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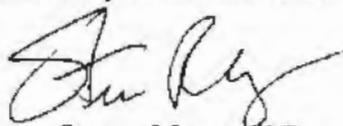
A Commitment to Kentucky's Sustainable Environment

The urban environment poses a unique set of problems and issues from an air quality perspective. Urban areas are both the source of large concentrations of air pollution (mobile, area and point sources), and contain population densities whose universal exposure to ambient air pose health risks.

Louisville is a typical metropolitan area, with a population of approximately 1 million. Air pollution has been, and remains, a serious threat to public health. Although it currently meets all federal air quality standards, Louisville will not be able to protect public health by meeting the proposed 8-hour ozone and PM_{2.5} particulate standards being adopted by the U.S. Environmental Protection Agency (EPA). In 2001, EPA ranked Louisville as the city having the highest health risk from air pollution in the southeast (Region 4). Concern about the health impacts from air pollution in Louisville date back to the early 1950's and was one of 10 urban areas studied by the U.S. Department of Public Health in 1956-7.

The issue of the health impacts of fine particulates is discussed in Dr. Joel Schwartz's article "Dust Kills." The article is a summary of a presentation given by Dr. Schwartz for KIESD in 1998. Dr. Schwartz was instrumental in conducting research that led the U.S. EPA in 1997 to amend the air standards to focus on the finer (<2.5 microns) particulates. He currently is a professor of epidemiology at the Harvard School of Public Health. The director of the Jefferson County (Louisville) Air Pollution Control District, Art Williams, and a staff member, Barry Zalph, provide a prospectus on air pollution control in Louisville. Concern today focuses on particulates 1/40th the diameter of the human hair, but it was not long ago that particulates in Louisville were measured in buckets. The U.S. in the past year refused to sign the Kyoto treaty to limit greenhouse depleting gases fearing that it would harm the nation's competitive economic advantage. Kentucky has the highest level of industrial emissions of ozone-depleting chemicals in the nation, and Jefferson County is the source of half of those emissions. The U.S. May 2002 report to the United Nations, "U.S. Climate Action Report 2002", is the Bush Administration's position and concludes that global warming is occurring. Although we sometimes associate this phenomena as "new", a 1958 news article reporting on a seminar at the University of Louisville predicts that global warming will occur as we release carbon dioxide in the atmosphere. Dr. Harrell Hurst with the University of Louisville School of Medicine discusses the health effects of many of the hazardous air pollutants being released in Louisville. His article focuses on the west Louisville area where air monitoring is being conducted by the University. Although hazardous air pollutants are most commonly associated with industrial activity, the majority of hazardous air pollutants are released by mobile sources—cars, trucks, etc. Dr. Paul Lederer, a Research Professor in the Speed Scientific School, examines the issue of hazardous air pollutants from mobile sources and some of the existing control methods for these pollutants.

The next issue of Sustain, scheduled for the fall/winter of 2003, will focus on brownfield redevelopment. The Institute welcomes any comments that you have about the journal. Please direct any comments to Dr. Allan Dittmer, School of Education, UofL, Louisville, KY 40292.



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The Kentucky Institute for the Environment and Sustainable Development (KIESD) was created in July 1992 within the Office of the Vice President for Research, University of Louisville. The Institute provides a forum to conduct interdisciplinary research, applied scholarly analysis, public service and educational outreach on environmental and sustainable development issues at the local, state, national and international levels.

KIESD is comprised of eight thematic program centers: Environmental Education, Watershed Research, Environmental Law, Sustainable Urban Neighborhoods, Pollution Prevention, Environmental and Occupational Health Sciences, Environmental Policy and Management, and Environmental Engineering.

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Dust Kills (Small Dust Kills Quicker) 3
by Dr. Joel Schwartz

Air Quality in Louisville: Past, Present, and Future 6
by Barry Zalph and Art Williams

Air Pollution May Melt Polar Caps 20
Source: Louisville Times, November 18, 1958

Chemical Air Pollutants in Jefferson County, KY; 21
Potential Health Effects
Source: Dr. Harrell E. Hurst

Mobile Emissions in Urban Areas: Current Trends 33
and The Outlook for Existing Control Methods
by Dr. Paul R. Lederer

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dare to be great

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Dust Kills

(Small Dust Kills Quicker)

**Dr. Joel Schwartz,
Associate Professor of Environmental Epidemiology
Harvard School of Public Health**

This paper is a summary of a seminar presentation by Dr. Joel Schwartz, Associate Professor of Environmental Epidemiology at the Harvard School of Public Health, given at the University of Louisville for the Kentucky Institute for the Environment and Sustainable Development on December 9, 1998.

Air pollution is a far more menacing health issue than most people believe. Of particular concern is urban air pollution since the concentrations of finer particles are not only greater because of the combustion of fossil fuels, there are also more people there to breathe them in. Contrary to common wisdom, air pollution doesn't just clog your furnace air filters, or spread a thin layer of dust on your car in the parking lot. The very tiny particles in most forms of urban air pollution are impacting public health, but not in the way we have believed for so long. One dramatic example of air pollution and health effects occurred December 4, 1952 in the city of London which experienced a protracted number of continuous days of heavy fog. The Great London Smog lasted for five days and led to around four thousand more deaths than usual. The deaths were attributed to the dramatic increase in air pollution during the period, with levels of sulfur dioxide increasing 7-fold, and levels of smoke increasing 3-fold. The peak in the number of deaths coincided with the peak in both smoke and sulfur dioxide pollution levels. This event established a link between high levels of airborne particles, sulfur dioxide, and increases in daily death rates. As this event was more carefully studied and compared to similar data in major large cities in the United States, it became clear that the high mortality rates were due to particles in the air, not the concentrations of sulfur dioxide.

So why do human defenses fail against air pollution generally, and very small particles in particular? The human lung is basically a

large porous sack filled with thousands of small sacks interlaced with blood vessels. As one goes deeper into the lungs and to the outer periphery, the regions known as the alveolar, the structures become smaller and finer, so that the air we breathe can be more efficiently transferred as oxygen to the blood stream. In other words, the lungs are the filters for the air we breathe.

As we breathe in air, the larger particles suspended in it are caught by the mucus in the nose and upper bronchial tubes, however the smaller particles bypass these structures and move into the deeper, finer structures of the lungs and are subsequently deposited in the blood stream where they now move through the vascular system.

Since 1970 (a mere thirty years ago) air pollution regulations focused on large dust particles. Known as the PM_{10} standard (airborne dust 10 microns or larger in diameter), these regulations have only recently been modified to include the much smaller particles known as the $PM_{2.5}$ standard (particles 2.5 microns in diameter). Incidentally, the City of Louisville does not meet the more recent stringent $PM_{2.5}$ standards proposed by the Environmental Protection Agency (EPA).

A study in Philadelphia confirmed that on high air pollution days, risks were higher, especially among the elderly, for pneumonia and cardiovascular disease. This led Joel Schwartz to look more closely at data from Cincinnati, Ohio between the years 1977 to 1982. The data contained both the total suspended particulate (TSP) concentrations and the daily

City	Percent Increase	City	Percent Increase
Amsterdam	8 (-1-16)		
Athens	8 (6-10)	Minneapolis	9 (4-15)
Birmingham A	11 (2-20)	Philadelphia	12 (7-17)
Chicago	8 (1-10)	Provo	15 (9-23)
Cincinnati	10 (5-17)	Santiago	11 (8-15)
Detroit	12 (5-16)	Santa Clara	8 (2-16)
Erfurt	12 (4-17)	Steubenville	8 (4-10)
Kingston	16 (-12-57)	St Louis	16 (1-34)
Los Angeles	5 (0-10)	Sao Paolo	14 (7-21)

Percent Increase in Deaths for a 100 microgram/m³ Increase in PM_{10}



How the human body is adapted to remove larger dust particles

counts of non-accidental deaths, temperatures, and dew points. Schwartz sought to replicate the Cincinnati analysis but delete the factor of daily temperature extremes in order to establish the primary causes of increased deaths and to compare this data with the Philadelphia study. Schwartz found that the patterns established in the Philadelphia study were strikingly similar to those he found in Cincinnati, i.e., that the total suspended particulate (TSP) concentrations and age-specific daily deaths in the two cities were remarkably similar. In other words, dust particles in the air (ambient environment) have an effect on daily death rates. In the conclusion of this study, Schwartz states...

“Although the mechanism by which airborne particles exacerbate illnesses and increase their mortality rates is not understood, neither is the mechanism by which tobacco smoking increases the risk of death from myocardial infarctions. This fact has not prevented a conclusion being drawn from the strong epidemiologic information in the case of smoking and it should not impede a similar conclusion in the case of respirable particles. Moreover, the London episode of 1952 provides ample demonstration of biological plausibility, it is clear that respirable particles increased mortality in that episode, although no mechanism was determined for that case either.” (p. 189)

In conjunction with two other colleagues at the Harvard School of Public Health, Joel Schwartz continued his research into dust in the air by comparing the data from the Cincinnati and Philadelphia study with data collected in 1974 in the Harvard Six Cities study. The Harvard Six Cities study looked at respiratory symptoms and pulmonary function among adults and elementary school children in Watertown, Massachusetts; Kingston and Harriman, Tennessee; St. Louis, Missouri; Steubenville, Ohio; Portage, Wisconsin; and Topeka, Kansas. In 1979 air pollution monitoring stations were placed in each of these cities in a central location to collect ambient air samples every day for a 24 hour period, or every other day for the same period. These constant samples were collected for almost 10 years. For a two-year period be-

tween 1983 to 1984, the samples were analyzed for particle size in order to determine if particle size played any role in daily deaths.

Schwartz and his colleagues had four goals in their research, the first of which was to extend the findings from the previous six eastern cities study as well as an earlier study of St. Louis, Missouri and Harriman, Tennessee to four additional cities. Second, they sought to confirm the association between daily variations in airborne particles (PM_{10}) and daily variations in deaths in these six locations, with the intention of determining whether air pollution and the resulting deaths were specifically caused by fine particles. Third, they tried to see if there was a link between sulfate acidity and the fine particles and, finally, they tried to determine whether the health risks were elevated for specific causes of death or for the elderly.

In addition to measuring coarse and fine air particles, sulfates and acidity, they also collected daily weather information such as temperature, dew point, and precipitation. The daily mortality data was collected from the county in which the air monitoring equipment was located and included the date of the death, the county in which it occurred, the age and sex of the person, and the cause of death. Additional data was collected on those deaths of persons 65 and over on deaths caused by ischemic heart disease.

Of the six cities studied, all except Topeka, Kansas had air particles in the fine range ($PM_{2.5}$). As the authors state, “The principle analysis of this paper was to compare different size ranges of PM_{10} to see whether the association was specifically with the fine mass particles.” (p.931) As suspected, $PM_{2.5}$ was associated with daily deaths. By statistically isolating numerous variables, Schwartz and his colleagues found that weather and sulfate acidity were not as significant in death rate correlations as was fine particle size. One surprising finding was that the relative risk for persons 65 and older was only slightly larger than for deaths of all ages, and the risk of dying from ischemic heart disease, primarily heart attack, was greater than all other causes of death, with chronic obstructive pulmonary disease and pneumonia running second, ahead of all other causes. Based on these findings, Schwartz and his colleagues concluded that

“Day-to-day changes in airborne particle concentrations were consistently associated with increased risk of death in six eastern U.S. metropolitan areas. The estimated effect was similar in magnitude to that seen in other U.S. cities. The particle associations were specifically with fine particle mass concentrations, with little additional

contribution from the coarse particle mass fraction.” (p.934)

Studies using animals have shown similar results. Rats exposed to urban air pollution with high PM_{10} concentrations experienced more heart disease mortality than rats in cleaner rural environments. In a study by Dreher (1966), rats were exposed to urban air from Washington, D.C. The toxicity was shown to be substantially eliminated if the particles were first washed to remove surface transition metals. And similar toxic effects were noted if transition metals were instilled in lungs in solution instead of on fine particles. Other studies have shown what occurs in animals with induced respiratory illnesses, specifically healthy rats and dogs did not have elevated death rates whereas animals who already were ill, experienced elevated death rates.

One form of toxicity associated with air pollution in the pulmonary system is the release of cytokines, cell tissue enzymes, some of which are specifically associated with hardening of the arteries and blood clots in the heart which lead to arrhythmia and death. These research findings tend to point to a stronger link between heart disease and fine particles in polluted air than to respiratory problems, a mildly counterintuitive conclusion.

Hence, while much remains to be learned, toxicologic evidence is beginning to accumulate supporting the role of fine particles in inflammatory lung damage and other reactions that may increase the risk of hospitalization or death for sensitive individuals, such as those with chronic lung disease. (p.936)

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Schwartz J., Nonparametric Smoothing in the Analysis of Air Pollution and Respiratory Illness. *Canadian J Stat*, 1994, 22:471-87

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The biographical sketch and a synthesis of the research of Joel Schwartz was written by Allan Dittmer, Editor, Sustain.

About the Author:

Among his many accomplishments, Joel Schwartz is credited with the research that led the Environmental Protection Agency in 1997 to tighten the regulations on the size of allowable microscopic particles from 10 microns in diameter to 2.5 microns or less, a change that has yet to be completely implemented. His doctorate is in theoretical solid-state physics and mathematics. He assumed a policy position as an energy economist with the Environmental Protection Agency. It was during this stint in Washington that he influenced the decision to eliminate lead in gasoline even as then President Regan and petroleum industry lobbyists were trying to halt the regulations. Schwartz received a prestigious MacArthur award in 1991. The \$250,000 cash bonus that goes to MacArthur award recipients allowed Schwartz to detach himself from the intense negative political pressure that surrounded him and his research while a federal agency employee, and assume a full-time position at the Harvard School of Public Health where he continues his research to this day.



Air Quality in Louisville: Past, Present, and Future

**Barry Zalph and Art Williams,
Air Pollution Control
District of Jefferson County**

Abstract

Air quality in metropolitan Louisville, Kentucky has improved dramatically over the past thirty years. Upon achievement of compliance with federal standards for carbon monoxide (CO) in 1990 and for ozone (O₃) in 2001, the metropolitan area now meets all current National Ambient Air Quality Standards (NAAQS). Growing knowledge of the health risks posed by air pollutants has led the US Environmental Protection Agency (EPA) to issue stricter standards for O₃ and fine particulate matter, however. These standards will likely take effect by 2004. EPA will likely also tighten standards for hazardous air pollutants (HAPs), organic chemicals that increase risks for cancer, birth defects, or other serious illnesses. The region will need continuing improvements in air quality to meet these new standards. This paper presents a historical overview of air quality in metropolitan Louisville, anticipated challenges over the next several years, and promising methods for meeting these challenges.

Air Quality in Louisville: A Historical Summary

Pre-Industrial Conditions

Various activities have introduced harmful substances into the air throughout history. The use of fire for cooking, heating, or to control plants or animals, releases carbon monoxide (CO), particulates, volatile organic compounds (VOCs), and nitrogen oxides (NO_x). Ground-disturbing activities such as agricultural tilling, clearing paths or roads, and building structures result in airborne dust. Natural events such as volcanic eruptions, wildfires, lightning, and windstorms also contribute large quantities of pollutants. Several pollutants can remain in the atmosphere long after their emission and travel far from points of origin. Particulates from forest fires and volcanoes thousands of miles away probably affected air quality in the

Ohio River valley many times before anthropogenic pollutants significantly altered air chemistry. Evidence suggests, though, that pre-industrial air would have met modern air quality standards readily except during episodes involving fires, volcanic eruptions, or dust storms.

The Era of Coal

Emissions from coal-fired residential furnaces, industrial boilers, and steam locomotives caused enormous atmospheric particulate loads, which in turn blanketed Louisville and other industrialized cities with thick haze. In the late 1940s, the Louisville Smoke Commission (predecessor of the Air Pollution Control District) monitored atmospheric particulates by suspending buckets on lampposts and weighing the collected soot. Coal- and wood-burning also resulted in high levels of invisible but harmful pollutants, including carbon monoxide (CO), nitrogen dioxide (NO₂), and sulfur dioxide (SO₂).



A balloon was used to monitor air quality in the 1950's

The Dawn of Air Quality Regulations

"Killer fogs" that enveloped Meuse Valley, Belgium in 1930 (killing 60 and causing thousands of illnesses), Donora, Pennsylvania in 1948 (killing 21 and sickening over 6000), and London, England in 1952 (killing 4000) brought to public awareness the potential deadliness of air pollution. In each of these instances, industrial pollutants trapped by a thermal inversion during a period of stagnant winds resulted in acutely toxic air and near-zero visibility. A combination of SO₂ and fine particulates most likely caused the deaths and illnesses. In the wake of these tragedies, many governments enacted air quality standards.

From January 1956 through May 1957, the Special Air Pollution Study of Louisville and Jefferson County, Kentucky gathered data that greatly expanded the understanding of the quantity, composition, and sources of air pollutants in western Jefferson County. According to the study's report, "It didn't require a catastrophe like the Donora, Pennsylvania smog of 1948 to make the people of Louisville and Jefferson County aware that something should be done about air pollution. There were no overwhelming incidents, but the citizens were conscious of the ever-increasing burden of fumes, odors, and dusts that were in the air."

Despite this nod to Donora, the study focused on the nuisance aspects of air pollution: dust settling on clothing, windows, etc., eye and lung irritation (presumed to have no lasting consequences), unpleasant odors, and haze. The health effects of extended exposure to pollutants at well below their acutely toxic levels had not gained scientific or public recognition. Although the toxicity of CO was well established, the study explicitly ignored it as a pollutant, presumably because it has no odor or opacity and causes no tissue irritation. Because of differences in measurement methods between this study and modern EPA standard methods, one cannot precisely correlate the study's results with more recent measurements. The study's results suggest, however, that Louisville in 1956-1957 significantly exceeded modern standards for particulates and SO₂. High reported levels of NO₂ and VOCs (the principal precursors to the formation of ground-level O₃) indicate a strong possibility of high peak O₃ concentrations as well.

The Special Air Pollution Study concluded with recommendations for improving the region's air quality. The authors called for control of the most egregious sources of airborne particulates from combustion and industrial processes, control of SO₂ by using coal of lower sulfur content, emission limits on industrial odorant gases, and installation of



An early air monitoring site in Louisville.

vapor control devices to reduce evaporation of fuels. These recommendations aimed to curtail the palpable inconveniences of air pollutants rather than to mitigate their long-term health effects.

From 1959 through the 1960s, the Air Pollution Control District of Jefferson County (APCD) enforced a relatively simple set of regulations that essentially embodied the recommendations of the Special Air Pollution Study. These regulations dealt largely with the proper construction and operation of industrial boilers and other combustion equipment. The regulations capped dust or fly ash emissions from industrial stacks at 850 ppm (by weight of flue gas), or at 400 ppm for steam plants with capacities above 200,000 pounds of steam per hour. For industrial process dust, the rules limited effluents to 850 ppm (by weight) of dust above 10 micrometers in particle size, with no more than 200 ppm constituting particles larger than about 45 micrometers (number 325 mesh). Vehicular and industrial stack emissions of smoke were regulated according to opacity, estimated visually. The regulations called for vapor suppression or vapor recovery devices to reduce evaporative hydrocarbon emissions from fuel and petroleum distillate tanks with capacities of over 40,000 gallons. The regulations did not require any monitoring or control of gaseous pollutants such as SO₂, NO₂, or CO.

The Darkest Hour (circa 1970)

Despite pioneering air quality regulations such as these, air pollution probably increased in much of the United States during the 1950s and 1960s. (The absence of comprehensive air monitoring data prior to 1972 prevents precise compari-

sons.) Population growth, rapid industrial growth, increasing household electricity use, and steeply growing automotive travel led to increasing emissions of pollutants.

The 1962 publication of *Silent Spring* by Rachel Carson ushered in the modern era of concern for the environment. In addition to building support for the creation in 1970 of the US Environmental Protection Agency (EPA), Carson's book convinced the public that odorless, invisible contaminants could cause disease and death in humans, other animals, and plants. Effective environmental protection would require control of substances present at or below the thresholds of human smell, vision, taste, and touch.

The federal Clean Air Act Amendments of 1970 required the EPA to establish National Ambient Air Quality Standards (NAAQS). EPA identified and set criteria for six air pollutants: sulfur oxides (SO_x), nitrogen oxides (NO_x), CO, total suspended particulate matter, hydrocarbons, and photochemical oxidants. These standards marked a major departure in regulatory policy in that they required measurement of ambient concentrations of pollutants in addition to measurement of emissions from large stationary sources. Further, they dealt almost entirely with substances not previously monitored routinely by industry or government. The NAAQS re-

quired the development of new emission control methods and equipment for factories, power plants, and motor vehicles and the development of new systems to monitor compliance. By establishing for each pollutant a primary standard to protect human health and a secondary standard to protect economic and ecological resources, the EPA acknowledged the importance of the wide range of effects of each pollutant.

The sweeping changes set in motion by the Clean Air Act took several years to implement as well as begin to improve air quality. In 1975, APCD's network of eight monitors in Jefferson County recorded its historic peak of 68 exceedances of the federal CO standard (an 8-hour average reading of 9 ppm or higher in ambient air), with 8-hour averages up to 22.8 ppm. The region's ground-level (tropospheric) O₃ concentrations generally increased through the 1970s before beginning a downward trend. The peak ozone reading reached 0.275 ppm in 1975, over twice the federal ceiling. Metropolitan Louisville's ambient air concentrations of the EPA-designated "criteria pollutants" excepting SO_x probably all peaked in the 1970s (SO_x levels had probably already declined significantly due to implementation of the 1959 Louisville regulations).

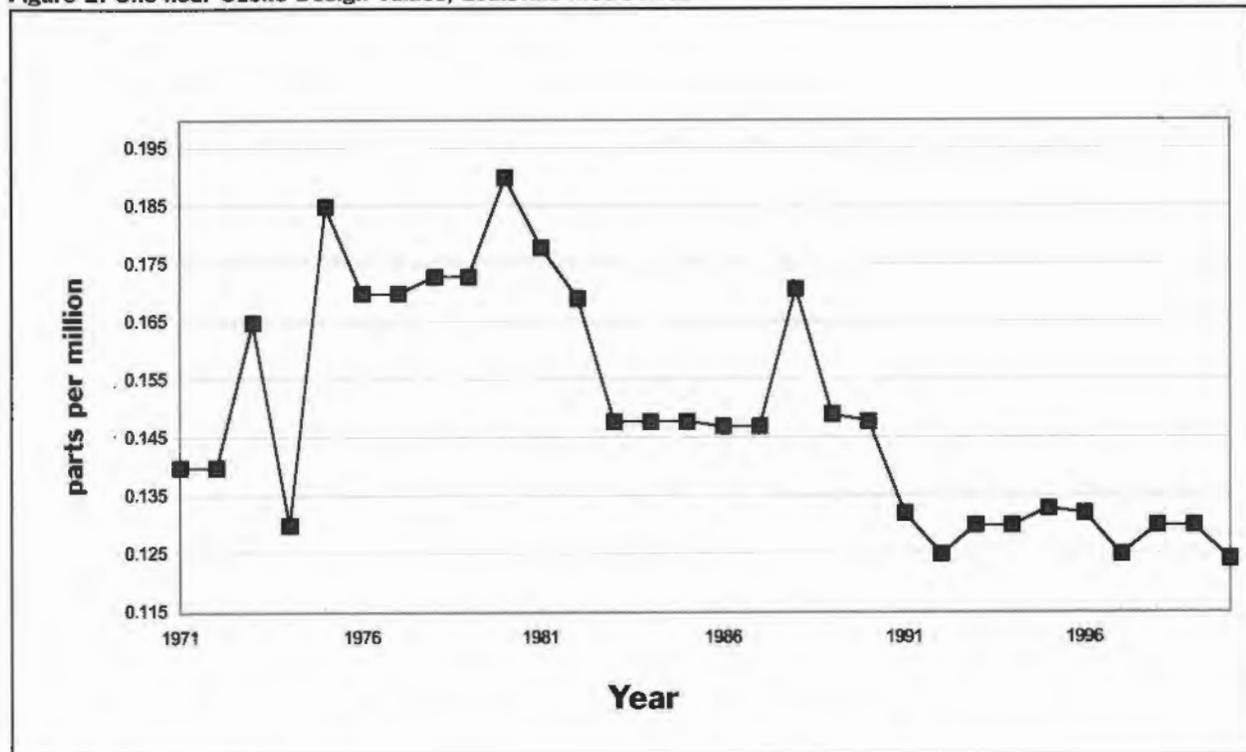
Figure 1: Example calculation of one-hour ozone design value.

Site	2001			2000			1999			Design Value		
	ppm	Date	Hour	ppm	Date	Hour	ppm	Date	Hour	ppm	Date	Hour
Charlestown	0.109	5/5	3 pm	0.105	8/17	3 pm	0.112	7/30	Noon	0.106	6/13/01	3 pm
	0.106	6/13	3 pm	0.101	6/1	2 pm	0.107	8/16	5 pm			
	0.101	6/19	5 pm	0.101	8/15	18	0.106	7/27	6 pm			
	0.101	8/1	3 pm	0.097	7/27	14	0.103	6/22	1 pm			
New Albany	0.107	8/1	3 pm	0.101	8/17	3 pm	0.120	6/10				
								1 pm	0.115	7/30/99	6 pm	
	0.096	8/7	4 pm	0.093	6/4	17	0.120	6/22	3 pm			
	0.088	6/18	5 pm	0.092	8/14	3 pm	0.116	7/8	4 pm			
	0.087	8/2	1 pm	0.092	8/15	17	0.115	7/30	6 pm			
Both sites:										0.115		

Notes:

ppm = one-hour ozone reading, parts per million. Each reading occurred at the date and time shown. Values in boldface represent the four highest readings at the given site during 1999-2001.

Figure 2: One-hour Ozone Design Values, Louisville Metro Area



Progress Since the 1970 Clean Air Act Amendments

National Ambient Air Quality Standards (NAAQS) Defined

The National Ambient Air Quality Standards (NAAQS) set by EPA must account for temporal and spatial variations in pollutant concentrations as well as the possibility of a brief period of erroneous or unrepresentative readings at a given monitor. APCD operates a network of monitors to record ambient concentrations of the six criteria pollutants in Jefferson County. The Indiana Department of Environmental Management and Kentucky Department for Environmental Protection operate other monitors in the metropolitan area. EPA regulates measurement methods, sampling periods, statistical methods, and manner of reporting. To provide a conservative reflection of the worst pollution exposure within a monitoring region, EPA defines a "design value" for each criteria pollutant.

Ozone (O_3), currently the greatest compliance challenge, presents a good example. O_3 monitors record one-hour averages. The design value for a given monitor is the fourth-highest daily peak one-hour reading recorded during the past three ozone seasons (from March 1 through October 31 each year). Figure 1 demonstrates the determination of the one-hour O_3

design value for 1999-2001 for two monitoring sites in the APCD network. The four highest daily peak one-hour readings recorded at the monitor in Charlestown, IN from 1999-2001 ranged from 0.106 ppm (on 7/27/1999 at 6 PM and 6/13/2001 at 3 PM) to 0.112 ppm (on 7/30/1999 at noon). Thus, for 1999-2001, the Charlestown, IN monitor had a design value of 0.106 ppm. For a network of monitoring sites, the design value constitutes the highest design value for the sites in the network. The two-site "network" in the example of Table 1 thus has a design value of 0.115 ppm.

For greater Louisville for 1998-2000, the Charlestown monitor had the highest O_3 design value (0.124 ppm) among the seven sites in the network. This gave the metropolitan Louisville air quality planning area a one-hour O_3 design value of 0.124 ppm for 1998-2000, narrowly in compliance with the NAAQS of 0.12 ppm (rounded to two decimal places, per EPA practice). As shown in Figure 2, reducing ambient ozone levels to meet the federal standard was a great achievement.

Progress on Criteria Pollutants

The standards set by EPA pursuant to the Clean Air Act Amendments of 1970, 1977, and 1990 required many changes in pollution-generating activities. New requirements have included emission controls on motor vehicles, power plants, and industrial processes, continuous emissions monitoring

on many industrial facilities, changes in the compositions of motor fuels and industrial fuels, and replacement or refurbishing of some high-emission equipment. Local and state environmental agencies enforce many of the federal standards, and promulgate and enforce additional regulations to improve their regions' air quality. Important steps by Jefferson County to meet the NAAQS have included:

- motor vehicle inspection and maintenance (I/M) or "vehicle emissions test" (VET) program [reduces CO, VOCs, and NO_x], 1984
- gasoline vapor recovery at fueling stations [reduces VOCs], 1993
- reformulated gasoline (RFG) [reduces CO, VOCs, NO_x, and hazardous air pollutants], 1995

The Clean Air Act Amendments of 1977 directed the EPA to review at five-year intervals the list of criteria pollutants and the NAAQS for each. Of the initial six criteria pollutants, only CO remains on the list. EPA established a NAAQS for lead (Pb) in 1978. Subsequent revisions to the list of criteria pollutants deleted hydrocarbons, substituted ozone for photochemical oxidants, substituted NO₂ for NO_x, substituted SO₂ for SO_x, and substituted particulate matter smaller than 10 micrometers (PM₁₀) for total suspended particulates. Metropolitan Louisville has only exceeded NAAQS for O₃ (and its superset, photochemical oxidants) and CO.

As noted above, Louisville's CO problems reached their peak in 1975, with 68 reported exceedances and two readings that more than doubled the applicable standard. From 1975 to 1985, the number of annual exceedances of the federal CO standard registered at APCD monitors dropped from 68 to one. Three exceedances occurred over the next eight years. Since 1993, no monitoring site in the Louisville metropolitan area has registered an exceedance of the CO standard. On 16 April 1990, the EPA recognized that Jefferson County had come into compliance with the NAAQS for CO (*Federal Register* vol. 55, no. 73, p. 14092-3). Much of the drop in CO probably stemmed from implementation of federal controls on motor vehicle exhaust. Maintaining compliance over the past eleven years in spite of increased motor vehicle use has resulted from continued improvements in motor vehicles as well as from the institution of the vehicle I/M, gasoline vapor recovery, and reformulated gasoline programs.

Ozone, the principle photochemical oxidant formed in "smog," arises from atmospheric reactions of NO_x and VOCs in the presence of solar ultraviolet radiation. CO, hydroxyl (OH) ion, water vapor, and other atmospheric chemicals also play roles in the reactions, which progress more rapidly at higher temperatures. High vehicular and industrial emissions of VOCs and high vehicular and utility emissions of NO_x result in high ambient O₃ concentrations on hot, sunny days with light winds. Excursions over the federal standard of 0.12 ppm occurred nearly every summer in Louisville until 1998, often several times per season. (EPA raised the 1-hour NAAQS from 0.08 ppm of total photochemical oxidants to 0.12 ppm O₃ in 1983, relaxing the standard by over 50%). Because O₃ forms in the atmosphere rather than appearing directly from emission sources, it is controlled indirectly by controlling its precursors. Several uncertainties regarding emission rates of biogenic VOCs (primarily from trees) and the aggregate photochemical reactivity of locally present anthropogenic VOCs further complicate understanding of how control measures influence ambient O₃ levels.

Nonetheless, federal, state, and local control strategies appear to work. Whether measured in terms of annual peak one-hour reading, design value, or hours per year above the NAAQS, metropolitan Louisville's O₃ levels have dropped considerably. In 1975 and 1980, O₃ reached the "serious" level as defined by EPA. In 1980, the peak recorded in Jefferson County reached 0.197 ppm, and 62 hours during 28 days had readings above the 0.12 ppm NAAQS. By contrast, during 1999-2001, no monitor in Jefferson County recorded a reading above 0.12 ppm. Even during the historically hot summer of 1998, only four excursions above 0.12



1950's Air Monitoring Station



1950's APCD Staff with balloon and air monitoring equipment.

ppm were recorded in Jefferson County, with a peak reading of 0.132 ppm.

Emissions inventories estimate total emissions from point sources (large industrial and utility facilities), mobile sources (motor vehicles and portable equipment), and area sources (small and dispersed sources such as dry cleaners, automobile body shops, and household fireplace use). While most industrial sources provide accurate emissions data by using continuous monitoring devices, quantifying emissions from mobile and area sources is much more time-consuming and approximate. Using EPA-approved methods, APCD has compiled complete emissions inventories for NO_x , VOCs, and CO every three years since 1990. The inventories cover Jefferson County and its O_3 "maintenance area" (formerly its "nonattainment area") including Clark and Floyd Counties in Indiana and portions of Bullitt and Oldham Counties in Kentucky.

According to APCD's estimates, VOC emissions dropped by half from 1990 to 1999 in Jefferson County but stayed roughly constant in nearby areas. Emission reductions came from improved manufacturing practices, improved motor vehicle technology, more stringent vehicle emissions testing, reformulated gasoline, and reduction in household and commercial use of solvents and oil-based paints. These reductions were partially offset by increased use of high-emission non-road vehicles and equipment such as diesel-powered construction equipment and gasoline-powered landscaping tools.

Regional NO_x emissions showed no clear trend from 1990 to 1999. An 82% increase in motor vehicle emissions offset

a 21% decrease in point source emissions. The rise in motor vehicle emissions arose from increased private automobile use without significant advances in motor vehicle NO_x control.

Regional CO emissions dropped by about 39% over the period due to a drop of nearly 52% in emissions from motor vehicles, the predominant source of CO. Improved vehicle technology coupled with the vehicle inspection and maintenance program and reformulated gasoline with oxygenates led to these improvements. Non-road mobile source emissions of CO nearly doubled, however. In the 1999 inventory, motor vehicles accounted for 74% of CO emissions (down from 93% in 1990), while non-road mobile sources accounted for 22% (up from 5% in 1990).

As noted above, the Louisville region has met the NAAQS for all criteria pollutants other than CO and O_3 since the inception of the standards. Ambient concentrations of CO, PM_{10} , Pb, NO_2 , and SO_2 have all dropped over the past thirty years, to levels generally less than half of the allowable limits.

Air Quality in Louisville: Current Conditions

Criteria Pollutants

As described earlier, the Louisville area meets all current NAAQS. Four concerns require continued vigilance regarding criteria pollutants, however:

- the potential for sporadic and localized exceedances of the O_3 and CO standards;
- the contributions of local pollutants, particularly NO_x and SO_2 , to environmental problems elsewhere;
- the potential for further improvement of local public health by reducing pollutants to well below maximum allowable values; and
- the implementation of more stringent federal standards, particularly for O_3 and particulates, over the next several years.

Small areas of high CO concentration, known as CO "hot spots" can form at congested road intersections with slow or

stalled traffic, and in "urban canyons" created by tall buildings lining the roads. High CO concentrations can cause headaches, dizziness, and slowed reflexes in drivers, pedestrians, and bicyclists traveling through hot spots. Highly localized and subject to dispersion by wind or traffic movement, a hot spot may show unacceptable CO levels at a point on the edge of the road and tolerable CO levels ten feet away. APCD uses a micro-scale model to predict potential CO hot spots at congested intersections during periods of peak traffic coinciding with calm winds. APCD has placed CO monitors at some predicted hot spot locations to provide continuous data from likely worst-case sites. APCD routinely models proposed new intersections and proposed large development sites to assess potential CO impacts. Approval of any proposed development rests in part on a determination that the new land use would not generate a CO hot spot by virtue of causing traffic congestion. Typically, changing the intersection or site design slightly (e.g., by adding another access/egress point or adding a preferential turn lane) will alleviate the CO concern by reducing the peak traffic congestion.

While metropolitan Louisville continues to experience a clear downward trend in ground-level O₃, one cannot safely presume that the area will not again see readings above the NAAQS of 0.12 ppm averaged over one hour. Very hot and clear weather coupled with inopportune excursions in NO_x or VOC levels might well result in O₃ peaks above 0.12 ppm. Unusual peaks in NO_x or VOC levels can arise from forest fires, chemical spills, or industrial accidents, among other causes. Local O₃ levels reflect NO_x from both local and distant sources, as NO_x can drift for hundreds of miles before its consumption in atmospheric reactions. Continued compliance with the 1-hour O₃ standard will require continued reduction of local emissions of O₃ precursors, to allow for spikes from uncontrolled sources.

Although greater Louisville has kept levels of SO₂ and NO₂ at less than half of the respective NAAQS, the locally generated SO₂ and NO₂ contribute to air and water pollution downwind. NO₂ emitted in the southern and midwestern US contribute to tropospheric O₃ formation on the eastern seaboard. Acid deposition in rural lakes, streams, and forests results from NO₂ and SO₂ transported from urbanized and industrialized areas including those in the midwest. The federal "NO_x SIP Call" of 1998 required 22 midwestern and southern states and the District of Columbia to develop state implementation plans (SIPs) to limit their emissions of NO_x and thereby facilitate O₃ compliance by urban areas to their east. The federal Acid Deposition Program established by Title IV of the Clean Air Act Amendments of 1990 calls for large per-

manent reductions of NO_x and SO₂, primarily by reducing emissions from coal-fired power plants.

APCD generally relies on EPA to set appropriate health-based ambient air quality standards. While not currently pursuing stricter local standards, APCD encourages institutions and individuals to reduce harmful emissions whenever possible through cost-effective voluntary measures. EPA sets the primary NAAQS to protect public health. Advances in knowledge of the health effects of air pollutants require periodic revision of the standards. Maintaining ambient pollutant levels below the federal standards may prove to be the most prudent way to protect public health, especially when subsequent research justifies tighter standards.

In 1997 epidemiological evidence led EPA to promulgate stricter NAAQS for O₃ and a new standard for fine particulates. Achievement of the new O₃ standard, 0.08 ppm averaged over eight hours, will reduce the risks of asthma and other breathing disorders. Continuous monitoring data from sites around the US prove the 0.08 ppm 8-hour standard more stringent than the 0.12 ppm 1-hour standard, which remains in force. The new EPA standard for airborne particulate matter applies to particles and droplets finer than 2.5 micrometers (PM_{2.5}). These fine particulates, which penetrate more deeply into the lungs than do coarser particulates, increase risks for breathing disorders and heart disease. Implementation of both of these new standards awaits resolution of legal challenges. The courts have upheld EPA's authority to promulgate the standards, but have remanded to the agency the schedule and other details of their implementation. Although greater Louisville complies with the PM₁₀ and 1-hour O₃ standards, data from the past three years indicate the need for further air quality improvements to meet the PM_{2.5} and 8-hour O₃ standards.

Hazardous Air Pollutants

The Clean Air Act Amendments of 1990 established a list of 189 hazardous air pollutants (HAPs or "air toxics") known to act as carcinogens, mutagens, or reproductive toxins or to have other serious health effects. EPA has subsequently revised the list to 188 chemicals. (Seventeen of the 188 are actually families of related chemicals, e.g., coke oven emissions, glycol ethers, and mercury compounds). EPA began in 1990 to establish maximum achievable control technology (MACT) standards to reduce emissions of each of the HAPs from the many industrial and commercial processes known to emit it. The law requires industrial sources of HAPs to operate using the appropriate MACT within ten years (or 16 years in certain cases) of the standard's enactment. Ten years after instituting each MACT requirement, EPA must

review the residual risk posed by the HAP in question. EPA may then promulgate tighter standards if needed to protect public health. Federal standards also require industrial monitoring and reporting of HAPs emissions.

APCD issues permits to sources of HAPs in Jefferson County, and reports to EPA annually the emissions of HAPs from these sources. Of the 188 air toxics, Louisville industries emitted about 53 in any given year since 1994. Of these 53 compounds, 24 were emitted in quantities of over five tons per year in 1994. (Fifteen HAPs in Jefferson County emissions were under 200 pounds per year). For each of these 24 HAPs, five or fewer sources accounted for at least 90% of the emissions. As a result, changes in production rates, manufacturing methods, or emissions controls at a single facility occasionally caused a large change in the County's emission inventory of a particular HAP.

Overall HAP emissions in Jefferson County have changed little over the past seven years, although emissions of some individual substances showed a significant trend. Emissions of bis (2-ethylhexyl) phthalate, methylene chloride, and 1,1,1-trichloroethane dropped to zero from 1994 to 2000. Some HAP emissions have increased significantly during the period: 1,3-butadiene, by 210%; ethylbenzene, by 78%; methylisobutyl ketone, by 71%; and methylmethacrylate, by 48%. Others have decreased: toluene, by 46%; methylethyl ketone, by 42%; formaldehyde, by 37%; styrene, by 31%; and acrylonitrile, by 26%.

Air toxics also arise from mobile sources and area sources. The EPA has identified diesel engine exhaust particulates as a likely human carcinogen at common atmospheric concentrations. Non-road diesel engines running on fuel with sulfur contents up to 3000 ppm add significantly to these toxic emissions. (Diesel fuel manufacturers voluntarily limit highway diesel fuel to a maximum of 500 ppm sulfur). Gasoline engines, particularly those without catalytic converters, also contribute to air toxics. Dry cleaning establishments in aggregate emit significant quantities of the HAP perchloroethylene. Similarly, automobile body shops and other small businesses using polymer resins collectively emit significant quantities of organic HAPs.

Greenhouse Gases

"Greenhouse gases" have high transparency to solar radiation (primarily at optical wavelengths of 350-700 nanometers) but absorb or reflect infrared wavelengths (5,000-17,000 nanometers) characteristic of the re-radiation of heat from earth to space. Higher atmospheric concentrations of greenhouse gases heat the earth by increasing the temperature at which the planet's surface reaches radiative equilibrium with the sun and space. The term "radiative forcing" describes an atmospheric constituent's tendency to raise (positive radiative forcing) or lower (negative radiative forcing) the planet's equilibrium temperature. Pre-industrial greenhouse gases including water vapor, carbon dioxide (CO₂), and methane (CH₄) caused radiative forcing that increased

earth's equilibrium temperature from about 5°F (with a hypothetically transparent atmosphere or in a vacuum) to about 60°F. The "global warming potential" of a substance measures its radiative forcing properties, its longevity in the atmosphere, and its tendency to contribute to atmospheric chemical reactions that form other greenhouse gases (e.g., O₃). Due to its abundance, CO₂ constitutes the most important human produced greenhouse gas. However, per unit mass, CH₄ has a global warming potential 22 times as great as that of CO₂. Various other gases, primarily industrial in origin, have global warming potentials from 100 to 10,000 times that of CO₂ on a mass basis.



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During the past 300 years, average atmospheric levels of CO₂ have increased from about 275 parts per million by volume (ppmv) to about 356 ppmv, a 29% rise. During the same period CH₄ has increased from about 0.75 ppmv to about 1.7 ppmv, a 127% rise. Analyses of ancient air samples from arctic ice show the current levels and rates of increase of CO₂ and CH₄ to have no precedent in the past 160,000 years. Fluorocarbons, chlorinated fluorocarbons, and other man made gases with very high radiative forcing potentials have appeared in the atmosphere only in the past century. The documented rise in greenhouse gas concentrations and mounting evidence of rising global average temperatures over the past century have led to a growing scientific consensus that human activities are contributing to global climate change.

No federal, Kentucky, or Jefferson County regulations currently cover emissions of greenhouse gases, except for those regulated for their other environmental consequences (e.g., carbon tetrachloride and 1,1,1-trichloroethane, both air toxics). Greenhouse gas control policies generally involve developing a greenhouse gas emissions inventory for a baseline year and pursuing reductions from the baseline emissions. In 1996, Dr. Hugh Spencer, KIESD prepared the report, *Kentucky Greenhouse Gas Inventory: Estimated Emissions and Sinks for the Year 1990* for the Kentucky Natural Resources and Environmental Protection Cabinet, Division of Energy. This report, which details all known significant biogenic and anthropogenic greenhouse gas sources and sinks in the state, estimated Jefferson County's 1990 net greenhouse gas emissions at 42,815,000 tons per year of CO₂ equivalent. (One ton/year of CH₄, for example, equals 22 tons/year CO₂ equivalent because CH₄ has a global warming potential 22 times that of CO₂). This total is by far the highest of the counties in Kentucky. Because of the extremely high global warming potentials of chlorinated fluorocarbons (CFCs) and halogenated hydrocarbons (HCFCs), releases of these compounds from three large manufacturing facilities in Jefferson County may account for over 5% of the county's total greenhouse gas emissions. At present, no agency maintains a greenhouse gas emissions inventory for Jefferson County or Kentucky, although a few other states maintain such inventories. Several bills pending before the US Congress call for establishing a national greenhouse gas emissions inventory.

Stratospheric Ozone-Depleting Compounds

Under the Montreal Protocol, adopted by the United Nations Environmental Programme in 1987, signatory nations are phasing out the production and use of substances that damage the stratospheric ozone layer. These include chlorine- and bromine-containing compounds that do not decompose in the lower atmosphere but, upon convective transport into the upper atmosphere, break down from exposure to ultraviolet radiation. The resulting free chlorine or bromine atoms readily react with O₃ and other atmospheric constituents with the net effect of consuming stratospheric O₃. Ozone in the stratosphere (at several times the concentrations that humans would find tolerable at ground level) strongly absorbs solar ultraviolet radiation, thereby providing an effective ultraviolet shield for the biosphere.

Jefferson County is home to three of Kentucky's five largest sources of stratospheric ozone-depleting chemicals, DuPont (1,870,000 lbs. in 1999), GE Appliances (434,000 lbs. in 1999), and Louisville Packaging (331,000 lbs. in 1999). Ozone-depleting compounds are also released as "fugitive

emissions" from small and widely dispersed sources, e.g., leaks in air-conditioning and refrigeration systems. Due to a 52% drop in DuPont's emissions from 1996 to 1999, and in spite of significant increases in emissions from the other two large sources, Jefferson County experienced a drop of about 39% in emissions of ozone-depleting compounds during that three-year period. Nonetheless, Jefferson County accounts for 49% of Kentucky's total emissions of ozone-depleting chemicals. **As of 1999, Kentucky had the highest on-site (industrial) emissions of ozone-depleting chemicals of any state.**

Air Quality Challenges Ahead

Tropospheric (Ground-Level) Ozone

Greater Louisville, having reached attainment with the NAAQS for O₃ in 2001, will face a new compliance challenge upon implementation (probably by 2007) of the new 8-hour O₃ standard. The complex and indirect relationships between tropospheric O₃ concentrations and local emissions of O₃ precursors present difficulties in crafting a compliance strategy. The transport of O₃ and its precursors into and out of the region may play a greater role than anticipated in modeling conducted to date. Recent measurements suggest that O₃ and its precursors may circulate in significant quantities even over transcontinental distances. The average rates, diurnal variations, and temperature dependence of biogenic emissions of VOCs remain subject to great uncertainty. These emissions may constitute over 50% of the region's VOC emissions inventory. Neither photochemical modeling nor empirical correlations have progressed far enough to provide reliable predictions of the emissions reductions needed to bring the region into compliance with the 8-hour O₃ standard.

In the face of these uncertainties, metropolitan Louisville will probably seek to meet the 8-hour O₃ standard by means similar to those that reduced the region's O₃ levels over the past twenty years. The replacement of older motor vehicles with models having modern emissions controls and on-board diagnostics, along with the introduction of cleaner drive trains and fuels, will reduce mobile source emissions of VOCs, NO_x, and CO. Continued reductions of NO_x emissions from industries and utilities should result from federal programs designed to reduce acid rain and east coast O₃ problems. Continuing replacement of solvent-based paints and coatings with water-based substitutes can reduce industrial and area-source emissions of VOCs.

PM_{2.5}

Data collected during the past three years indicate that the

region will need to reduce fine particulates by roughly 15% to meet the federal $PM_{2.5}$ standards expected to take effect in the next few years. Data from "speciation" monitors, which determine the chemical composition of the collected particulates, will allow APCD to formulate control strategies on the basis of the predominant chemical species present. Aerosol sulfates and nitrates, two major constituents of $PM_{2.5}$, form primarily through atmospheric reactions involving SO_x and NO_x , respectively. Fugitive dust consists of fine solid particulates released incidental to manufacturing, agricultural, construction, and other activities. According to the Kentucky Division for Air Quality, fugitive dust makes up over 60% of $PM_{2.5}$ emissions in Kentucky, but it may constitute a smaller fraction of metropolitan Louisville's $PM_{2.5}$ emissions. Measures aimed at reducing SO_x and NO_x will reduce the sulfate and nitrate components of $PM_{2.5}$. Local control of fugitive dust may involve additional industrial controls as well as measures beyond those already in place to reduce dust arising from construction, demolition, and vehicle use on unpaved surfaces.

Intercontinental transport of fine particulates contributes to observed local peaks in $PM_{2.5}$. Forest fires in Central America, volcanic eruptions in Asia, and dust storms in North Africa have caused spikes in $PM_{2.5}$ values in the US, including Louisville. Upon establishing a clear correlation between a distant source of particulates and widespread high readings in the US, the EPA may discount the unusually high readings for purposes of establishing compliance with the NAAQS. Nonetheless, these uncontrollable distant events may affect public health in the US.

HAPs

Increasing understanding of the health consequences of HAPs may lead to tighter regulation of specific compounds. EPA plans to limit mercury emissions from coal-fired power plants, the largest sources of atmospheric mercury. EPA has issued standards to reduce sulfur content in highway diesel fuel to 15 ppm by 2006. In addition to direct reductions in sulfur-containing particulates, the cleaner fuel will enable the use of catalytic converters that will dramatically reduce HAPs and NO_x in diesel exhaust.

Haze

Visibility-impairing haze arises principally from particulates and NO_2 . Haze worsens in humid weather, when sulfate aerosols and other particles absorb atmospheric moisture and grow in size. The control strategies for $PM_{2.5}$ apply also to regional haze. Due to the long-distance transport of

fine particulates, haze seriously affects areas far from the responsible emission sources. National parks and other scenic areas have suffered large losses in visibility because of man made haze from pollution generated in distant industrialized or urban areas.

Acid Rain

Despite improvements over the past fifteen years, rainfall collected at sites across Kentucky remains more acidic (approximately pH 4.5 on average) than the unimpaired norm of pH 5.0 – 5.6. Studies in other states have shown that lakes and streams have rebounded less quickly from acid rain than regulators had hoped even with the current regimes of SO_2 and NO_x controls.

Greenhouse Gases

Voluntary measures to curtail greenhouse gas emissions, as described below, offer large potential reductions. The absence of a national greenhouse gas control program, however, reduces the economic incentives available to promote emission reductions.

Avenues for Cleaner Air in Louisville

A variety of regulatory and voluntary methods will likely contribute to air quality improvements over the next twenty years. The causal links between some substances or activities and several air quality problems makes possible harmonized approaches in which one action can benefit air quality in several ways. While targeted efforts to limit the release of a single pollutant from a particular process will continue to be important, harmonized approaches with multiple benefits will likely yield the largest improvements.

National Initiatives with Local Implications

Federal regulations have largely driven the improvements in air quality noted over the past thirty years. The Clean Air Act Amendments call for periodic review and revision of the federal standards, which will maintain their link to the state of the science in toxicology and environmental health. Implementation of the NAAQS already issued for O_3 (8-hour) and $PM_{2.5}$ will press areas including Louisville to strengthen existing control programs. New federal standards for diesel fuel sulfur content, gasoline sulfur content, highway vehicle emission controls, and non-road equipment emission controls should result in large reductions in mobile source SO_2 , NO_x , particulates, and the related problems of tropospheric O_3 , regional haze, and acid deposition. The latter set of federal controls will assist Louisville and other communities in meeting the former set of standards.

Federal regulation of air pollution from industries and utilities will likely change significantly over the next two years. The legislative and executive branches continue to debate a range of regulatory reforms that could recast the options available to companies to meet their air quality obligations. "Cap-and-trade" systems would relieve point sources of individual emission limits or requirements to install specific emission reduction devices. Instead, the government would allot a limited number of emission allowances each year to existing sources of a given pollutant. By reducing the annual allotment of allowances for a pollutant, EPA would reduce the nationwide total allowable emissions of that pollutant without dictating how to achieve the reductions. By permitting trading of the allowances, the government would foster the most cost-effective means of reducing emissions. Multi-pollutant cap-and-trade strategies enable companies to reap additional financial rewards by taking measures that reduce two or more pollutants simultaneously. The multi-pollutant approach also frees companies from needing to install specific pollution control devices for each of several pollutants, resulting in higher costs and greater-than-needed emissions reductions. Opponents cite two disadvantages of cap-and-trade systems: the flexibility they offer to continue running a profitable but dirty plant by purchasing additional allowances, thereby causing regional emissions hot spots; and the likelihood that a free market in emissions allowances will lead companies in aggregate to exactly meet the national emissions limits for the pollutants in question. By contrast, existing "technology-forcing" standards often lead to facility-by-facility emissions reductions well above those required by law. The Kyoto Protocol, not ratified by the US, has established an international trading system for CO₂ allowances. The US Congress and administration are contemplating mechanisms to allow voluntary trading of CO₂ allowances by US companies. The Bush administration currently opposes mandatory reductions of greenhouse gases.

The federal government also sponsors voluntary, incentive-based programs that can benefit air quality. Two areas of focus include reducing automotive travel demand and improving efficiency in the use of energy. EPA and the Federal Highway Administration provide technical assistance and some funding to communities exploring and using strategies to reduce suburban sprawl, encourage non-automotive transportation, and otherwise reduce private automobile use and its numerous environmental consequences. EPA's growing Energy Star® program promotes energy-efficiency in appli-



Laboratory facility for air testing in the 1950's

ances, office equipment, buildings, and large institutions. US Department of Energy (DOE) runs or collaborates in a host of programs to increase energy-efficiency, especially in industry. The National Renewable Energy Laboratory of DOE promotes the development and application of low- and zero-emission energy resources. Through its national laboratories, DOE conducts research on advanced energy technologies and technologies to increase the energy-efficiency of buildings and industrial processes. In addition to reducing emissions of criteria pollutants and their contributions to acid deposition and regional haze, these programs provide avenues for enormous reductions in CO₂ emissions.

The federal government has also initiated work on practical means to mitigate the urban heat island effect. Many surfaces exposed to sunlight in urban areas have higher thermal mass (heat capacity) and solar absorbance than the corresponding surfaces in rural or undeveloped areas. Black asphalt roofs and pavements are examples of urban surfaces that absorb and slowly release solar radiation. As a result, cities tend to reach higher summer temperatures than do their surrounding suburbs that, in turn, reach higher temperatures than the surrounding fields and forests. The heat island effect can cause urban peak temperatures 2 – 10 °F higher than in the surrounding countryside. Higher summertime temperatures harm urban air quality in at least four ways: 1) increasing the rate at which ground-level O₃ forms; 2) increasing energy demand for cooling buildings and motor vehicles, and thereby causing additional energy-related emissions; 3) increasing evaporative emissions of VOCs from motor vehicle fuel systems; and 4) increasing biogenic emissions of VOCs from trees. These effects can be large: a modest heat island

effect of 3 °F may increase Louisville's peak O₃ levels by 5-10%. Lawrence Berkeley National Laboratory (LBNL) and the National Aeronautics and Space Administration are engaged in research to characterize the heat islands of several US cities and the air quality implications of those heat islands. LBNL researchers also develop and test materials and methods to reduce the heat island effect. EPA disseminates information, promotes actions to mitigate the heat island effect, and provides technical assistance to municipal officials developing local heat island policies and programs.

Local Initiatives

Greater Louisville has many options for improving its air quality beyond the improvements promised by forthcoming federal standards. Four promising areas are: reducing transportation-related emissions; reducing energy-related emissions; reducing point source and area source emissions through pollution prevention; and taming the urban heat island. Successful work in any of these areas will cause declines in more than one pollutant.

Reducing Transportation-Related Emissions

Transportation-related emissions can be reduced by cutting emissions per mile or by reducing the vehicle-miles of travel (VMT) in the region. Local reductions in emissions per mile can come from:

- encouraging the use of low-emission vehicles;
- improving the efficiency of the road network, to allow motor vehicles to operate more consistently within the ranges of speeds and accelerations that yield lowest emissions;
- mandating local use of fuels that provide lower emissions; and
- repairing or retiring from service motor vehicles that do not meet modern emission standards.

The second and third of these options already have found use in Jefferson County, in the form of downtown streets with synchronized traffic signals and the local requirement to sell only reformulated oxygenated gasoline. Refinement, extension, and further application of these three general strategies will build on the emissions reductions achieved to date.

Several approaches may help to reduce VMT. They fall into two general categories:

- reducing travel demand; and
- encouraging shifts to other travel modes from private automobile use.

Travel demand relates strongly to land use patterns. Segregation of land uses (e.g., commercial, residential, industrial) increases average distances from home to work and other destinations. Trends away from multi-family housing and toward larger lots for single-family homes increase the diameter of the urban area for any given population. Residential subdivisions with relatively large lots, no sidewalks, and no focal point for spontaneous social interaction (e.g., a neighborhood park) increase the need to travel. Regional and community form exert a strong influence on travel demand.

Regional and community form also influence the viability of non-automotive travel modes. Decreases in population density result in fewer people living within walking distance of any given transit stop. Coupled with longer average trip distances, this increases transit operating costs while decreasing fare revenue per mile. Bicycling and walking also become less attractive as distances from origin to destination expand.

Through the Cornerstone 2020 comprehensive plan, Jefferson County is taking steps toward community design that would allow citizens to meet more of their needs closer to home. Encouraging a mixture of residential and commercial uses in a compact area may lead to more opportunities for people to live close to places where they work, shop, and enjoy pastimes. Increased urban redevelopment and creation of suburban neighborhoods that include parks and pedestrian and bicycle connections to nearby activity centers may similarly reduce automotive travel demand.

Programs to encourage car-pooling, transit use, telecommuting, bicycling, and walking can reduce the demand for motor vehicle travel. The success of such programs relies on presenting the traveler with a choice that compares favorably with driving. Costs in time and money, and benefits in flexibility, safety, comfort, enjoyment, and health, will factor into each individual's travel choice. As long as the costs of roads, traffic enforcement, accidents, pollution, and noise remain separate from an individual's perceived costs of driving, people will have far less incentive to shift to more cost-effective and environmentally benign travel modes.

Reducing Energy-Related Emissions

Fostering energy efficiency offers direct economic benefits as well as emission reductions. Locally, increased education and technical support can increase adoption of cost-effective energy conservation measures. Residences, businesses, and institutions all offer large potential energy savings. Industrial managers often reject energy-saving changes in manufacturing processes to avoid the possibility of disrupt-

tions to production or product quality. A change that saves energy but increases downtime, for example, will rarely earn management approval. Careful scrutiny will often reveal measures that will raise energy efficiency while also improving the productivity, reliability, or safety of the process.

Local government can encourage energy efficiency by a variety of means. Promising options include:

- providing technical support and training to architects and builders, residents, business owners, and factory managers;
- operating or promoting an energy rating system for buildings, to guide buyers of homes and businesses;
- improving the energy efficiency of municipally-owned facilities and setting high standards for the energy efficiency of new facilities; and
- encouraging homeowners to plant shade trees on the east or west sides of their homes.

Combined heat and power (CHP or "cogeneration") provides on-site generation of electricity and heat for a facility that needs both. Using the byproduct heat from electrical generation raises overall fuel efficiency from about 35% to 70% or more. CHP using natural gas-fired microturbine, fuel cell, or other clean generating methods can provide electricity and heat with low emissions. CHP may play an important role in reducing CO₂ emissions and criteria pollutant emissions from coal-fired power plants. It has its greatest potential in commercial, industrial, and multi-family residential sites.

Low- and zero-emission sources of heat and electricity will increasingly play a role in reducing the need to burn carbon-based fuels. Jefferson County receives enough sunlight to make good use of solar energy for space heating and water heating. Current generation costs of solar electricity make it economically unattractive for most applications in Jefferson County. Average wind speeds in the area generally do not allow for cost-effective wind-generated electricity. The primary renewable sources of electricity in the region will remain refuse-derived and biomass-derived fuels (e.g., landfill gas and biodiesel refined from used cooking oil) and hydroelectric power. Capital improvements at the Louisville Gas and Electric Company Ohio Falls Hydroelectric Station could boost that plant's peak capacity from 80 MW to about 100 MW.

Mitigating the Urban Heat Island Effect

Four main tools exist for reducing the urban heat island effect: urban forestry, land use planning, cool roofing materials, and cool paving materials. Trees anywhere within the urban area will reduce air temperature by evaporation of moisture from their leaves. They also shade more absorptive and heat-retaining surfaces. When placed close to houses and other buildings (preferably not on the south side where they will block desirable winter solar heat gain), trees provide additional cooling season energy savings. Compact land development patterns reduce overall paved area and leave more land for green space including forests. Studies show that reducing suburban sprawl and increasing tree canopy coverage have the largest potential effect on a city's heat island. White elastomeric roof membranes and some elastomeric roof coatings offer high albedo (solar reflectance) and high infrared emissivity (tendency to re-emit heat to the sky), so they absorb little solar energy and readily re-radiate it. Incentives to reduce the initial cost of these roofing materials, in conjunction with promotional campaigns to improve their acceptance on visible rooftops, could speed the adoption of this technology. Light-colored pavement materials, including blended cement concretes made with fly ash or blast furnace slags, can offer excellent durability and relatively high albedo. For light-duty parking areas, grass-filled or gravel-filled pervious paving systems can replace asphalt with a significant reduction in heat absorption. Pavement substitutions offer slightly less overall heat island reduction potential than do roofing material substitutions.

Pollution Prevention

Great advances in environmental protection can come from the redesign of industrial and commercial processes to eliminate harmful effluents rather than installing pollution control devices to capture and treat effluents from less elegant processes. In manufacturing, this can take the form of designing a facility so the effluent of one process becomes a feedstock for another, with the final process in the chain producing no noxious substances. Sometimes, adding a mechanical process can obviate a chemical process with an undesirable waste product. Increasingly households and small businesses as well as large industries can replace solvent-based coatings and cleaners with water-based substitutes. Public education and technology transfer constitute the key means to encourage pollution prevention.

Challenges to Improving Regional Air Quality

Government, business, and citizens at large will need to cooperate to achieve further improvements in regional air quality. Some potential challenges include:

- continuing growth in VMT and trend toward heavier vehicles, increasing CO₂ emissions even with projected advances in motor vehicle emissions controls and fuels;
- continuing growth in developed land area, exacerbating the urban heat island effect, fueling continued VMT growth, and probably increasing fugitive dust emissions;
- continued growth in per capita living space, increasing energy demand and the urban heat island effect, and hence urban O₃ levels;
- continued reliance on coal as the primary fuel for electrical generation, producing large CO₂ emissions and contributing to acid rain, regional haze, and ground-level O₃;
- further delays in the implementation of new federal standards for mobile source fuels and emissions controls; and
- adverse economic conditions, reducing the availability of capital to invest in industrial pollution prevention and energy efficiency measures.

Peering into the Crystal Ball: Louisville's Air Quality, 2020

With continued public support, elected officials will continue to work to improve environmental quality. Environmental non-governmental organizations, businesses, and private individuals will collaborate with government agencies to define necessary standards of environmental quality and find ways to meet those standards. By 2020 the current criteria air pollutants will probably have minimal significance, particularly if acid deposition and haze have declined to acceptable levels. Air toxics (perhaps with some important modifications to the current list) will probably require ongoing scrutiny and reduction. Greenhouse gases may pose the most urgent challenge. Given the complexities of atmospheric chemistry and epidemiology, the science and practice of air pollution control will evolve for decades to come. Some current practices will prove highly effective. Others will probably prove less so, due to gaps in current understanding. Improvements from 1970 to 2001 provide hope that pollution control efforts to date have moved in the direction of improving public health and protecting natural resources while preserving economic vitality.

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Air Pollution May Melt Polar Ice Caps

Auto-Exhaust. Action Urged

Washington, Nov. 18 (AP)—A spokesman for the American Association for the Advancement of Science said today increasing air pollution will make the earth hotter and might even slowly melt the polar ice caps. He also said air pollution is as much to blame as cigarettes for increasing lung cancer.

Dr. Chauncey D. Leake, assistant dean of the Ohio State University School of Medicine, said there is a "tremendous increase in the blanket of carbon dioxide we are throwing above us, which will inevitably tend to increase heat capture from the sun."

"What will we do if this occurs with gradual melting of the huge polar ice caps, and the gradual rise of our oceans, drowning out still further our shorelines" he asked.

Leake addressed the opening session of a national conference on air pollution. The three-day meeting was called by U.S. Sur-

geon General Leroy S. Burney to get the views of scientists and civic leaders on how to prevent contamination of the air we breathe.

More Trees Advised

Leake suggested the carbon dioxide "blanket" might be reduced by extensive planting of trees and other green things which absorb the gas along city streets. "Maybe 10 trees planted for every automobile, with 100 for every truck, would help," he said.

Leake said about half of air pollution is traceable to automobile exhausts. He suggested that manufacturers "turn from the foolishness of silly style whims, from oversized models and from too much horsepower to the essential but tough job of controlling exhausts."

Senator Thomas H. Kuchel (R., Calif.), a self-styled "recently escaped smog refugee," said he plans to introduce legislation in Congress next year to continue and possibly broaden the Federal air pollution con-

trol program. The program, calling for Federal studies and research on the causes and control of air pollution, now is due to expire July 1, 1960.

Kuchel said unchecked continuation of air contamination "undeniably and eventually will halt the growth and progress of any community as surely as a Chinese wall" around it. He said cities may have to fight smog with "air zoning" laws for industries and autos.

Dr. Herman E. Willeboe, New York State health commissioner, called for a "crash" recruitment and training program in air pollution control by the U.S. Public Health Service. He said a "massive effort" is needed to get states and communities started on effective air pollution control programs.

More Research Pledged

Retired Army General John E. Hull, president of the Manufacturing Chemists Association, said scientific investigation "offers probably the best hope for sensible and effective control of air pollution."

He pledged that the chemical industry, which now spends about \$250,000,000 annually to curb or avoid air pollution, "will continue to be one of the leading partners" in solving the problem.

The conference, first national meeting of its kind, has a twofold purpose:

1. To awaken public interest in the problem of air pollution, which costs the public an estimated \$1,500,000,000 to four billion dollars a year, not counting any damage to health.

2. To develop a 10-year plan to cope with air pollution, which Burney calls "an unwanted by-product of progress."

About 1,000 persons are expected to participate in the discussions. They include doctors, engineers, meteorologists, chemists, State and local health officials, city planners and representatives of industry, auto associations, Chambers of Commerce, women's clubs, the Council of State Governments and the American Municipal Association.

Excerpt from the Louisville Times, November 18, 1958



SMOGGY CORNER—Winter's first serious smog which blanketed the city early today was clearing a bit when this picture was taken at Jefferson looking north on Fourth, but vehicles still had to keep their lights on. The U.S. Weather Bureau said that in the business district it was half smoke and half fog, but the City Smoke Commission thought it largely fog. At 8 a.m. Bowman Field reported ceiling and visibility at zero, but air lines said they were able to operate on schedule. Fogs were encountered, pilots said, at Nashville, Cincinnati, Dayton, Columbus and Akron. The sun pushed its way through the soup at midmorning.

Photo Excerpt from the Louisville Times, November 20, 1946

Chemical Air Pollutants in Jefferson County, KY; Potential Health Effects

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The Ohio River was instrumental in providing settlers access to the area now known as Jefferson County, KY. Here in May 1778, George Rogers Clark set up a base of operations for the Revolutionary War on Corn Island, now submerged near the Falls of the Ohio. As Governor of the Dominion of Virginia, Thomas Jefferson signed a charter for the town of Louisville in 1780. This community supported forts for Clark's troops, including Fort Nelson, which was founded in 1781 near today's intersection of Seventh and Main. With the end of the American Revolutionary War in 1783, a fledgling city emerged that thrives today as an economic center of services and manufacturing.

It is of interest that war and the Ohio River also provided impetus for development of the major chemical industry in Jefferson County, KY. Petrochemical industrialization of the area began in 1918 when Standard Oil of Kentucky constructed the Riverside Refinery in the area of western Jefferson County. Convenient access to the Ohio River, railroads, and highways led other industries to open plants in Jefferson County to manufacture a variety of chemical and industrial products. Bounded and served by the Ohio River, western Jefferson County became a major site for the manufacture of synthetic rubber during World War II. Loss of natural rubber supplies from Southeast Asia made the production of synthetic rubber a high priority of the U.S. Office of War Production and Management. In 1941, the Office contracted with National Carbide to construct a plant for calcium carbide-derived acetylene gas. The B.F. Goodrich Corporation built an adjacent plant, to which acetylene was piped to manufacture vinyl chloride monomers. Nearby that same year the E.I. DuPont de Nemours & Company built a neoprene synthetic rubber plant. In this facility, acetylene gas was converted to vinyl acetylene. When chlorinated, this produced chloroprene, which then was polymerized into neoprene rubber. In 1945, Union Carbide built a plant in the complex to manufacture butadiene from grain alcohol that was piped to the complex from distilleries in Louisville. During that year a consortium of tire companies, National Synthetic Rubber, opened a plant to make styrene-butadiene

rubber for tires needed in the war effort. After World War II, the federal government continued to operate the styrene-butadiene rubber plant until 1955 when it was auctioned off to a consortium of some 20 rubber companies. This area of western Jefferson County near the Ohio River became known as Rubbertown.

Stacks in Rubbertown area.



Rank	Chemical	Fugitive Air	Stack Air	Total Air Emissions	Total Releases
1	Sulfuric Acid Aerosols	670	2,604,456	2,605,126	2,605,126
2	Chlorodifluoromethane	308,858	1,858,547	2,167,405	2,167,405
3	Xylene (mixed isomers)	74,521	1,154,672	1,229,193	1,389,259
4	Toluene	327,293	765,701	1,092,994	1,119,835
5	Ammonia	418,737	567,930	986,667	1,023,608
6	Glycol ethers	209,027	428,947	637,974	638,364
7	Hydrochloric Acid Aerosols	18,428	568,589	587,017	587,017
8	Chloroprene	53,634	458,668	512,302	512,302
9	N-Butyl Alcohol	66,172	371,591	437,763	451,773
10	1,1-Dichloro-1-fluoroethane	327,460	106,300	433,760	433,760
11	Methyl Methacrylate	62,333	207,468	269,801	270,851
12	1,3-Butadiene	28,045	233,272	261,317	262,405
13	Methyl Isobutyl Ketone	9,265	227,402	236,667	334,917
14	Ethyl benzene	21,809	182,223	204,032	260,292
15	Aluminum (fume or dust)	8,909	148,478	157,387	157,387
16	1,2,4-Trimethylbenzene	29,481	124,032	153,513	165,513
17	Styrene	35,477	73,293	108,770	110,355
18	N-Methyl-2-pyrrolidone	2,619	83,969	86,588	86,588
19	Methanol	4,563	79,817	84,380	84,636
20	Acrylonitrile	3,528	71,432	74,960	78,107
21	Methyl Ethyl Ketone	33,864	15,696	49,560	49,810
22	Phenol	19,888	24,860	44,748	74,553
23	Nitric Acid	520	42,932	43,452	43,462
24	Formaldehyde	30,730	6,760	37,490	38,255
25	Hydrogen Fluoride	21,156	5,886	27,042	27,042
26	Ethyl Acrylate	9,010	16,493	25,503	26,013
27	2-Chloro-1,1,1,2-tetrafluoroethane	23,704		23,704	23,704
28	Methyl tert-Butyl Ether	3,357	7,608	10,965	10,965
29	Butyl Acrylate	3,370	5,633	9,003	9,683
30	Nickel Compounds	373	8,149	8,522	120,304
31	Vinyl Chloride	3,430	4,364	7,794	7,794
32	1-Chloro-1,1-difluoroethane	6,129		6,129	6,129
33	Ethylene Glycol	5,139	679	5,818	5,887
34	tert-Butyl Alcohol	10	5,800	5,810	6,570
35	Benzene	460	2,783	3,243	3,433
36	n-Hexane	290	2,734	3,024	3,864
37	Nicotine (and salts)	5	2,900	2,905	2,905
38	Zinc Compounds	797	1,985	2,782	315,136
39	Lead Compounds	250	2,058	2,308	65,089
40	Boron Trifluoride	1,752	89	1,841	1,841
41	Dichlorofluoromethane	1,560		1,560	1,560
42	Naphthalene	1,531	5	1,536	1,536
43	sec-Butyl Alcohol	1,530	5	1,535	1,535
44	Dichlorodifluoromethane	1,431		1,431	1,431
45	Cobalt Compounds	5	1,394	1,399	48,209
46	Vinylidene Chloride	180	1,200	1,380	1,380
47	Chloroform	1,100	200	1,300	1,880
48	Vinyl Acetate	170	930	1,100	1,100
49	Chromium Compounds	186	829	1,015	88,978
	Total	2,185,612	10,485,299	12,670,911	14,391,429

Table 1. Major Chemicals Released in Jefferson County, Kentucky, 1999, All Industries. Data (in pounds) are from 1999 releases reported as of Aug. 1, 2001 in the Toxics Release Inventory. Total Air Emissions >1,000 pounds have been selected and ranked.

These chemical-manufacturing facilities in the Rubbertown area evolved into multi-corporation complexes. During the mid-fifties, Dupont built a Freon production plant adjacent to its neoprene plant. In 1960, Dupont constructed an additional facility to manufacture vinyl fluoride, used exclusively to manufacture the plastic Tedlar. The Union Carbide plant was sold in 1961 to the Rohm and Haas Corporation, and in 1968 a division began making acrylic plastics (Plexiglas) and related products in west Louisville. This corporation recently sold its Plexiglas patent to Atofina, which currently operates portions of this facility, while Rohm and Haas continues to make acrylic emulsions used in latex paints. In 1979, the Borden Chemical Corporation opened a new facility to produce formaldehyde, urea-formaldehyde resins, phenolic resins, and adhesives. The former B.F. Goodrich plant has been divided partially into Zeon Chemicals LP, PolyOne and Oxy Vinyls LP, which currently operate in the complex. DuPont Dow Elastomers, which opened for business in 1996 as a joint venture between DuPont and Dow Chemical Company, manufactures a variety of products ranging from thermoset polymers used in the general rubber industry to high-performance fluoroelastomers used by the chemical processing and automotive industries. Former DuPont products offered by that joint venture include neoprene, Viton, and others. Over the years other manufacturing industries have taken root, developed, and become major economic powers in the area.

These include traditional industries related to tobacco (Brown & Williamson, Philip Morris) and alcohol (Brown-Forman), as well as manufacturing of consumer products (General Electric Appliance Park, Ford Motor Company). Many smaller service facilities, such as dry cleaners and automotive service stations, located across the county as urban landscape sprawled into what had been farmland. These manufacturing industries, numerous others, and a general population of some 680,000 people in Jefferson County require electric power, other utilities, transportation, and waste disposal facilities. In addition to desirable products of commerce, activities of manufacturing, power generation, transportation, and waste management produce numerous gaseous or evaporated materials that are released into the atmosphere, thereby becoming air pollutants.

Major Air Pollutants from Jefferson County Industries

As required by provisions of the Emergency Planning and Community Right-to-Know Act of 1986 and expanded by the Pollution Prevention Act of 1990, industries must report to the Environmental Protection Agency (EPA) estimates of chemicals released into air during commercial activities. These reports are combined into a publicly available EPA database, known as the Toxics Release Inventory (TRI),

which represents best estimates of contributions to air pollution from stationary source plant sites. TRI data are public record, and can be accessed through the Internet^{1,2} for examination in detail. Given the systematic nature and accessibility of this database, TRI data have been chosen as the basis for review of air pollution in Jefferson County. The reader should understand that it is an incomplete review of extant air pollution. These data do not include contributions from mobile sources, which have been estimated to contribute some 6,500,000 pounds of volatile organic compounds annually within Jefferson County. Likewise, air pollution from noncommercial activities and commercial activities that emit less than 500 pounds per year are missing from this review.

		Total Air	Chemical	Electric	Automobile and Trailer	Appliance, Metal, and Other Product	
	Top 20 Chemicals	Emissions	Industries	Utilities	Manufacture	Manufacture	Total
Rank	Chemical	Pounds	% of Total	% of Total	% of Total	% of Total	%
1	Sulfuric Acid	2,605,126	0.1	99.8			99.9
2	Chlorodifluoromethane	2,167,405	100.0				100.0
3	Xylene	1,229,193	6.3		89.6	2.9	98.8
4	Toluene	1,092,994	94.3		3.8		98.1
5	Ammonia	986,667	95.0			4.4	99.4
6	Glycol ethers	637,974	1.1		93.1	5.8	98.0
7	Hydrochloric Acid	587,017	19.6	74.1		6.3	100.0
8	Chloroprene	512,302	100.0				100.0
9	N-Butyl Alcohol	437,763	10.9		89.1		100.0
10	1,1-Dichloro-1-fluoroethane	433,760				100.0	100.0
11	Methyl Methacrylate	269,801	100.0				100.0
12	1,3-Butadiene	261,317	100.0				100.0
13	Methyl Isobutyl Ketone	236,667	0.7		87.3	5.9	100.0
14	Ethyl benzene	204,032	7.7		91.8		99.5
15	Aluminum Fume or Dust	157,387				100.0	100.0
16	1,2,4-Trimethylbenzene	153,513	8.7		90.5		99.3
17	Styrene	108,770	78.0			22.2	100.2
18	N-Methyl-2-Pyrrolidone	86,588			97.5		97.5
19	Methanol	84,380	13.0		82.8		95.7
20	Acrylonitrile	74,960	100.0				100.0

Table 2. Jefferson County Industry-Reported Contributions to Air Pollution. Percentage of Total Air Emissions allocated by industry for top 20 air pollutants, as reported in 1999 Toxics Release Inventory Data.

Table 1 presents a listing of chemicals in order of amount of Total Air Emissions in the Toxics Release Inventory of 1999, the most recent data set currently available. These reported emissions arise by release through discharge stacks or fugitive losses by other means from such sources. In Table 1, air emissions can be compared with Total Releases, which additionally include discharge into waterways, underground, and land disposal. It is evident that most volatile materials such as gaseous or volatile liquids contribute most to air pollution, while less volatile materials such as metal compounds are released into other media.

Table 2 summarizes and attributes reported releases by major industries in Jefferson County for the 20 most abundant chemicals as ranked by Total Air Emissions. This table illustrates the chemicals included in reported chemical emissions of major industries, and characterizes sources of most of the reported releases by type of industry.

The Clean Air Act of 1970, which was amended in 1974, 1977, and 1990, provides a charge to EPA to protect public health with an "ample" margin of safety. However as is often the case with legislative mandates, the specifics required for implementation prove to be difficult. Analysis of potential risks to health of the public requires interpretation of complex toxicological data, and this process is fraught with uncertainties. Difficulties inherent in implementation of such public health policy stem from the intricacies of society, benefits versus potential risks of byproducts from many desirable human activities, debate over conflicting priorities within society, incomplete knowledge regarding impact of pollutants on living systems and on the environment, and the complexity of interactions among chemicals and living systems. Scientific judgments regarding the latter issues fall within the venue of toxicology, the science that attempts to understand the adverse effects on living systems. Within this science arises the imperfect scientific art of risk assessment, which is used to justify decisions and policies that are meant to protect public health. The process of risk assessment relies on toxicological data, which must in large part be derived from tests on animal species rather than tests on humans.

Overview of Toxicological Testing

At this point it may be useful to consider toxicological paradigms that are used to assess the potential toxic effects of chemicals, because a lack of understanding of the following tenets underlies much of the confusion regarding toxicity testing results. The effect of *dose*, or amount of chemical presented to the living system, is foremost and fundamental to the understanding of potential toxic effects. *Toxicity* is the unfavorable integrated response of the organism that has been overwhelmed at some level in some critical subsystem by too much material for successful defensive processing. Living systems, in fact, are intricate chemical systems that are replete with membrane barriers, delivery systems, enzymes, sensors, genetic blueprints, and other chemical systems that control their internal chemical milieu. Throughout life, ex-

Tank in the Rubbertown area.



ogenous chemicals present continual challenges to living systems, which function remarkably in maintaining homeostasis of the organism. However, each of these processes exhibit limits in capabilities for coping with chemical challenges. The object of toxicological testing is to define the critical subsystem(s) that are overwhelmed with increasing chemical dose, and the respective dose limits under conditions of chemical stress. The type of adverse response is of primary interest, and of particular concern are cellular changes that may lead to cancer. Given the potential irreversibility and lethality of many cancers, special rules and policies apply to risk assessments of carcinogenic chemicals.

The *time* of exposure is second only to dose in importance as a determinant of toxicity. Testing paradigms include the experimental situation of *acute* exposure, which describes immediate adverse effects of a relatively large single exposure. However, chronic exposure is more typical of air pollution, which usually involves minute to moderate quantities that may persist for months, years, or lifetimes. For the sake of efficiency and the need for preliminary data, acute testing of toxic chemicals is conducted initially. If needed after acute toxicological testing, *subchronic* dosing involves repeated dosing of animals over about 10% of the lifespan of the test species. Most demanding and expensive is *chronic* animal testing. The latter paradigm involves most of the lifespan of the test species, which usually are young healthy rodents.

Experimental chronic testing rarely proceeds without some compromise in relevancy of the experimental model to the situation of interest. The lack of similarity of animal models to humans in physiology, disparity between dosage and duration of experimental exposures versus real-life situations, inability of experimental exposures to mimic potential toxic effects, and complexity of potential toxic end points all contribute to uncertainty in such testing. In the design of studies, doses are typically chosen over a limited range of 5 to 50-fold. The chosen dose range is based on results obtained from subchronic tests. These studies attempt to include in the dose range a maximum tolerated dose (MTD) in which some frank toxicity is evident, a dose producing a minimal, low effect level (LOAEL), and a level causing no overt adverse effect (NOAEL). The rationale is to produce toxicity that can be studied, and to look at exposure levels just below toxic levels to understand the transition into toxicity. Lower doses are not usually studied, as it is presumed no effect would be evident.

These tests are fraught with limitations consequently testing may not detect very subtle changes at low doses. On the other hand, large dosage, such as the MTD, often overwhelm normal defenses that serve to protect the organism at routine exposures. There is no endpoint that directly indicates safety in these tests. Rather, that desirable negative entity, safety, is noted by the absence of toxicity. Given the focus of testing at the point of toxicity on the dose scale, little information is available regarding the dose-response function until toxicity is evident. For these reasons the relevancy of animal toxicological testing to low-dose, chronic toxicity is often subject to question, and this absence of information is described as test *uncertainty*. Rarely are results of toxicity testing satisfying to the public. Proponents of industry argue that governmental environmental policy based on such testing is overly restrictive and burdensome economically, while environmental interests and many residents of affected areas ar-

gue that such regulations are insufficient to protect public health. Rarely do participants in these debates understand the limitations inherent in policy underlying exposure risk assessment. However imperfect, decisions must be made on the basis of available data.

Toxicological tests conducted on animals must be *extrapolated* to humans, and this scientific judgment must involve some means to compensate for differences in physiology and other factors that influence internal exposure and sensitivity to toxicants. Given the uncertainties inherent in toxicological testing, governmental regulators must evaluate data and set standards by a combination of science and policy. To this end, the EPA has developed a system of reference inhalation concentrations and oral doses, which represent daily exposures that are believed to result in no significant adverse effects. These reference values include uncertainty factors, which are multiplicative safety factors. These uncertainty adjustments include factors of up to 10-fold each for variations in human susceptibilities, for extrapolation from animals to man, for conversion from subchronic to chronic exposure data, and for extrapolation from LOAEL (lowest data point at which there was an observed toxic or adverse effect) to NOAEL (highest data point at which there was not an observed toxic or adverse effect) if not evident in the data. These are the actual data points from human clinical or experimental animal studies. As stated, these factors are multiplicative and are applied sequentially; this policy may result in reference doses being set at some 10,000 times less than doses that actually produce toxicity in animal studies.

For health risk assessments, the EPA has compiled a database of toxicological studies known as the Integrated Risk Information System (*IRIS*), which is available on the Internet³. The following are summaries of toxicological studies along with evident toxic effects and citations to the primary work. Recommended exposure limits, including the inhalation reference concentration (*RfC*) and oral reference dose (*RfD*), are based on the assumption that thresholds exist for certain toxic effects such as cellular necrosis. Of relevance to air pollutants, the inhalation *RfC* considers toxic effects for both the respiratory system and for effects peripheral to the respiratory system. The *RfC* is expressed in units of mg per cubic meter (mg/m^3). To convert commonly used volumetric units of parts per million (*ppm*) to mg/m^3 requires the compound molecular weight (*MW*) and the following equation, adjusted by the molar gas volume at a temperature of 25 °C and 760 mm Hg atmospheric pressure:

$$mg/m^3 = \frac{ppm \times MW}{24.45}$$

In addition to experimental testing, governmental environmental policy often relies on information derived from epidemiological studies. These data are derived from retrospective studies under exposure conditions relevant to human situations. Provided that such studies are carefully controlled for potentially confounding, extraneous exposures, epidemiological studies may provide our best evidence of increased risk with chronic low-level exposure to chemicals. Additional information is derived from exposure in the workplace. For occupational exposure, the Occupational Safety and Health Administration (OSHA) has promulgated legal limits for worker exposures, known as Permissible Exposure Limits (*PEL*). Similarly the American Conference of Governmental Industrial Hygienists (ACGIH) provides guidelines known as Threshold Limit Values (*TLV*) as recommended limits, which are believed to be safe for exposure in the workplace on a 40 hour/week basis. *TLV* limits generally are published as time-weighted average (*TLV-TWA*) values, but short-term (15 minute) exposure limits (*TLV-STEL*) and absolute ceiling limits (*TLV-C*) are listed for certain toxic compounds where *TLV-TWA* are not sufficiently protective. Panels of experts set these limits through judgments based on past experience and on data from epidemiological studies. These limits periodically are revised (usually downward), as new adverse health effects are discovered or toxic effects understood. These limits are designed for normal healthy workers, but may not provide protection to more sensitive members of the population at large.

Potential Health Effects of Major Air Pollutants

From these expert sources and other literature, potential effects are summarized below for the 20 most abundant air pollutants reported as released in Jefferson County. These are listed by compound with Chemical Abstracts registry number (*CASRN*), molecular weight (*MW*), general uses, potential health effects, testing data, and exposure reference concentrations, as available. These summaries reveal the quality of data used to make judgments about how to protect public health with an ample margin of safety.

Sulfuric Acid Aerosols (*CASRN* 7664-93-9, *MW* 98.08)

This pollutant is a suspension of very corrosive aqueous sulfuric acid in air. It is a byproduct of combustion, primarily of coal that contains sulfur. In solution, its acidity and corrosivity depends on the concentration of acid in water. This acid is soluble in moist tissues and stimulates bronchoconstriction and mucous production. Adverse health effects include exacerbation of asthma, bronchitis, and in-

creased airway resistance at exposures in the range of 1 - 5 ppm. The EPA IRIS database does not list this air pollutant, but sulfuric acid is closely related to the hydration product of sulfur dioxide, which is an EPA criteria pollutant under the National Ambient Air Quality Standards. Under these regulations, primary standards are established for pollutants considered to be harmful to public health and the environment. The Clean Air Act established these limits to protect public health, including the health of sensitive populations such as asthmatics, children, and the elderly. Among these primary standards is the 24-hour average limit for sulfur dioxide of 0.14 ppm. For sulfur dioxide exposure in industrial situations, the ACGIH and OSHA have set a *TLV-TWA* of 2 ppm and a *TLV-STEL* of 5 ppm. Sulfuric acid aerosols are a major contributor to acid rain, and are believed to contribute to exposures of fine particulate materials with health effects on the pulmonary and cardiovascular systems.

Chlorodifluoromethane (*CASRN* 75-45-6, *MW* 86.46)

This hydrochlorofluorocarbon, also known as CFC22, has been used largely as a refrigerant and foaming agent for foam insulation. Use of this material is slated for phase out by 2010 under EPA plans to reduce use of materials that are considered responsible for destruction of the stratospheric ozone layer. Such ozone depleting chemicals increase the amount of ultraviolet radiation reaching the surface of the earth. This ultraviolet radiation, normally absorbed by stratospheric ozone, causes increased incidence of skin cancer and cataract formation. The EPA IRIS Reference Concentration (*RfC*) for chlorodifluoromethane has been set at 50 mg/m³ (14 ppm). This value involves an uncertainty factor of 100, which includes a factor of 10 to protect unusually sensitive individuals. OSHA and ACGIH have an 8-hour *TLV-TWA* of 1,000 ppm chlorodifluoromethane. Experimental studies involved rats exposed for 5 hours/day, 5 days/week for over 2 years to air containing 0, 1000, 10,000, or 50,000 ppm of chlorodifluoromethane. There were no exposure-related effects on mortality, clinical signs, food consumption, body weight, behavior, ocular characteristics, hematology, clinical pathology, urinalysis, organ weights, or gross or microscopic pathology. Female rats in the 50,000-ppm group exhibited a statistically significant increase in liver, kidney, adrenal, and pituitary weights. Non-neoplastic effects were similar for both treated and control animals and were limited to typical age-related degenerative changes. This substance/agent has not yet undergone a complete evaluation for determination of human carcinogenic potential under the EPA IRIS program.

Xylene (CASRN 1330-20-7, MW 106.17)

This mixture of dimethylbenzene isomers is used largely as a solvent in chemical and plastics applications. Based on ACGIH recommendation, OSHA has set limits for industrial exposure to a TWA of 100 ppm and a 15-minute STEL of 150 ppm to prevent risks of narcosis, changes in blood cell levels, and irritant effects at elevated levels. At this time IRIS does not provide an RfC for xylene. However a reference oral dose (RfD) has been set to 2 mg/kg body weight/day, based on hyperactivity, decreased body weight and increased mortality observed in studies of male and female rats and mice given oral doses of 0, 250, or 500 mg/kg/day (rats); and 0, 500, or 1000 mg/kg/day (mice) for 5 days/week for 103 weeks. Animals were observed for clinical signs of toxicity, body weight gain, and mortality. All animals that died or were killed at sacrifice were given gross necropsy and histological examinations. Dose-related mortality increased in male rats, and the increase was significantly greater in the high-dose group when compared with control animals. Mice treated with the high dose exhibited hyperactivity, which is a manifestation of central nervous system toxicity. There were no compound-related histopathologic lesions in any of the treated rats or mice. There is no available evidence of human carcinogenicity for xylene, and orally administered technical xylene mixtures did not result in an insignificant increase in tumor incidence in rats or mice of either sex. Therefore the EPA classification is D, not classifiable as to human carcinogenicity.

Toluene (CASRN 108-88-3, MW 92.14)

Toluene is a flammable, colorless liquid with an aromatic hydrocarbon odor. It is an organic solvent used in preparation of chemicals, adhesives, resins, coatings, and paint. As with chemically similar xylene, ACGIH and OSHA have set exposure limits for toluene at 100 ppm as an 8-hour TWA and 150 ppm as a 15-minute STEL. In humans, toluene is a known respiratory irritant with central nervous system effects. A cross-sectional epidemiological study was conducted involving 30 exposed female workers employed at an electronics assembly plant where toluene was emitted from glue. Toluene levels reported in the study were from personal sample monitoring. A battery of eight neurobehavioral tests were administered to all exposed and control workers. From this study the LOAEL was 332 mg/m³ (88 ppm). Because the CNS effect was judged to be a more severe and relevant endpoint than respiratory irritation, this toxic effect was used to derive the EPA RfC of 0.4 mg/m³ (0.1 ppm). With respect to carcinogenicity, EPA has toluene classified as group D, not classifiable as to human carcinogenicity due to lack of human data and insufficient chronic animal studies. At present there is no evidence of carcinogenicity.

Ammonia (CASRN 7664-41-7, MW 17.03)

This colorless gas is used in chemical syntheses, and as a refrigerant. Ammonia has a pungent odor characteristic of drying urine, which is perceptible at concentrations above about 50 ppm. Exposures to high concentrations cause symptoms including eye, nose, and throat irritation, difficulty in breathing, bronchospasm and chest pain, pulmonary edema, and chemical burns due to the alkaline nature of aqueous ammonia solutions. IRIS provides an RfC value of 0.1 mg/m³ (0.14 ppm), which includes an uncertainty factor of 30 relative to NOAEL determined in studies. The critical end points used in this determination were changes in subjective symptoms in epidemiological studies. In one such study a questionnaire was administered to workers to obtain information on exposure and work histories and to determine eye, skin and respiratory symptomatology. Differences in reported symptoms and objective lung function tests were evaluated using spirometry values with age, height, and cigarette pack-years smoked as covariates in linear regression analysis. No statistical difference in the prevalence of symptoms was evident between the exposed and control groups, although workers reported that exposure at the plant had aggravated specific symptoms including coughing, wheezing, nasal complaints, eye irritation, throat discomfort and skin problems. In another study, groups of four healthy human volunteers were exposed 5 days/week to 25, 50, or 100 ppm of ammonia for 6 weeks. Subjective and objective indications of eye and respiratory tract irritation, pulse rate, respiration rate and function, and difficulty in performing simple cognitive tasks were examined to assess toxicity. No abnormalities of the chest, heart, vital organs, neurological response, apparent motor function, or significant weight changes were observed during weekly medical examinations. Transient irritation of the nose and throat was observed at 50 ppm or greater. Ammonia has not undergone evaluation or determination of potential for human carcinogenicity.

Certain Glycol Ethers

This is a heterogeneous group of chemicals used as solvents for resins, varnishes, coatings, and sealants. As such, the group does not stipulate specific compounds. A member of this group, 2-methoxyethanol (CASRN 109-86-4, MW 76.10), has been evaluated and included in the IRIS database, and has been assigned the RfC value of 0.02 mg/m³ (0.006 ppm), which includes an uncertainty factor of 1000. This congener appears to be more toxic than 2-ethoxyethanol (MW 90.12, RfC 0.2 mg/m³) and 2-butoxyethanol (MW 118.18, RfC 13 mg/m³). Human case studies report that the neurological and hematological systems are target organ systems for 2-methoxyethanol toxicity. One human case study examined the possible effects of exposure on the fertility of

workers and found no reproductive effects. Data in animals suggest that the testes and the developing fetus may be targets for 2-methoxyethanol toxicity. The rabbit is more sensitive to the testicular effects as compared with rats and mice. IRIS does not include assessment of potential carcinogenicity of methoxyethanol.

Hydrochloric Acid Aerosols

This acidic mist is an aqueous solution of hydrogen chloride gas (CASRN 7647-01-0, MW 36.46). Like sulfuric acid, its acidity and corrosivity depends on the concentration of acid in water. Corrosive burns will result from inhalation of acid fumes or skin contact with concentrated acid, and chemical pneumonitis may occur after inhalation of acid vapor. The toxicity is dependent on the concentration of acid and duration of exposure. IRIS lists an RfC of 0.02 mg/m³ (0.013 ppm) for pure hydrogen chloride gas, which includes an uncertainty factor of 300. This value is based largely on a chronic inhalation study in rats, which noted increased epithelial or squamous hyperplasia in the nasal mucosa of exposed animals. Such cellular changes are common with toxicants that cause rapid turnover due to cellular destruction.

Chloroprene (CASRN 126-99-8, MW 88.54)

This volatile, reactive monomer (2-chloro-1,3-butadiene) is used in production of polychloroprene or neoprene rubber, which is used for manufacture of tires, wire coatings, and tubing. As its commercial use is limited primarily to two facilities in the US, health effects of this monomer have not been as widely studied as many other industrial chemicals. Epidemiological studies have been inconclusive for increased risk of cancer due to occupational exposures. OSHA has established an 8-hour TWA PEL of 10 ppm, with a notation of susceptibility of dermal exposure. ACGIH has a 10-ppm TLV-TWA, with a skin notation, while NIOSH recommended a limit of 1 ppm, measured over a 15-minute period. Chloroprene is currently under review by the National Toxicology Program (NTP), which has conducted a 2-year inhalation study in rats and mice at 0, 13, 32, and 80 ppm. Concentration-dependent increases in incidence of adenomas or carcinomas of the oral cavity, kidney, and thyroid were seen at higher exposures in male rats. Similar cancers in oral cavity and kidney, and fibroadenoma in mammary gland tissue were observed at highest concentrations in female rats. Mice were more sensitive than rats. Survival was significantly less in all treated female mice, and with two highest-treated male groups of mice, than with untreated control animals. Increased incidences of hepatocellular carcinomas were observed in all treated groups of female mice. Based on its similarity in structure to 1-3-butadiene and the weight of evidence, which is inconclusive in humans but positive in two species of ani-

mals, chloroprene likely will be classified by EPA as a probable human carcinogen (Group B2). Given an absence of NOAEL in animal studies, no safe Reference Concentration has been set.

N-Butyl Alcohol (CASRN MW 74.12)

N-Butyl alcohol is a colorless, highly refractive liquid with a mild vinous odor that causes irritation of the eyes and headaches in occupational settings. This alcohol is used as a solvent for fats, waxes, varnish, and in manufacture of lacquers, rayon, and detergents. The OSHA and ACGIH limits are a 50-ppm ceiling, with a skin notation. EPA IRIS has not determined an RfC, but has evaluated toxicity following subchronic oral testing in rats. Groups of male and female rats were orally dosed daily with 0, 30, 125 and 500 mg/kg/day of n-butanol for 13 weeks. Data did not show any dose-related differences between control and treated animals in body and organ weight changes, food consumption, morbidity, mortality, and in ophthalmologic, gross, and histopathologic examinations. Ataxia and hypoactivity were consistently observed in high-dosed (500 mg/kg/day) males and females during the final 6 weeks of the dosing period. Application of an uncertainty factor of 1000 derived an RfD of 0.1 mg/kg/day, or 9 mg/day for a 70-kg person. EPA has not evaluated its potential as a carcinogen. Based on the lack of data, EPA has classified n-butanol as Class D, not classifiable as to human carcinogenicity.

1,1-Dichloro-1-fluoroethane (CASRN 1717-00-6, MW 116.95)

This hydrochlorofluorocarbon, also known as HCFC 141b, is used as a refrigerant and as a foaming agent for application of urethane and other foam insulation. This HCFC is slated for phase out in 2003 after which production or importation will be prohibited, as it is an ozone-depleting chlorofluorocarbon. In published studies, acute toxicity in animals is fairly low, with lethal concentration (LC50) values usually above 500,000 ppm. In a subchronic inhalation toxicity study in rats and rabbits, a reduction in body weight and an increase in serum cholesterol and triglycerides was observed at 8,000 ppm in males and 20,000 ppm in females. Recent reports suggest that mammalian oxidative enzymes can activate 1,1-dichloro-1-fluoroethane to reactive metabolites, but the extent to which this happens is unclear from available data. EPA IRIS does not include a listing for 1,1-dichloro-1-fluoroethane.

Methyl Methacrylate (CASRN 80-62-6, MW 100.12)

This pungent monomer polymerizes easily to form transparent plastic, known commercially as Lucite, Plexiglas, or Perspex. Inhalation studies were conducted for 2 years in rats at levels up to about 400 ppm. These noted increased incidence at high concentrations of inflammatory reactions in mucosa and submucosa, as well as hyperplasia of submucosal glands in the anterior regions of the nasal cavity. This cytotoxicity led to degeneration and atrophy in epithelium of the olfactory region. These effects are believed related to hydrolysis of methyl methacrylate to methacrylic acid. Support for this mechanism stems from observations that methyl, ethyl, and butyl acrylates, as well as acrylic and acetic acids cause similar olfactory-specific lesions. An RfC value of 0.7 mg/m³ (0.17 ppm) has been set, which includes an uncertainty factor of 10 derived from these studies. Results of 2-year studies conducted by the NTP in three animal species have led to characterization of methyl methacrylate as a Group E chemical. This designation indicates evidence of non-carcinogenicity for humans, based on the weight of evidence from animal and epidemiological studies.

1,3-Butadiene (CASRN 25339-57-5, MW 54.09)

This colorless gaseous monomer is used in high volume for production of a variety of materials, including butadiene, styrene, and nitrile rubber materials and acrylonitrile-butadiene-styrene (ABS) plastic. Toxicological studies include 1 to 2 year inhalation studies in rats and mice, which revealed tumors in each species. In mice inhaling 625 or 1250 ppm of butadiene, tumors occurred throughout the body and included hemangiosarcomas of the heart, lymphomas and alveolar/bronchiolar adenomas/carcinomas. Rats tested with 1,000 or 8,000 ppm exhibited significant increases in incidence in tumors including mammary gland tumors, thyroid follicular adenomas and carcinomas, and Leydig cell adenomas and carcinomas. Carcinogenic effects of 1,3-butadiene are attributed to the oxidative metabolites 3,4-epoxybutane and/or 1,2,3,4-diepoxybutane. These metabolites are potent alkylating agents, and have been shown to be mutagenic and carcinogenic in separate tests. From these studies 1,3-butadiene has been classified as B2, a probable human carcinogen. Linear extrapolation from animal studies has produced a risk estimate of 1 in 1,000,000 for lifetime exposure to a concentration of 4 ng/m³ (10⁻⁹g/m³, 1.18 x 10⁻⁶ ppm). Given the carcinogenic risks of this chemical, safe exposure limits in forms of TLV, PEL, or RfC have not been determined.

Methyl Isobutyl Ketone (CASRN 108-10-1, MW 100.16)

This colorless liquid, known also as MIBK, is most often used as a solvent in general industrial application. An occupational exposure TLV limit of 50 ppm has been set. A few reports exist in scientific literature of an interaction that enhances neurological toxicity of n-hexane and its metabolites. EPA IRIS data has been withdrawn pending review. No RfC is available.

Ethylbenzene (CASRN 100-41-4, MW 106.17)

This colorless, flammable liquid closely related to toluene is used for production of styrene and as a solvent for resins. Exposures to high concentrations are irritating to eyes and mucous membranes, and can cause headache, dermatitis, and narcosis. The OSHA PEL establishes limits of 100 ppm TWA and 125 ppm STEL for ethyl benzene; these limits are consistent with the ACGIH recommendation. Transient eye irritation occurs in humans at vapor concentrations of 200 ppm; the short-term limit is necessary to protect exposed workers from risk of such irritation in brief excursions above the 100-ppm level. Various animal tests involving rats and rabbits have shown little evidence of carcinogenicity, but have indicated developmental toxicity at high exposure levels. EPA IRIS indicates a presumed safe RfC of 1 mg/m³ (0.23 ppm), which includes an uncertainty factor of 300, which is based on effects in developmental studies. The weight of evidence for carcinogenicity classification is D, not classifiable as a human carcinogen.

Aluminum Fume or Dust

Aluminum inhalation exposure is an issue in industries that generate aluminum dust by machining or fumes through smelting operations. At issue is the particle size, as particles of 5 - 10 µm in diameter will be inhaled into airways, and fine particles of 2.5 µm or less in diameter will reach alveolar spaces in the lungs. Pulmonary fibrosis has been reported in workers exposed to fine aluminum dust. Such exposures have resulted in severe encephalopathy with lack of coordination, tremor with intentional movement, and cognitive deficits observed in heavily exposed workers. Aluminum smelter workers exposed to long term, low level exposures developed spinocerebellar degeneration without involvement of peripheral nerves. The OSHA PEL limit is 15 mg/m³ total particulate limit for this substance. The ACGIH recommends an 8-hour average limit of 10 mg/m³ for aluminum metal and oxide, and 5 mg/m³ for aluminum fumes. No RfC value is available for safe public exposure.

1,2,4-Trimethylbenzene (CASRN 95-63-6, MW 120.19)

This material is a solvent related to xylene. The OSHA PEL and ACGIH TLV for all isomers of trimethylbenzene is 25 ppm as an 8-hour TWA, which is based on reports of symptoms among 27 workers exposed to a solvent containing 30 percent 1,3,5-trimethylbenzene and 50 percent 1,2,3-trimethylbenzene. A significant number were reported to have experienced nervousness, tension and anxiety, and asthmatic bronchitis. Samples of peripheral blood of these workers noted a tendency to hypochromic anemia and a somewhat abnormal clotting ability. These workers had been occupationally exposed to total hydrocarbon concentrations ranging from 10 to 60 ppm for several years. EPA does not list an RfC for trimethylbenzene.

Styrene (CASRN 100-42-5, MW 104.15)

Styrene monomer is a colorless, oily liquid with an aromatic odor that is used to make polystyrene and ABS plastics. It is employed extensively in construction of fiberglass boats. Given its widespread use for manufacturing plastics, it has been studied extensively. ACGIH TLV and OSHA PEL values have been set at 50 ppm for the 8-hour TWA and 100 ppm as a 15-minute STEL, which are based on its potential effects on the central nervous system at higher exposure. Workplace exposures to styrene are associated with health effects ranging from irritation to narcosis to neuropathies, which constitute impairments of health. EPA has determined an RfC of 1 mg/m³ (0.23 ppm), which includes an uncertainty factor of 30 fold. The carcinogenic potential of styrene is subject to scientific debate. As yet the EPA has not published a classification of styrene with respect to its carcinogenicity to humans.

N-Methyl-2-pyrrolidone (CASRN 872-50-4, MW 99.13)

N-methyl-2-pyrrolidone (NMP) is a clear liquid with a high boiling point. This solvent is used in a variety of industries, including as a medium for polymerization and as a solvent for finished polymers, for petroleum refining, microelectronics applications, and as a replacement for dichloromethane in paint stripping operations. As a result of its high boiling point, NMP exhibits a low vapor pressure at room temperature, which offers the advantage of diminished potential exposure for industrial uses. NMP is miscible with both aqueous and organic solvents, and this property promotes absorption through skin. There is a relative paucity of information concerning human exposure to this material, despite its increasing use. From studies available in the sci-

entific literature, NMP is readily absorbed through the skin, the respiratory, and gastrointestinal tracts; is distributed to all major organs; and is biotransformed to polar metabolites that are excreted in urine. Animal studies have shown that exposure to NMP may cause degenerative changes in the respiratory system, the hematopoietic system, and in lymphoid tissues. Effects including irregular respiration and lethargy after inhalation and oral administration may be due to a neurotoxic effect. Studies on reproductive toxicity show that NMP may cause developmental toxicity at doses causing mild or no maternal toxicity, with a noted effect of fetal resorption or stillbirth, and low birth weight and delayed ossification in surviving young. The toxicity of NMP in humans is not well known. In the occupational setting, an irritant effect noted with skin and eyes predicts that NMP may be a moderate to severe irritant. Reversible dermatitis has been reported in workers after a few days of work with NMP, and experimental skin exposure to NMP in humans caused transient irritation. Studies in Sweden of 6 male volunteers exposed to NMP for 8 hours at concentrations of 10, 24, or 50

Coal fired power plant in west end of Louisville.



mg/m³ noted no subjective self reported sensations of eye, nasal, or respiratory irritation. Neither were the pulmonary functions or the nasal cavities affected by the NMP exposure. This study characterized NMP as a mild irritant. A convincing human case report exists in recent literature concerning a case of intrauterine growth retardation followed by fetal demise at 31 weeks gestation. This involved a laboratory worker with no other apparent risk factors, who sustained substantial occupational exposure to NMP throughout the first trimester of pregnancy. Reference concentrations for safe human exposure are not readily available from EPA, OSHA, or ACGIH.

Methanol (CASRN 67-56-1, MW 32.04)

Methyl alcohol is widely used in industrial applications as a solvent, reagent for synthesis of formaldehyde and pharmaceuticals, fuel, and antifreeze and octane booster for diesel oil, and in domestic applications as fuel for picnic stoves and a component of refinishing solutions and polishes. There is substantial human experience with methanol exposure, as it has been the source of poisonings through intentional or mistaken ingestion as an alternative to ethyl alcohol. Methanol is a mucosal irritant and produces nausea, vomiting, and abdominal pain in more than half of the cases following ingestion. Pancreatitis is commonly seen, as is elevation of hepatic aminotransferase enzymes, which are early indicators of liver toxicity. A key feature noted with severe methanol poisoning is ocular toxicity; a major oxidative metabolite, formic acid, is toxic to the optic nerve. OSHA, ACGIH, and NIOSH have promulgated limits as an 8-hour TWA of 200 ppm, a STEL of 250 ppm, and include a skin warning.

EPA has published reference dose recommendations in IRIS based on subchronic feeding studies in rats, but has not established reference concentrations. Adverse effects determining the NOAEL were increased levels of liver enzymes. The RfD was set at 50 mg/kg body weight /day, and this value includes an uncertainty factor of 1000 based on need for extrapolation from animal studies, from subchronic to chronic studies, and for sensitive individuals. No carcinogenicity risk estimate for lifetime exposure has been set.

Acrylonitrile (CASRN 107-13-1, MW 53.06)

Acrylonitrile is used in making acrylic fibers, synthesis of acrylic and ABS plastics, coatings, and adhesives. Acute poisoning results in liberation of cyanide through oxidative metabolism, and poorly understood excitatory events that suggest neurological toxicity. From IRIS the critical effects noted in chronic animal studies are degeneration and inflammation of nasal respiratory epithelium and hyperplasia of mucous secreting cells. Studies using inflammation and degeneration of nasal respiratory epithelium and hyperplasia of mucous secreting cells as toxic endpoints yielded an RfC of 2 µg/m³ (9 x 10⁻⁴ ppm), which includes an uncertainty factor of 1,000. Evidence for human carcinogenicity includes a weight-of-evidence characterization of acrylonitrile as EPA category B1; a probable human carcinogen. Observation of a statistically significant increase in incidence of lung cancer in exposed workers, and observation of tumors, generally astrocytomas in the brain in two rat strains exposed by various routes (drinking water, oral dosage, and inhalation) formed the basis for this classification. Linear extrapolation from animal studies has produced a risk estimate of 1 in

Table 3. Comparison of Selected Toxic Air Pollutants Measured in 1955-57 and 2000-02.

Compound	Maximum Concentration 1956-57 Special Air Pollution Study ⁽⁴⁾	Maximum Concentration 2000-02 UofL Study ⁽⁶⁾
	ppb	ppb
Acrylonitrile	335	1.1
Benzene	144	3.1
1,3-Butadiene	1,830	6.0
Chloroform	43	1.3
Chloroprene	218	36.6
Toluene	265	91.1
Xylene	121	1.0
Vinyl Chloride	5,930	2.0

*Parts per billion volumetric measure; 1 part pollutant per 1 billion parts air; 1 ppb = 0.001 ppm.

Values are maximum observed levels evident in published data, but are not comparable in sampling location or time.

1,000,000 for lifetime exposure to a concentration of 20 ng/m^3 ($20 \times 10^{-9} \text{ g/m}^3$, 9.2×10^{-6} ppm). Comparison of this risk estimate with that of the RfC above illustrates the uncertainty inherent in such risk analysis, which involves extrapolation of higher dose-response relationships. Safe exposure limits in forms of TLV or PEL have not been determined.

Evaluation of Air Pollution in Jefferson County

Jefferson County air pollution was evaluated in a special air pollution study during 1956 and 1957. Results of this study were presented in response to a 1992 petition filed by residents of west Louisville. The Agency for Toxic Substances and Disease Registry (ATSDR) has compiled information and reviewed available environmental monitoring and health outcome data for the area. (For details of these studies see ⁴). In response to continuing public concerns, the EPA has joined with stakeholders in this community to provide additional environmental monitoring and assessment of air pollution through a Community Based Environmental Protection (CBEP) Project ⁵. The stated goal is "to reduce human health and ecological risks and improve conditions to enhance the environment and the community's quality of life in West Louisville, Kentucky." Initial environmental sampling under the CBEP project was accomplished during the period of April 2000 to April 2001 through joint efforts of EPA Region IV, Jefferson County Air Pollution Control District, and the University of Louisville on behalf of the West Jefferson County Community Task Force. The University of Louisville currently continues these efforts and publishes environmental air monitoring data via the Internet⁶. Data from these efforts will result in risk assessment and risk management work plans to address the stated goals of the project under auspices of the Jefferson County Air Pollution Control District.

From initial inspection of this monitoring data, many of the toxic chemicals noted in this article are present continuously in Louisville air at measurable concentrations. However, present monitoring efforts indicate that concentrations of these chemicals are considerably less than those measured during the study conducted in 1956-57, as presented in Table 3. Presumably this improvement is due to increased control of industrial processes and other efforts that have developed in response to increased antipollution legislation, awareness of air pollution and its potential health effects, and realization of the economic benefits of diminished emissions. It may be reassuring to consider that concentrations of chemical pollutants in the air at present are several orders of mag-



Stacks in Rubbertown Area

nitude less than those that cause the frank health effects noted above. Efforts by industry, prompted by public awareness and increased environmental regulation, have reduced levels of air pollutants. On the other hand, present monitoring efforts indicate the need for continued efforts to reduce emissions in order to diminish the negative effects of air pollutants on public health.

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Mobile Emissions in Urban Areas: Current Trends and the Outlook for Existing Control Methods

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INTRODUCTION

Mobile emissions are a significant source of the ozone precursors, volatile organic compounds (VOCs) and nitrogen oxides (NO_x), carbon monoxide, and air toxics. Significant reductions in these pollutants have occurred over the last thirty years as a result of environmental and transportation legislation such as the Clean Air Act of 1970, the Clean Air Act Amendments of 1990, and the Intermodal Surface Transportation Efficiency Act of 1991. These laws require significant technological improvements in automobiles and trucks, changes in available fuels, and integration of air quality concerns into the transportation planning process. As a result, these emissions have been reduced ninety to ninety-eight percent since 1967, and further reductions are expected from introduction of the Supplementary Federal Test Procedure (SFTP) for vehicle testing, the introduction of the Low Emission Vehicle program, and Tier 2 standards.

Despite the significant progress that has been made, approximately 62 million people still live in counties that have air quality concentrations above the NAAQS with around 54 million people in counties that violate the ozone NAAQS alone. In addition, the recent court approval of the 8-hour ozone standard will increase the number of people in counties violating an NAAQS to 125 million as shown in Figure 1. While the trend in mobile emissions has been steadily downward, the levels of reductions have been decreasing indicating some minimum level that can be attained while using the current type of vehicle powered by the internal combustion engine.



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BACKGROUND

Air pollutant emissions come from four primary sources: stationary, area, mobile, and biogenic. Stationary, or point sources are factories, power plants and other large emitters. Area sources represent smaller point sources that may be distributed throughout an urban area such as dry cleaners and body shops. Mobile sources are further divided into two categories. On-road sources represent cars and trucks. Off-road vehicle emissions come from airplanes, marine vessels, and other land-based equipment such as farm equipment, construction equipment and yard equipment. Biogenic source pollutants are naturally occurring sources such as wind-blown dust, wildfires, and volatile organic compound emissions from vegetation.

Urban air quality is most directly affected by emissions from stationary, area, and mobile sources, and pollution control agencies have adopted control strategies specific to each

type of emission. Stationary and area sources can be controlled and evaluated through permitting and continuous monitoring. Inspection/maintenance programs, fuel restrictions, and transportation planning and construction are used to limit mobile emissions. Since biogenic emissions are naturally occurring, their control is limited, but the amount and type of emissions can affect the control strategies that are adopted by a specific region.

The Clean Air Act of 1970 and the Clean Air Act Amendments of 1990 defined National Ambient Air Quality Standards (NAAQS) for six criteria pollutants: carbon monoxide (CO), lead (pb), nitrogen dioxide (NO₂), ozone (O₃), particulate matter (PM), and sulfur dioxide (SO₂). In addition, the USEPA has established regulations for air toxic emissions that specify maximum levels of exposure for 188 hazardous air pollutants of which thirty-three are deemed to be the most destructive to human health. All of the standards are set at levels required to protect human health during differing lengths of exposure to the pollutants. Figures 2 through 7 present the relative contributions of the primary stationary and mobile emissions sources as determined by the USEPA National Air Pollution Emission Trends, 1900 - 1998. An examination of these figures shows that mobile sources are the major source of VOCs, NO_x, and CO, and are a significant contributor to PM₁₀ and PM_{2.5}.

MOBILE EMISSIONS TRENDS

Mobile sources are significant contributors of the emissions that lead to violations of the NAAQS for carbon monoxide, ozone and particulate matter. Carbon monoxide and particulate matter are emitted directly from motor vehicles while ozone forms in the atmosphere from the emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOC). In 1999, mobile sources accounted for 79, 47, and 53 percent of CO, VOCs, and NO_x, respectively. These percentages are averages across all areas of the United States, and the contribution from mobile sources in some urban areas can be significantly higher.

The pollutants of most concern in examining mobile emissions are VOCs and NO_x, which form ozone, and carbon monoxide, particulate matter, and toxic emissions. An examination of Table 1 reveals the contributions from mobile sources to pollutant levels has remained constant over the last ten years for carbon monoxide and shows slight increases for VOCs and

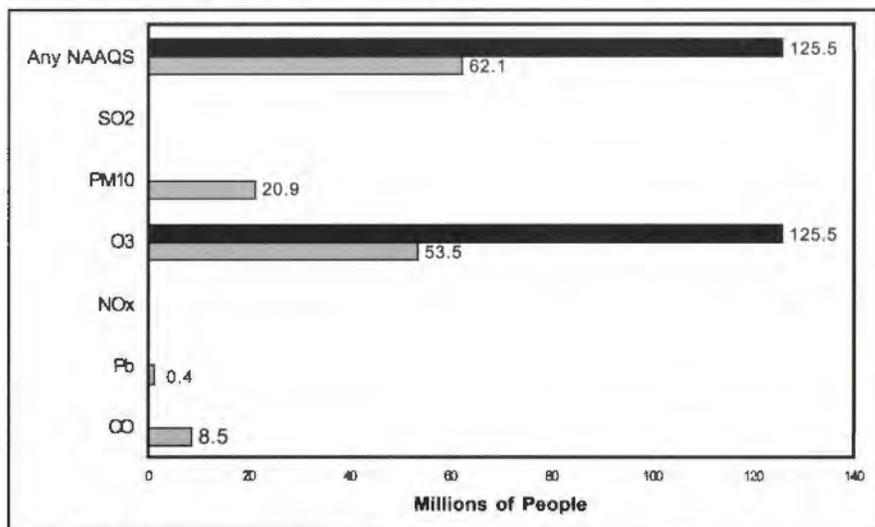
NO_x. As one can see in Figures 8 through 10 for CO, VOC, and NO_x emissions, respectively, CO mobile emissions have been decreasing at the same rate as emissions from all other sources, while VOC mobile emissions have been decreasing at a slower rate than from other sources. NO_x emissions have increased steadily during the same time period. Currently, toxic emissions from mobile sources are calculated as a percentage of VOCs so that one can assume that air toxics follow the same trends as VOCs.

ON-ROAD EMISSIONS

One interpretation of this data can be seen as encouraging. Total emissions, stationary emissions, and mobile emissions of CO and VOCs have been decreasing since 1970, and fewer people live in counties that have violations of the NAAQS. Total emissions of CO, and VOCs have been reduced by 31 percent and 42 percent, respectively, since 1970. In contrast, NO_x has increased by 17 percent over the same period of time. For mobile emissions, VOCs are down by 48 percent, while CO and NO_x are up by 45 percent and 40 percent, respectively since 1970. The on-road segment of mobile emissions shows reductions of 43 and 59 percent for CO and VOCs, respectively, and NO_x emissions are up 5 percent. Off-road emissions, however, are all up by 66 percent, 31 percent, and 173 percent for CO, VOCs, and NO_x, respectively.

In other words, mobile emissions are being reduced at or near the same rate as stationary emissions. However, a less

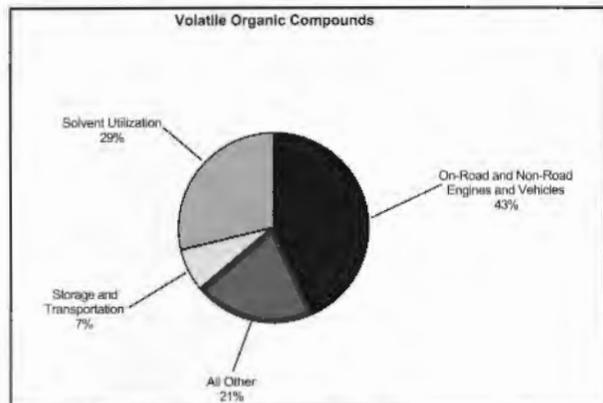
Figure 1
Number of People Living in Counties with Air Quality Concentrations Above the Level of the NAAQS in 1999



Black bars represent proposed 8-hour ozone standard

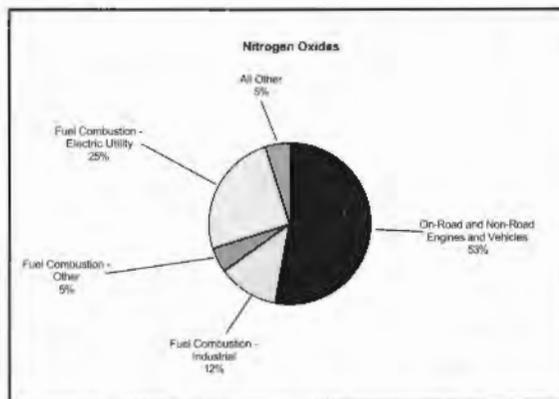
Source: USEPA; Office of Air Quality Planning and Standards; Latest Findings on National Air Quality: 1999 Status and Trends, EPA-454/F-00-002; Research Triangle Park, NC; August 2000.

Figure 2



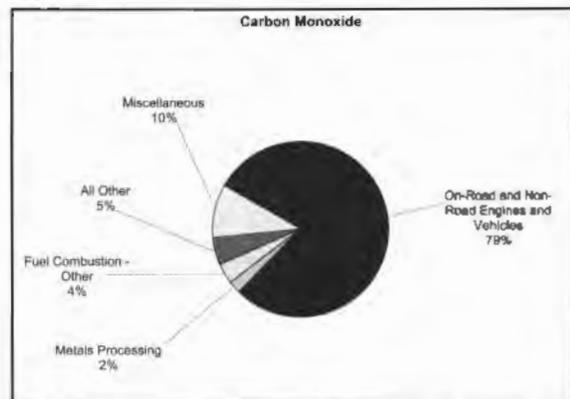
Principal Sources of Volatile Organic Compounds in 1998

Figure 3



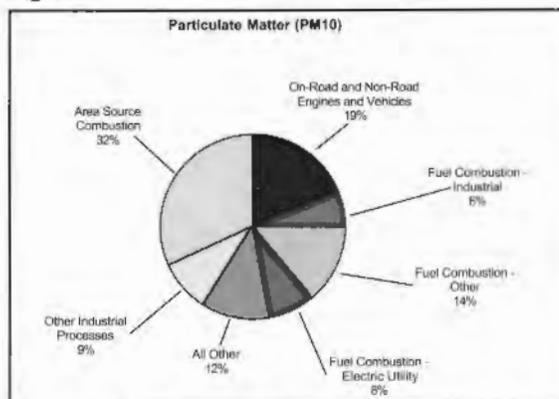
Principal Source of Nitrogen Oxides in 1998

Figure 4



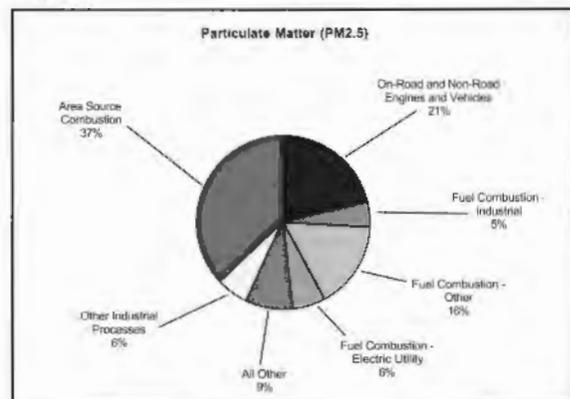
Principal Sources of Carbon Monoxide in 1998

Figure 5



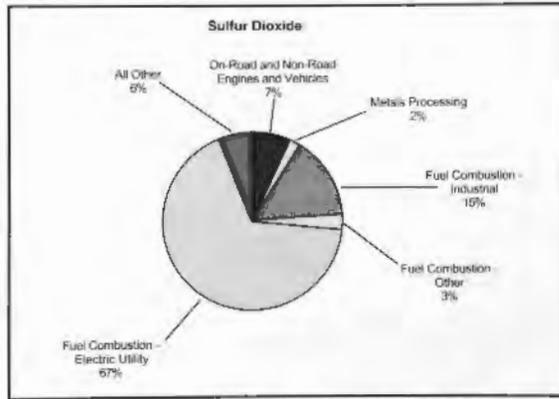
Principal Sources of PM10 in 1998

Figure 6



Principal Sources of PM2.5 in 1998

Figure 7



Principal Sources of Sulfur Dioxide in 1998

Figure 8 - Carbon Monoxide

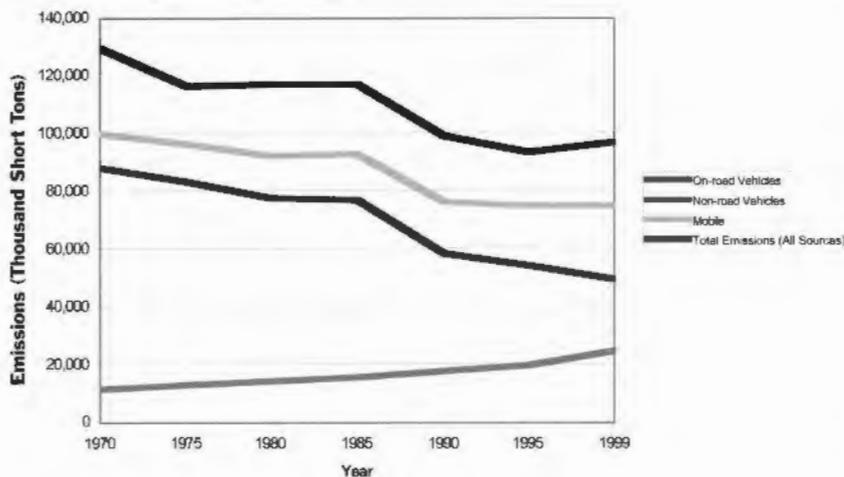


Figure 9 - VOCs

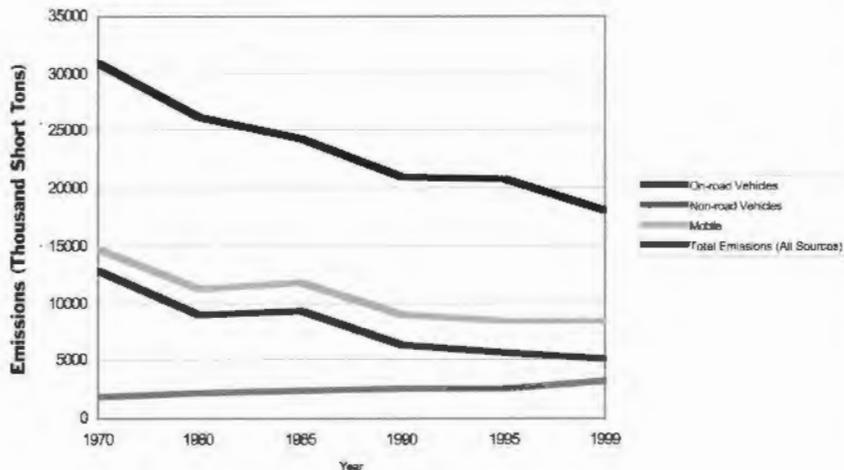
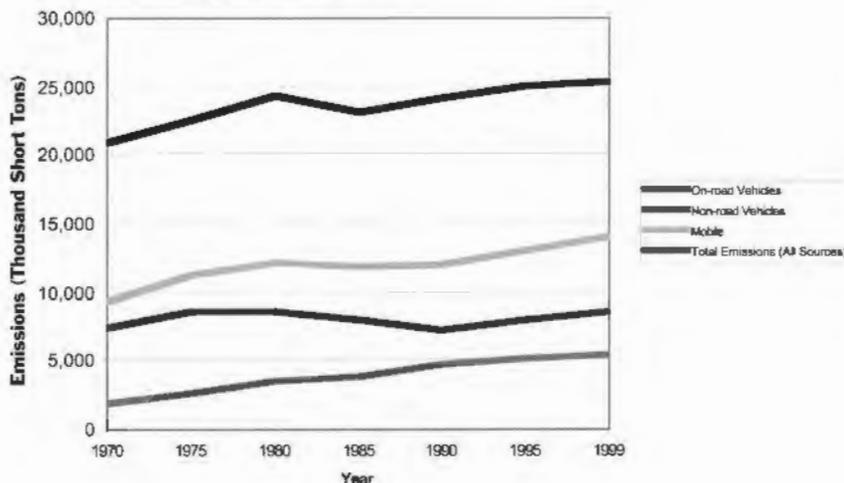


Figure 10 - Nitrogen Oxides



optimistic interpretation is that mobile emissions are still large despite reductions in emissions from new vehicles of over ninety percent. These reductions have come about through advances in engine and pollution control technology and the introduction of low-vapor-pressure and oxygenated fuels for on-road vehicles that have resulted from the lower emissions standards shown in figures 11, 12, and 13. It is clear from these figures that the size of required emissions reductions have been large in both absolute and percentage measurements. It is equally clear that future decreases in emission standards will produce relatively small absolute decreases even though the percentage decreases are large.

In addition, there are other factors that indicate that lower emissions standards for on-road vehicles alone will not achieve the total emissions reductions that are desired. First, while the emissions per vehicle have been decreasing, the total number of miles that vehicles are being driven has been steadily increasing with no signs of leveling off. While the population is up approximately 53 percent since 1960, VMT (vehicle miles traveled) has increased about 335 percent. This increase in total miles has offset some of the huge reductions in vehicle emissions levels, and with much smaller potential absolute emissions reductions looming on the horizon, increases in VMT will produce increases in on-road emission levels in the future.

The other factor that will effect the ability to achieve future emissions reductions is the presence of gross emitters. Gross emitters are vehicles that have malfunctioning engines or pollution control devices. USEPA analyses of the emissions from these vehicles have shown that their emissions levels are independent of model year and emissions standards. The rationale for this assumption is that newer vehicles are more dependent on catalyst conversion efficiency to achieve the lower standards, and that a malfunction of the catalytic converter will then produce similar emissions levels regardless of the model year. These vehicles, which represent about ten percent of the vehicle fleet, produce approximately 50% of the emissions of VOCs and CO. Therefore, as long as the current type of internal

combustion engine is dominant, the reduction of emissions will be limited by the presence of gross emitters in the fleet.

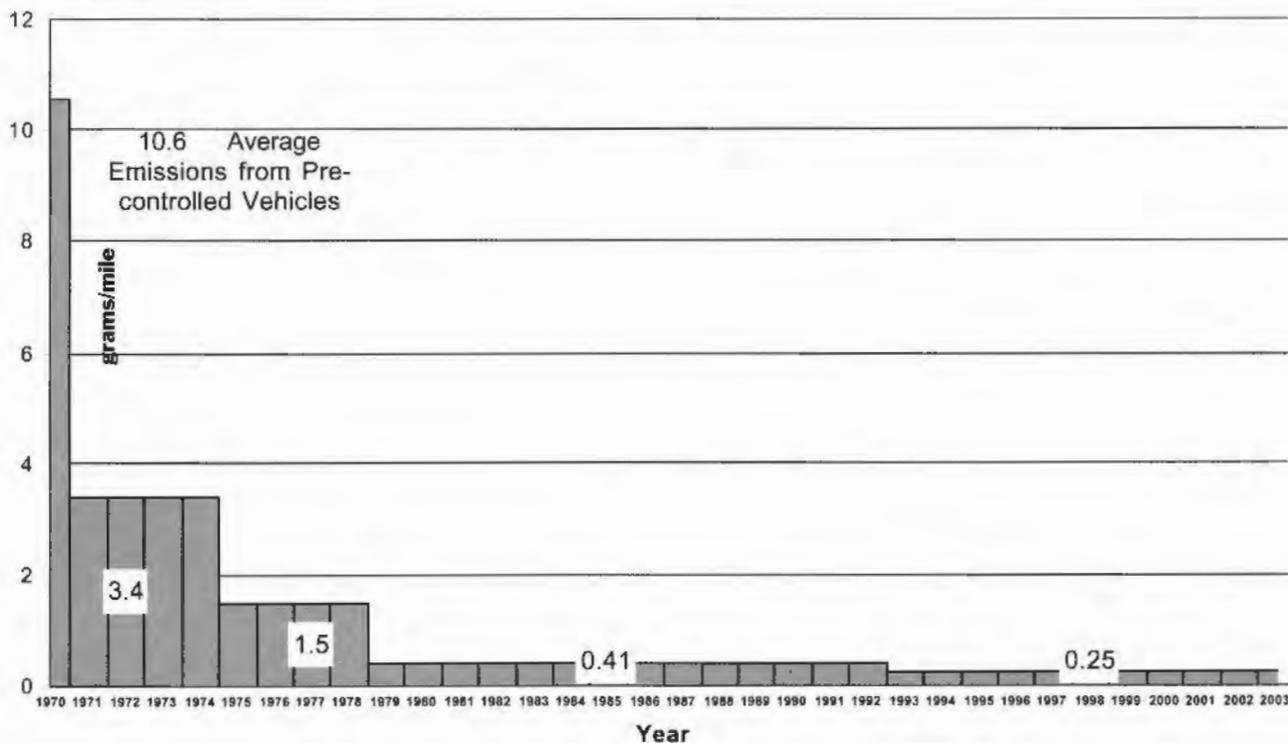
OFF-ROAD EMISSIONS

The restrictions on off-road emissions is a matter that is coming under increasing scrutiny. In most urban areas, the major contributions of off-road emissions come from lawn, construction, and industrial equipment. In 1995, the USEPA issued new Phase I standards taking effect in 1997 and Phase 2 standards to be totally phased-in by 2007 for small spark-ignition engines such as those used in common lawn and garden equipment. These two standards combined are predicted to reduce emissions by over 50 percent; however, maintenance on this type of equipment is worse than that of on-road vehicles and actual in-use emissions may be overly optimistic. In addition, assimilation of the newer engines into the existing fleet will take years to achieve. It takes nearly eight years for passenger vehicles to turnover half of the vehicle fleet. Many off-road engines are in use for considerably longer periods. Actual emissions levels from new and existing equipment is difficult to estimate because there is little information on the typical operation of the equipment. In the lawn and garden category, actual reductions may require a transition to electrically powered equipment.

CONCLUSIONS

If technological improvements to internal combustion engines only provide limited reductions in the levels of mobile emissions, other options must be explored to meet the NAAQS. One approach has been to increase mobility by increasing the capacity of congested transportation facilities. Information from the 2001 Urban Mobility Study published by the Texas Transportation Institute casts doubt on this approach. Congestion has steadily increased since 1982 despite the addition of new roadways. As more and more cars and trucks crowd the roadways, and old roadways require more and more repairs causing detours, lane blockages, and slower speeds through construction areas, the likelihood of more grid locked traffic snarls increases. Backups due to accidents and other road mishaps add to the "parking lot" effect that brings traffic to a standstill. These incidents contribute significantly to the higher percentage of the urban emissions inventory. Increased efforts such as public information systems (Lexmark signs in Louisville) and incident management (alternate traffic routes, television cameras and up-to-date real time traffic information on the radio and television) can reduce some of these impacts, but often by the time drivers are aware of problems it's too late to avert the gridlock that results.

Figure 11 - VOC Emissions Standards



Since emissions levels are directly tied to VMT, the most direct method of mobile emissions control is to promote methods to limit VMT. To date, attempts at this have usually been limited to public service announcements. Attempts to increase mass transit ridership have met stiff resistance from the public. So far, neither economic nor convenience advantages have been sufficient to entice commuters away from single occupancy vehicles.

The huge reductions in the emission rates of new trucks and automobiles are primarily the result of improved engine technology, more effective pollution control devices, and cleaner-burning fuels. The implementation of the legislation and regulations to bring about these improvements have required the United States Environmental Protection Agency (USEPA) to work closely with a relatively few vehicle manufacturers and fuel producers. Likewise, reductions in emissions from stationary sources have been achieved through interactions between state and local environmental air pollution control districts (APCDs) with local businesses. APCDs, therefore, have developed procedures to effectively deal with local businesses, developers, and transportation planners. Interactions with the public have been limited to public service announcements and pleas to limit emissions-producing activity during high-ozone periods.

The future emissions reductions that will be required to meet existing NAAQS and the new 8-hour ozone standard will require more direct involvement with residents and drivers and affect many areas of their purchasing and travel behavior. These changes may include more effective vehicle testing for high emitters, changes in current zoning restrictions to include neighborhood businesses, limitations on purchasing choices for off-road polluters like lawnmowers, leaf

blowers, and personal water craft. In addition, transportation additions and improvement might include design changes that reduce high-emissions vehicle activity while restricting some mobility. Recent experience with inspection/maintenance (I/M), however, has shown that the public is highly resistant to making even minor lifestyle changes. APCDs, therefore, will have to develop effective methods to convince the public to make the required changes.

Figure 12 - CO Emissions Standards

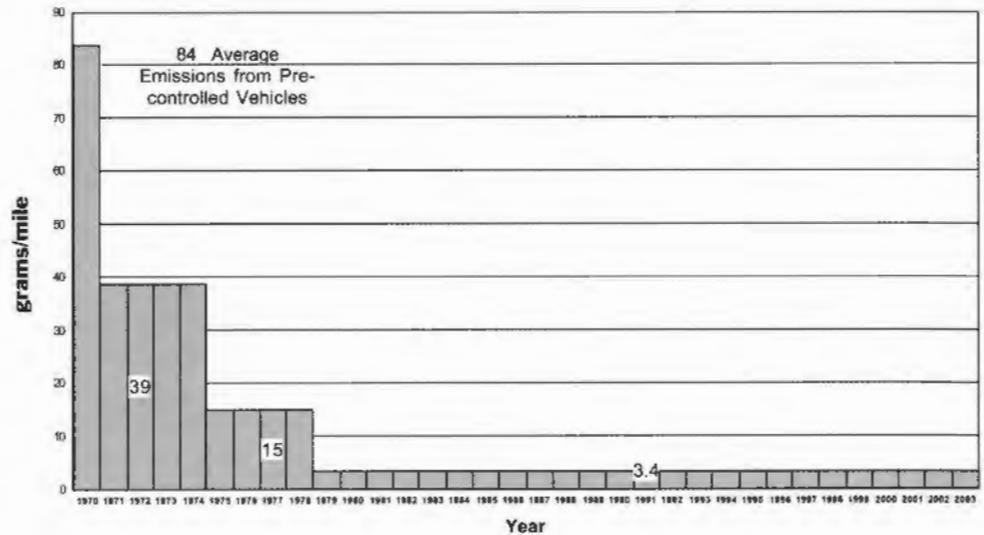
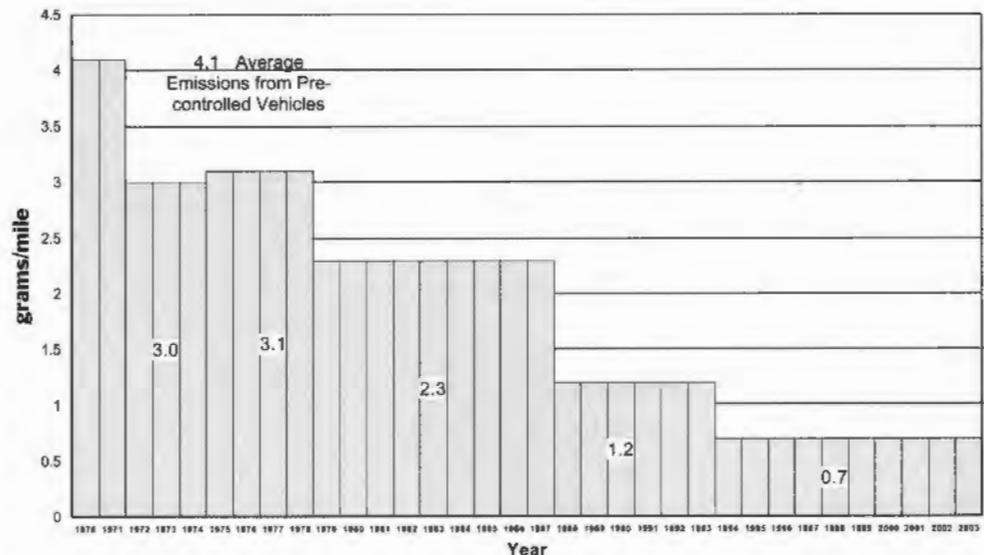


Figure 13 - NO_x Emissions Standards



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