median emissions factor 171.8 g/10 min yields 1,145,333 m^3 of air required to dilute the PM10 (104.6 m cube).

B. Homeowner Leaf Blower Usage

Using the same methods as above produces the emissions shown in Table 3. As discussed above, this exposure model assumes a worst case in which there is no dispersion of pollutants out of the immediate area. Actual exposures would be somewhere between the worst case and zero. Table 4 presents emissions data based on the yr 2000 control levels. Fugitive dust emissions are not repeated from Table 1 in this section, as they do not change.

Table 3. Leaf Blower Emissions and Mixing Space for the Homeowner, 0.8 hp average and 50% load factor, 1999

	Exhaust Emissions, g/bhp-hr	Exhaust Emissions, g/10 min	Mixing Space Necessary to Not Exceed the NAAQS
Hydrocarbons	141.82	9.45 g	NA
Carbon Monoxide	297.93	19.86 g	497 m^3
Particulate Matter	3.6	0.24 g	1,600 m^3

Table 4. Leaf Blower Emissions and Mixing Space for the Homeowner, 0.8 hp average and 50% load factor, Based on 100% compliance with yr 2000 standard

	Exhaust Emissions, g/bhp-hr	Exhaust Emissions, g/10 min	Mixing Space Necessary to Not Exceed the NAAQS
Hydrocarbons + NOx	54	3.6 g	NA
Carbon Monoxide	400	26.67 g	666.7 m^3
Particulate Matter	1.5	0.1 g	66.7 m^3

For comparison, for CO (Table 3) the mixing space necessary to avoid exceeding the standards is equivalent to a cube of air 8 m, or 26 ft, on each side. For fugitive dust (Table 3), 1.8 g of PM10 emitted in ten minutes would need to be mixed in a volume of 12,000 m^3 of air in order to avoid exceeding the 24-hour standard for PM10. This is an amount of air equivalent to a cube 22.9 m, or 75.1 ft, on each side. As with the commercial exposure, this is a potentially hazardous exposure, but because the homeowner is likely using leaf blowers for a very short time each week, the concern is much lower than for commercial gardeners. Still, staff would recommend that even homeowners wear a dust particulate filtering face mask.

APPENDIX K

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