Recent developments in atmospheric particles, their composition, their effects, and programs to address them are indeed “many things.” Whether measured by number, size, shape, or chemistry, what we call particulate matter is a complex mixture consisting of many parts. This issue of *EM* highlights developments in U.S. programs for fine particles (i.e., particles less than 2.5 micrometers in diameter or PM$_{2.5}$) emphasizing the PM$_{2.5}$ National Ambient Air Quality Standards (NAAQS).

Particles and their precursors play an important role in a wide array of effects, including significant increases in mortality and morbidity, climate change, visibility impairment, acid precipitation, and soiling. Analyses of major programs to reduce particles generally find benefits far in excess of costs. As our understanding of these issues has increased, programs to address the range of particles, effects, and sources have increasingly developed multifaceted, multi-pollutant approaches. The good news is, these programs are working to effect measureable improvements.

This extended introduction to the topic outlines some measured and forecast improvements from past regulations, summarizes some recent policy and legal developments, and notes implications of the above for the challenges that remain. The articles that follow address specific state, local, and industry efforts to reduce fine particle pollution. Lynn Terry and coauthors (page 10) outline California’s progress in developing and implementing programs for multiple PM$_{2.5}$ sources. Jayme Graham (page 16) addresses the role of a local agency in reducing emissions from a major steel complex in Pennsylvania. Finally, John Crouch (page 22) discusses the hearth products industry efforts to demonstrate the benefits of improved wood stoves and fireplaces.

**The Science/Policy Particle Chase**

Early 20th century air pollution programs focused on visible smoke, particularly coal smoke. Although it took many decades, these programs and energy shifts to oil and gas began to bite in the late 1940s through the 1960s. In the process, the United States made great progress in reducing some of the most harmful particles to health and the environment, including components such as black carbon, metals, and polycyclic organic compounds. Urban concentrations markedly decreased, particularly in wintertime.

By the mid-1970s, however, ambient monitoring and studies of visibility and acid rain noted a marked increase in acid sulfate particles formed in the atmosphere over broad regions of the eastern United States, particularly in warmer seasons.
These increases in both urban and rural regions were linked to increased sulfur oxide emissions from coal-fired power plants. Other particles formed from gases emitted from a variety of sources included nitrates, ammonium, and some organic compounds. These so-called “secondary” particles comprised the majority of fine particles in many locations, but were a much smaller portion of total suspended particulate matter or even later PM$_{10}$ standards violations. Accordingly, while reviews of air quality standards and new visibility regulations in the 1970s highlighted the problem, it would take decades before the 1990 Clean Air Act Amendments and new regulations would begin to address these secondary particles directly.

The 1990 amendments called for substantial reductions in sulfur dioxide (SO$_2$) and limiting projected increases in emissions of nitrogen oxides (NOx) under the acid rain program. Emerging health effects studies and recognition of the distribution of particles finally resulted in new fine particle (PM$_{2.5}$) standards in 1997 that prompted a much harder look at composition and sources. Delayed by court challenges and the need for monitoring, the U.S. Environmental Protection Agency (EPA) and many eastern states moved to address sulfates and nitrates, the largest regional components, in the Clean Air Interstate rule (CAIR) in 2005. California and other western states also developed programs motivated by the PM$_{2.5}$ standards and/or visibility regulations. National and state/local/tribal programs also continued to address direct fine particle emissions from diesels, wood burning, and industry.

The collective success of these programs on SO$_2$ and secondary sulfate particles is shown in Figure 1. Even though CAIR and a successor program (Cross-State Air Pollution Rule; CSAPR) have run afoul of court challenges, the data show states and sources continued to implement the reductions. These, diesel, and the other programs have markedly reduced PM$_{2.5}$ over the past decade. All but two of the 39 areas designated as nonattainment for the 1997 standards (15 µg/m$^3$ annual, 65 µg/m$^3$ daily) in 2004 had levels meeting these standards as of 2009–2011. Only 10 of the 32 areas designated as nonattainment for the revised daily standard (35 µg/m$^3$) issued in 2006 had levels failing that standard in 2009–2011.

### Remaining Challenges

At least 17 western areas, particularly in southern and central California, the greater northwest, and Salt Lake City do not meet the 2006 daily standard. This includes seven new areas that were not originally designated nonattainment for PM$_{2.5}$ in 2004. Only one designated eastern area (Allegheny County, near Pittsburgh) measured levels not meeting the daily standard in 2009–2011.

Although limited, the most recent available data on chemical composition show marked differences among these areas (see Figure 2). These and more detailed speciation data offer clues to the nature of the most important sources that contribute to elevated annual and daily levels. Significant organic and black carbon fractions indicate influence of motor vehicles, particularly diesels, in all regions. Wood smoke and other biomass burning increases wintertime levels of this “carbonaceous” fraction in many areas of the western United States, including Seattle, Salt Lake City, and the San Joachim Valley, above the annual values shown in Figure 2. Secondary nitrates and organics are also important contributors in California and Utah. Against the regionally high levels of sulfates and motor vehicle sources in western Pennsylvania, peak daily levels are also affected significantly by direct emissions.
Recent policy and legal developments (see sidebar “New Policy and Legal Challenges”) add to the challenges. Based on 2009–2011 data, 66 additional counties, most of them in the East and California, would not meet the newly revised annual standards today.3 Based on EPA modeling of the expected “base case,” including federal rules such as Mercury and Air Toxics Standards (MATS) and CAIR/CSAPR SO2 reductions and diesel standards that reduce carbonaceous particles, as well as state programs to attain the 2006 standards, all but seven of these counties (all in California) are projected to meet the new annual standard by 2020.4,5

As noted above, meeting the daily standard remains a challenge for dozens of areas. The near-road monitoring requirements,6 which by 2017 will apply to 52 urban areas with populations over a million, may increase the number of areas that

**New Policy and Legal Challenges**

### EPA Revises the PM2.5 NAAQS

On December 14, 2012, EPA finalized the most recent revision to the PM2.5 standards,9 lowering the level of the annual standard from 15 μg/m³ to 12 μg/m³. The daily standard remained unchanged at 35 μg/m³. This decision was based on a review of the science in the 2009 Integrated Science Assessment (ISA) and provisional assessment of newer work published after the ISA. A number of studies found effects at PM2.5 levels permitted in areas that met the previous standards. These revisions also represent EPA’s response to a court remand of the 2006 annual standards. In that review, the external Clean Air Scientific Advisory Committee (CASAC) and EPA staff had recommended tighter annual standards. The court found that EPA had failed to explain why retaining the 1997 annual standards in the 2006 review provided requisite levels of health and welfare protection. The new annual standard level is in the range recommended by CASAC in the most recent review. EPA also revised monitoring requirements, most notably by phasing in a near-road component to the PM2.5 monitoring network in larger cities.

EPA has requested states to provide recommended nonattainment designations by December 2013 based on 2010–2012 data, and plans to issue final designations no later than December 2014.10 Assuming implementation is consistent with a recent court ruling (below), areas would have six years (late 2020) to attain with possible extensions.

### D.C. Circuit Court Remands PM2.5 Implementation Rules11

On January 4, 2013, the U.S. Court of Appeals for the D.C. Circuit remanded two EPA PM2.5 rules: a 2007 rule implementing the 1997 standards and a 2008 rule outlining the New Source Review (NSR) Program for PM2.5. In effect, the court found that PM2.5 implementation should follow the “Subpart 4” provisions for PM in the 1990 Clean Air Act Amendments. This requires that all nonattainment areas be classified as “moderate” and if they do not attain in six years, be bumped up to “serious” with attendant “best available control measures” (BACM) and progress requirements.

EPA issued a preliminary outline of its intent to develop to classify all areas as “moderate” initially and to develop new rules in response, but has not yet provided details on classification or requirements for serious areas.10,12 At this stage, however, it does not appear that the classification requirement would slow the implementation process for the new standard. The NSR ruling is potentially more disruptive, as it vacates two significance limits that were used to exempt sources from certain preconstruction monitoring and review requirements. EPA recently issued a question-and-answer document13 and proposed new NSR modeling guidance14 that reflect its initial approach for addressing the court rulings.
exceed the standards because these sites will be located nearer heavily traveled roads. Increased traffic and industrial activity accompanying the economic recovery may also put upward pressure on levels measured during the recession years of 2009–2011.

A further challenge for both implementation and standard setting is the variation in and variety of substances that comprise PM$_{2.5}$ (see Figure 2). It appears unlikely that all fine particles contribute equally to the health effects caused by fine particles. A number of studies suggest carbonaceous materials, particularly near roadways, are of particular importance. Some studies have suggested effects that continue to be associated with sulfates may be, in large part, due to trace elements. Yet standards reviews have not found sufficient information to eliminate any of the major components or to assign all health effects to any one class. In the case of climate effects, a small fraction of directly emitted combustion particles, mainly black carbon (BC), can produce significant warming while secondary particles (e.g., sulfates and nitrates) generally cause cooling. BC and sulfates are both particularly effective at reducing visibility. Regional haze regulations already take these well-established differences into account.

While future studies and reviews may permit further refinement of health-based standards and strategies, data and forecasts noted above suggest additional SO$_2$ emissions reductions beyond those already planned are not needed to meet the PM$_{2.5}$ standards. Strategies will need to focus on the remaining sources, a substantial fraction of which will be local or sub-regional, including traffic, wood-smoke, and inadequately controlled industrial sources. The move toward near-road monitoring will focus additional emphasis on mobile sources. The remaining articles in this issue will summarize some of the real work that state and local agencies and industry are doing in each of these areas.

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References
11. U.S. Court of Appeals District of Columbia Circuit; No. 08-1250.