CHAPTER TEN

SCIENCE VS. TECHNOLOGY:

DETERMINING STANDARDS

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I. INTRODUCTION

Historically, there have been two distinct approaches to the development of pollution control regulations. The technological approach asks, what emission controls are possible, or perhaps, are reasonable? The other approach asks, what controls are needed to protect, for example, the public health? More recently, pollution taxes and markets have been recruited from the "dismal science" of economics as a third approach.

As always, the difficulties arise when we get down to details. If we opt for the technological approach, we must define what we mean by "possible" or "reasonable". Working back from the demands of public health requires both a definition of "the public health" and a scientific understanding of the physical properties and atmospheric chemistry of the pollutant and its effects. Both approaches produce a standard, a value, like a speed limit, that is not to be exceeded. For air pollutants, a standard developed from the technological perspective is generally a concentration in a smoke stack while a standard developed from a public health perspective is generally an ambient air concentration.

The technological approach to air pollution standards was codified in the Alkali Inspectorate acts in the United Kingdom in the nineteenth century. This approach relied on the inspectors to determine, on a case-by-case basis, the Best Practicable Means for controlling emissions.

The public health approach was codified into U.S. law in water pollution control legislation in 1964 and 1965 in response to disputes between upstream and downstream states. Reports were called for to establish "criteria" on the adverse effects of water pollutants, allowing "standards" to be developed to guide the clean up efforts of the upstream states. The criteria are the fundamental scientific understandings about the pollutant and its effects which are then used to justify the particular standard chosen.

Thus in 1967, when the U.S. Congress moved to enact a Clean Air Act, the use of criteria and standards was one clear option. The other option was federal emission limits for major sources, based on available technology. New technological standards had recently been adopted for motor vehicles in California and motor vehicle emissions were one of the key targets of clean air advocates. This was the proposal that President Johnson sent to the Congress. The new "urban coalition" of labor, big city mayors, and public interest groups supported the technology-based approach of the administration bill. However, Senator Muskie, chairman of the Senate committee that had written the water pollution laws and would write the air pollution law, was firmly committed to the criteria-standards approach.

Although everyone agreed on federal emission standards for motor vehicles, the prospect of federal emission standards for industry was feared as being potentially too strict, requiring controls in places where none were really necessary. The criteria and standards approach promised a state-by-state evaluation of what the ambient air could absorb and only the controls minimally necessary to achieve the standards would be required. Many in Congress became convinced that with the criteria and standards approach only California and a few eastern states would be affected. The law which eventually passed was taken almost word-for-word from the water pollution law.

Thus, with the passage of the 1967 act, this "air resources management" scheme became the basic approach to stationary source air pollution control in the United States. This required studies by meteorologists to define regional air-sheds and studies by scientists of the health and environmental effects of the most widely recognized air pollutants. The federal government began a process of designating the regional air-sheds and publishing criteria documents, on which the state ambient air quality standards were to be based.

Many industrialists were dismayed by the intensity of the public response and the demands for stricter standards at the state hearings. The industrialists believed that some state standards had been set at unnecessarily stringent levels. They appealed to the new Republican President for more reasonable, national standards. The new motor vehicle standards were pointed to as an example of a reasonable, measured approach. In 1970, the Nixon administration proposed that the federal government take over the standards setting activity but also recommended some uniform national emission standards for especially hazardous air pollutants.

Again the urban coalition supported national emission standards. The House agreed to the administration proposals, but Senator Muskie upped the ante, arguing "the issue is public health" and calling for the federal standards to be met in three years. The public clamor for action continued to grow and by the time a bill emerged from the conference committee it was more strict than the bill from either house. The standards now required that the public health be protected with an "adequate margin of safety" and a broad requirement for national emission standards for newly constructed sources was included. And, almost all references to considerations of economic feasibility in the two bills were carefully excised by the conference committee.

When the nation's air was not clean within the three years set by the Act, the Congress added more provisions, including in the 1977 amendments an entirely new permit program for the "prevention of significant deterioration" (PSD) of air quality in clean air areas with both new, lower ambient air quality requirements and case-by-case development of emission standards which would reflect the capability of the "best available control technology". In the areas where the current ambient standards were being exceeded, the Congress required larger new sources to meet an even stricter emission standard, reflecting the "lowest achievable emission rates".

The 1990 amendments strengthened the national emission standards for hazardous air pollutants by rewriting them as a technology-based standard, but including a subsequent check against their level of public health protection.

This brief history of the Clean Air Act should make two points very clear. First, the Act is not a pure reflection of any one air pollution control philosophy. In fact, it encompasses both ambient standards and direct emissions controls in different sections, and in some cases, even in the same section. Second, the emphasis on the protection of the most sensitive individuals are not some last minute inspiration of one or two members of Congress. These requirements have grown organically out of the Anglo-American tradition of emphasis on the importance of the individual above the importance of the society as a whole and a preference for social equity above economic efficiency.

II. AMBIENT STANDARDS

The 1970 amendments required the EPA to develop standards for any pollutant which has an "adverse effect on public health and welfare." This standard must "protect the public health" with "an adequate margin of safety." A second, separate standard is to "protect the public welfare from any known or anticipated adverse effects."

Immediately the questions begin to arise: does an "adverse effect" include only sickness and disability, or does it include discomfort and subtle physiological effects? Who is to be protected; even those who are already weakened by some disease? What characteristic of the pollutants should be controlled to protect the public health? At what maximum exposure to the pollutant will we be safe? What if we just don't have enough information about a pollutant to know what is safe?

A. ADVERSE EFFECT.

When California wrote their air quality standards in the mid-50's, "adverse" was defined as "untoward symptoms" which might discomfort individuals and lead them to seek medical attention. In a challenge heard in 1976, a federal appeals court agreed that "actual harm must result" (*Ethyl Corp vs. EPA*, 541 F.2d 14).

Congress responded to this ruling by amending the Clean Air Act, deleting the "adverse effects" language and replacing it with a requirement for standards to be issued whenever a pollutant would "cause or contribute to air pollution which may reasonably be expected to endanger public health or welfare," thus adopting a strong precautionary stance and providing EPA with additional leeway in dealing with often difficult to interpret scientific results.

The "adverse effect" language remains in the definition of a hazardous air pollutant, but there the emphasis is on mortality from cancer, birth defects, and clearly overt human health events.

B. PROTECTED GROUPS.

The question of who is to be protected was addressed in the Senate committee report on the 1970 amendments. "[T]he Committee emphasizes that included among those persons whose health should be protected by the ambient standard are particularly sensitive citizens such as bronchial asthmatics and emphysematics . . ." The Committee went on to explain that epidemiological studies would be sufficient evidence ("a statistically related sample of persons in sensitive groups") of harm.

> "For purposes of this description, a statistically related sample is the number of persons necessary to test in order to detect a deviation in the health of any person within such a sensitive group which is attributable to the condition of the ambient air."

The Congress clearly intended to include aggravation of pre-existing diseases in its definition of "public health". The discussion of sampling makes it equally clear that an increased frequency of health disorders and the increased risk of future disease, should be considered in setting the standard.

The Congress muddied the waters somewhat when it adopted the new PSD provisions. Their purpose is stated as "to protect the public health and welfare from any actual or potential adverse effect" which might occur "notwithstanding attainment and maintenance of all national ambient air quality standards." This seems to presume that there are adverse effects which will not be protected against even by the new, all inclusive language that was adopted for ambient standards at the same time.

C. MARGIN OF SAFETY.

The requirement for a margin of safety implies that there must be some ambient concentration of the pollutant which is safe, some concentration we can reduce below. While this is clearly the case for some pollutants, others do not appear to have any measurable, safe level of exposure. And where a clear "threshold" exists, the magnitude of the "margin of safety" that should be chosen is open to debate.

A margin of safety of 1.5 is used in structural engineering, but this lower limit is used only when the loads and materials are known absolutely. Aircraft design of simple systems commonly uses a factor of 10 to 12. The Food and Drug Administration claims to use a factor of 100 in their analysis of test data. The Nuclear Regulatory Commission has used safety factors of 100,000 to 1,000,000. A study by EPA researchers found that the implicit safety margins in the adopted ambient standards vary from none to better than a factor of 100, although more recent research has eroded some of these margins.

D. STANDARD SETTING.

An ambient standard will be expressed as a concentration in the air over an averaging period. The averaging period will usually be chosen in response to the character of the demonstrated health effect that is being protected against. A specific method for monitoring the air for that pollutant will also be specified. The monitoring method will, essentially, define the pollutant.

Carbon monoxide (CO) can provide an example of the way an ambient standard is determined. This pollutant is generated naturally in the human body and a mechanism exists to carry it to the lungs to be discharged. The system will work backwards if the atmospheric content of CO is high, pumping CO into the body. For example, a man sitting in an atmosphere containing 30 ppm of CO will raise his blood levels to 2 percent after one hour of exposure, increasing to about 3 percent after two hours, and a maximum of 5 percent after about 12 hours of exposure. A person with lower body weight or faster respiration because of exercise will respond more quickly.

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Carbon monoxide in the body directly interferes with vital energy pathways and may have neurologic effects. The heart muscle is extremely sensitive to the low blood oxygen levels caused by increased CO levels. During exercise all muscles, including the heart, increase their demand for oxygen. The heart, which must work harder during exercise, can increase its oxygen supply only by increasing the rate of blood flow through the heart muscles. If the blood vessels of the heart are inflexible or narrowed by heart disease (atherosclerosis), the rate of blood flow cannot increase sufficiently, leading to heart failure as heart muscle tissues die from oxygen starvation. If the oxygen carrying ability of the blood is reduced by CO exposure, the death of heart muscle tissue can occur more easily.

Clinical studies of persons with existing heart disease have observed a lower ability to tolerate exercise before the onset of incapacitating pain when blood levels are elevated. Epidemiological studies have recorded significantly more people reporting to an emergency room with complaints of chest pains on days with higher average ambient CO levels than on days with lower CO levels.

An ambient air quality standard for CO must then recognize the rise in blood levels over longer periods, but also the rapid increase possible when people are working or exercising. Thus EPA established two standards for CO exposure, one an eight-hour average and the other a one-hour average. The eight-hour standard has an implicit safety factor of 2 to 3, based on the inhalation rates of an adult man at rest. However, when we calculate the response of an exercising adult woman the one-hour standard should be about half of what it is.

However, many commentators have argued that it is appropriate to have a high one-hour standard and that the eight-hour standard should be raised, possibly doubled, because the effects carry natural warning signals. Anyone with heart disease has learned to sense and respond to early chest pains by resting, although heart disease events often do not come on gradually.

The standards for dust and dirt in the air can also illustrate the standards-setting process. The effects of airborne particles on human health depends on their size and composition. Very small (or, fine) particles and larger particles differ in their physical behavior. The fine particles are more nearly the size of the atmospheric gas molecules, so they remain suspended in the air much longer and can penetrate much deeper into the human lung when inhaled. The larger particles collect on the surfaces in the nose and throat and are swallowed. The smaller particles reach the lung and up to 50 percent will deposit there. Particles in the deep lung remain there for a long time, making it possible for pollutants collected on the particle surfaces to enter the bloodstream. For example, about 10 times as much lead will enter the blood from particles in the lung as from the same mass of lead particles in the stomach.

The process by which airborne particulate matter relates to respiratory disease is not as well understood as is the relation between CO exposures and heart disease. It is generally believed that chronic adult respiratory illness has its origins in repeated instances of juvenile respiratory disease. Among the many contributors to juvenile respiratory disease is moderately high ambient air levels of particulate matter. Epidemiological studies have found a lower rate of respiratory disease or symptoms in areas with lower airborne particulate matter, but no ambient level has been demonstrated to be safe. In fact, the most recent studies suggest there may be no threshold of effects. Clinical studies have demonstrated specific responses in sensitive individuals, but single exposure studies have not provided a clear guide to a standard. Nor is it clear what particles may be more likely to cause a response. Current thinking suggests it may just be the number of very small particles in the lung that is important, not their chemical composition.

Clearly it is necessary to have a standard which protects from repeated, moderately high exposures. To do this EPA has adopted both an annual average and a daily (24-hour) average standard. The annual average would be exceeded if the daily concentrations were too often near, but not over, the daily standard. The choice of ambient concentrations for the standards was more dependent on the conditions at the cleaner air side of comparison studies than any identification of thresholds. The daily standard recommended by the World Health Organization is just less than half the daily standard adopted by EPA.

The monitoring methods for ambient particulate matter have changed over the years. With the changes, the specific particulate matter sources that most influence the overall reported value have changed. Some of the earliest methods filtered air through a paper tape and measured the amount of captured particulate matter by shining a light on or through the tape. The reported mass concentration in the air could vary widely depending on the character of the dust. For example, the same value would be recorded for 1450 micrograms per cubic meter ($\mu g/m^3$) of a white limestone dust as for 65 $\mu g/m^3$ of a black coal dust. Later sampling devices collected more or less all of the suspended particulate matter in the air (although the amount collected could depend on the wind direction relative to the monitor), which was weighed after 24 hours of operation. During the '80s, monitors came into use which collect only that portion of the suspended particulate matter which is less than 10 micrometers (µm) in size and without preference for wind direction. Sampling only the smaller size particles is expected to more closely measure the particles that have potentially adverse health effects. More recently, electronic samplers have become available that can provide hourly average readings of fine particles, not just daily averages. Other samplers are now available that can collect a sub-set of the fine particles, those less than 2.5 µm in size, which are suspected by some investigators of a more important role in the observed health effects.

II. TECHNOLOGICAL STANDARDS

Technology-based standards rely more directly on the available control technology for a given type of source. For most sources and pollutants, spending more money will buy a more efficient control system that will provide lower pollutant emissions. Thus the choice among technologies is mainly an economic issue, although in some cases there are technical reasons why a technology that works well on one type of source cannot be used on another.

A. NEW SOURCE PERFORMANCE STANDARDS.

The federal New Source Performance Standards (NSPS) establish emission rates for specific pollutants from specific, newly constructed sources; for example, a requirement that the sulfur dioxide (SO_2) emissions from a municipal waste incinerator firing more than 250 tons of waste per day must not exceed 30 parts per million (ppm) or must be reduced by 80 percent through the gas control device. This standard was developed without reference to any public health need to reduce SO_2 concentrations near any municipal waste incinerator but was based only on the demonstrated technological capabilities of existing, large municipal waste incinerators. Financial capability is also considered. It is expected that when the standards are published for smaller incinerators they will be less strict, simply because of the cost of compliance.

Each NSPS includes a description of the specific type of source that is covered, an emission limit of a specific pollutant, and a description of how the emission is to be measured. The emission limit may be expressed as a work practice (as with the asbestos standard) rather than as a concentration in the exhaust stack. Many, but not all, NSPS include a continuous emission monitoring method to continuously record the emission rate. The continuous monitoring methods may measure the pollutant directly in the stack or may extract a sample of exhaust gas and process it through a separate instrument. The measured value will generally be recorded electronically every few seconds and averages over minutes or an hour reported.

The Clean Air Act directs EPA to publish new source standards for all the more important sources of air pollutants. It was originally intended that with strict new source standards, the air would gradually become cleaner than the ambient standards and currently clean air areas would remain clean. However the slow pace of EPA in developing and publishing new source standards (partially caused by extended litigation by newly regulated sources or disappointed environmental groups) led the Congress to require a case-by-case development of technological standards for major new sources.

In the PSD permit program, larger newly constructed sources in clean air areas must demonstrate that they propose to use the "best available control technology" (BACT). In the permit program for new sources locating in areas that exceed the current ambient standards, they must demonstrate that they will use controls that meet the "lowest achievable emission rate" (LAER). The burden of demonstration was on the applicant, with the states validating the applicant's findings during their review of the PSD application.

B. BEST AVAILABLE CONTROL TECHNOLOGY.

The law required the BACT standard to be at least as stringent as the NSPS standard, where one existed, but allowed consideration of economic, environmental, and energy factors. In practice, in many states, the BACT standard was seldom more strict than the NSPS, where one existed, and much less than EPA engineers felt appropriate in other cases. Applicants were frequently presenting a description of their proposed control technology and an argument, in varying degrees of detail, why anything more stringent would be too costly.

This led EPA to introduce a specific method for evaluating BACT, called "top-down BACT." Under this procedure, the applicant must first present an evaluation of the most efficient control technology that is known and available. This technology can only be rejected if the applicant demonstrates it is ruled out by "substantial or unique technical, environmental, or economic objections." The use of a particular technology by similar facilities within the same industry is assumed by EPA to be "prima facie evidence that the economic cost . . . is not prohibitive."

Top-down BACT makes it necessary for the applicant to use a technology with an equivalent control effectiveness, or to clearly demonstrate that technical aspects of the applicant's process make it impossible to apply in this case or that the cost of applying the technology in this case is substantially greater than in other situations where it is applied. This rule is currently under review and an additional, clarifying ruling on BACT analysis is anticipated.

A BACT analysis will generally involve, for example, a review of the recent decisions by other agencies in issuing permits for a similar source. A data base of agency decisions is maintained by the EPA but few agencies promptly record their actions. Direct inquiries to states that are likely to have a similar source are usually necessary. Once a list is compiled of recent actions, the technology used to achieve the most strict emission limit is identified. If this is the technology proposed to be used by the new source, and the emission limit can be met by the source, no further action is necessary. If not, it is necessary to show that, in this case, source-specific technological differences make the application of the strict controls to the new source infeasible or that the costs of applying the strict controls is too high. For example, it was possible to show that the cost of transporting chemicals for a control system to a remote Alaskan village (given FAA requirements for transporting hazardous substances by air) would have increased the already high cost of electricity by an unrealistic amount.

Washington state law goes beyond federal law and requires BACT as a minimum for any new source in the state, not just major sources. Existing sources must utilize "reasonably available control technology" (RACT) which differs from BACT both in a greater consideration of costs and a consideration of the impact of the source on air quality. To the extent possible, RACT is to be established by rule for classes of sources and not on a case-by-case basis.

C. LOWEST ACHIEVABLE EMISSION RATE.

In areas that already exceed the ambient air quality standards, major new sources are required to both meet a strict emission limit and to offset their new emissions by eliminating an equal or greater amount of emissions from another, local source. In this case the source must not exceed an emission rate equal to the most stringent emission limitation that is achieved in practice elsewhere by a similar source or that is required elsewhere in a federally-approved plan, unless the source can show that such a requirement is impossible to achieve. Costs are not considered in an LAER analysis.

III. <u>MIXED STANDARDS</u>

As enacted in 1970, the emission standards for hazardous air pollutants were actually a health-based standard, with the emission rate calculated so that it would provide "an ample margin of safety" to anyone exposed to the pollutant. This was the approach followed by EPA in developing their first several hazardous air pollutant standards. But when EPA proposed a standard for vinyl chloride emissions they found they could no longer follow the conventional rubric. Vinyl chloride is an demonstrated human car-

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cinogen and even extremely small exposures could place a nearby resident at risk. There was no threshold and therefore no margin of safety.

Initially EPA concluded that although the Clean Air Act could be read to completely prohibit emission of any apparent non-threshold pollutant, in this case such a rule would effectively ban domestic vinyl chloride production as the existing facilities "could not comply with zero emission limits using currently feasible control technology."

When EPA set a stringent, but non-zero emission limit, they were challenged by environmental organizations, which argued that "the standard must be based on the degree of control necessary to protect health, not on the degree of control which existing technology can achieve" and urged EPA to prohibit emissions of vinyl chloride. EPA argued that the obvious effects were beyond the intent of Congress.

The Congress recognized the difficult position the EPA faced in dealing with non-threshold pollutants. In the 1990 amendments it revised the requirements for hazardous air pollutants and shifted the standards from health-based to a mixed technology-based standard, backed up by a health-based requirement. These basis for these standards is being referred to as maximum achievable control technology (MACT). Unlike the NSPS, BACT, and LAER standards, which only apply to new sources, a MACT standard will also be developed for existing sources.

The new hazardous air pollutant standards are to achieve the "maximum degree of emission reduction . . . (including a prohibition on such emissions, where achievable)". The MACT standard for new sources is to be at least as stringent as the performance of the best controlled existing, similar source. The standard for existing sources may be less stringent, but it can be equal to the standard for new sources. If the EPA, based on economic considerations, provides a less stringent MACT standard for existing sources, it cannot be less stringent than the average emission level of the best controlled 12 percent of similar sources (subject to some qualifications).

Even if a clear health threshold does exist, EPA is not required to consider it at this time when determining the emission limits for hazardous air pollutants. However within eight years the EPA must revisit the standards and issue new standards that do "protect the public health" with "an ample margin of safety" if an exposure threshold does exist. If the pollutant is a human carcinogen, and thus assumed to have no threshold, the EPA must determine if the lifetime risk of cancer to the individual most exposed to the emissions will exceed one in a million. Although the language in the Clean Air Act suggests the EPA should proceed to adopt a more stringent MACT standard in that case, it does not require it. It is expected that the Congress will revise this section before the second round of MACT standards are prepared.

Some insight into the possible path of MACT standards under dual technology and health constraints can be gained from the experience with standards for carcinogenic metals in the boilers and industrial furnaces (BIF) rules issued under the Resource Conservation and Recovery Act (RCRA). The maximum allowable emission rates can be calculated from atmospheric dispersion models and a maximum concen-tration at the location of a most exposed individual. The maximum concentration represents an inhalation risk of cancer of one in one hundred thousand (a factor of ten less stringent than the MACT alternative requirement). In evaluating permit applications under this procedure it has become clear that the emission rates which this procedure allows are substantial. In fact, they are sufficiently high that they have proved to be a political liability to the sources. Even reducing the target risk level by a factor of ten would not solve the problem. As a result, both sources and environmental organizations are supporting a move by the EPA to substitute technologically-based emission limits which would be more strict.

IV. IMPLEMENTATION OF STANDARDS

A. TRADITIONAL MANAGEMENT STRATEGIES

The implementation of ambient standards ultimately requires emission standards imposed on specific sources. For example, in an area which has not attained the particulate matter ambient standards, the responsible agency will generally establish an emission standard for new sources which could be achieved by a known piece of control equipment. A standard for existing sources will often be defined by the capabilities of a different, and less expensive, piece of control equipment. If the ambient standard cannot be achieved, and the agency believes more strict control of stationary sources will contribute to lower ambient levels, the emission standard for some or all existing sources must be lowered and new control equipment must be installed to meet it.

The development of such emission standards and the choice of sources to be controlled must be guided by an understanding of the science behind the ambient air quality standard. For example, the size of the particulate matter which drives the standard is critical. The current standard for particles less than 10 µm includes not only particles from combustion sources, but also a certain amount of dust picked up by the wind or kicked up from roads by traffic. However, for particles less than 2.5 µm, almost none of it is from fugitive and resuspended dust. Thus a control policy that undertakes the paving and cleaning of roadways might help to meet a standard with a 10 µm limit, but would be of no benefit in meeting a standard with a 2.5 µm limit.

The emission standards must also define a measurement method for the pollutant that reflects the character of the pollutant. The measurement of particulate matter emissions from a stack illustrates the importance of procedures as a definition of the pollutant. A stainless steel probe with a heated quartz glass inner liner is used to extract samples from the stack. The probe is equipped to monitor the velocity and the exhaust gas temperature at each sampling point. The extracted exhaust gas is filtered through a glass-fiber filter and later weighed. The Puget Sound Air Pollution Control Agency (PSAPCA) requires an additional measurement to the weight required by the EPA and most other state and local agencies. They require the source also count the hydrocarbon material that condenses in the cooled part of the source test equipment. The EPA method measures only the particulate matter that is present in the stack while the PSAPCA method adds in material that will condense to particulate matter in the ambient air, after the gases leave the stack. The PSAPCA results are thus always greater than results reported using the EPA procedures.

If it is necessary to reduce the emissions of particulate matter from industrial sources to meet a new ambient standard, it will be very difficult to follow the traditional path of broad, new emission standards, since in many areas all sources of any significant quantities of particulate matter are already using a control technology that represents BACT. If anything more is to be done, it will be necessary for processes to be changed, operating hours reduced, new control technologies developed, etc. In short, the answers will be difficult and complex.

B. MARKET-BASED STRATEGIES

Students of market-based strategies have suggested several approaches that would be driven more by economic forces. The economic approach to reducing emissions rests on the reality that when goods are subsidized, too much is produced and consumed. The same goes for pollution. When it is too cheap, too much is created. A market-based strategy would place a price on pollution and change that price until the market cleared, with only the "right" amount of pollution being produced.

For example, assume the ambient standard for particulate matter were reduced by half in response to evidence that this is necessary to meet public health goals. Rather than imposing new emission standards, one alternative would be the imposition of a modest tax on each pound of pollution released from significant sources in the community. This could include a tax on gasoline, as the nitrates from motor vehicles can be an important part of the particles less than 2.5 µm in size, and a tax on domestic woodstoves, as well as a tax on industries. Those who can afford to reduce their particulate matter emissions at less cost than the tax would do so, and the ambient levels would decline. If, after a year or two, the ambient standards are still exceeded, the tax could be increased. At some level of taxation it would be cheaper for enough people to reduce emissions than to pay the tax and the emission rates would be reduced to the level of the standard.

An alternative approach would utilize tradeable emission rights. For example, analysts at the air pollution control agency would calculate the total amount of particulate matter that could be released on the days that cause the violations of the standard. Then each resident of the city would be sent a voucher for their share of the allowable emissions. Those who desire to operate woodstoves, drive, or release particulate matter from their smokestack would need to acquire the necessary vouchers on the open market. Some residents would decide they want the air cleaner than the target standard and would withhold their vouchers. The price that must be paid for vouchers to bring enough onto the market would define the price an industrial source would be willing to pay to implement alternative production or control strategies.

Another approach to marketable permits would be to award the vouchers only to current stationary sources of particulate matter, but with a fraction of them that expire each year (motor vehicle emissions would have to be handled separately). In order to keep operating, woodstove owners or industrial sources would have to acquire someone else's remaining vouchers when their control efforts could no longer keep up with the decrease in their voucher values. This would simply shut down the source that sells its voucher.

There are as many difficulties in implementing these market-based strategies as in finding new, effective emission limits. It is doubtful, especially in the current political climate, that it would be possible to raise the particulate matter tax to the level necessary to meet the standard. The problems with a full-fledged market that includes motor vehicle emissions leads to impossible situations and amusing images, such as touts at the airport leasing vouchers to arriving vacationers. And enforcement of a market that mixes industrial sources capable of careful measurement of their emission rates with woodstoves that can have a wide range of emission rates would be equally problematic.

A successful market-based response to a more stringent ambient standard would no doubt include a bit of everything: some new emission regulations on certain sources, taxes on others, and marketable permits within certain source groups. And to achieve a particulate matter standard at half the current standard will require all the imagination and courage we have.

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