Urban Forest Research

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Center for Urban Forest Research   Pacific Southwest Research Station • USDA Forest Service

SPECIAL EDITION

Air Pollution Control—The Tree Factor

How healthy is your air?

It should come as no surprise to you that millions of us live in areas where air pollution can cause serious health problems. Ground-level ozone and airborne particles are two pollutants that pose the greatest threat to human health. And carbon dioxide (CO_2), once thought to be the product of perfect combustion, is now considered a pollution concern.

Have you ever thought about how healthy the air is in your community and what role trees play in cleaning the air and making our communities healthier places to live? This special edition of our newsletter will explore what air pollution is, why it is unhealthy, and how trees can play a bigger role as air pollution control devices. We have also assembled a special Fact Sheet that summarizes air pollution laws and regulations as they relate to urban forestry.

Air pollutants—the bad guys!

Ground-level or "bad" ozone (O_3)[1], also known as smog, is not emitted directly into the air but is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence of sunlight. Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NOx and VOC. Ozone levels are highest during the warm months in the presence of

strong sunshine, high temperatures, and atmospheric inversions. The resulting smog can irritate your respiratory system, reduce lung function, aggravate asthma, even trigger asthma attacks.

Particle pollution[1], also known as particulate matter (PM_{10} and $PM_{2.5}$), consists of microscopic solids or liquid droplets so small that they can be inhaled deep into our lungs and cause serious health problems. Most of them start as smoke and diesel soot and form in the air from nitrogen oxides (NOx) and sulfur

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The CRITERIA POLLUTANTS

An air pollutant for which acceptable levels of exposure can be determined and for which an ambient air quality standard has been set. Examples include ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, PM_{10}, and $PM_{2.5}$.

Source: CA Air Resources Board

How do we establish a value for CO_2 and criteria pollutants?

Option 1—Consult local Emissions Trading Markets.

Option 2—Obtain estimate of control costs or avoided damages from local air quality office.

Option 3—Calculate from population and mean concentrations using formula developed by Wang and Santini in 1995.

Particle pollution is...

Complex

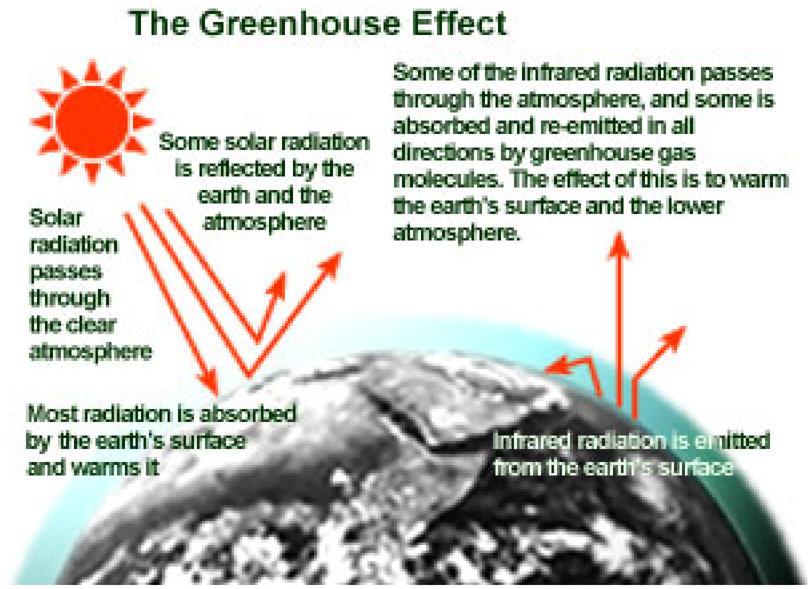
Perhaps no other pollutant is as complex as particle pollution. Also called particulate matter or PM, particle pollution is a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small that they only can be detected using an electron microscope. These tiny particles come in many sizes and shapes and can be made up of hundreds of different chemicals. Some particles are emitted directly from a source, while others form in complicated chemical reactions in the atmosphere. And some can change back and forth from gas to particle form. Particle pollution also varies by time of year and by location and is affected by several aspects of weather, such as temperature, humidity, and wind.

A continuum of sizes

In general, particle pollution consists of a mixture of larger materials, called "coarse particles," and smaller particles, called "fine particles." Coarse particles have diameters ranging from about 2.5 micrometers (µm) to more than 40 µm, while fine particles, also known as known as $PM_{2.5}$, include particles with diameters equal to or smaller than 2.5 µm. EPA monitors and regulates PM_{10}, which refers to particles less than or equal to 10 µm in diameter. PM_{10} includes coarse particles that are "inhalable"—particles ranging in size from 2.5 to 10 µm that can penetrate the upper regions of the body's respiratory defense mechanisms. "Ultrafine" particles are a subset of $PM_{2.5}$, measuring less than 0.1 µm in diameter.

Source: Environmental Protection Agency

NOTE: 100 million people in the United States currently live in non-attainment areas.



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oxides (SOx), even obscuring our visibility. When exposed to these small particles, people with heart or lung diseases and older adults are more at risk of hospital and emergency room visits or, in some cases, even death. Even if you are healthy, you may experience temporary symptoms from exposure to elevated levels of particles: irritation of the eyes, nose, and throat; coughing; phlegm; tightness in the chest; and shortness of breath.

Carbon dioxide[1], or CO_2, is another pollutant that we need to discuss. The U.S. Environmental Protection Agency (EPA) originally viewed carbon dioxide as a product of perfect combustion but now views it as a pollution concern.

Although carbon dioxide does not directly impair human health, it is a greenhouse gas that traps the earth's heat and contributes to global warming. Other greenhouse gases include those that occur naturally such as water vapor, methane, nitrous oxide, and ozone, along with man-made gases such as hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride from a number of industrial processes.

Human activities add greenhouse gases to the atmosphere at a rate of about 3 percent of annual natural emissions. Although they are a small percentage of total emissions, human-produced greenhouse gases are enough to exceed the balancing effects of natural sinks. CO_2 is one of the two most important greenhouse gases produced by people, the other

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[1]Source: EPA.

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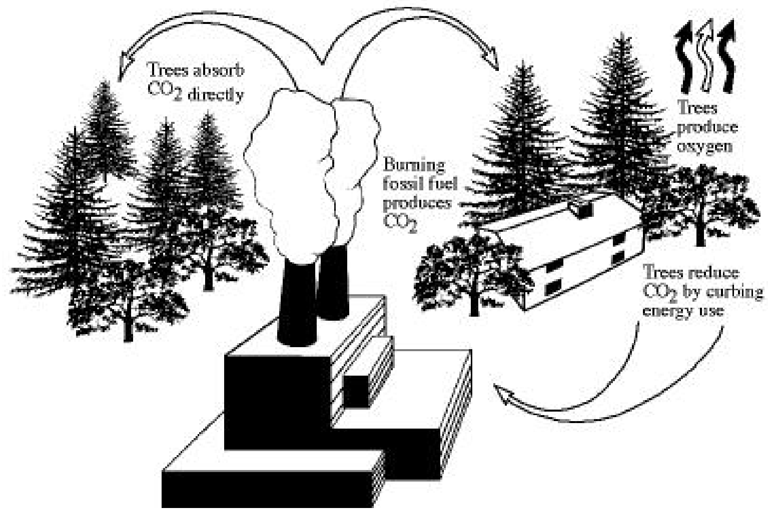
Dry deposition occurs when trees absorb gaseous pollutants or intercept particulate pollutants without the aid of precipitation. Deposited pollutant gases and particles can be chemically altered by plant tissues and may be metabolized or cause leaf injury. Some particles are re-suspended by wind or rain and carried away or washed to the ground. Absorbed pollutants are deposited on the ground surface as litter or leaf fall.



being methane (CH_4). It is emitted whenever solid waste, fossil fuel, or wood is burned. Methane is emitted when garbage and waste products decompose in landfills and sewage treatment plants. But, our focus here is CO_2 because trees absorb and store CO_2.

Green cleans

Community trees help to reduce air pollution by:

- absorbing the gaseous pollutants through leaf stomata during the normal exchange of gases
- binding or dissolving water soluble pollutants onto moist leaf surfaces
- intercepting and storing larger particulates on outer leaf surfaces, the epidermis, which may be waxy, resinous, hairy, or scaly
- capturing and storing particulates on the uneven, rough branch and bark surfaces
- sequestering CO_2 aboveground in woody tissue and belowground in the roots
- reducing local air temperatures through transpiration and shading, and reducing wind infiltration, ultimately lessening the demand for cooling and heating and the attendant hydrocarbon emissions and ozone formation.

Unlocking the mystery of deposition

Reducing Atmospheric Carbon Dioxide

As we've just seen, community trees reduce atmospheric CO_2 by sequestering it or by reducing demand for heating and cooling. On the other hand, vehicles, chain saws, chippers, and other equipment release CO_2 during the process of planting and maintaining trees. And eventually, all trees die and most of the CO_2 that has accumulated in their woody biomass is released into the atmosphere through decomposition.

Our most comprehensive study of these "opposing" effects was conducted in Sacramento County, CA (and built on our earlier work in Chicago, IL). We looked at Sacramento's 6,000,000 trees and found that they contribute to an annual net reduction of CO_2 by about 335,000 tons. Of that total, 262,300 tons of CO_2 remain sequestered in the trees. But the encouraging piece of this annual reduction is that an additional 83,300 tons—nearly 25% of the reduction—is attributable to tree shade on homes, buildings, and other structures.

We also found that CO_2 released due to tree planting, maintenance, and other program-related activities is only about 2–8 percent of annual CO_2 reductions from *sequestration* and *avoided power plant emissions*. The release of CO_2 through decomposition accounts for only another 1 percent. So, the total CO_2 released in

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Ozone from trees?

It is important to note that most trees emit various *biogenic volatile organic compounds (BVOCs)* such as isoprene and monoterpenes. These are considered air pollutants and can contribute to ozone formation. The ozone-forming potential of different tree species varies considerably—as much as 10,000 times. A computer simulation study for the Los Angeles basin found that increased tree planting of low BVOC emitting tree species would reduce ozone concentrations and exposure to ozone, while planting of medium- and high-emitters would increase overall ozone concentrations.

To see which trees are "good" or "bad" in your community go to the *SelecTree* website and select *biogenic emissions*.

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Sacramento is less than 10,600 tons per year.

Reducing Ozone and Particle Pollution

Three factors principally affect the uptake of ozone and particulates: concentrations of pollutants, canopy cover, and "surface roughness." Let me illustrate this from a subsequent study of Sacramento County's 6,000,000 trees. We found that these trees remove approximately 1,607 tons of "bad" air pollutants annually. As we expected, they were most effective at removing ozone and particulate matter (PM_{10}). These trees removed 665 tons of ozone and 748 tons of PM_{10}, while only removing 164 tons of NO_2, and 30 tons of SO_2. Ozone uptake, or deposition (tons/yr), however, was less in rural areas even though total canopy cover and leaf surface area were greater in these less populated areas of the county than in the combined city and suburban areas. We suspect that this is simply a factor of ozone concentrations (which were significantly lower in rural areas) and higher deposition rates in the city/suburbs (because buildings in cities and suburbs impede wind, causing higher deposition rates per tree, a phenomenon often called "surface roughness.") Keep in mind that in some rural areas downwind from a metropolitan area, concentrations may be higher than in adjacent urbanized areas, in which case rural uptake may be similar or even greater than in the city.

But, what about PM_{10}? We found that the deposition of PM_{10} was roughly equivalent in both city/suburban (341t/yr) and rural areas (338t/yr), even though concentrations were similar. We expected the reduction of PM_{10} to be greater in rural areas because of the higher amount of tree canopy and leaf-surface area. However, this was not the case. Again, city/suburban trees had the edge. The reduction of PM_{10} in rural areas was nearly identical to that of the combined city and suburban areas—the key difference being higher "surface roughness" in the combined city and suburban areas.

So the take-away message is that city, suburban, and rural trees are equally good at cleaning our air. However, city and suburban trees are more effective in reducing air pollution because of their placement within the "built" environment, which adds to the overall "surface roughness" and, thus, higher deposition rates.

"Green" economics

What is the value of the work that trees do to reduce air pollution? Our findings indicate that the reduction of atmospheric CO_2 by the 6,000,000 trees in Sacramento County has a current annual value of $3.3 million. That means that each tree's contribution is worth $0.55/yr on average. The total value of the annual reduction of ozone and particle pollution is $28.7 million, or nearly $5 per tree on average.

To put this in perspective, however, it is important to know that, even though trees are highly efficient at reducing air pollution, their contribution to the overall reduction of air pollutants is fairly small, amounting to only about 2 percent of the total emitted. In other words, nearly 98 percent of air pollution is not being "treated" by trees.

Planting pollution control

What an opportunity! In fact, the contribution of trees could be substantially increased if we strategically plant a large number of trees and provide long-term stewardship to maximize their health and longevity. This will maximize their benefit potential and provide us with future energy savings and improved air quality. In a study we did 2 years ago, summarized in "Green Plants or Power Plants," we found that 50 million new trees in California would eliminate the need for seven new 100-Megawatt power plants—and all of the resultant air pollution.

Reference Cities Program—*coming to a city near you*

By refining our modeling process we have created a way to calculate the air quality benefits for different regions throughout the United States and give you a much better idea of what could happen in your community. We are calling it our Reference Cities Program. We have identified one city in each of the 19 US climate regions, the reference city. By taking i-Tree/STRATUM to this key city in each region, we are now able to model the environmental benefits and costs, as well as effects on property value, for an entire climate region using street-tree growth data from the reference city's 22 most common species.

We produce a Community Tree

How similar are deposition rates?

We looked at other simulations for annual pollutant deposition rates and found that Sacramento's rates compared favorably to other urban areas. For example: pollutant deposition rates for the Chicago area were estimated to range between 9.7 and 19.4kg/ha/yr. For the Sacramento study area, deposition rates averaged 10.9kg/ha/yr. Estimated annual ozone deposition in Sacramento, however, was greater than in Chicago by a factor of 1.3. But, this can be attributed to the longer foliation period in Sacramento. With appropriate adjustments for differences in air pollution concentrations, tree species, weather, pricing, and so forth, the model can customize benefits and value for your climate region and city.

Table 1. Annual air quality benefit, and value of that benefit, provided by 100 trees of different public tree types at year 40 in various reference cities.

Reference City	Tree Type	Pollutant Uptake (lbs)	Value ($)	CO_2 (lbs)	Value ($)
Modesto, CA	Large	1014.0	4,480	27,300	409
	Small	87.2	391	3,500	53
Santa Monica, CA	Large	505.6	4,454	23,400	351
	Small	104.2	860	2,100	32
Claremont, CA	Large	604.2	6,434	41,200	617
	Small	131.7	1399	5,300	79
Longview, WA	Large	235.5	543	46,600	699
	Small	67.0	162	2,700	40
Fort Collins, CO	Large	253.6	1,116	24,100	181
	Small	139.8	583	4,700	35
Glendale, AZ	Large	305.1	2,009	51,300	385
	Small	463.0	557	20,200	151

Guide for each climate region. Within the climate region, the data can be customized for each community using the reference city's tree growth data as the starting point. Then we determine whether adjustments are needed for geographical variables such as climate, building construction types, energy use patterns, fuel mix for energy production, and air pollutant concentrations.

We have completed six reference cities, and have three more nearly complete, in our effort to compile data for all 19 climate regions/reference cities. See *table 1* for data for the reference city in your climate region. Stay tuned for future additions.

In our reference city studies our model is set up to measure typical trees—large, medium and small. As you can see from *table 1,* there is a range of benefits and values between cities and typical trees. The annual net reductions for pollutants range from 10.1 lbs for a 40-year-old large tree to 0.7 lbs for a 40-year-old small tree. And values range from $64 for a 40-year-old large tree to $1.62 for a 40-year-old small tree. In table 1 we show the CO_2 benefit and its value for public trees. If we had selected for trees opposite west-facing house walls (so trees *shaded* the west side of the house), the benefit and value would have been far greater due to reduced emissions (from power plants) associated with energy savings.

Fitting trees into the regulatory process

What if we added millions of trees to every state? What would our communities be like? What would our air quality be like? These are questions we need to be asking in every one of our states!

What we already know is that local air quality management districts provide pollution abatement credits to businesses and institutions by permitting the use of controls or processes, provided they are technically feasible and cost effective, based upon guidelines in Best Available Control Technology (BACT) manuals (*see Fact Sheet with this issue for more background*). Typically a BACT analysis is applied to *stationary sources*, but if we apply them to large-scale urban tree plantings we can demonstrate a cost effective means to improve air quality. Look at what is already happening in a couple of cities:

- In Sacramento CA, the city just met attainment for fine particulates but is still in non-attainment for ozone and has already lost some Federal highway dollars. Since 1990, the Sacramento Municipal Utility District (SMUD) has conducted its Shade Tree Program and has planted 350,000 trees around 125,000 homes. Studies have determined that this effort will result in a net air quality benefit to the community. What this suggests is that applying the BACT analysis to a large tree planting effort can provide resource

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Shaded parking lots, an unexpected air quality benefit

Trees in a Davis, California, parking lot were found to reduce air temperatures up to 3 °F. This was accompanied by reductions in surface temperatures by as much as 36 °F, vehicle cabin temperatures by over 47 °F, and fuel tank temperatures by nearly 7 °F. Thus (because of the shade), there were fewer hydrocarbon emissions from gasoline that evaporated out of leaky fuel tanks and worn hoses. These evaporative emissions are a principal component of smog, and parked vehicles are a primary source. We also found that planting trees to achieve 50 percent canopy cover in parking lots can reduce hydrocarbon emissions comparable to the levels achieved through existing programs conducted by local air quality districts (e.g., graphic arts, waste burning, and vehicle scrappage). See our report and research summary: "Where are all the cool parking lots?"

managers and other potential investors with one way to assess the implied value of air quality benefits from the new urban forest.

- The Houston Green project will use the latest digitized satellite imagery and professional field data collection combined with a resource analysis model (i-Tree/UFORE) to analyze the existing tree resource of the Houston area. From this existing tree resource analysis, a *State of the Urban Forest* report will be produced that will accurately describe what Houston's trees are currently doing to reduce ozone and other air pollutants, greenhouse gases, and the urban heat island effect. Results of the model analyses will be presented to the Environmental Protection Agency for review, with the goal of including urban trees as an air quality improvement strategy with State Implementation Plans in the future.

A final thought

It appears that we are pointed in the right direction. We now have a clearer understanding of the opportunities, challenges, and limitations presented by the Clean Air Act (*see Fact Sheet for more details*). By coupling that understanding with the power of trees in mitigating air pollution, we can, together, mount a compelling argument for adding more trees to our communities.

EPA has opened the door for us by raising the limit for voluntary measures (trees) from 3 percent to 6 percent (*see text box on this page*), sending a message to local and regional air quality districts and state air boards to look more favorably on these kinds of mitigation measures. I also suspect that increased funding at the local, state, and federal level will be another positive result of this action. Let's begin to take advantage.

—*Jim Geiger*

State Implementation Plan credits for trees

The EPA recently issued its final policy regarding the granting of explicit State Implementation Plan (SIP) credits for voluntary stationary source emission reduction programs under section 110 of the Clean Air Act. The reason this is important for us is that trees are viewed as a stationary-source-voluntary-measure that has the potential to contribute, in a cost-effective manner, to emission reductions.

The EPA policy states that one example of a type of stationary-source-voluntary-measure is:

- "Heat island programs to encourage activities that will reduce center-city temperatures during the summer, e.g. replacing roofs with Energy Star-labeled roof products or **planting shade trees.**"

However, before you get too excited, there is a limitation. The EPA policy states that:

- "It is appropriate to limit the amount of emission reductions allowed in a stationary-source-voluntary-measure program. At this time, we believe an appropriate limit for stationary-source-voluntary-measures would be **6 percent of needed reductions for rate of progress (ROP), and reasonable further progress (RFP), or attainment demonstration purposes.**"

This is not 6 percent of an area's total emission inventory. For example, if a State projects emissions in the attainment year to be 100 tons per day over the emissions needed to show attainment, the State could take credit for emission reductions from stationary source voluntary measures of up to 6 tons per day.

NOTE: *To place this in a larger context, Sacramento County's 6,000,000 trees remove 1607 tons of pollutants per year, or 4.4 tons per day. This reduction is about 2 percent of the total emitted. The 6 percent EPA limitation on stationary-source-voluntary-measures allows plenty of opportunity to plant trees.*

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Fact Sheet: Air Pollution and the Law[1]

For trees to take on a larger role in mitigating air pollution, we must first understand the status of current control measures.

The 1990 Clean Air Act

Although the 1990 Clean Air Act is a Federal law covering the entire country, the states do much of the work to carry out the Act. The EPA sets limits on how much of a pollutant can be in the air anywhere in the United States. This ensures that all of us have the same basic health and environmental protections. The law allows individual states to have stronger pollution controls, but not weaker controls, than those set for the whole country.

States are required to develop **State Implementation Plans (SIPs)** that explain how each state will do its job under the Clean Air Act. A SIP is a collection of the regulations a state will use to clean up polluted areas. States must involve the public, through hearings and opportunities to comment, in the development of each state implementation plan.

States are required to develop State Implementation Plans (SIPs) that explain how each state will do its job under the Clean Air Act.

The EPA must approve each SIP, and if a SIP isn't acceptable, EPA can take over, enforcing the Clean Air Act in that state. EPA assists the states by providing scientific research, expert studies, engineering designs, and money to support clean air programs.

What is a SIP?

A SIP is an enforceable plan developed by states to explain how they will comply with air quality standards, according to the Federal Clean Air Act. In order to understand SIPs, you need to understand the role of the following:

- **Federal Clean Air Act**

Amended in 1990, the Federal Clean Air Act is the legal foundation for the national air pollution control program. The Act requires each state to produce and regularly update a State Implementation Plan. The Act also requires that SIPs include a description of control strategies, or measures to deal with pollution, for areas that fail to achieve national ambient air quality standards (NAAQS). Finally, this Act grants powers of enforcement to the EPA.

- **Environmental Protection Agency (EPA)**

The Clean Air Act grants the EPA power to establish national air quality standards, to approve or reject SIPs, to replace SIPs with Federal Implementation Plans (FIPs) when deemed necessary, and to monitor achievement of goals laid out in SIPs and FIPs.

- **National Ambient Air Quality Standards (NAAQS)**

NAAQS are established by the EPA as directed by the Federal Clean Air Act. These standards measure six outdoor air pollutants:

- Ground-level ozone (smog)
- Particulate matter (PM)
- Lead (Pb)
- Nitrogen dioxide (NO_2)
- Carbon monoxide (CO)
- Sulfur dioxide (SO_2)

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[1]Source: EPA.

Failure to produce a SIP has consequences

If a state fails to submit or implement a SIP, or if it submits a SIP that is unacceptable to the EPA, the EPA has the power to impose sanctions or other penalties on that state. Typical sanctions include cutting off Federal highway funds and setting more stringent pollution offsets for certain emitters. Offsets are the reduction of current emissions at a rate equal to or greater than the amount of emissions expected to be produced in a new project.

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Fact Sheet: Air Pollution and the Law (continued)

These "criteria pollutants" are commonly occurring air pollutants that can injure health, harm the environment, and cause property damage. NAAQS set nationally acceptable levels of concentrations of these pollutants. Since SIPs are mandatory in nonattainment areas, or areas that fail to attain NAAQS, the need for SIPs is based on NAAQS.

The control strategy

The most important section of a SIP is the control strategy. This section details the state's effort to meet NAAQS by describing the targets, plans, and control strategies for each area designated *nonattainment*. The implementation plans of specific control strategies required by the EPA are also addressed in this section. This section is the only section that is constantly revised and updated. These revisions are known as "SIP revisions."

What are SIP revisions?

Only ***one*** SIP exists for each state. Revisions are necessary when new Federal or state requirements are enacted, when new data improves modeling techniques, when a specific area's attainment status changes, or when an area fails to reach attainment.

Revisions are typically prepared for a specific area. However, SIP revisions are sometimes prepared for a particular control strategy. SIP revisions typically include an assessment of the problem and measures to fix the problem. Assessments of the situation include monitoring data, emissions inventory, and photochemical modeling; measures to "fix" problems are known as control strategies.

EPA's "New Source Review" (NSR) Program

Under this program, if a company is planning to build a new plant or modify an existing plant such that air pollution emissions will increase by a large amount, then the company must obtain an NSR permit. The NSR permit is a construction permit that requires the company to minimize air pollution emissions by changing the process to prevent air pollution and/or installing air pollution control equipment. For more information on the NSR program, go to www.epa.gov/nsr.

The terms RACT, BACT, and LAER are acronyms for different program requirements under the NSR program.

- RACT, or Reasonably Available Control Technology, is required on existing sources in areas that are not meeting national ambient air quality standards (i.e., non-attainment areas).
- BACT, or Best Available Control Technology, is required on major new or modified sources in clean areas (that is, attainment areas).
- LAER, or Lowest Achievable Emission Rate, is required on major new or modified sources in non-attainment areas.

BACT and LAER (and sometimes RACT) are determined on a case-by-case basis, usually by State or local permitting agencies. EPA established the **RACT/BACT/LAER Clearinghouse**, or **RBLC**, to provide a central database of air pollution technology information (including past RACT, BACT, and LAER decisions contained in NSR permits) to promote the sharing of information among permitting agencies and to aid in future case-by-case determinations. However, data in the RBLC are not limited to sources subject to RACT, BACT, and LAER requirements. Noteworthy prevention and control technology decisions and information are included even if they are not related to past RACT, BACT, or LAER decisions.

Why do we need SIPs?

There are numerous reasons why SIPs are necessary and important.

- **SIPs protect our air:** They play a key role in attaining good air quality and protecting citizen health.
- **SIPs are required by law:** The Federal Clean Air Act requires states with counties failing to meet national ambient air quality standards to produce a SIP.

How do SIPs affect me?

As an individual

- **Protect your health:** setting air quality standards improves air quality to a degree that is beneficial for the health and well-being of you and your family.
- **Regulations:** rules may place restrictions on you by creating requirements that may affect the operation, design, and emissions level of your property (your motor vehicle), or rules may offer you incentives to choose technologies that further the SIP's goal.

As a business

- **Regulations:** Regulations may place restrictions on activities and equipment used in your business that affect quality levels. Other regulations may provide incentives that your firm may be able to take advantage of.