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Master's Thesis

MINIMIZING AIR POLLUTION DURING THE CONSTRUCTION OF AIR FORCE FACILITIES

APPROVED:

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Dedication

This thesis is dedicated to my loving wife, Denise, and my children, Jordan and Jaemyn. Thanks for putting up with the countless hours I spent sitting at the computer, and the more than occasional bad moods as I was trying to get finished. I promise I'll make up for it. I love you.

MINIMIZING AIR POLLUTION DURING THE CONSTRUCTION OF AIR FORCE FACILITIES

by

JEFFREY SCOTT SORENSON, B.S.

THESIS

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in Partial Fulfillment

of the Requirements

for the Degree of

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ABSTRACT

MINIMIZING AIR POLLUTION DURING THE CONSTRUCTION OF AIR FORCE FACILITIES

by

JEFFREY SCOTT SORENSON, MASTER OF SCIENCE IN ENGINEERING

THE UNIVERSITY OF TEXAS AT AUSTIN, 1993

SUPERVISOR: RICHARD L. TUCKER

As contributors to air pollution, construction projects in general have been largely ignored in the United States. The Air Force is interested in taking efforts to reduce construction-generated pollution. This paper introduces the reader to air pollution and the causes and effects of common pollutants. The two sources of pollution that are specifically associated with construction are then identified, and methods of minimizing those sources of pollution are proposed. Finally, a number of contract clauses that may be incorporated into Air Force construction contracts are included for consideration.

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CHAPTER ONE

INTRODUCTION

1.0 Introduction

Man-made air pollution is a relatively recent phenomenon. This is mostly as a result of the worldwide increase in industry and technology.

Over 100 years ago, energy was measured in terms of manpower and animal power. At that time, soil that was so loose it could be shoveled up without being loosened by a pick was called "earth of one man." If it were so hard that it required one man to be constantly employed picking and loosening the earth, it was called "earth of two men." The average laborer could shovel 10 to 14 cubic yards of loosened soil into a cart in a ten hour day. At wages of one dollar per day, the cost of shoveling was therefore seven to ten cents per cubic yard. For hauling excavated material, a laborer with a wheelbarrow could move a 90 foot distance for 8.2 cents per cubic yard, or 900 feet for 44.1 cents per cubic yard. By comparison, an ox-team with cart and driver, would cover the 90 feet for 8.9 cents per cubic yard. The extra power available, however, caused the cost to drop to 13.4 cents per cubic yard for the 900 foot haul. (Stander, 1976)

Steam powered equipment fired with either wood or coal came into construction work in the 1870s. Earliest types were traction engines used to pull road graders or steam rollers for asphalt paving. Steam shovels were in use first in railroad construction in the 1840s, then remained the most useful excavating machine until the 1920s. During World War I, track-laying vehicles were utilized which, in conjunction with the development of the diesel engine in 1930, caused the decline and eventual discontinuance of steam power in construction and the emergence of the diesel tractor. So we have multiplied our efficiency and capacity to perform work principally by the transition from muscle power to steam power to diesel power over the past 120 years. With that transition, however, has come an increase in pollutants emitted from our technological advancements.

The first question that one might ask when considering a study of construction-generated air pollution is "Why worry about it?" Why, indeed? Isn't air pollution regulated at just about every government level? And isn't the level of air pollution as a result of construction relatively insignificant, anyway? Perhaps.

The US. construction industry continues to consume a significant portion of the nation's economy each year. Total construction spending for 1991 was $401 billion, growing 6 percent in 1992 to $425.8 billion. (ENR, 1993) The Department of Defense (DoD) spends billions of dollars each year on military construction projects. And in spite of the military reductions in force and base closures taking place, major construction projects are occurring at other bases to handle the relocation of displaced units. The fiscal year 92 (Oct 1, 1991 - Sep 31, 1992) military construction budget was $8.5 billion, and the DoD asked for $10.2 billion for fiscal year 93. The Air Force share of this for fiscal year 93 is expected to be approximately $3.5 billion. (Engineer, 1992b)

Each of these projects contributes some amount of air pollutants to the atmosphere, impacting on both local and global air pollution. Most people, however, would argue that one construction project generates very little air pollution relative to that of automobiles or industrial factories, and this, of course, is true. And although it's also true that the automobile is the largest consumer of energy and major source of many air pollutants, we cannot afford to ignorantly close our eyes to any source of air pollution, no matter how seemingly insignificant. In fact, after 20 to 30 years of major emphasis on controlling emissions from automobiles and light trucks, the US. Environmental Protection Agency (EPA) is now giving serious attention to heavy-duty vehicles, both on- and off-highway, as a result of the Clean Air Act Amendments of 1990. (Okurowski, 1993)

But how can the Air Force, or any project owner for that matter, dictate environmental issues to a contractor? Besides the fact that almost any requirements can be put into a contract, many investigators have found that market forces play a major role in technological advancement. A series of studies in many industries lead to the conclusion that market demand triggers innovation and strongly influences the process of innovation. (Tatum, 1989) In other words, if we want to see reductions in construction-generated air pollution, designers and owners of construction projects can play this major role. They should set project objectives and requirements that challenge existing construction equipment and methods, leading to innovation and advancement of construction equipment.

1.1 Purpose

The purpose of this thesis is to identify methods of minimizing air pollution generated during the construction of Air Force facilities; in a way that identifies the sources of air pollution generated during construction, along with the costs and effects of air pollution; and identifies methods for minimizing construction-generated air pollution; so that contractual clauses requiring minimization of construction-generated air pollution can be developed for incorporation into new Air Force facility construction contracts.

1.2 Scope

Although there are many types of construction projects and other types of pollution in addition to air pollution, the scope of this thesis has been purposely limited. The general scope of this thesis covers new construction projects on vacant, unimproved building sites, with no demolition involved (primarily to avoid concerns with asbestos removal). No remodeling or repair projects were considered. The scope covers only the construction phase of projects and only considers activities which occur within the confines of the construction site or area. Many of the construction activities and sources of pollution discussed have applications in areas outside the scope of this thesis. As a result, the methods of minimizing construction-generated air pollution will also have applications in other types of construction. It is hoped that this research will result in benefits in those areas, as well.

1.3 Methodology

The primary research methodology has consisted of intensive literature review, as well as interviews with experts in the field of air pollution and in construction. The intention of the research methodology was to gather together available air pollution information and apply it to the construction industry (Air Force Military Construction projects, specifically), in ways that were not currently being practiced, or were at least proposed improvements in current practice. Applications to Air Force construction projects will be equally as applicable to other public and private projects, as well, since the Air Force does not typically practice or require uncommon methods. Likewise, applications to non-Air Force projects will likely apply to the Air Force projects just as well.

1.4 Thesis Organization

To begin a study of construction-generated air pollution, a fundamental understanding of air pollution (Chapter Two) along with its effects (Chapter Three) and costs (Chapter Four) is required. Chapter Five then identifies the sources of air pollution, including the construction sources. The methods of minimizing these construction sources are then discussed in Chapter Six, with Chapter Seven being the specific contract clauses that can be used to implement the methods identified in the previous chapter. Conclusions and recommendations in Chapter Eight complete the research.

CHAPTER TWO

INTRODUCTION TO AIR POLLUTION

2.0 History of Air Pollution

Natural processes such as forest fires, decaying vegetation, dust storms, and volcanic eruptions have always contaminated the air. The global distribution and dispersion of these natural pollutants, however, result in low average concentrations. By precipitation, oxidation, and absorption into the oceans and the soil, the atmosphere can cleanse itself of all known pollutants given sufficient time. On the other hand, man-generated pollutants are usually concentrated in small geographic regions. Currently the rate at which pollutants are discharged into the atmosphere in highly populated regions at times exceeds the cleansing rate of the atmosphere; hence, most air pollution problems are truly man-made. Air pollution is considered a public problem, a concern not only of those who discharge the pollution, but also of those who may suffer as a result.

In A.D. 61, the Roman philosopher Seneca reported this on the conditions in Rome:

> As soon as I had gotten out of the heavy air of Rome and from the stink of the smoky chimneys thereof, which, being stirred, poured forth whatever pestilential vapors and soot they had enclosed in them, I felt an alteration of my disposition. (Stern, 1984)

The primary air pollution problem of the nineteenth century was smoke and ash from the burning of coal or oil in the boiler furnaces of stationary power plants, locomotives and marine vessels, and in home heating fireplaces and furnaces. As far back as 1272, King Edward I of England tried to clear the smoky sky over London by banning the use of "sea coal".

In the United States, smoke abatement (as air pollution control was known) was considered a municipal responsibility. There were no federal or state smoke abatement laws or regulations. The first municipal ordinances limiting the emission of black smoke and ash appeared in the 1880s and were directed toward industrial, locomotive, and marine sources. (Stern, 1984)

Automobiles emerged in the early 1900s and numbered over 6 million by 1925. Smog first appeared in Los Angeles, California in the 1940s. The first national air pollution symposium in the US. was held in 1949, and the first US Technical Conference on Air Pollution was held in 1950.

In 1955, the first federal air pollution legislation was enacted, providing federal support for air pollution research, training, and technical assistance. Responsibility for the administration of the federal program was given to the Public Health Service of the US Department of Health, Education, and Welfare, and remained there until 1970 when it was transferred to the new US Environmental Protection Agency (EPA). The initial federal legislation has been amended many times, the latest of which is the Clean Air Act Amendments of 1990.

2.1 Definition of Air Pollution

Air pollution may be defined as:

> the presence in the outdoor atmosphere of one or more contaminants or combinations thereof in such quantities and of such duration as may be or may tend to be injurious to human, plant, or animal life, or property, or which unreasonably interferes with the comfortable enjoyment of life or property or the conduct of business. (Wark, 1981)

Each state in the country also has a similar definition of air pollution. The state of Wisconsin, for example, further defines contaminants as: dust, fumes, mist, liquid, smoke, other particulate matter, vapor, gas, odorous substances, or any combination thereof but shall not include uncombined water vapor. (Wark, 1981)

Air pollution is often thought of as an urban problem that can be escaped by getting away from the city into the clean air of the country. Unfortunately, the rural air is becoming increasingly contaminated by urban air and by the long-distance transport of pollutants. The reality of air pollution is that all air, to one degree or another, is polluted. In other words, unpolluted air is only a concept - what the composition of air would be if man and his works were not on the earth. (Table 2-1) Even at the most remote locations at sea, at the poles, and in the deserts and the mountains, the air may be best described as dilute polluted air. It closely approximates unpolluted air, but still contains vestiges of diffused and aged man-made pollution. (Stern, 1984)

The gaseous composition in Table 2-1 is expressed as parts per million (ppm) by volume. To avoid confusion between volume or weight basis for ppm, most air pollutant concentrations are expressed as micrograms per cubic meter ($\mu g/m^3$), also shown in Table 2-1. To convert from units of ppm (vol) to $\mu g/m^3$, it is assumed that the ideal gas law is accurate under ambient conditions. A generalized formula for the conversion at 25°C and 760 mm Mercury is

$$1 \text{ ppm (vol) pollutant} = 40.9 \times \text{molecular weight } \mu g/m^3.$$ (Stern, 1984)

The Gaseous Composition of Unpolluted Dry Air (Table 2-1)

Component	Parts Per Million (Vol)	10^{-6}g/m^3 (μg/m^3)
Nitrogen	780,900	8.95×10^8
Oxygen	209,400	2.74×10^8
Water	-	-
Argon	9,300	1.52×10^7
Carbon Dioxide	315	5.67×10^5
Neon	18	1.49×10^4
Helium	5.2	8.50×10^2
Methane	1.0 - 1.2	$6.56 - 7.87 \times 10^2$
Krypton	1.0	3.43×10^3
Nitrous Oxide	0.5	9.00×10^2
Hydrogen	0.5	4.13×10^1
Xenon	0.08	4.29×10^2
Organic Vapors	Approx. 0.02	-

Source: "Fundamentals of Air Pollution, Second Edition" by Stern, Boubel, Turner, and Fox (1984)

2.2 Effects of Meteorology on Air Pollution

2.2.1 Wind

Increased wind speeds generally cause a reduction in pollution concentrations near the source of the pollution. In doing so, however, wind spreads the pollutants, contributing to both regional and potentially overall global pollution.

2.2.2 Atmospheric Stability

The stability of the lower atmosphere, of which change of temperature with height is an indication, affects the dispersion of air pollutants. The more rapidly the air temperature decreases with height, the more unstable the air becomes. Unstable air enhances vertical dispersion and generally results in lower ground-level pollutant concentrations. (IJC, 1971) A layer in which the temperature increases with height is called an inversion layer. Inversions inhibit vertical dispersion and dilution of pollutants. Prolonged inversions, such as may occur during atmospheric stagnation of several days, can result in the excessive concentration of air contaminants. Inversion layers are not uncommon in the greater Los Angeles area.

2.2.3 Sunshine

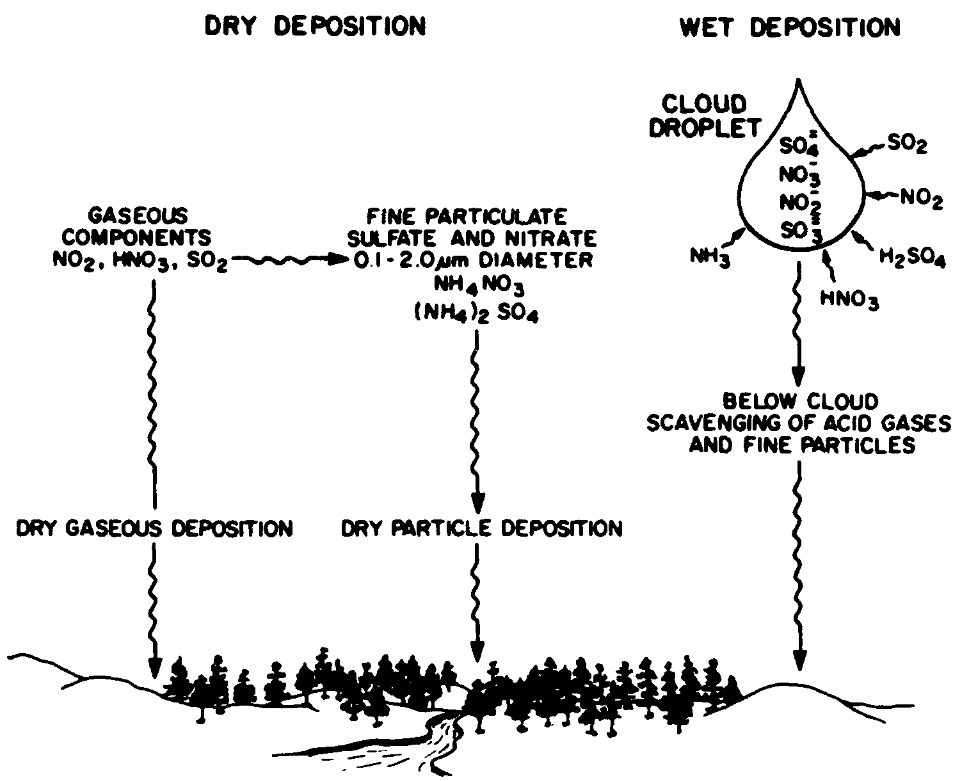
Photochemical reactions may take place between emitted pollutants (primary pollutants) or between pollutants and components of the ambient air to produce compounds (secondary pollutants) more objectionable and hazardous than the original one(s). Smog is a product of such photochemical reactions. As sunlight is the source of energy for these reactions, the amount of sunshine is an important factor in local or regional air pollution studies.

2.2.4 Precipitation

Precipitation is an important weather element affecting air pollution because of its washout or scavenging effects on the large particulates suspended in the air. In addition, to particles, many gases are readily soluble and may be transported out of the atmosphere to the earth below. Rainfall is thus desirable because air is partially cleansed by the interaction of the pollutants with the raindrops. These benefits of cleansing the atmosphere, however, have a negative side effect in what is often referred to as acid rain. What is commonly called acid rain is actually the wet form of acidic deposition which consists of both wet and dry deposition. Clean or natural raindrops, at a temperature of 20°C, will have a pH of 5.6. This represents the baseline for comparing the pH of rainwater which may be altered by SO_2 (or NO_x) oxidation products. In the simplest case, CO_2 dissolves in raindrops forming carbonic acid. Sulfuric acid (H_2SO_4) or nitrous acid (HNO_3) will also dissolve or form in the droplets. The overall pH of any given droplet is a combination of the effects of carbonic acid; sulfuric and nitric acids; and any neutralizers such as calcium, magnesium, or ammonium. (Figure 2-1)

2.3 Summary

Most air pollution problems are man-made, and although air pollution is typically worse near the source, there is truly no unpolluted air on the earth. Meteorology plays a key role in the dispersion of air pollutants and in their effects on humans, plants, and materials, as will be discussed in the next chapter



<u>**Atmospheric Processes Involved in Acidic Deposition (Figure 2-1)**</u>

Source: ***Fundamentals of Air Pollution, 2nd Edition*** **by Stern, Boubel, Turner, and Fox**

CHAPTER THREE

AIR POLLUTANTS AND THEIR EFFECTS

3.0 Types of Air Pollutants

The major portion of the recognized air pollutants from man-made sources are gases and vapors such as carbon monoxide, carbon dioxide, the oxides of nitrogen, the oxides of sulfur, and unburned hydrocarbons from fossil fuel combustion; and hydrogen sulfide, ammonia, hydrogen chloride, and hydrogen fluoride from industrial processes. Substances such as these, emitted directly from sources, are called primary pollutants. Chemical reactions may occur among the primary pollutants and the constituents of the atmosphere. These manufactured pollutants are called secondary pollutants; they are responsible for most of the smog, haze, and eye irritation, and for many of the forms of plant and material damage attributable to air pollution.

A general classification of air pollutants is as follows:

1. Particulate matter
2. Sulfur-containing compounds
3. Organic compounds
4. Nitrogen-containing compounds
5. Carbon monoxide
6. Halogen compounds
7. Radioactive compounds. (Wark, 1981)

Of specific interest to most air pollution studies and reports, and of particular interest to the US Air Force (USAFOEHL, 1988) are the following air pollutants: carbon monoxide, hydrocarbons, sulfur dioxide, oxides of nitrogen, and particulate matter. These specific pollutants are among the most widespread and are responsible, either directly or indirectly for most of the adverse effects attributed to air pollution in general. Each of these pollutants will be discussed in detail, followed by a discussion of the effects of these pollutants on materials, plants, animals, and humans, later in this chapter.

3.1 Effects of Air Pollutants

Air pollution has a geographical impact on three different scales: local (less than 100 kilometers,) regional (measured in hundreds of kilometers,) and global. The effect on these areas will be dependent on the type(s) of pollutant, meteorological conditions, and pollutant receptors in each area.

Air pollution has a primarily adverse affect on receptors in our environment. These receptors rely on the ambient environment (essentially air and sunlight) for their growth, or simply for their continued existence in their current state. Receptors of air pollution may be a person or animal that breathes the air and whose health is affected, or whose eyes may be irritated or whose skin made dirty. It may be a plant or a tree that dies, or the growth, yield, or appearance of which is adversely affected. It may be a material such as paper, leather, cloth, metal, stone, or paint that is affected. The receptor may even be the atmosphere itself.

In developing air pollution cause-effect relationships with receptors, we must be constantly on guard, lest we blame air pollution for an effect caused by something else. Material damage due to pollution must be differentiated from that due to ultraviolet radiation, frost, moisture, freeze-thaw cycles, bacteria, fungi, insects, and animals. Likewise, air pollution damage to vegetation must be separated from quite similar damage attributable to bacteria and fungal diseases, insects, drought, frost, soil mineral deviations, hail, and cultural practices. In addition, there are many instances of visibility reduction in the atmosphere by fog or mist for which air pollution is not a causative factor.

3.1.1 Effects on Materials and Vegetation

Most materials will eventually deteriorate, even when exposed to an unpolluted atmosphere. However, under the influence of air pollutants, deterioration is accelerated, along with unsightly appearance.

The dirtying of material surfaces caused by air pollution results in a negative appearance and thus, an increased washing of the surfaces. This increased frequency in washing, in addition to the deteriorating effect of the pollutant, results in greater wear on the surfaces.

The principal effects of air pollution on metal materials are corrosion of the surface, with eventual loss of material from the surface, and alteration in the electrical properties of the metals. Non-ferrous metals (those containing no iron) such as zinc, aluminum, copper, and silver, are less susceptible to corrosion from air pollution than are ferrous metals (those containing iron). (Stern, 1984) Zinc is often used as a protective coating over iron to form galvanized iron. Nevertheless, in industrial settings exposed to sulfur dioxide (SO_2) and humidity, the zinc coating is still subject to sufficient corrosion to destroy its protective capacity. (Table 3-1) Three factors influence the rate of corrosion of metals - moisture, the type of pollutant, and temperature. Typically, dry or cold locations will experience the lowest rates of corrosion of metals.

A number of studies of the effects of air pollution on plants have been done over the past 20 years. The major air pollutants which are toxic to plants are ozone (O_3),

SO_2, NO_2, fluorides, and peroxyacetyl nitrate (PAN), which is a product of NO_x and hydrocarbons. (Stern, 1984) Damage done to plants is due to the reduction of solar radiation, deposits on the leaves and stomata, the scorching of growing plants by acidic deposition, and the acidification of the soil. (Rose, 1973) Many species of plants will not grow or will grow only feebly in polluted atmospheres, so this may result in heavier costs or reduced productivity in agricultural or market gardening.

The US. Department of Agriculture makes a distinction between air pollution damage and air pollution injury to plants. Injury is considered to be any observable alteration in the plant when exposed to air pollution. Damage is defined as an economic or aesthetic loss due to interference with the intended use of a plant. (Stern, 1984)

Weight Loss of Metal Panels After 20 Years' Exposure in Various Atmospheres (Table 3-1)

	Average Loss in Weight (Percent)					
City	**Commercial Copper**	**Commercial Aluminum**	**Brass**	**Nickel**	**Commercial Lead**	**Commercial Zinc**
Altoona, PA	6.1	-	8.5	25.2	1.8	30.7
New York	6.4	3.4	8.7	16.6	-	25.1
La Jolla, CA	5.4	2.6	1.3	0.6	2.1	6.9
Key West, FL	2.4	-	2.5	0.5	-	2.9
State College, PA	1.9	0.4	2.0	1.0	1.4	5.0
Phoenix, AZ	0.6	0.3	0.5	0.2	0.4	0.8

Source: *Fundamentals of Air Pollution, 2nd Edition*, by Stern, Boubel, Turner, and Fox (1984)

3.1.2 Effects on Human Health

To study damage to materials, plants, and animals, we can set up lab experiments in which most confusing variables are eliminated and a direct cause-effect relationship is established between pollutant dosage and resulting effect. We cannot do this with humans. Our cause-effect relationships for humans are based upon 1) extrapolation from animal experiments, 2) clinical observations of individual cases of persons exposed to the pollutant or toxicant (industrially, accidentally, suicidally, or under air pollution episode conditions,) and 3) most importantly, epidemiological data (dealing with the incidence, distribution, and control of disease in a population) relating population, morbidity, and mortality to air pollution. (Stern, 1984) There are no human diseases uniquely caused by air pollution. In all air pollution-related diseases in which there is a buildup of toxic material in the blood, tissue, bone, or teeth, part or all of the buildup could be from ingestion of food or water containing the material. Those diseases which are respiratory can be caused by smoking or occupational exposure. They may be of a bacterial, viral, or fungal origin rather than the inhalation of man-made pollutants in the ambient air. These causes in addition to the variety of congenital, degenerative, nutritional, and psychosomatic causes of disease must all be ruled out before a disease can be attributed to air pollution. However, air pollution commonly exacerbates an existing disease condition, of a primarily respiratory nature.

A 1985 EPA study concluded that the estimated cancer risk in the US due to air pollution was between 5 - 7.5 cases per million people per year. Therefore at that time, the total estimated annual cancer cases from all types of air pollution was 1,300 - 1,700. (Lidy, 1987) However, a more recent study by the EPA and the Harvard

School of Public Health estimated that up to 60,000 American deaths each year are caused by particles alone in the air. (Time, 1993) Besides their role in the induction of cancer, air pollutants may have the ability to cause a wide variety of health-related impacts ranging from eye irritation to the induction of heart disease. Many air pollutants have been shown to be teratogens (tending to cause developmental malformations,) immunosuppressors (suppressers of natural immune responses,) and allergens (substances that induce allergy) when individuals or test animals are exposed to elevated doses of selected substances.

The assessment of health risks associated with low-level multiple-pollutant environmental exposures is extremely complex and is subject to many uncertainties. For example, one could ask a very simple yet difficult question: What is an adverse health effect? It can be defined as a biological change that reduces the level of well being or functional capacity in the human organism. To adequately investigate the health implications of environmental chemicals, it is necessary to resolve questions related to exposure, environmental and population variation, health end points, and extrapolation from animal to man and high vs. low-dose effects. (Lidy, 1987)

The injury to health from air pollution is less easy to determine with any precision than is the case with most other epidemiological injury. Air pollution does not cause diseases peculiar to itself, as does, for instance, polluted water. (Rose, 1973) The diseases with which it is mostly associated, namely bronchitis and other respiratory disorders, may be induced primarily by other factors, with air pollution aggravating and intensifying the condition. Such seems to be the case with the EPA and Harvard study results mentioned earlier.

3.2 Common Air Pollutants

3.2.1 Carbon Monoxide

Carbon monoxide (CO) is a colorless and odorless gas. It is very stable and has a lifetime of two to four months in the atmosphere. CO is the most widely distributed and most commonly occurring air pollutant. The total emissions of CO to the atmosphere exceed those of all other air pollutants combined. The national emissions of CO in 1980 were roughly 85.4 million metric tons, of which approximately 90 percent was from man-made sources. (USAFOEHL, 1988) The largest single source of CO pollutant emissions is highway vehicles.

Effects: The health effects of carbon monoxide are well known and have been extensively documented. (Lidy, 1987) CO enters the human body by inhalation and is absorbed directly into the bloodstream. CO interferes with the body's exchange of O_2 and CO_2 between the lungs and the bloodstream. High concentrations of CO can cause physiological and pathological changes and ultimately death. It can severely aggravate cardiovascular diseases. Evidence has been presented that CO concentrations in the Los Angeles basin are associated with excess mortality. (Wark, 1981)

3.2.2 Hydrocarbons

Hydrocarbon (HC) pollutants originate primarily from the incomplete combustion of fuels, particularly the more volatile fuels such as gasoline, and from the use of hydrocarbons to process raw materials such as solvents. The major man-made sources are gasoline-powered vehicles, but also include other types of vehicles and aircraft. Man-made stationary sources which are primarily HC emitters involve petroleum and petrochemical operations, solvent usage and waste burning.

Effects: The primary effect of hydrocarbons is not in their direct action upon materials, plants, or people, but in their reactions with other constituents in the atmosphere under the influence of sunlight. In other words, the effect of hydrocarbons is seen in their role in photochemical reactions. Research seems to indicate that nearly every hydrocarbon (with the possible exception of methane) is capable of being photo-oxidized to some form of oxidant. (Wark, 1981) One of these oxidants which is a major pollutant is peroxyacetyl nitrate (PAN). This compound is a strong eye irritant and causes plant damage. Another strong eye irritant is the oxidant peroxybenzoyl nitrate (PBN).

3.2.3 Sulfur Dioxide

Sulfur dioxide (SO_2) is the dominant oxide of sulfur present in the atmosphere. SO_2 is a nonflammable, non-explosive, colorless gas. It can act as either a reducing agent or as an oxidizing agent and it readily reacts, either photochemically or catalytically with other atmospheric contaminants to form sulfur trioxide, sulfurous acid, and sulfate salts. Many substances, especially particulate matter and the oxides of nitrogen act as the catalysts for these reactions. Sulfur trioxide reacts very rapidly with water vapors to produce sulfuric acid. Sulfur dioxide is generated during combustion of any sulfur-bearing raw materials. Combustion of fuels accounts for over 90 percent of all SO_2 emitted. (USAFOEHL, 1988) This is due to the relatively high sulfur content of some bituminous coals and residual fuel oils, and to the very large amounts of these fuels consumed in this country and around the world as a source of power.

Effects: Gases such as sulfur dioxide (SO_2) are sufficiently soluble to dissolve in water and be removed from the atmosphere as sulfuric acid by wet deposition in the form of rain or fog. Sulfuric acid is very corrosive and responsible for severe damage to materials and plants.

Research also suggests that the ultraviolet light we need to produce vitamin D in our skin is blocked by sulfur oxides in the air. The resulting vitamin D deficiency is the key to increased cancers of the colon and breast. In sulfur-polluted regions, less than one percent of the sunlight at the critical wavelength for vitamin D production reaches the earth. Vitamin D is critical for the proper metabolism of calcium. Studies on animals have shown that a lack of properly metabolized calcium causes colon-lining cells to inflame and proliferate, and years of such cellular irritation could lead to cancer. Similar conditions occur in breast cells. (Luoma, 1988b)

Another study commissioned by the European Economic Community showed that a 34 percent reduction in SO_2 emissions would increase average life expectancies by about 1 1/2 years. (Luoma, 1988a)

3.2.4 Oxides of Nitrogen

Of the various oxides of nitrogen (NO_x), only nitric oxide (NO) and nitrogen dioxide (NO_2) are considered important air pollutants. NO is formed when combustion takes place at a high enough temperature to cause a reaction between the nitrogen and oxygen in the air. Temperatures this high are reached only in efficient combustion processes or when combustion takes place at high pressure. These conditions are primarily found in automobile or aircraft engine cylinders, electric power plants, and other very large energy conversion processes. Nitric oxide, which is relatively harmless, is the form generally emitted into the atmosphere. It will, at varying times, oxidize to NO_2 which is a considerably more toxic gas. Oxides of nitrogen are also commonly involved in photochemical reactions, producing such oxidants as PAN and PBN.

Effects: The oxides of nitrogen, as with most other air pollutants, have primary effects on the human respiratory system. NO_2 can cause increased susceptibility to respiratory pathogens (specific agents which cause respiratory diseases). In addition, atmospheric haze can occur over regions of several thousands of square kilometers, caused by the oxidation of SO_2 and NO_2 to sulfate and nitrate in relatively slow-moving air masses. Also, see discussion under Precipitation (2.2.4) for discussion of the role of NO_x in acid rain.

3.2.5 Particulate Matter

Particulate matter (PM) or total suspended particulates (TSP) are defined as any material (except water vapor) that exists as a solid or liquid in the atmosphere or in a gas stream under standard conditions of temperature and pressure. (USAFOEHL, 1988) PM is frequently divided into subclasses which include fine dust (less than 100 microns in diameter), coarse dust (above 100 microns in diameter), fumes (0.001 - 1 micron in diameter), and mists (0.1 - 10 microns in diameter). Dusts are produced by condensation and combustion, as well as from mechanical processes such as grinding, spraying, and pulverization by vehicles and pedestrians. Fumes are particles formed by condensation, sublimation, or chemical reaction, and sometimes are designated as smoke. Mists are comprised of liquid particles formed by condensation. Natural PM sources include ocean salt, volcanic ash, wind erosion, forest fire smoke and ash, and plant and seed pollen. Most man-made PM is a result of industrial processes, with other sources, such as diesel engine emissions and paint spraying providing an additional small portion. During a study in Newark, New Jersey, paint spraying was estimated to contribute approximately 13 percent of the inhalable particulate matter in the ambient atmosphere. (Lidy, 1987)

Effects: One of the most common effects of air pollution is the reduction in visibility resulting from the absorption and scattering of light by airborne particulate matter. The presence of fine particulates (0.1 - 1.0 microns in diameter) in the atmosphere causes atmospheric haze. A survey by national park personnel indicated that large areas of the U.S. are subject to varying degrees of visibility degradation. (Stern, 1984) This can be particularly significant for major national parks such as the Grand Canyon, Yosemite, and Zion Park. Visitors not only go to these parks for the camping, hiking, and enjoying of solitude, but for enjoying the views, as well. To fully enjoy these views, one must have good visibility of up to 50 kilometers.

Reduction in visibility not only is unpleasing to an individual, but also may have strong psychological effects. It is depressing to live in a gloomy, grimy environment.

Particles suspended in the atmosphere will eventually settle out, and may come into contact with man-made materials such as painted surfaces, building materials, or automobiles. Many buildings in older cities have suffered from soot buildup for decades. This not only results in increased cleaning and maintenance of buildings, but intensifies drabness and urban squalor. This is particularly noticeable in cities such as London, where periodic cleaning is required to remove particulate matter residue. Tourist disappointment is hard to measure when landmarks such as Big Ben, the Houses of Parliament, and Westminster Cathedral are at least partially encapsulated in scaffolding while workers remove the blight of air pollution from these famous structures. Buildings in the United States, as well, are susceptible to this effect of particulate matter air pollution.

Air pollution in the form of particulate matter also contributes to the soiling of fabrics. The increased frequency of washing to remove dirt results in more wear on the fabric, causing it to deteriorate in the cleaning process.

Of primary concern, however, is PM's effect on animals and humans. Particles smaller than 10 micrograms (10^{-6} grams) in diameter, referred to as PM-10, are not only respirable, but have the added ability of carrying toxic chemicals along with them. As mentioned earlier, a recent EPA report indicates that 60,000 Americans die each year from PM-10. This particulate matter is mainly from industrial factories and diesel engines, even though the PM emission levels seldom exceeded the legal limits! The deaths were mostly children with respiratory problems, asthmatics of all ages, and elderly people with respiratory illnesses. (Hilts, 1993) Particulate matter, then, seems to be one of the most dangerous of the air pollutants. The table below (Table 3-2) shows the micrograms per cubic meter of air of suspended particles that are 10 microns in diameter or less in selected metropolitan areas in 1990. It is important to note, however, that the federal government does not regard particulate matter as harmless until the concentration reaches 150 micrograms per cubic meter for a 24 hour period. (40 CFR 50.6a, 1992)

3.3 Summary

There are many air pollutants, but the most prevalent and of the most interest to the Air Force are carbon monoxide, hydrocarbons, sulfur dioxide, oxides of nitrogen, and particulate matter. Although it is difficult to attribute specific effects to a particular pollutant, it is known that these pollutants have an adverse effect on humans, plants, and materials. These effects are costly, as will be considered in the next chapter.

SUSPENDED PARTICLES IN METROPOLITAN AREAS, 1990 (TABLE 3-2)

CITY	HI (µg/m³)	AVG. (µg/m³)
ANAHEIM, CA	108	48
ATLANTA	110	51
CHICAGO	149	45
DETROIT	114	35
LOS ANGELES	132	56
MINNEAPOLIS/ST. PAUL	140	34
NEW YORK	103	37
OAKLAND, CA	118	33
PITTSBURGH	191	43
RIVERSIDE, CA	278	82
ST. LOUIS	164	82

Source: EPA, from "Studies Say Soot Kills up to 60,000 in US Each Year", *NY Times*, July 19, 1993

CHAPTER FOUR

COSTS OF AIR POLLUTION

4.0 Introduction

Just as it costs money to control air pollution, it also costs the public money not to control it. The annual cost of air pollution control in the US exceeds $30 billion. (Patrick, 1991) Yet there are many more costs that are a result of, or are related to, the air pollutants that are either not controlled or are inadequately controlled.

As was discussed in the last chapter, it is very difficult to attribute damage or injury to specific air pollutants. The question of what even constitutes damage to health is judgmental and therefore debatable. The question of what damage to well-being is acceptable is even more judgmental and debatable. Some jurisdictions may opt for a pollution level that allows some damage to vegetation, animals, materials, and the atmosphere, as long as they are assured that there will be no damage to their constituents' health.

The costs, then, of air pollution damage are also difficult to estimate. Nevertheless, there are certain known costs of air pollution based on studies and cause-effect relationships that will be reviewed below.

4.1 Costs of Material Soiling

Materials, in the broadest sense, consist of every non-living thing exposed to the polluted environment in which we live. On a regular basis, day after day, people wash their cars, wash their windows, and wash or paint their buildings, all to remove the buildup of dirt and grime caused by air pollution. According to a recent study, the nationwide annual cost of removing the effects of air pollution from building surfaces, including glass, exceeds $1.5 billion. (Steiner, 1992) If a conservative estimate for the number of automobiles in the US is 15 million, and on the average each one is washed on a monthly basis, the annual cost of washing automobiles in the US would be approximately $180 million. The costs of many of these other activities are not practically obtainable, however. For example, one might reasonably argue that only coatings, such as paint, that require more frequent replenishment than they would in an unpolluted atmosphere, should enter into the estimation of air pollution damage costs. This data could theoretically be gathered, but at what cost?

4.2 Costs of Plant Damage and Injury

In general, air pollution's most economically detrimental effect on plants is its damage to income producing agriculture. The costs of air pollution's effects on agriculture are the sum of the loss in income from the sale of crops and the added costs necessary to raise the crops for sale. To these costs must be added the loss in value of agricultural land as its income potential decreases, and the loss suffered by those segments of local industry and commerce that are dependent on farm crops and the farmer for their existence. Estimates indicate annual crop losses of between $1 - 2 billion (or 2 - 4 percent of total crop production) for the US. (Stern, 1984)

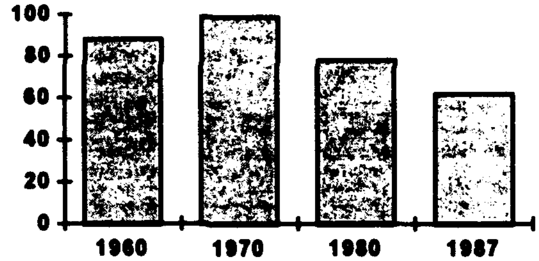
4.3 Costs of Human Health Effects

Spending on hospitals, physicians, and other health services rose to over $750 billion in 1991. Medicare and Medicaid, both of which depend on federal funding, totaled $216.7 billion. (Time, 1993) What, however, are the costs that can be directly linked to air pollutants? There are numerous amounts of research associating air pollution with human health problems, and even death. (Luoma, 1988a/b; NRC, 1981; Fackelman, 1990; Hilts, 1993) Yet there is no accurate research that ties illnesses and medical costs to specific air pollutants. And, without trying to seem emotional, what price do we attach to a human life? If, as the EPA and Harvard study claims, 60,000 people die each year from illnesses aggravated by the inhalation of particulate matter, what does that equate to in dollars? There are doubtless some medical and death-related costs involved.

No other air pollutant is known to be directly associated with even close to 60,000 deaths each year. In fact, previous EPA research indicated that only 1,300 to 1,700 cancer cases per year were due to all types of air pollution. (Lidy, 1987) Since we are now looking at more than a 30-fold increase in not just cases, but actual deaths, it is safe to say that reductions in particulate matter (such as those generated during construction) will result in substantial savings each year in medical and death-related costs.

A 1982 study showed that air pollution reductions between 1970 and 1978, brought about by the Clean Air Act of 1970, saved about $14 billion per year in costs associated with early death and another $2 billion annually in costs associated with illness. (See Figure 4-1) Another study calculated that a 34 percent reduction in SO_2 emissions would increase average life expectancies by one and one half years and save $6 billion. (Luoma, 1988a)

Carbon Monoxide Emissions in the US
(Fig 4-1)



Source: "Clearing the Air", by Anthony D. Cortese, *Environmental Science and Technology*, Vol. 224, No 4, 1990

According to a report by the American Lung Association, health benefits of $50 billion could be realized each year in the US if air quality standards were met. (Cortese, 1990) And there is little doubt that some of the standards are lax, such as that for particulate matter. Nevertheless, a conservative estimate of health savings, then, is $50 billion annually.

4.4 Summary

With very few exceptions, there are no hard dollar figures to quantify what reductions in air pollutants can or will save in damaging effects to materials, plants, or humans. In addition, there is not necessarily a direct correlation between the amount of pollutant emitted and the cost of its damage. A 50 percent reduction in particulates will not guarantee a saving of 30,000 lives each year. Minimizing air pollution, nevertheless, will result in significant savings, both in lives and dollars, and so the next chapter will investigate the sources of air pollution.

CHAPTER FIVE

SOURCES OF AIR POLLUTANTS

5.0 Introduction

The place from which pollutants are emitted are called sources. Air pollutants are emitted by both natural and man-made sources. Natural processes such as forest fires, volcanoes, decaying vegetation, and dust storms have always contaminated the air. But the atmosphere was skillfully created for removing these naturally-occurring pollutants. The man-made sources of pollution, then, are those that need to be identified and controlled.

5.1 Broad Sources of Air Pollutants

The man-made sources of air pollution are far too many and too diverse to be listed in any one document. Virtually every activity in which man is involved emits a number of air pollutants. The most significant source categories, however, are as follows.

5.1.1 Motor Vehicles

Motor vehicles nationwide contribute over 40 percent of total air pollution releases, with higher percentages in urban areas. (Patrick, 1991) 1984 estimates of emissions from all transportation sources in the US. exceeded 50 billion kilograms (kg) of CO per year, 20 billion kg of unburned hydrocarbons, and 20 billion kg of NO_X per year. (Stern, 1984) Motor vehicles, by definition, are mobile sources of air pollution, and thus are capable of moving from one area or region to another. Although these mobile sources predominately congregate in urban areas and so have a greater effect on local air pollution conditions, they can also have some effect on regional and even global conditions.

Gasoline-powered motor vehicles outnumber all other transportation sources combined: in the number of vehicles, the amount of energy consumed, and the mass of air pollutants emitted. It is not surprising that they have received the most governmental attention at all levels regarding emission standards and air pollution control systems.

Gasoline-powered motor vehicles emit primarily CO, CO_2, NO_x, SO_2, unburned hydrocarbons, and particulate matter. Exhaust emissions from gasoline-powered vehicles are influenced by such factors as gasoline formulation, air-fuel ratio, ignition timing, compression ratio, engine speed and load, engine deposits, engine condition, coolant temperature, and combustion chamber configuration.

Diesel-powered vehicles emit CO, NO_x, SO_2, unburned hydrocarbons, (namely methane, benzene, ethylene, propylene, toluene, and acetylene,) and particulate matter. The profile of diesel exhaust emissions varies significantly and is dependent upon such factors as engine type and aspiration; fuel-air ratio; fuel injector design; fuel grade and combustion; engine temperature, speed, and load; engine maintenance; and engine duty cycles. Diesel particulates can be 50 to 100 times greater than that of spark ignition engines. (Ferrone, 1991)

Smoky exhaust is a common characteristic of diesel engines, but high levels of smoke is a valid indication of a malfunctioning engine. Opacity is one commonly used measurement of the amount of smoke emitted from a diesel engine. Opacity is the fraction of a beam of light, passed through a plume of smoke, which fails to penetrate that plume. (40 CFR 86.082-2b, 1992) While 0 percent opacity is the goal, and 30 percent is obvious to the naked eye, 20 percent opacity is considered good. (Crowther, 1993) Black smoke indicates that particles of carbon, usually smaller than 1 micron in diameter, have escaped the combustion process. White smoke is usually due to condensed water vapor or liquid fuel droplets. Blue smoke is due to droplets from incomplete burning of fuel or lubricating oil. (SAE, 1988) All of these forms of smoke are particulate matter pollution. The three primary causes of excessive smoke emissions are improper air-fuel ratio control settings, fuel injection timing problems, and inadequate intake air (restricted air filters are common). (Jacobs, 1991) Each of these causes is typically cured by maintenance and can be avoided altogether by routine and preventive maintenance.

5.1.2 Stationary Sources

Stationary sources of air pollutants, such as industrial factories, contribute significant amounts of pollutants to the atmosphere. The primary pollutants from combustion of fossil-fuels at stationary sources are CO, NO_x, SO_2, unburned hydrocarbons, and particulate matter. Stationary sources, as a rule, are not mobile, and therefore have a much greater effect on local air pollution conditions than on regional or global conditions. Construction projects, although geographically stationary, do not qualify as stationary sources of air pollution as they are typically short in duration, relative to other stationary sources.

5.2 Construction Sources of Air Pollutants

The EPA does not recognize construction itself as a source of air pollution. It does, however, recognize specific activities during construction and components of the construction process as sources of air pollutants. If we were to first attempt to list every source of air pollutants on a construction site, the list would include such items as volatile organic compounds (VOCs) emitted from new carpet, new vinyl wall coverings, fresh paint, pipe glue, etc.; welding fumes; roofing tar kettle smoke; paint spraying; dust and dirt from excavation and dirt roads; and diesel and gasoline engine exhaust. The list of VOCs emitted from construction materials alone would be several pages long. (Stokes, 1993) The EPA, however, does not categorize all of these potential air pollution sources as being construction specific. Consider, for example, the enormous amount of paint that is applied to surfaces in the US each year, most of it being for maintenance of surfaces, not new applications. Paint spraying releases particulate matter into the atmosphere, and the fresh paint emits VOCs. The EPA, however, categorizes paint, along with all other VOC emitting sources, as general community emissions. These are estimated on an annual basis by community. What the EPA does consider as construction-related air pollution sources are construction equipment exhaust emissions and fugitive dust emissions. (Stevens, 1993) See Appendix B for additional discussion of VOCs.

5.2.1 Construction Equipment Exhaust Emissions

Emissions from diesel engines that power equipment used in construction activities are not presently controlled at the state or federal levels. (Philip, 1989) In fact, until the Clean Air Act Amendments (CAAA) of 1990, there was no regulation of any off-highway construction equipment at all, diesel or gasoline. (Okurowski, 1993) For the purposes of this research, the focus will be on heavy-duty diesel-powered construction equipment, and their emissions. This is validated by the fact that less than five percent of construction equipment sold use gasoline engines, and the trend is toward complete dieselization. (EPA, 1985b) Using the EPA definition, a heavy-duty vehicle is a vehicle rated at more than 8,500 pounds GVWR or that has a curb weight of more than 6,000 pounds or that has a basic vehicle frontal area in excess of 45 square feet. (40 CFR 86.082-2b, 1992)

The Society of Automotive Engineers categorizes off-road construction equipment as follows: Tractors, loaders, backhoe loaders, graders, tractor-scrapers, dumpers, excavators, continuous diggers, augers, cranes, pavers, soil stabilizers, rollers and compactors, and pipelayers. (SAE, 1992b) A survey taken approximately seven years ago showed that the US population of mobile construction and industrial equipment is over one million units. (Philip, 1989) These one million units contribute a significant amount of air pollutants into the atmosphere - a fact which was recognized by the CAAA of 1990, and will result in new regulations covering off-road engines beginning with the 1996 model year. (Okurowski, 1993)

Diesel exhaust consists of many recognized toxic agents in two phases, gas and particulate. The gas phase contains primary pollutants such as CO, SO_2, NO_x, and unburned hydrocarbons. These influence the production in the atmosphere of secondary products such as ozone (O_3,) NO_2, and peroxyacetyl nitrate (PAN).

The particulate phase contains small (less than 10 microns in diameter, referred to as PM-10) respirable carbonaceous particles that can aggregate. These provide a surface on which a number of toxic organic chemicals can be adsorbed, most notable, polycyclic aromatic hydrocarbons (e.g., benzo(a) pyrene). (NRC, 1981) Diesel exhaust particulates are easily inhaled and deposited deep within the lungs, carrying with them their toxic passengers. Because the particulates emitted in diesel exhaust are so small, they can stay suspended in the air for considerable periods of time and be dispersed throughout large areas by winds.

An EPA document (AP-42) identified the emission factors for heavy-duty construction equipment, including gasoline-powered and diesel-powered equipment. (EPA, 1985b) An emission factor is an average value which relates the quantity of a pollutant released to the atmosphere with the activity associated with the release of that pollutant. It is usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity that emits the pollutant. Using such factors permits the estimation of emissions from various sources of air pollution. These factors are simply estimates of emissions and are not intended to be used as regulatory standards.

The emission factors for ten categories of heavy-duty diesel-powered construction equipment are shown in Table 5-1. The miscellaneous category includes such mobile and semi-mobile equipment as log skidders, hydraulic excavators/crawlers, trenchers, concrete pavers, compact loaders, crane lattice booms, cranes, hydraulic excavator wheels, and bituminous pavers. Note that only grams per horsepower-hour (g/hphr) are shown, as this is the best method of calculating emissions. The emissions are calculated by taking the product of the emission factor, the usage in hours, the power available (that is, the rated power), and the load factor (the power actually used divided by the power available).

5.2.2 Fugitive Construction Dust Emissions

Oftentimes, construction sites can be easily identified by the tell-tale dust clouds floating overhead or worse yet, drifting across the road. Significant atmospheric dust arises from the mechanical disturbance of granular material exposed to the air. Dust generated from these open sources is termed "fugitive" because it is not discharged to the atmosphere in a confined flow stream such as out the tailpipe of a car. According to one estimate, construction in the US generates on the order of 24.8 tons per year of fugitive dust. (EPA, 1982) Common construction sources of fugitive dust include temporary unpaved haul roads, aggregate storage piles, and heavy construction (primarily grading and excavating) operations. The dust generation process for these sources is caused by two basic phenomena:

1. Pulverization and abrasion of surface materials by application of mechanical force through implements (wheels, blades, etc.)

2. Entrainment of dust particles by the action of turbulent air currents, such as wind erosion of an exposed surface by wind speeds over 19 kph (12 mph).

For a typical mean wind speed of 16 kph (10 mph) particles larger than 100 microns are likely to settle out within 20 - 30 feet of the edge of the source. Particles 30 - 100 microns are likely to settle within a few hundred feet of the source. Smaller particles, particularly those less than 10 - 15 microns have much slower gravitational settling velocities and are much more likely to have their settling rate retarded by atmospheric turbulence. (EPA, 1985a) Just as with PM-10 from diesel engine exhaust, fugitive PM-10 has the same toxics carrying capacity and respiratory infusion potential.

Volume One of the aforementioned EPA document (AP-42) provides methods (equations or factors) for estimating fugitive dust emissions from unpaved roads, aggregate storage piles, and heavy construction operations. The quantity (kg) of size specific particulate emissions per vehicle kilometer traveled on an unpaved road can be estimated given the type of road material, vehicle speed and weight, and no. of vehicle wheels. It is not required for the purpose of this paper to know the formula, only to know that there is one.

Emission Factors for Heavy-Duty Diesel-Powered Construction Equipment, in Grams per Horsepower-Hour (g/hphr) (Table 5-1)

Pollutant	Track-Type Tractor	Wheeled Tractor	Wheeled Dozer[a]	Scraper	Motor Grader
Carbon Monoxide	2.15	7.34		2.45	1.54
Hydro-carbons	0.75	1.76		0.55	0.36
Nitrogen Oxides	7.81	11.91		7.46	7.14
Sulfur Oxides	0.851	0.851	0.867	0.901	0.874
Particulate Matter	0.692	1.27	0.411	0.789	0.625

a - The wheeled dozer $CO/HC/NO_X$ emissions are included in the off-highway truck category.

Table 5-1, Continued

Pollutant	Wheeled Loader	Track-Type Loader	Off-Highway Truck	Roller	Miscel-laneous
Carbon Monoxide	2.71	2.26	2.28	6.03	4.60
Hydro-carbons	0.97	1.11	0.37	0.97	1.01
Nitrogen Oxides	8.81	9.30	8.15	13.05	11.01
Sulfur Oxides	0.857	0.853	0.887	1.00	0.932
Particulate Matter	0.805	0.655	0.502	0.778	0.902

Source: *Compilation of Air Pollution Emission Factors, Volume II: Mobile Sources, 4th Edition*, EPA AP-42, Sep 1985

During aggregate handling and storage, dust emissions occur at several points: during material loading onto the pile, during disturbances by strong wind currents, and during removal from the pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust. When freshly processed aggregate is loaded onto a storage pile, its potential for dust emissions is at a maximum. Fines are easily disaggregated and released to the atmosphere upon exposure to air currents from aggregate transfer or high winds. As the aggregate weathers, however, potential for dust emissions is greatly reduced. Moisture causes aggregation and cementation of the fines to surface of larger particles. Any significant rainfall soaks the pile and drying of the interior is very slow. Worse case emissions from storage pile areas, then, occur under dry wind conditions on fresh aggregate piles. Emissions from aggregate storage operations also vary in direct proportion to the percentage of silt (less than 75 microns in diameter) in the aggregate material.

Adding or removing aggregate material from a pile usually involves dropping the material from a front-end loader or a truck. AP-42, Volume One provides an equation to estimate the quantity of particulate emissions generated by such a dropping operation. An additional equation allows the estimating of emissions from wind erosion of active storage piles. Again, knowing that these equations are available is adequate at this time.

For heavy construction operations, AP-42, Volume One provides an approximate emission factor of 1.2 tons of fugitive dust per acre of construction per month of activity. This factor is based on field measurements of suspended dust emissions from apartment and shopping center construction projects. This value applies to construction projects with "medium" activity level, moderate silt content (approximately 30 percent,) and a semiarid climate. (EPA, 1985a) Different conditions will require a judgmental adjustment of the 1.2 tons factor, until such a time as research provides other such factors.

5.3 Summary

The two categories of construction-generated air pollution, as recognized by the EPA, are construction equipment exhaust emissions and fugitive dust emissions. Both of these categories are common to almost every Air Force construction project, meaning that Air Force projects produce air pollution. By using the emission factors and formulas identified, the total emissions for an Air Force project can be estimated in advance. The next chapter discusses methods that are available to reduce those emissions.

CHAPTER SIX

MINIMIZING CONSTRUCTION AIR POLLUTION

6.0 Introduction

The obvious first question to ask when we begin researching ways of minimizing construction air pollution is "What exactly are we trying to minimize?" As a reminder, the two areas that the EPA considers under construction-generated air pollution, are construction-equipment engine emissions and fugitive dust emissions.

The next logical question seems to be "How far should we go to minimize air pollution?" Control technology cannot be expected to result in zero atmospheric emissions. The cost of controlling any given air pollution source is usually an exponential function of the percentage of control. Benefit-cost ratios can be helpful, yet as seen with determining the health effects and costs attributable directly to air pollution, the benefits associated with air pollution control are equally as elusive. Almost any source of pollution, however, can be almost eliminated if cost is no factor. But reality is that cost is a factor, and a big one at that. Much soul searching is required before one accepts the questionable human health effects research and is accused of imposing large costs on the public by so doing; or of rejecting these results and being accused of subjecting the public to potential danger.

Finally, we might ask, "What restrictions are currently in force against such sources of air pollution?" Thus, we will begin this chapter with a discussion of the regulatory environment regarding air pollution in general, and then regarding specific construction sources.

6.1 Air Pollution Regulation and Legislation

6.1.1 General

The first federal air pollution legislation was enacted in 1955. The most recent of the federal legislation was the Clean Air Act Amendments (CAAA) of 1990. The CAAA required very specific action from the EPA with regard to studying air pollution issues, and developing and implementing regulations to protect the health and welfare of the general populace. The primary means through which the EPA has attempted to ensure or improve the quality of the air has been through the establishment of National Ambient Air Quality Standards (NAAQS). The NAAQS simply regulate the concentration of a specific pollutant that is allowed in the ambient air over a given time period. (Ambient air means that portion of the atmosphere, external to buildings, to which the general public has access.) (CFR, 1992) For example, the NAAQS for particulate matter (PM-10) is 150 micrograms per cubic meter ($\mu g/m^3$), maximum 24 hour concentration; or 50 $\mu g/m^3$, annual arithmetic mean. (CFR, 1992) The specific pollutants for which there are NAAQS are SO_2, PM-10, CO, Ozone, NO_2, and lead.

In addition to NAAQS, the EPA has established "significant harm levels" for certain pollutants. They are as shown in Table 6-1.

As mandated by the CAAA, states are required to prepare and implement, subject to EPA approval, plans which include a control strategy providing emission reductions necessary for attainment and maintenance of the NAAQS. It is at the state level, in fact, that most, if not all, air pollution regulation and control takes place.

Austin, Texas, for example, does not regulate air pollution. The Texas Air Control Board (TACB) has jurisdiction in Austin. (DeRoche, 1993) It is interesting to note that little if any control must take place in what are called "attainment areas", aside from the prevention of significant deterioration. These are areas which currently meet the NAAQS, as opposed to "non-attainment areas" which do not meet the standards.

SIGNIFICANT HARM LEVELS (Table 6-1)

Pollutant	**Harm Level**
SO_2	2,620 μg/m^3 (24 hour avg.)
PM-10	600 μg/m^3 (24 hour avg.)
CO	57.5 mg/m^3 (8 hour avg.)
	86.3 mg/m^3 (4 hour avg.)
	144 mg/m^3 (1 hour avg.)
Ozone	1,200 μg/m^3 (2 hour avg.)
NO_2	3,750 μg/m^3 (1 hour avg.)
	938 μg/m^3 (24 hour avg.)

Source: Code of Federal Regulations, Part 40, Paragraph 51.151, July 1, 1992

6.1.2 Construction-Related

There are currently no federal regulations or controls over air pollution generated during construction. Fugitive dust controls are at the discretion of local or state agencies. In Texas, the TACB regulates any fugitive dust (construction-generated or otherwise) under the "Nuisance Rule". (Crowther, 1993) Essentially, if no one complains, the dust is unregulated. Cities may have more stringent standards, but the City of Austin, for example, does not. (DeRoche, 1993) The CAAA did, however, require the EPA to investigate emissions of oxides of nitrogen from off-road engines and vehicles, which include construction equipment.

The EPA is developing emission standards for off-road diesel engines with greater than 50 horsepower (hp). All construction heavy equipment exceeds 50 hp. Beginning with model year 1996, all off-road diesel construction equipment must not emit more than 6.9 grams per horsepower hour (g/hphr) of NO_X. (Okurowski, 1993) Existing equipment emits approximately 10-12 g/hphr.

For on-road heavy-duty engines (including dump trucks and concrete mixers,) the current standard for NO_X is 5.0 g/hphr. This standard has been in effect since the 1991 model year. Beginning with the 1998 model year, the on-road NO_X standard will be reduced to 4.0 g/hphr, and will apply to all heavy-duty engines, gas, diesel and methanol. (FR, 1993) There are other emission standards for on-road heavy-duty engines, but as they only apply to the transient construction equipment, such as a concrete mixer making a delivery, and not to the majority of construction equipment on a typical site, we will concentrate our discussion on off-road heavy-duty equipment.

6.2 Minimizing Off-Road Diesel Construction Equipment Emissions

Technologies which could reduce construction equipment emissions include combustion modifications, fuel modifications, alternative fuels, and exhaust aftertreatment.

A variety of measures to modify the diesel engine combustion process have been researched. In order to meet the new 1996 NO_X standard, techniques such as timing retard, intake air cooling, tailored fuel injection, exhaust gas recirculation, and real time engine optimization through electronic control may be used. Other techniques, such as modifying combustion chamber geometry and increasing injection pressure can also reduce emission levels. Combustion modifications could be an attractive long term solution to controlling emissions since they are relatively cost effective, reliable, and enforceable. (Philip, 1989) However, a key challenge will be the research and development effort since each engine model requires individual development.

Modifications to conventional diesel fuel could include desulfurized fuel, water-fuel emulsions, or proprietary additives to reduce emission levels. In fact, effective Oct 1, 1993, EPA requires a 20 percent reduction, by weight, of sulfur in on-road diesel fuel. (Ferrone, 1991) Desulfurized fuel is not only effective in reducing particulate emissions, but it will reduce engine wear and maintenance and can increase engine life by 30 percent. Desulfurized fuel, however, is not a renewable energy source and will not last forever. Emulsions with water have shown the ability to significantly reduce NO_X emissions. (Philip, 1989)

Increasing attention is being given to methanol and compressed natural gas (CNG) as renewable alternatives to diesel fuel. Methanol does not produce engine particulates and contains less NO_X than diesel fuel. It only contains about 45 percent of the energy content of diesel, however, meaning more fuel consumed doing the same work. (Ferrone, 1991) There is also still considerable development required to use methanol in heavy-duty diesel engines. CNG requires replacing the diesel injection system with a carburetion and spark ignition system. CNG will reduce emissions of both CO and NO_X, (McGraw, 1993), but the elaborate refueling system required would cause severe problems in the field. In fact, both CNG and methanol lack the infrastructure to make either one a viable alternative construction equipment fuel at the present time.

Exhaust aftertreatment methods include traps, trap oxidizers, and catalysts. Trap oxidizer prototype systems have shown themselves capable of 70 - 90 percent reduction in particulate emissions. (Walsh, 1987) Basically, they all rely on trapping a major portion of the particulate and consuming them before they accumulate sufficiently to saturate the filter and cause fuel economy, performance, or other problems. These require further development due to space constraints on the equipment as well as verification of reliability and durability during construction equipment operating cycles.

In spite of the difficulties in bringing about emissions reductions for construction equipment (Philip, 1989), there are a number of operating practices that can help to lower emissions with the given diesel equipment. Engine emission can be reduced by emphasizing engine and equipment maintenance, matching the right equipment to the job, operating the equipment properly, and optimizing dump truck/loader usage. Although these practices were originally proposed to improve fuel efficiency, they are equally suited to reduce engine emissions. After all, the more fuel burned, the more emissions.

Engine emissions are very susceptible to the operating condition of the engine. Hence, periodic and regular engine and equipment maintenance should be accomplished. The easiest maintenance to perform and yet the most influential is the changing of air and fuel filters. (Dietrich, 1976) Other typical operator checks are important, as well, such as tire pressures and battery charge/condition.

By matching the right equipment to the job requirements, needless overkill can be avoided, as can repeat operations. For example, use the proper size backhoe or excavator bucket to match the required trench size. An oversized bucket causes more fuel to be burned and pollutants to be emitted. An undersized bucket requires more cycles than necessary, also wasting fuel and increasing emissions.

Operating equipment properly is a broad category, but has great potential for controlling emissions. One area is that of allowing diesel equipment to idle, rather than shutting it off. In practice, this seems wasteful, yet anyone who has watched the smoke pour out of a diesel exhaust as the engine roars to life might be led to think otherwise. In fact, diesel engines typically produce low emissions under an idle operating condition. (Jacobs, 1991) In light of this, a good rule of thumb is to allow the diesel engine to idle if it will be operated again within 30 to 35 minutes. If not, it should be shut off. Another proper operating consideration includes keeping haul routes smooth and level to avoid increasing the load on the engine (and thus the smoke and other emissions). Smooth operation of the throttle can also have an effect on engine emissions. This is not a viable option under most conditions, however, other than when unloaded or empty.

Optimization of dump trucks and loaders has been covered by other research, under the auspices of economics, primarily. (Karshenas,1988) At the same time, however, this optimization will also minimize emissions by ensuring full use of operating equipment.

With no changes to existing equipment or fuel, the aforementioned practices can reduce air pollution emissions of diesel-powered construction equipment.

The largest technical challenge that is faced when attempting reduction in all diesel engine pollutants is the trade-off between NO_X and particulate matter. Many researchers agree that reductions of hydrocarbons and NO_X emissions could be achieved more quickly and possibly more cost effectively if particulate emissions could remain at or near present day levels. (Philip, 1989) In fact, in most construction projects, PM emissions are dominated by fugitive dust, and not diesel engine exhaust.

(See Table 6-2) This data suggests that reduction in the PM emissions from construction equipment engines would not significantly reduce overall PM emissions from some types of construction activities. Again we are faced with a cost-benefit situation to attempt to determine how far we carry pollution control. It seems apparent, however, from Table 6-2, that first efforts should be to control the fugitive dust emissions.

CONTRIBUTION OF DIESEL ENGINES AND FUGITIVE DUST TO CONSTRUCTION PM EMISSIONS FOR A LARGE OIL/GAS PROCESSING FACILITY (TABLE 6-2)

	Diesel Engines	Fugitive Dust
Total PM	7.3%	92.7%
PM-10	17.1%	82.9%

Source: "Challenges in Developing Emission Control Technology for Off-road Construction Vehicles" by Laurence W. Philip, Air and Waste Management Association 82nd Annual Meeting, June 1989

6.3 Minimizing Fugitive Construction Dust Emissions

Many people will claim that contractors already control fugitive dust. While it's true that most water their unpaved areas being worked, it's generally too infrequent and ineffective. Table 6-3 identifies the common construction sources of fugitive dust, along with applicable control techniques. These sources can be grouped into three primary categories, namely, unpaved roads, aggregate storage piles, and excavating and grading operations. These will each be dealt with separately, along with their applicable controls.

Fugitive Dust Emission Sources and Applicable Control Techniques

(Table 6-3)

	Wet Suppression	Stabilization	Speed Reduction	Transport. Controls	Wind Breaks	Good Oper. Practices
Unpaved Roads	X	X	X			
Excavating and Grading	X			X		X
Disturbed Soil Surfaces		X			X	X
Inactive Piles	X	X				
Active Piles	X				X	X

Source: EPA, *Control Techniques for Particulate Emissions from Stationary Sources, Volume I*, Sep 1982

6.3.1 Unpaved Roads

Unpaved roads have been identified as the single largest source of fugitive dust emissions, contributing on the order of 295 tons per year of particulate emissions. (EPA, 1982b) The three primary means of controlling fugitive dust from unpaved roads, as shown in Table 6-3, are wetting the road surface, using stabilization, and reducing operating speeds on the unpaved roads.

Wetting unpaved roads is by far the most common. Wetting twice per day with approximately 2 liters of water per square meter will result in a 30 - 50 percent reduction in fugitive dust. (EPA, 1982a) This is certainly an improvement, but is temporary and requires constant monitoring and attention. To ensure watering is performed on a regular basis, and is applied effectively, the use of a Water Application Log, similar to that shown at Figure 6-1 should be required of the contractor. Better than watering, however, improved effectiveness can be realized by surface stabilization techniques.

Stabilization (including oiling) of unpaved roads typically improves suppression of fugitive dust by at least 50 percent. The use of chemical stabilizers provides longer dust control but may be costly, have adverse effects on plants and animals, or contaminate the treated material. By mixing chemical stabilizers into the top 3 inches of the unpaved road surface, suppression effectiveness can be improved up to 95 percent and last more than 5 months. Gravel over an exposed surface can reduce fugitive dust emissions by an estimated 50 percent. What might be considered the ultimate in stabilization, asphalt paving will give up to 85 percent fugitive dust control effectiveness. The remaining 15 percent is in consideration of fugitive dust from paved roads due to truck spills, street repairs, motor vehicle exhaust and tire wear, vegetation, litter, etc. Choice of treatment for unpaved roads must consider the initial cost of treatment and the annual maintenance costs based on the required life of the road. Paving is initially the most expensive of the stabilization options, and is typically not a viable consideration for a temporary construction road. The initial cost and maintenance cost of alternative road surfaces are shown in Table 6-4. Note that these were 1982 figures for Maricopa County in Arizona. Table 6-5 identifies available chemical stabilizers and their manufacturers. Figure 6-2 is a typical form that may be used to record the application of chemical dust suppressants, similar to the water application log.

WATER APPLICATION LOG

Date	Time	Application intensity (gal/yd^2)	Area(s) treated	Climatic parameters		Equipment used	Operator initials	Comments
				Amb. temp. (°F)	Date/amt. of last rainfall			

Example Water Application Log (Figure 6-1)

Source: *Inspection Manual for PM-10 Emissions from Paved/Unpaved Roads and Storage Piles*, USEPA, Oct 89

Date	Time	Type of chemical	Dilution ratio	Application intensity, gal/yd^2	Area(s) treated	Equipment used	Operator initials	Comments

Example Chemical Dust Suppressant Application Log (Figure 6-2)

Source: *Inspection Manual for PM-10 Emissions from Paved/Unpaved Roads and Storage Piles*, USEPA, Oct 89

INITIAL COST AND MAINTENANCE COST OF ALTERNATIVE ROAD SURFACES APPLIED BY MARICOPA COUNTY HIGHWAY DEPT., ARIZONA (TABLE 6-4)

Road Surface Type	Initial Cost ($/km)	Annual Maintenance ($/km)
Gravel	10,000	378
Oiled (Low Cost Application)	1,260 - 1,890	1,260 - 1,890
Oiled (Dust Control Oil)	3,340	3,340
Chip Seal Coat	22,000	500
7.5 cm Asphalt	34,650 - 63,000	100

Source: *Control Techniques for Particulate Emissions from Stationary Sources, Volume 2*, USEPA, Sep 1982

CHEMICAL STABILIZERS (TABLE 6-5)

A. Type: Bitumens

Product	Manufacturer
AMS 2200, 2300	Arco Mine Sciences
Coherex	Witco Chemical
Docal 1002	Douglas Oil Company
Peneprime	Utah Emulsions
Petro Tac P	Syntech Products Corporation
Resinex	Neyra Industries, Inc.
Retain	Dubois Chemical Company

B. Type: Salts

Product	Manufacturer
Calcium Chloride	Allied Chemical Corporation
Dowflake, Liquid Dow	Dow Chemical
DP-10	Wen-Don Corporation
Dust Ban 8806	Nalco Chemical Company
Dustgard	G.S.L. Minerals and Chemicals Corporation
Sodium Silicate	The PQ Corporation

C. Type: Other

Product	Manufacturer
Acrylic DLR-MS	Rohm and Haas Company
Bio Cat 300-1	Applied Natural Systems, Inc.
CPB-12	Wen-Don Corporation
Curasol AK	American Hoechst Corporation
DCL-40A, 1801, 1803	Calgon Corporation
DC-859, 875	Betz Laboratories, Inc.
Dust Ban	Nalco Chemical Company
Flambinder	Flambeau Paper Company
Lignosite	Georgia Pacific Corporation
Norlig A, 12	Reed Lignin, Inc.
Orzan Series	Crown Zellerbach Corporation
Soil Gard	Walsh Chemical

Source: *Inspection Manual for PM-10 Emissions from Paved/Unpaved Roads and Storage Piles*, USEPA, Oct 89

Speed reduction on unpaved roads is another very effective method of controlling fugitive dust emissions. In addition to being hard to enforce, however, it may also have a large impact on construction operations and schedule, depending on the length of unpaved haul required. Based on an uncontrolled speed of 64 kilometers per hour (approximately 40 miles per hour), reduced vehicle speeds would produce the following estimated fugitive dust reductions from unpaved roads: (EPA, 1982a)

Speed	Reduction
64 kph	0%
48 kph	25%
32 kph	65%
24 kph	80%

As a side comment, paved roads also produce fugitive dust. A portion of this is attributable to spilled materials from trucks. The factors which affect fugitive dust emissions due to spillage are vehicle speed, silt content of the bulk material transported, moisture content of the material, vehicle body configuration, condition of the vehicle, and whether or not the load is covered. Transporting fine materials can be improved by wetting, covering, or enclosing the load. Respective estimated effectiveness for these three methods are poor, fair, and good. (EPA, 1982b)

6.3.2 Aggregate Storage Piles

The emissions of fugitive dust from aggregate storage piles are dependent on the frequency of use of the piles, the method of operating the piles, the sizes of the aggregate, and the moisture content of the pile. Approximately 40 percent of the fugitive emissions from piles are due to equipment and vehicle movement in the storage area, but this can be controlled by methods for unpaved roads. The remaining

60 percent is due to wind erosion and loading onto and from piles. (EPA, 1982b) Methods of controlling dust emissions from storage piles include full or partial enclosures, wet or chemical stabilization, and operating controls.

Fully enclosing materials is the most effective means of reducing emissions from stockpiles because it allows the emissions to be captured. Storage bins or silos used for this purpose, however, are very expensive and impractical for active piles. Small to medium-sized inactive piles may be fully covered with tarps. One alternative to full enclosure is to segregate the material and enclose the fines in silos while placing the heavy material in open storage. Again, this is not typically workable in an active construction storage scenario. Windbreaks or partial enclosure of storage piles (2 or 3 sides) can effectively reduce wind erosion losses although they don't permit capturing the fugitive emissions. The effectiveness of windbreaks typically extends downwind approximately 10 times the height of the windbreak.

Water or chemical treatments are used to agglomerate exposed fine material and prevent wind erosion. These treatments are very effective until the treated surface is disturbed. Continuous watering may work well for active piles, but otherwise, water and chemical surface treatments work best for inactive piles. The water and chemical suppressant logs introduced in Figures 6-1 and 6-2 can be useful for storage piles also.

Operating controls have immediate benefit potential with little or no additional outlay for materials or equipment. Minimizing the dropping distance from the loader bucket to the pile or truck bed will decrease the amount of dust generated. This requires a conscious effort by the equipment operator, but is a feasible operation. Chutes for loading onto a storage pile will minimize dust generated from dump trucks or loaders. Such chutes may require custom fabrication and frequent relocation, so are not likely to be practical for construction uses.

For maximum reduction of storage pile emissions, two actions are recommended. Continuous chemical treatment of material loaded onto piles, coupled with watering or treatment of storage area roadways, can reduce total particulate emissions from aggregate storage operations by up to 90 percent. (EPA, 1985a)

6.3.3 Excavating and Grading Operations

Continual working of exposed soil by excavating and grading operations is the largest obstacle to effective control of fugitive dust emissions by these construction sources. Wetting and stabilizing are the most common control techniques used, reducing emissions by 60 to 70 percent. Repetitive applications will improve control when areas are being worked.

For excavated or graded areas not currently being worked, watering will be effective, but it is temporary. Stabilization is the best control technique for this situation.

Finally, perhaps the most important control technique for grading and excavating is prevention. Good construction management will limit the amount of exposed earth to only those areas being worked on.

6.4 Summary

There are technologies which can reduce engine emissions, but require factory or after-market modifications. Some of these technologies and alternative fuels applications require further developments for use in heavy construction equipment. Operating practices, especially proper and timely maintenance, can ensure lower engine emissions. Good operating practices can also play a role in reducing fugitive dust emissions. While wet suppression of surfaces is certainly the most common and perhaps the most economical technique, it is not the most effective. If carefully applied in a proper and timely manner, however, and especially if used in conjunction with other techniques, wet suppression can provide a reasonable level of control over fugitive dust emissions.

The next chapter will draw upon the techniques mentioned here for specific application to Air Force projects. This will be done by developing contractual clauses for incorporation into Air Force contracts.

CHAPTER SEVEN

PROPOSED CONSTRUCTION CONTRACT CLAUSES

7.0 Introduction

The construction contract between the US Air Force and a selected contractor is essentially an agreement between the two parties that identifies the responsibilities of each party. It typically determines the manner of construction, the quality and timeliness of construction, the method and frequency of payments, and any other stipulations between the parties. The contract documents include the plans and specifications for the work to be done.

Within the construction contract, the government may direct the contractor to conform to certain policies or procedures that are not required for private contracts. For example, the government typically prohibits the purchase of foreign-made items for government use, and disallows the installation of used materials in new work. It is therefore within the authority of the government to place tighter controls on the emissions of air pollutants during a government construction contract. In fact, according to the Code of Federal Regulations,

> It is the policy of the Federal Government to improve and enhance environmental quality. (40 CFR 15.1a, 1992)

Current contract clauses used for Air Force military construction contracts do not adequately cover the air pollution concerns that have been put forth in this paper. The Army Corps of Engineers (COE), as the primary design and construction agent for the Air Force uses many of their own specifications and contract clauses for Air Force projects. Typically, COE specifications include a section on Environmental Protection. (See Appendix A). Unfortunately, much of the emphasis of this section is on corrective rather than preventive action. Yet, two positive aspects are included, namely, that no burning is allowed on site, and that the area of bare soil exposed at any one time by construction operations will be held to a minimum. This section on Environmental Protection also refers to US Army Corps of Engineers EM 385-1-1, *Safety and Health Requirements Manual.* (Oct 87) The only statement regarding anything even close to air pollution in this manual is "Dust controls shall insure safe operation at all times." (COE, 1987)

An additional requirement of the COE specification is that the contractor provide his proposal for implementing the requirements for environmental pollution control. This has the potential for requiring specific methods and techniques from a contractor, yet the only approved proposal analyzed was as vague or more so than the specification. To protect the identity of the contractor, that proposal has not been included in this paper.

Because there are currently no adequate air pollution minimizing clauses in Air Force construction contracts, recommended contract clauses follow. The intention is that each contracting officer, in coordination with the project engineer/manager, will consider these contract clauses and incorporate those that are applicable for minimizing construction-generated air pollution for their particular project.

7.1 Clauses Minimizing Construction Equipment Emissions

> All vehicles and construction equipment brought on-base for use in this project are subject to emission testing by the Government, at the discretion of the Contracting Officer.

All vehicles and construction equipment brought on-base for use in this project must meet or exceed all applicable federal, state, and local emission standards and regulations.

All vehicles and construction equipment brought on-base for use in this project will have as a minimum; functional oil, fuel, and air filters, replaced in accordance with engine manufacturer's instructions.

As evidence to the above, the Contractor shall provide, for each vehicle and piece of construction equipment, full maintenance records covering the previous 24 months. As a minimum, records must include work performed, servicing location, date, and equipment hours or mileage at time of work.

7.2 Clauses Minimizing Fugitive Construction Dust Emissions

The Contractor shall use every method under his control to minimize fugitive dust emissions before they happen. These methods shall include, but not be limited to, watering, chemical stabilization, speed reduction, and good operating practices.

The Contractor shall locate aggregate storage areas with consideration of prevailing winds. For example, use naturally occurring windbreaks as much as possible, and locate piles so that wind will carry dust emissions away from inhabited areas.

The Contractor shall maintain a Water Application Log as set forth in Figure 6-1 of this paper. The log shall be completed on a daily basis and be available for inspection by the Contracting Officer or his designated representative. Said logs shall be turned in to the Contracting Officer upon completion of this project.

As applicable, the Contractor shall use the Chemical Application Log as set forth in Figure 6-2 of this paper. The log shall be completed as chemicals are applied and be available for inspection by the Contracting Officer or his designated representative. Said logs shall be turned in to the Contracting Officer upon completion of this project.

Any chemicals proposed for use in fugitive dust control, shall be approved in writing by the Contracting Officer prior to being applied.

The Contractor shall water unpaved areas subject to vehicle traffic at least twice each day with a minimum of 2 liters of water per square meter.

In lieu of watering, the Contractor may use other means of dust control at no additional cost to the government, and with the approval of the Contracting Officer.

Good operating practices are not optional, and must be practiced by the Contractor. These practices include speed control on unpaved surfaces and reduced dropping height at aggregate storage piles. Vehicle speed is at the Contractor's discretion, but excessive dust emissions from speeding vehicles will result in mandated speeds by the Contracting Officer.

Active aggregate storage piles will be watered on a regular basis to reduce dust from loading and unloading operations. Optional proposals from the Contractor will be considered by the Contracting Officer.

Inactive aggregate storage piles (not used for seven consecutive calendar days) will be covered, chemically treated, or regularly watered to minimize fugitive dust emissions.

7.3 Other Clauses

At the preconstruction conference, along with his proposed construction schedule, the Contractor shall submit an estimate of air pollution emissions during construction, including, but not limited to, fugitive dust emissions, and diesel and gasoline engine emissions. In preparing these estimates, the Contractor shall use the example format in Figure 7-1, and the following documents:

Compilation of Air Pollution Emission Factors: Volume One, Stationary, Point and Area Sources, 4th Edition, USEPA AP-42

Compilation of Air Pollution Emission Factors: Volume Two, Mobile Sources, 4th Edition, USEPA AP-42

Manual Calculation Methods for Air Pollution Inventories, US Air Force Occupational and Environmental Health Laboratory, Report No. 88-070EQ0111EEB

Constr. Phase	Construction Task	Equipment Operating Hrs. Gas	Diesel	Other	Estimate Equip. Emissions Gas	Diesel	Other

Constr. Phase	No. Aggreg. Storage Piles	Estimated Pile Fugitive Dust Emissions	Length Unpaved Roads (LF or KM) Est. Road Emissions

Estimated Emissions Submittal Format (Figure 7-1)

Constr. Phase	Area of Excavating/ Grading	Estimated Excavating and Grading Fugitive Dust Emissions	

Estimated Emissions Submittal Format (Figure 7-1, Continued)

7.4 Administration

Administration of the above contract clauses will require a working knowledge of air pollution by the Contracting Officer and the Inspectors/Quality Assurance Evaluators (QAEs). (See Recommendations in the next chapter). Methods and techniques for inspecting emissions can be gleaned from the referenced EPA documents. Perhaps the most lucrative means of ensuring contractor compliance, however, is by use of a proposal submission clause such as that used in the COE specification. For example:

> Prior to commencement of work the Contractor will submit his proposal for implementing the provisions of this section and other sections of these specifications for air pollution control.

Such a proposal, when done properly and only accepted by the Contracting Officer when it is, provides a useful measuring tool for determining the contractors level of compliance with not just the specifications, but his own proposal based on the specifications.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

8.0 Conclusions

a. The current system of contracting Air Force construction projects barely addresses construction-generated air pollution.

b. Methods are available, some at little or no cost, to minimize construction-generated air pollution.

c. The costs of the effects of air pollution are hard to quantify.

d. Estimating construction emissions and possible reductions is possible.

e. The most readily apparent result of decreased Air Force construction emissions will be at the local level, likely from the reduction in fugitive dust emissions.

f. The regional or global contribution of reduced emissions from Air Force construction projects is likely to be slight and undetectable.

The Air Force seems to be at the forefront of concern for the environment. Few, if any other agencies, public or private, are paying much attention to small pollution generators such as construction.

Of the $3.5 billion the Air Force will spend on construction projects this year, most of it will go towards new construction, as addressed by the scope of this thesis. That amount, though small in comparison to the total annual construction industry spending, represents an amount of air pollution that can be reduced. In fact, the methods of minimizing air pollution contained herein can be applied to the majority of the projects in the construction industry. Hopefully, as was mentioned in the beginning of this paper, the methods and contract clauses set forth here will be used in other types of construction projects and will not remain limited to new facility construction. These methods and techniques for minimizing air pollution during construction should be broadly applicable.

Unfortunately, there is no index to relate construction emissions to project cost - each project is unique and too many variables are involved for a simple metric. Only on a project-by-project basis, can the emissions and emissions reductions be estimated.

Continuing efforts should be made to apply pollution minimization methods into construction and other areas that have been treated as insignificant. Only air pollution has been discussed in this research, but the other types of pollution must be considered as well.

8.1 Recommendations

A number of recommendations have become evident during the development of this research. Although many recommendations could be made, these are felt to be the most important and the most timely for the present and the near future. These recommendations concern both continuing research and applying currently available data and methods to Air Force construction projects.

8.1.1 Further Study

a. Study should be done regarding other forms of construction-generated pollution.

b. The Air Force should investigate fleet conversions to alternative fuels.

The CAAA contain requirements for fleets with 10 or more vehicles to convert 30 percent by 1998. By 2000, 70 percent of these fleets must operate on cleaner fuels. Numerous agencies in Texas, both government and private, operate fleets of alternatively-fueled vehicles. These include the Texas Air Control Board, the General Land Office, Capitol Metro, and Southwestern Bell Telephone. (Bryce, 1993)

8.1.2 Air Force Application

a. Air Force construction inspectors and quality assurance evaluators (QAEs) should be sent for air pollution/environmental training.

b. Inspectors should be issued and become familiar with *Inspection Manual for PM-10 Emissions from Paved/Unpaved Roads and Storage Piles*, USEPA 340/1-89-007.

c. Design engineers should prepare emissions estimates for construction projects.

d. The Air Force should develop a bid system to include a contractor's emissions estimates as a factor in the selection process.

The Air Force Center for Environmental Excellence (AFCEE) at Brooks Air Force Base, Texas or the Air Force Institute of Technology (AFIT) at Wright-Patterson Air Force Base, Ohio, should develop and offer short-courses in pollution recognition and control. These courses would be most desirable for QAEs and inspectors, but could be equally useful for design engineers and contracting officers. Emphasis for QAEs and inspectors should be on identifying and remedying non-compliance by contractors.

Air Force and Corps of Engineers design engineers need to become familiar with the emissions estimating documents, essentially those by the EPA and USAFOEHL. They should consider minimizing emissions during the design of projects, such as keeping haul routes on unpaved roads as short as possible, and locating aggregate storage areas downwind of natural windbreaks.

A bid system could be developed to include a contractor's emissions estimates as a factor in the selection process. A contractor using the emissions estimating format at Figure 7-1 should be required to submit that as a part of his bid. The emissions estimate would then be factored in with the contractors bid price to determine the overall low bid. A low bid price with a high emissions estimate is not necessarily in the best interest of the Air Force. The 1993 DoD estimate of $1.3 billion for environmental cleanup (Engineer, 1992a) is a very expensive lesson teaching pollution prevention.

APPENDIX A

<u>Corps of Engineers Specifications, Section 01510, Environmental Protection</u>

1.01 SCOPE

The work covered by this section consists of furnishing all labor, materials and equipment and performing all work required for the prevention of environmental pollution during and as the result of construction operations under this contract except for those measures set forth in other Technical Provisions of these specifications. For the purpose of this specification environmental pollution is defined as the presence of chemical, physical, or biological elements or agents which adversely affect human health or welfare; unfavorably alter ecological balances of importance to human life; affect other species of importance to man; or degrade the utility of the environment for aesthetic and recreational purposes. The control of environmental pollution requires consideration of air, water and land, and involves noise, solid waste-management and management of radiant energy and radioactive materials, as well as other pollutants.

1.02 APPLICABLE REGULATIONS

In order to prevent, and to provide for abatement and control of, any environmental pollution arising from the construction activities of the Contractor and his subcontractors in the performance of this contract, they shall comply with all applicable Federal, State, and local laws, and regulations concerning environmental pollution control and abatement, and all applicable provisions of the Corps of Engineers EM 385-1-1, entitled "Safety and Health Requirements Manual" as well as the specific requirements stated in this section and elsewhere in the contract specifications.

1.03 NOTIFICATION

The Contracting Officer will notify the Contractor in writing of any observed non-compliance with the foregoing provisions, the Contractor shall, after receipt of such notice, immediately take corrective action. Such notice, when delivered to the Contractor or his authorized representative at the site of the work, shall be deemed sufficient for the purpose. If the Contractor fails or refuses to promptly take corrective action, the Contracting Officer may issue an order stopping all or part of the work until satisfactory corrective action has been taken. No part of the time lost due to any such stop orders shall be made the subject of a claim for extension of time or for excess costs or damages by the Contractor unless it was later determined that the Contractor was in compliance.

1.04 SUBCONTRACTORS

Compliance with the provisions of this section by subcontractors will be the responsibility of the Contractor.

1.05 IMPLEMENTATION

Prior to commencement of the work the Contractor will:

1. Submit in writing his proposals for implementing the provisions of this section and other sections of these specifications for environmental pollution control;

2. Meet with representatives of the Contracting Officer to develop mutual understandings relative to compliance with these provisions and administration of the environmental pollution control program.

1.06 PROTECTION OF LAND RESOURCES

A. General: The land resources within the property of the Government but outside the limits of permanent work performed under this contract shall be preserved in their present condition or be restored to a condition after completion of construction that will appear to be natural and not detract from the appearance of the project. Insofar as possible, the Contractor shall confine his construction activities to areas defined by the plans or specifications, to areas to be cleared for other operations, or to quarry, borrow or waste areas indicated on the plans. At the onset of borrow excavation, topsoil shall be saved for use in restoring the borrow area. Waste and borrow areas shall be leveled or trimmed to regular lines and shaped to provide a neat appearance. In all instances the restored area shall be well drained, so as to prevent the accumulation of stagnant water. The following additional requirements are intended to supplement and clarify the requirements of Contract Clauses entitled Protection of Existing Vegetation, Structures, Equipment, Utilities, and Improvements; Operations and Storage Areas; and Cleaning Up.

B. Prevention of Landscape Defacement: Except in areas shown on the plans or specified to be cleared, the Contractor shall not deface, injure, or destroy trees or shrubs, nor remove or cut them without special authority from the Contracting Officer. Trees designated to be saved shall be protected from either excavation or filling within the root zone closer than the normal drip line of the tree. No ropes, cables, or guys shall be fastened to or attached to any existing trees for anchorage unless specifically authorized by the Contracting Officer. Where such special emergency use is permitted, the Contractor shall first adequately wrap the trunk with a sufficient thickness of burlap or rags over which softwood cleats shall be tied before any rope, cable, or wire is placed. The Contractor shall in any event be responsible for any damage resulting from such use. Where, in the opinion of the Contracting Officer, trees may possibly be defaced, bruised, injured, or otherwise damaged by the Contractor's equipment or by his blasting, dumping, or other operations, he may direct the Contractor to protect adequately such trees by placing boards, planks, or poles around them. When earthwork operations are liable, in the opinion of the Contracting Officer, to cause rock to roll or otherwise be displaced into uncleared areas, the Contractor shall construct barriers to protect the trees. Rocks that are displaced into uncleared areas shall be removed. Monuments, markers, and works of art shall be protected similarly before beginning operations near them.

C. Restoration of Landscape Damage: Any trees or other landscape feature scarred or damaged by the Contractor's equipment or operations shall be restored as nearly as possible to its original condition at the Contractor's expense. The Contracting Officer will decide what method of restoration shall be used, and whether damaged trees shall be treated or removed and disposed of under requirements for clearing and grubbing. All scars made on trees (not designated on the plans to be removed) by equipment, construction operations, or by the removal of limbs larger than 1-inch in diameter shall be coated as soon as possible with an approved tree wound dressing. All trimming or pruning shall be performed in an approved manner by experienced workmen with saws or pruning shears. Tree trimming with axes will not be permitted. Where tree climbing is necessary, the use of climbing spurs will not be permitted. The use of climbing ropes will be required by the Contracting Officer where deemed necessary for safety. Trees that are subsequently damaged by the Contractor and are beyond saving in the opinion of the Contracting Officer, shall be immediately removed and replaced with a nursery-grown tree of the same species and size approved by the Contracting Officer.

D. Location of Temporary Field Offices, Storage, and Other Construction Buildings: The location on Government property of the Contractor's temporary field office, storage, and other construction buildings, required temporarily in the performance of the work, shall be upon cleared portions of the job site or areas to be cleared, and shall require written approval of the Contracting Officer. The preservation of the landscape shall be an imperative consideration in the selection of all sites and in the construction of buildings. Plans showing temporary field office, storage, and other construction buildings shall be submitted for approval of the Contracting Officer. Where buildings or tent platforms are constructed on sidehills, the Contracting Officer may require cribbing to be used to obtain level foundations. Benching or leveling of earth may not be allowed, depending on the location of the proposed facility.

E. Temporary Excavation and Embankments: If the Contractor proposes to construct temporary roads or embankments and excavations for plant and/or work areas, he shall submit the following for approval at least thirty (30) days prior to scheduled start of such temporary work.

1. A layout of all temporary roads, excavations, and embankments to be constructed within the work area.

2. Details of road construction.

3. Details of the completed quarry or borrow excavation.

4. Plans and cross sections of proposed embankments and their foundations, including a description of proposed materials.

5. A landscaping plan prepared by a competent landscape architect showing the proposed restoration of the area. Removal of any necessary trees and shrubs outside the limits of required clearing or quarry, borrow, or waste areas shall be indicated. The plan shall also indicate location of required guard posts or barriers required to control vehicular traffic passing close to trees and shrubs to be maintained undamaged. The plan shall provide for the obliteration of construction scars as such and shall provide for a reasonably natural appearing final condition of the area. Modification of the Contractor's plans shall be made only with the written of the

Contracting Officer. No unauthorized road construction, excavation or embankment construction (including disposal areas) will be permitted.

F. Post-Construction Clean Up or Obliteration: The Contractor shall obliterate all signs of temporary construction facilities such as haul roads, work areas, structures, foundations of temporary structures, stockpiles of excess or waste materials, or any other vestiges of construction, as directed by the Contracting Officer. It is anticipated that excavation filling, and plowing of roadways will be required to restore the area to near natural conditions which will permit the growth of vegetation thereon, the disturbed areas shall be graded and filled as required, sufficient topsoil shall be spread to provide a minimum depth of 4 inches of suitable soil for the growth of grass, and the entire area seeded. Restoration to original contours is not required.

1.07 PROTECTION OF HISTORICAL AND ARCHEOLOGICAL RESOURCES

A. Preservation of Existing Historical, Archeological, and Cultural Resources: Any known existing historical, archeological and cultural resources within the Contractor's work area are designated on the contract drawings. The Contractor shall take precautions during this contract to preserve all resources as they existed at the time of contract award. The Contractor shall install all protective devices such as off limits markings, fencing, barricades or other devices as designated on the contract drawings and shall be responsible for preservation of the sites during this contract.

B. Recording and Preserving Historical and Archeological Finds: All items having any apparent historical or archeological interest outside of designated areas which are discovered in the course of any construction activities shall be carefully preserved. The Contractor shall leave the archeological find undisturbed and shall flag an area of 50 feet radius around the find, and shall immediately report the find to the Contracting Officer so that the proper authorities may be notified. Any work required to preserve or protect these finds will be accomplished by change order under the clause entitled Change of the Contract Clauses.

1.08 PROTECTION OF WATER RESOURCES

A. General: The Contractor shall not pollute streams, lakes, or reservoirs with fuels, oils, bitumens, calcium chloride, acids, construction wastes, or other harmful materials. It is the responsibility of the Contractor to investigate and comply with all applicable Federal, State, County, and Municipal laws concerning pollution of rivers and streams. All work under this contract shall be performed in such a manner that objectionable conditions will not be created in lakes, reservoirs, or streams through or adjacent to the project areas.

B. Erosion Control: Prior to start of construction the Contractor shall submit a plan for approval of the Contracting Officer showing his scheme for controlling erosion and disposing of wastes. Surface drainage from cuts and fills within the construction limits, whether or not completed, and from borrow and waste disposal areas, shall, if turbidity producing materials are present, be held in suitable sedimentation ponds, or the areas shall be graded to control erosion within acceptable limits. Temporary erosion and sediment control measures such as berms, dikes, drains, or sedimentation basins, if required to meet the above standards, shall be provided and maintained until permanent drainage and erosion control facilities are completed and operative. The area of bare soil exposed at any one time by construction operations shall be held to a minimum. Unless otherwise approved by the Contracting Officer, the Contractor shall apply as soon as practicable an approved temporary mulch on denuded ground. This shall apply to all areas not subject to appreciable traffic during construction, including areas that are to receive some form of construction later, if ground is to be exposed 60 days or more. Stream crossings by fording with equipment shall be limited to control turbidity and in areas of frequent crossings temporary culverts or bridge structures shall be installed. Any temporary culverts or bridge structures shall be removed upon completion of the project. Fills and waste areas shall be constructed by selective placement to eliminate to the extent practicable silts or clays on the surface that will erode and contaminate adjacent streams or lakes.

C. Spillage: Special measures shall be taken to prevent chemicals, fuels, oils, greases, bituminous materials, waste washings, herbicides and insecticides, and cement from entering streams, rivers, or lakes.

D. Disposal: Disposal of any materials, wastes, effluents, trash, garbage, oil, grease, chemicals, etc., in areas adjacent to streams shall be subject to the approval of the Contracting Officer. If any waste material is dumped in unauthorized areas the Contractor shall remove the material and restore the area to the condition of the adjacent undisturbed area. If necessary, contaminated ground shall be excavated, disposed of as directed by the Contracting Officer, and replaced with suitable fill material, compacted and finished with topsoil all at the expense of the Contractor.

1.09 PROTECTION OF FISH AND WILDLIFE

The Contractor shall at all times perform all work and take such steps required to prevent any interference or disturbance to fish and wildlife. The Contractor will not be permitted to alter water flows or otherwise disturb native habitat adjacent to the project area which, in the opinion of the Contracting Officer, are critical to fish or wildlife. Fouling or polluting of water will not be permitted. Wash waters and wastes shall be processed, filtered, ponded, or otherwise treated prior to their release into a river or other body of water.

1.10 JANITOR SERVICES

The Contractor shall furnish daily janitorial services for the temporary field office, storage, and other construction buildings on the project site and perform any required maintenance of facilities and grounds as deemed necessary by the Contracting Officer during the entire life of the contract. Toilet facilities shall be kept clean and sanitary at all times. Services shall be performed at such a time and in such a manner to least interfere with the operations but will be accomplished only when the buildings are occupied. Services shall be accomplished to the satisfaction of the Contracting Officer. The Contractor shall also provide daily trash collection and clean up of the buildings and adjacent outside areas, snow removal in season, and shall dispose of all discarded debris, aggregate samples and concrete test samples in a manner approved by the Contracting Officer.

1.11 BURNING

No material shall be burned at the project site unless otherwise specified in other sections of these specifications or authorized by the Contracting Officer.

1.12 DUST CONTROL

The Contractor will be required to maintain all excavations, embankments, stockpiles, haul roads, permanent access roads, plant sites, waste areas, borrow areas, and all other work areas within or without the project boundaries free from dust which would cause a hazard or nuisance to others.

1.13 MAINTENANCE OF POLLUTION CONTROL FACILITIES DURING CONSTRUCTION

During the life of this contract the Contractor shall maintain all facilities constructed for pollution control under this contract as long as the operations creating the particular pollutant are being carried out or until the material concerned has become stabilized to the extent that pollution is no longer being created. During the construction period the Contractor shall conduct frequent training courses for his maintenance personnel. The curricula shall include methods of detection of pollution, familiarity with pollution standards, and installation and care of vegetation covers, plants, and other facilities to prevent and correct environmental pollution.

1.14 PESTICIDES

Application of all pesticides (herbicides, insecticides, fungicides, etc.) shall be accomplished by certified pest control personnel or under the supervision of a certified pest control operator. Delivery and storage of pesticides will be monitored by certified personnel to insure the adequacy of containers and the safe storage of toxic materials. Disposal of containers and chemicals will be monitored to prevent pollution of natural drainage systems.

END OF SECTION

APPENDIX B

Volatile Organic Compounds (VOCs) in Construction Coatings

When any liquid coating is applied to a surface, it dries to a solid. Some components of that coating - pigments, resins, extenders, and driers - remain in the film that adheres to the substrate. The remaining components are solvents, or VOCs, that are emitted into the air upon drying. These compounds include such common solvents as toluene, benzene, xylene, methulene, chloride, and 1,1,1 trichloroethane. Exempt VOCs which are not subject to regulation include ammonium carbonate, carbonates, carbonic acid, carbon dioxide, and metallic carbides.

A typical project contributes considerable amounts of spent solvents being released into the atmosphere. The VOC portion contained in a single gallon of conventional lacquer, for example, would be approximately six pounds per gallon (lb/gal). (Whitesell, 1989) This means that every time a gallon of lacquer is applied to a surface, six pounds of VOCs evaporate into the air to contribute to air pollution. The pollution from VOCs is in the form of ozone or smog.

The EPA and individual states and localities have enacted legislation to limit the amount of VOCs in individual coatings. There are three basic ways to develop coatings with lower VOC levels. The solids can be increased while reducing the solvent levels, a water-based coating system can be used, or solvents can be replaced with carbon dioxide

Increasing the product solid volume while lowering the solvent levels can cause problems with the resulting coating. The nature of the coating and its properties can be negatively affected - especially application properties, appearances, drying and curing. (Whitesell, 1989)

Water-based coatings are an effective choice because product integrity and performance can be maintained and good results ensured. As a group, the water-based coatings tend to have VOC contents well below 2 lb/gal, and some are even below 1 lb/gal. (Joseph, 1991) With water-based coatings, many products have proven to be as good or better than their solvent-based counterparts. VOC-compliant acrylic enamels, for example, can replace the noncompliant solvent-based alkyd enamels and provide a higher gloss finish. They also provide better color and gloss retention.

Supercritical carbon dioxide (CO_2) has been proposed as a replacement for up to 80 percent of the solvents in conventionally-formulated coatings. (White, 1991) The critical temperature of CO_2 (88°F) is easily obtained, as is the critical pressure of CO_2 (1070 psi). This pressure is well within the range of existing airless paint sprayers. CO_2 is nonflammable and mostly inert, and is readily available in large or small quantities.

It is, then, possible to reduce the VOCs generated during construction, simply by focusing attention on the coatings used in projects. VOCs, of course, are generated in many other ways, and each of these should be considered.

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