9

The Philosophy of Air Pollution Control

I. STRATEGY AND TACTICS: THE AIR POLLUTION SYSTEM

Since primary pollutants may have the dual role of causing adverse effects in their original unreacted form and of reacting chemically to form secondary pollutants, air pollution control consists mainly of reducing the emission of primary pollutants to the atmosphere. Air pollution control has two major aspects: strategic and tactical. The former is the long-term reduction of pollution levels at all scales of the problem from local to global. This aspect is called *strategic* in that long-term strategies must be developed. Goals can be set for air quality improvement 5, 10, or 15 years ahead and plans made to achieve these improvements. One notable example is the requirement of the Clean Air Act Amendments (CAAA) of 1990 to reduce the emissions of hazardous air pollutants (so-called "HAPs"). The law requires the US Environmental Protection Agency (EPA) to establish an inventory to track progress in reducing HAPs in ambient air. The first step of this strategy was given in Section 112(d) of CAAA, which requires EPA to promulgate technology-based emission standards (maximum achievable control technology, i.e. MACT). For major sources of HAPs, Section 112(f) requires standards to address risks remaining after implementation of MACT standards, known as residual risks standards. Section 112(c)(3) and Section 112(k) of the CAAA requires EPA to address the emissions and risks of HAPs from area sources and to show a 75% reduction in cancer incidence of emissions from stationary sources of HAPs since 1990. To monitor the success in meeting these strategies in reducing emissions and human health, EPA compiles the National Emissions Inventory (NEI) for HAPs. The EPA previously compiled a baseline 1990 and 1996 National Toxics Inventory (NTI) and 1999 NEI for HAPs and has recently completed version 3 of the 2002 NEI.

The NEI includes major point and area sources, non-point area and other sources, and mobile source estimates of emissions. Stationary major sources of HAPs are defined as sources that have the potential to emit 10 tons per year or more of any single HAP or 25 tons per year or more of any combination of HAPs [2]. Stationary area sources of HAPs are defined as sources that have the potential to emit less than 10 tons per year or more of any single HAP or less than 25 tons per year or more of any combination of HAPs. Mobile sources include onroad vehicles, non-road equipment, and aircraft/locomotive/commercial marine vessels (ALM). EPA has developed the National Air Toxics Assessment (NATA) to estimate the magnitude of HAP emissions reductions and demonstrate reduced public risk from HAP emissions attributable to CAA toxics programs [2].

Emissions of HAPs emissions fell through the 1990s in response to the MACT standards and mobile source regulations. However, area and other source emissions have increased because EPA has not yet fully implemented its area source program as required by Section 112c(3) and 112(k) of the CAAA. Figure 9.1 and Table 9.1 present emissions trends for the sum of 188 HAPs by source sectors. Toxicity-weighted emissions have also declined between 1990 and 2002 for cancer and non-cancer respiratory and neurological effects. Figures 9.2–9.4 and Tables 9.2–9.4 provide the toxicity-weighted

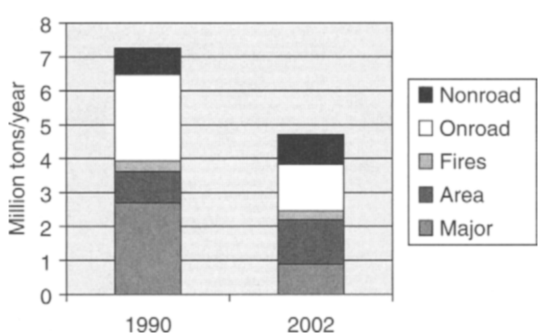

Fig. 9.1. Trends in US emissions of HAPs. *Note*: Aircraft, Locomotive and Commercial Marine Vessels is not reported. *Source*: A. Pope and M. Strum, *1990–2002* NEI HAP Trends: Success of CAA Air Toxic Programs in Reducing HAP Emissions and Risk, 16th Annual International Emission Inventory Conference, *Emission Inventories: "Integration, Analysis, and Communications"*, Raleigh, NC, May 14–17, 2007.

TABLE 9.1.

Sum of Emissions of the 188 HAPs listed in the CAAA of 1990

Sector	1990 Emissions	2002 Emissions	% Reduction
TOTAL	**7.24 milion tons**	**4.7 million tons**	**35**
Major	2.69 million tons	0.89 million tons	67
Area	0.91 million tons	1.29 million tons	−42
Fires (Wildfires & Prescribed Burns)	0.34 million tons	0.28 million tons	18
Onroad Mobile	2.55 million tons	1.36 million tons	47
Non-road Mobile	0.75 million tons[b]	0.86 million tons	−15
ALM Mobile[a]		0.02 million tons	

[a] ALM – Aircraft, Locomotive and Commercial Marine Vessels
[b] 1990 Non-road Mobile includes ALM
Source: A. Pope and M. Strum, 1990–2002 NEI HAP Trends: Success of CAA Air Toxic Programs in Reducing HAP Emissions and Risk, 16th Annual International Emission Inventory Conference, *Emission Inventories: "Integration, Analysis, and Communications"*, Raleigh, NC, May 14–17, 2007.

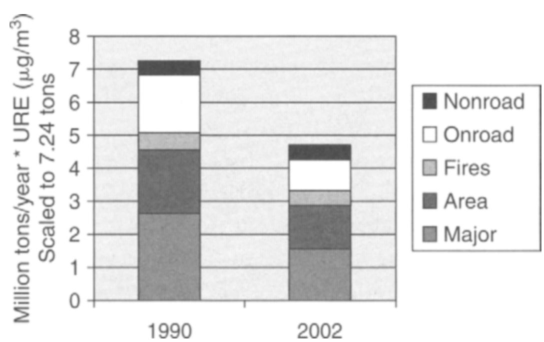

Fig. 9.2. Trends in scaled cancer toxicity-weighted US emissions of HAPs. *Note*: Unit risk estimate (URE) is upper bound risk estimate of an individual's probability of contracting cancer over a lifetime of exposure to a concentration of 1 µg of the pollutant per cubic meter of air. For example, if an URE is 1.5×10^{-6} per $\mu g\, m^{-3}$, 1.5 excess tumors are expected to develop per 1 000 000 people if they are exposed daily for a lifetime to 1 µg of chemical in 1 cubic meter of air. Aircraft, Locomotive and Commercial Marine Vessels is not reported. *Source*: A. Pope and M. Strum, 1990–2002 NEI HAP Trends: Success of CAA Air Toxic Programs in Reducing HAP Emissions and Risk. 16th Annual International Emission Inventory Conference, *Emission Inventories: "Integration, Analysis, and Communications"*, Raleigh, NC, May 14–17, 2007.

emissions scaled to the sum of 7.24 million tons for 1990 total emissions. Table 9.5 identifies the sectors contributing the larger share of the pollutants shown in Figure 9.5. In 2002, benzene accounts for 28% of cancer risks in the toxicity-weighted NEI, whereas manganese accounts for 77% of non-cancer

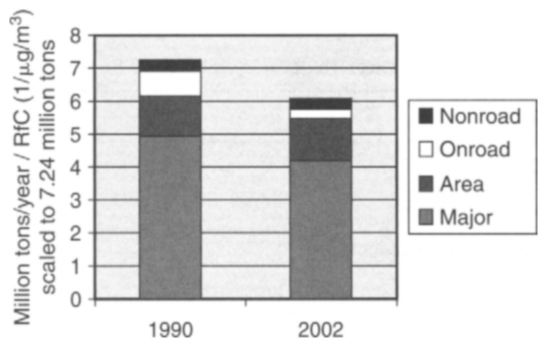

Fig. 9.3. Trends in scaled non-cancer neurological toxicity-weighted US emissions of HAPs. *Note*: RfC is the reference concentration, i.e. the level below which no adverse effect is expected. Aircraft, Locomotive and Commercial Marine Vessels is not reported. Fires is not reported. *Source*: A. Pope and M. Strum, 1990–2002 NEI HAP Trends: Success of CAA Air Toxic Programs in Reducing HAP Emissions and Risk. 16th Annual International Emission Inventory Conference, *Emission Inventories: "Integration, Analysis, and Communications"*, Raleigh, NC, May 14–17, 2007.

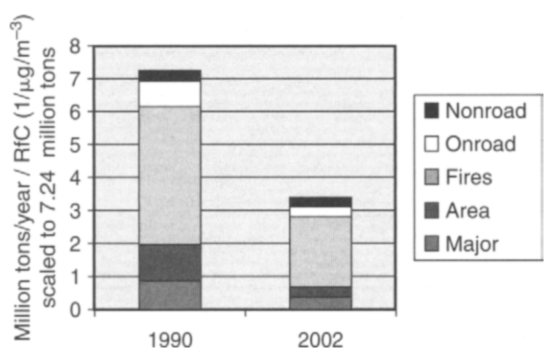

Fig. 9.4. Trends in scaled non-cancer respiratory toxicity-weighted US emissions of HAPs. *Note*: RfC is the reference concentration, i.e. the level below which no adverse effect is expected. Aircraft, Locomotive and Commercial Marine Vessels is not reported. *Source*: A. Pope and M. Strum, 1990–2002 NEI HAP Trends: Success of CAA Air Toxic Programs in Reducing HAP Emissions and Risk. 16th Annual International Emission Inventory Conference, *Emission Inventories: "Integration, Analysis, and Communications"*, Raleigh, NC, May 14–17, 2007.

neurological effects in the toxicity-weighted NEI, and acrolein accounts for 90% of non-cancer respiratory effects in the toxicity-weighted NEI [2].

There can be a regional strategy to affect planned reductions at the urban and local scales; a state or provincial strategy to achieve reductions at the state, provincial, urban, and local scales; and a national strategy to achieve them at national and lesser scales. The continental and global scales require an international strategy for which an effective instrumentality is being developed.

TABLE 9.2

Trends in Scaled Cancer Toxicity-Weighted US Emissions of HAPs

Sector	% Reduction from 1990 to 2002
TOTAL	**36**
Major	44
Area	31
Fires (Wildfires & Prescribed Burns)	−4
Onroad Mobile	49
Non-road Mobile	7.5

Source: A. Pope and M. Strum, 1990–2002 NEI HAP Trends: Success of CAA Air Toxic Programs in Reducing HAP Emissions and Risk. 16th Annual International Emission Inventory Conference, *Emission Inventories: "Integration, Analysis, and Communications"*, Raleigh, NC, May 14–17, 2007.

TABLE 9.3

Trends in Scaled Non-cancer Neurological Toxicity-Weighted US Emissions of HAPs

Sector	% Reduction from 1990 to 2002
TOTAL	**16**
Major	15
Area	−7
Fires (Wildfires & Prescribed Burns)	0
Onroad Mobile	62
Non-road Mobile	12

Source: A. Pope and M. Strum, 1990–2002 NEI HAP Trends: Success of CAA Air Toxic Programs in Reducing HAP Emissions and Risk. 16th Annual International Emission Inventory Conference, *Emission Inventories: "Integration, Analysis, and Communications"*, Raleigh, NC, May 14–17, 2007.

The other major aspect of air pollution reduction is the control of short-term episodes on the urban scale. This aspect is called *tactical* because, prior to an episode, a scenario of tactical maneuvers must be developed for application on very short notice to prevent an impending episode from becoming a disaster. Since an episode usually varies from a minimum of about 36 h to a maximum of 3 or 4 days, temporary controls on emissions much more severe than are called for by the long-term strategic control scenario must be implemented rapidly and maintained for the duration of the episode. After the weather conditions that gave rise to the episode have passed, these temporary episode controls can be relaxed and controls can revert to those required for long-term strategic control.

The mechanisms by which a jurisdiction develops its air pollution control strategies and episode control tactics are outlined in Fig. 9.6. Most of the boxes

TABLE 9.4

Trends in Scaled Non-cancer Respiratory Toxicity-weighted US Emissions of HAPs

Sector	% Reduction from 1990 to 2002
TOTAL	**54**
Major	69
Area	64
Fires (Wildfires & Prescribed Burns)	50
Onroad Mobile	58
Non-road Mobile	35

Source: A. Pope and M. Strum, *1990–2002 NEI HAP* Trends: Success of CAA Air Toxic Programs in Reducing HAP Emissions and Risk. 16th Annual International Emission Inventory Conference, *Emission Inventories: "Integration, Analysis, and Communications"*, Raleigh, NC, May 14–17, 2007.

TABLE 9.5

Source Sector Contribution to Pollutants in Fig. 9.5

HAP	Largest sector
Acrolein	Fires
Arsenic	Major
Benzene	Mobile
1,3-Butadiene	Mobile
Chlorine	Major
Hexavalent chromium	Major
Cyanide	Area
Hydrochloric acid	Major
Manganese	Major
Toluene	Mobile
Xylenes	Mobile

in the figure have already been discussed—sources, pollutant emitted, transport and diffusion, atmospheric chemistry, pollutant half-life, air quality, and air pollution effects. To complete an analysis of the elements of the air pollution system, it is necessary to explain the several boxes not yet discussed.

II. EPISODE CONTROL

The distinguishing feature of an air pollution episode is its persistence for several days, allowing continued buildup of pollution levels. Consider the situation of the air pollution control officer who is expected to decide when to use the stringent control restrictions required by the episode control tactics

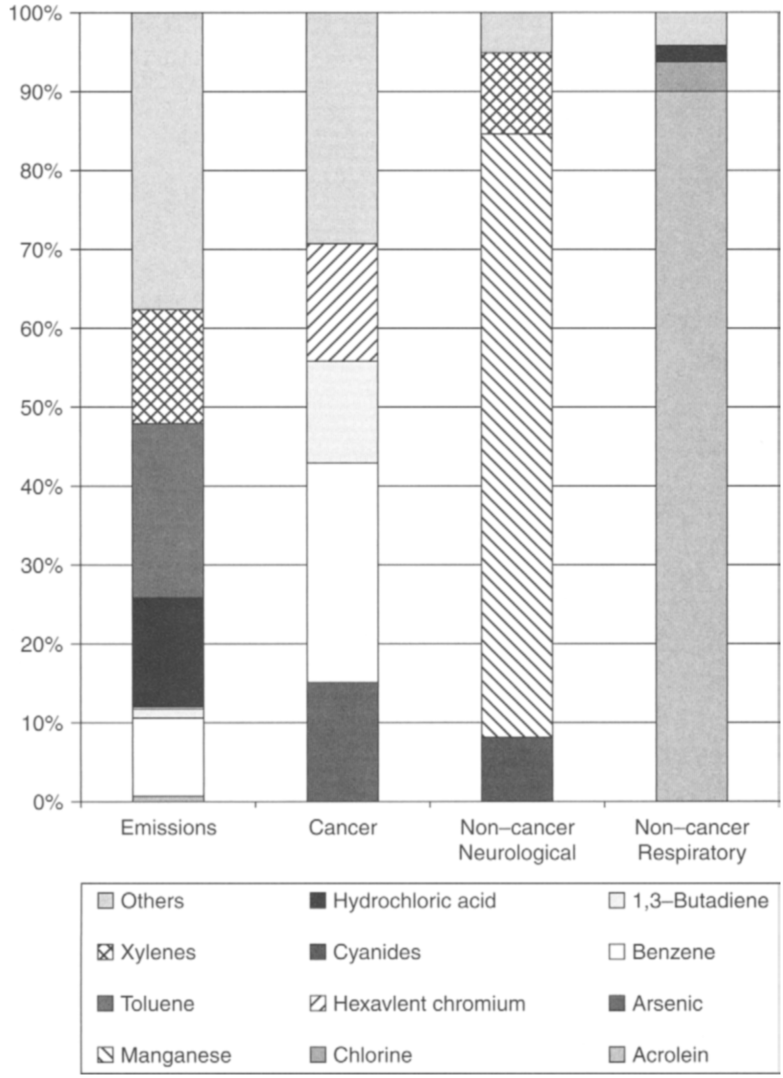

Fig. 9.5. Percent Contribution of US HAPs to 2002 emissions and toxicity-weighted emissions. *Source*: A. Pope and M. Strum, 1990–2002 NEI HAP Trends: Success of CAA Air Toxic Programs in Reducing HAP Emissions and Risk. 16th Annual International Emission Inventory Conference, *Emission Inventories: "Integration, Analysis, and Communications"*, Raleigh, NC, May 14–17, 2007.

scenario (Fig. 9.7 and Table 9.6). If these restrictions are imposed and the episode does not mature, i.e. the weather improves and blows away the pollution without allowing it to accumulate for another 24 h or more, the officer will have required for naught a very large expenditure by the community and a serious disruption of the community's normal activities. Also, part of the

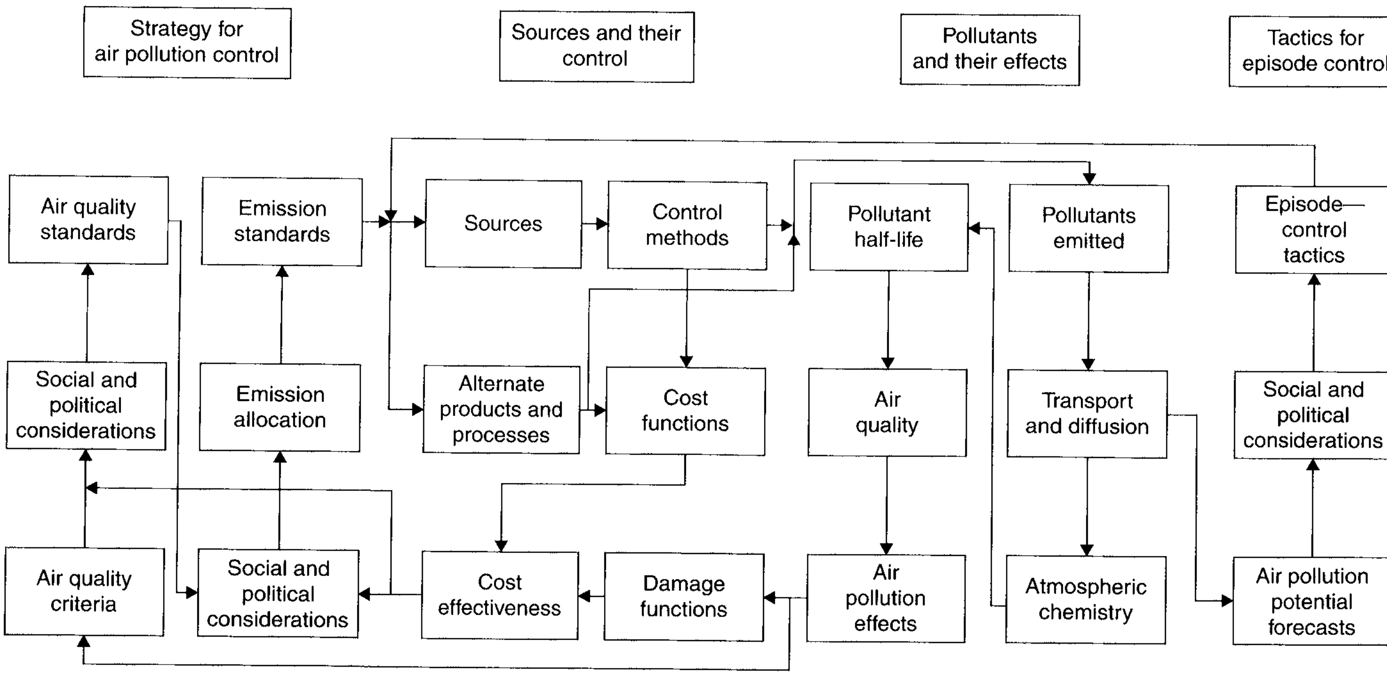

Fig. 9.6. A model of the air pollution management system.

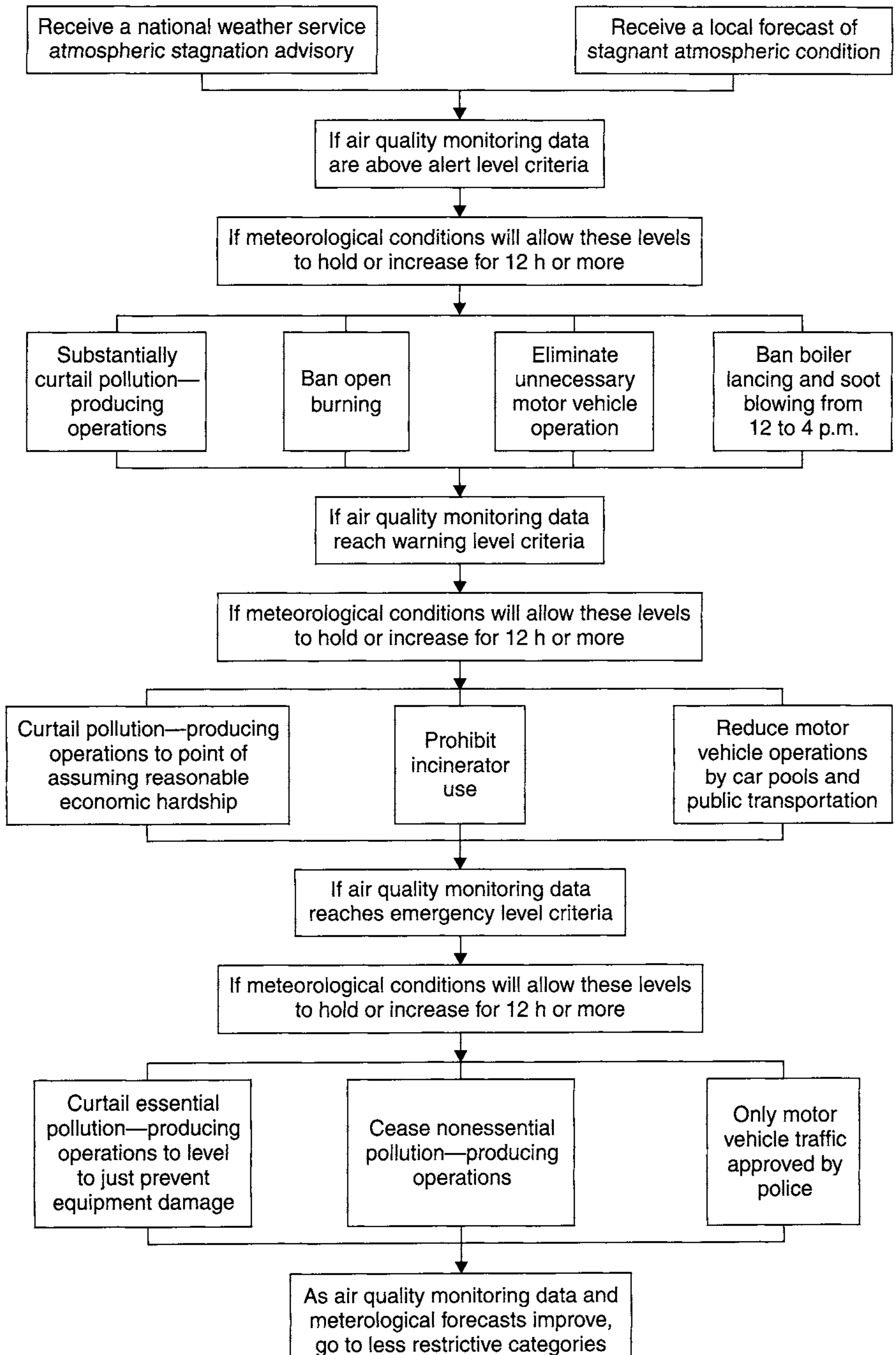

Fig. 9.7. Air pollution episode control scenario (see Table 9.6).

TABLE 9.6

United States Alert, Warning, and Emergency Level Criteria[a,b,c]

Alert level criteria	
SO_2	
	800 μg m^{-3} (0.3 ppm), 24-h average
PM_{10}	
	350 μg m^{-3}, 24-h average
CO	
	17 mg m^{-3} (15 ppm), 8-h average
Ozone	
	400 μg m^{-3} (0.2 ppm), 1-h average
NO_2	
	1130 μg m^{-3} (0.6 ppm), 1-h average; 282 μg m^{-3} (0.15 ppm), 24-h average
Warning level criteria	
SO_2	
	1600 μg m^{-3} (0.6 ppm), 24-h average
PM_{10}	
	420 μg m^{-3}, 24-h average
CO	
	34 mg m^{-3} (30 ppm), 8-h average
Ozone	
	800 μg m^{-3} (0.4 ppm), 1-h average
NO_2	
	2260 μg m^{-3} (1.2 ppm), 1-h average; 565 μg m^{-3} (0.15 ppm), 24-h average
Emergency level criteria	
SO_2	
	2100 μg m^{-3} (0.8 ppm), 24-h average
PM_{10}	
	500 μg m^{-3}, 24-h average
CO	
	46 mg m^{-3} (15 ppm), 8-h average
Ozone	
	1000 μg m^{-3} (0.1 ppm), 1-h average
NO_2	
	3000 μgm^{-3} (0.6 ppm), 1-h average; 750 μg m^{-3} (0.15 ppm), 24-h average

[a] 2003 Code of Federal Regulations, Title 40-Protection of Environment, Chapter 1—Environmental Protection Agency, Appendix L, Example Regulations for Prevention of Air Pollution Emergency Episodes, 1.1 Episode Criteria, pp. 351–352.
[b] There is no criterion for lead, due to the chronic nature of the health effects of concern.
[c] *Note*: Append to each entry: Meterological conditions are such that pollutant concentrations can be expected to remain at the above levels for 12 or more hours or increase, or in the case of ozone the situation is likely to reoccur within the next 24 h unless control actions are taken.

officer's credibility in the community will be destroyed. If this happens more than once, the officer will be accused of crying wolf, and when a real episode occurs the warnings will be unheeded. If, however, the reverse situation occurs—i.e. the restrictions are not invoked and an episode does occur—there can be illness or possibly deaths in the community that could have been averted.

In deciding whether or not to initiate episode emergency plans, the control officer cannot rely solely on measurements from air quality monitoring stations, because even if pollutant concentrations rise toward acute levels over the preceding hours, these readings give no information on whether they will rise or fall during the succeeding hours.

The only way to avert this dilemma is for the community to develop and utilize its capability of forecasting the advent and persistence of the stagnation conditions during which an episode occurs and its capability of computing pollution concentration buildup under stagnation conditions. The details of how these forecasts and computations are made are discussed in Chapter 21, but at this point the foregoing discussion should explain the reason for the box in Fig. 9.6 labeled air pollution potential forecasts. The connecting box marked social and political considerations provides a place in the system for the public debates, hearings, and action processes necessary to decide, well in advance of an episode, what control tactics to use and when to call an end to the emergency. The public needs to be involved because alternatives have to be written into the scenario concerning where, when, and in what order to impose restrictions on sources. This should be done in advance and should be well publicized, because during the episode there is no time for public debate. In any systems analysis, the system must form a closed loop with feedback to keep the system under control. It will be noted that the system for tactical episode control is closed by the line connecting episode control tactics to sources, which means that the episode control tactics are to limit sources severely during the episode. Since it takes hours before emergency plans can be put into effect and their impact on pollution levels felt, it is possible that by the time the community responds, the situation has disappeared. Experience has shown that the time for community response is slowed by the need to write orders to close down sources and to respond in court to requests for judicial relief from such orders. To circumvent the former type of delay, orders can be written in blank in advance. To circumvent the latter type of delay, the agency's legal counsel must move as rapidly as the counsel seeking such relief.

III. AIR QUALITY MANAGEMENT CONTROL STRATEGY

Now let us consider the system for long-range strategy for air pollution control. The elements in this system that have not yet been discussed include several listed in Fig. 9.6 under sources and their control and all those listed under "Strategy for Air Pollution Control." Control of sources is affected in several ways. We can (1) use devices to remove all or part of the pollutant from the gases discharged to the atmosphere, (2) change the raw materials used in the pollution-producing process, or (3) change the operation of the

TABLE 9.7

Control Methods

I. Applicable to all emissions
  A. Decrease or eliminate production of emission
    1. Change specification of product
    2. Change design of product
    3. Change process temperature, pressure, or cycle
    4. Change specification of materials
    5. Change the product
  B. Confine the emissions
    1. Enclose the source of emissions
    2. Capture the emissions in an industrial exhaust system
    3. Prevent drafts
  C. Separate the contaminant from effluent gas stream
    1. Scrub with liquid

II. Applicable specifically to particulate matter emissions
  A. Decrease or eliminate particulate matter production
    1. Change to process that does not require blasting, blending, buffing, calcining[a], chipping, crushing, drilling, drying, grinding, milling, polishing, pulverizing, sanding, sawing, spraying, and tumbling, etc.
    2. Change from solid to liquid or gaseous material
    3. Change from dry to wet solid material
    4. Change particle size of solid material
    5. Change to process that does not require particulate material
  B. Separate the contaminant from effluent gas stream
    1. Gravity separator
    2. Centrifugal separator
    3. Filter
    4. Electrostatic precipitator

III. Applicable specifically to gaseous emissions
  A. Decrease or eliminate gas or vapor production
    1. Change to process that does not require annealing, baking, boiling, burning, casting, coating, cooking, dehydrating, dipping, distilling, expelling, galvanizing, melting, pickling, plating, quenching, reducing, rendering, roasting, and smelting, etc.
    2. Change from liquid or gaseous to solid material
    3. Change to process that does not require gaseous or liquid material
  B. Burn the contaminant to CO_2 and H_2O
    1. Incinerator
    2. Catalytic burner
  C. Adsorb the contaminant
    1. Activated carbon

[a] Calcining is the process of heating a substance to a temperature less than melting or fusing point, but sufficiently high to cause moisture loss, redox, and decomposition of carbonates and other compounds.

process so as to decrease pollutants emitted. These are control methods (Table 9.7). Such control methods have a cost associated with them and are the cost functions that appear in the system. There is always the option of seeking alternate products or processes which will provide the same utility to the public but with less pollutants emitted. Such products and processes have their own cost functions.

Just as it costs money to control pollution, it also costs the public money not to control pollution. All the adverse air pollution effects represent economic burdens on the public for which an attempt can be made to assign dollar values, i.e. the cost to the public of damage to vegetation, materials, structures, animals, the atmosphere, and human health. These costs are called damage functions. To the extent that there is knowledge of cost functions and damage functions, the cost effectiveness of control methods and strategies can be determined by their interrelationship. Cost effectiveness is an estimate of how many dollars worth of damage can be averted per dollar expended for control. It gives information on how to economically optimize an attack on pollution, but it gives no information on the reduction in pollution required to achieve acceptable public health and well-being. However, when these goals can be achieved by different control alternatives, it behooves us to utilize the alternatives that show the greatest cost effectiveness.

To determine what pollution concentrations in air are compatible with acceptable public health and well-being, use is made of air quality criteria, which are statements of the air pollution effects associated with various air quality levels. It is inconceivable that any jurisdiction would accept levels of pollution it recognizes as damaging to health. However, the question of what constitutes damage to health is judgmental and therefore debatable. The question of what damage to well-being is acceptable is even more judgmental and debatable. Because they are debatable, the same social and political considerations come into the decision-making process as in the previously discussed case of arriving at episode control tactics. Cost effectiveness is not a factor in the acceptability of damage to health, but it is a factor in determining acceptable damage to public well-being. Some jurisdictions may opt for a pollution level that allows some damage to vegetation, animals, materials, structures, and the atmosphere as long as they are assured that there will be no damage to their constituents' health. The concentration level the jurisdiction selects by this process is called an air quality standard. This is the level the jurisdiction says it wishes to maintain.

Adoption of air quality standards by a jurisdiction produces no air pollution control. Control is produced by the limitation of emission from sources, which, in turn, is achieved by the adoption and enforcement of emission standards. However, before emission standards are adopted, the jurisdiction must make some social and political decisions on which of several philosophies of emission standard development are to be utilized and which of the several responsible groups in the jurisdiction should bear the brunt of the control effort—its homeowners, landlords, industries, or institutions. This latter type of decision-making is called emission allocation. It will be seen in Fig. 9.6 that the system for strategic control is closed by the line connecting emission standards and sources, which means that long-range pollution control strategy consists of applying emission limitation to sources.

IV. ALTERNATIVE CONTROL STRATEGIES

There are several different strategies for air pollution control. The strategy just discussed and shown in Fig. 9.6 is called the *air quality management* strategy. It is distinguished from other strategies by its primary reliance on the development and promulgation of ambient air quality standards. This is the strategy in use in the United States. The second principal strategy is the *emission standard* strategy, also known as the *best practicable means of control* approach. In this strategy, neither air quality criteria nor ambient air quality standards are developed and promulgated. Either an emission standard is developed and promulgated or an emission limit on sources is determined on a case-by-case basis, representing the best practicable means for controlling emissions from those sources. This is the strategy in use in Great Britain. A third strategy controls pollution by adopting financial incentives (Table 9.8).

TABLE 9.8

Financial Incentives to Supplement or Replace Regulation

Taxes	
Sales taxes	On fuel, fuel additives, ingredients in fuel, pollution-producing equipment
Ultimate disposal taxes	On automobiles or other objects requiring ultimate disposal
Land-use taxes	For pollution-producing activities
Tax remission	
Corporate income tax	For investment in or operation of pollution control equipment; accelerated write-off of pollution control equipment
Property taxes	For pollution control equipment
Fines, effluent charges, and fees	
Fines	For violation of regulations
Effluent charges	For permission to emit excessive quantities of pollution; paid after emission
Fees	For permission to emit excessive quantities of pollution, paid before emission
Subsidies	
Direct	Governmental production (e.g. nuclear fuel)
Grants-in-aid	For pollution control installations
Indirect (low-interest bonds and loans)	For pollution control process or equipment development
Import restraints	
Duties and quotas	On materials, fuels, and pollution control-producing apparatus
Domestic production restraints	
Quotas, land, and offshore use restraints	On material and fuels

Source: From Stern, A. C., Heath, M. S., and Hufschmidt, M. M., A critical review of the role of fiscal policies and taxation in air pollution control, *Proceedings of the Third International Clean Air Congress*, Verein Deutscher Ingeniuere, Dusseldorf, 1974, pp. D-10–12.

This is usually but not necessarily in addition to the promulgation of air quality standards. Among the countries that have adopted tax, fee, or fine schedules on a national basis are Czechoslovakia, Hungary, Japan, The Netherlands, and Norway. There is additional discussion of this strategy in Chapter 29, Section III. A fourth strategy seeks to maximize cost effectiveness and is called the *cost–benefit* strategy. These strategies may result in lower emissions from existing processes or promote process modifications which reduce pollution generation.

V. ECONOMIC CONSIDERATIONS

The situation with regard to economic considerations has been so well stated in the First Report of the British Royal Commission on Environmental Pollution [1] that this section contains an extensive quotation from that report:

> Our survey of the activities of the Government, industry and voluntary bodies in the control of pollution discloses several issues which need further enquiry. The first and most difficult of these is how to balance the considerations which determine the levels of public and private expenditure on pollution control. Some forms of pollution bear more heavily on society than others; some forms are cheaper than others to control; and the public are more willing to pay for some forms of pollution control than for others. There are also short and long-term considerations: in the short-term the incidence of pollution control on individual industries or categories of labor may be heavy; but ... what may appear to be the cheapest policy in the short-term may prove in the long-term to have been a false economy.
>
> While the broad outlines of a general policy for protecting the environment are not difficult to discern, the economic information needed to make a proper assessment of the considerations referred to in the preceding paragraph ... seems to us to be seriously deficient. This is in striking contrast with the position regarding the scientific and technical data where, as our survey has shown, a considerable amount of information is already available and various bodies are trying to fill in the main gaps. The scientific and technical information is invaluable, and in many cases may be adequate for reaching satisfactory decisions, but much of it could be wasted if it were not supported by some economic indication of priorities and of the best means of dealing with specific kinds of pollution.
>
> So, where possible, we need an economic framework to aid decision making about pollution, which would match the scientific and technical framework we already have. This economic framework should include estimates of the way in which the costs of pollution, including disamenity costs, vary with levels of pollution; the extent to which different elements contribute to the costs; how variations in production and consumption affect the costs; and what it would cost to abate pollution in different ways and by different amounts. There may well be cases where most of the costs and benefits of abatement can be assessed in terms of money. Many of the estimates are likely to be speculative, but this is no reason for not making a start. There are other cases where most of the costs and benefits cannot be given a monetary value. In these cases decisions about pollution abatement must not await the results of a full economic calculation: they will have to be based largely on subjective judgments anyway. Even so, these subjective judgments should be supported by as much quantitative information as possible, just as decisions about health and education are supported by extensive statistical data. Further, even if decisions to abate pollution

are not based on rigorous economic criteria, it is still desirable to find the most economic way of achieving the abatement.

As air pollution management moves forward, economics has a major role in reducing pollution. Multimedia considerations are forcing a blend of traditional emission reduction approaches and innovative methods for waste minimization. These efforts are directed toward full cost accounting of the life cycle of products and residuals from the manufacturing, use, and ultimate disposal of materials.

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QUESTIONS

1. Explain why certain important long-range air pollution control strategies will not suffice for short-term episode control, and vice versa.
2. Develop an episode control scenario for a single large coal-fired steam electric generating station.
3. In Fig. 9.6, the words "Social and political considerations" appear several times. Discuss these considerations for the various contexts involved.
4. Discuss the relative importance of air quality criteria and cost effectiveness in the setting of air quality standards.

5. The quotation in Section V contains the words "what may appear to be the cheapest policy in the short-term may prove in the long-term to have been a false economy." Give some examples of this.
6. Draw a simplified version of Fig. 9.6 with fewer than 10 boxes.
7. In the early 1970s, some experts expected the regulatory measures against air pollutants to be temporary until market forces supplanted them. Give examples of situations in which these experts were right and when they were wrong. What role do you believe that the marketplace will have in reducing air pollution in the future? Explain the obstacles and promise for at least one conventional pollutant (i.e. criteria pollutant) and one toxic pollutant (i.e. HAP).
8. How would one go about developing an air pollution damage function for human health?
9. The Organization for Economic Cooperation and Development (OECD) has been a proponent of the "polluter pays" principle. What is the principle and how can it be implemented?
10. Study Table 9.7 and determine whether there are any control methods that you believe should be added or deleted.