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I. Introduction

The focal point of the Clean Air Act (CAA) has been the national ambient air quality standards (NAAQS). The NAAQS addresses air pollution that endangers public health and welfare, and has been established for six pollutants: sulfur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter (PM), carbon monoxide (CO), ozone (O_3), and lead.[1]

The original primary and secondary NAAQS for PM were promulgated on April 30, 1971.[2] The standards were expressed in terms of total suspended particles or TSP. These are particles between 25 to 45 micrometers (μm) based on the capabilities of the high-volume sampler specified for collecting TSP.[3]

In 1987, the standard was revised to regulate inhalable particles, or

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1. *See* 40 C.F.R. pt. 50 (2000).

2. Promulgation of the National Ambient Air Quality Standard for Particulate Matter, 36 Fed. Reg. 8186 (Apr. 30, 1971).

3. Revision of the National Ambient Air Quality Standard for Particulate Matter, 52 Fed. Reg. 24634 (July 1, 1987).

particles that can deposit in the respiratory tract and therefore have a greater potential for causing adverse health effects.[4] These are particles with an aerodynamic diameter of 10 μm or less (PM_{10}). A primary NAAQS for PM_{10} was set at 150 micrograms per cubic meter ($\mu g/m^3$) averaged over 24 hours and at 50 $\mu g/m^3$ averaged over one year.

On July 18, 1997, EPA decided to retain the current PM_{10} standards and add both daily and yearly standards for particles 2.5 μm or less in aerodynamic diameter.[5] The 24-hour standard is 65 $\mu g/m^3$ and the annual standard 15 $\mu g/m^3$. The rationale for the new standards was to provide increased protection against a wide variety of health effects related to PM. It is the $PM_{2.5}$ standard that is currently the law in the United States.

From 1970 until its most recent revision, the PM NAAQS standard has focused on a mass concentration basis. That is, the weight of the gas in a cubic meter of air. Nevertheless, recent epidemiological studies indicate health effects on the general population at air particulate mass concentrations that lie significantly below the existing PM NAAQS. The main topic of interest related to these studies is the effect that ultrafine particles, those with diameters of <0.1 μm, play in relation to those health effects. While ambient ultrafine particles contribute very little to the overall mass concentration, they are dominant in terms of the particle number concentration. If ambient ultrafine particles can induce such adverse responses, the question arises whether a mass concentration standard is sufficiently protective of human health or whether a particle number concentration standard should be implemented instead. This article argues that the latter is more appropriate for adequately addressing the number concentration of ultrafine particles and should be implemented as the more protective regulatory standard in conjunction with a mass based concentration standard. It is proposed that a combination of mass based and number based standards will result in the reduction of overall mass loadings of fine and ultrafine particulate matter to the atmosphere while insuring adequately reductions in the number of ultrafine particles adversely impacting health. This is because the current mass based approach provides an incentive for facilities to target the high end of the NAAQS range in order to come into compliance with either the PM_{10} or $PM_{2.5}$ standard. As a result, technologies are not as efficient as they could be and the rest of the PM fraction remains uncaptured. In contrast, a number-based standard would target the full range of the PM fraction in order to come into compliance.

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4. *Id.*

5. National Ambient Air Quality Standard for Particulate Matter, 62 Fed. Reg. 38652 (July 18, 1997).

The U.S. Congress laid the foundation for a national effort to control air pollution through the enactment of the CAA. The process under the CAA is an iterative one designed to result in continuing improvements over time and is driven by the NAAQS. In theory, goals like the NAAQS are established after public health, and other scientific inquiries, demonstrate adverse affects from certain pollution concentrations. Next, emission reductions are determined through monitoring, emission inventories, and modeling. Finally, pollution control programs are developed and implemented to reduce pollution to levels where they will no longer adversely affect public health and the environment.

This article examines the potential regulation of ultrafine particles through this CAA regulatory process. First this article discusses the current understanding of particle science generally. Next this article discusses the health effects of ultrafine particle pollution. Dosimetry modeling of ultrafine particles is examined. This article then examines the legal foundations for establishing the PM NAAQS. The next section of this article discusses the form of a revised PM NAAQS based on a number concentration. The next section of this article looks at the implementation and development of an ambient PM number based standard. Then this article examines the development and implementation of a PM number-based ambient monitoring program, stationary source regulatory program, and mobile sources and diesel engine regulatory program. Lastly this article will conclude with some observations on a number-based PM standard.

II. Particulate Matter Characteristics and Distribution

A. Introduction

PM is not a single pollutant, but rather is a collective term used to describe small solid and liquid particles that are present in the atmosphere. PM also consist of three separate classes of pollutants—ultrafine, fine, and coarse particles.[6] These particles differ in sources, formation, mechanisms, composition, atmospheric lifetimes, and size. Moreover, PM can also be emitted into the atmosphere as a primary pollutant or formed secondarily by a combination of precursor pollutants. As a result of its multi-component nature, ambient PM is a uniquely complex form of air pollution.

6. SHELDON K. FRIEDLANDER, SMOKE DUST AND HAZE: FUNDAMENTALS OF AEROSOL DYNAMIC 188 (2000).

B. Physical Characteristics

1. Size

Particle size, usually measured by its aerodynamic diameter,[7] is the primary physical property concern of public health and environmental professionals because it determines atmospheric lifetime and deposition patterns in human lungs. Aerodynamic diameter is defined as the diameter of a sphere of a unit density of $1 g/cm^3$ that has the same terminal falling speed in the air as the particle under consideration.[8] In other words, particles with the same physical size, shape, and density will fall to the earth at the same rate. The size distribution of particles in the atmosphere is generally characterized as bimodal with a coarse and fine mode.[9] The distribution of particles between 1 and 3 μm are referred to as "coarse" mode. The distribution of particles with diameters less than 1 μm is referred to as "fine" mode. Particles in the fine mode implicitly include ultrafine particles. However, because the properties and effects of ultrafine particles are different from those of larger particles, researchers believe, it is appropriate to identify "fine" and "ultrafine" particles as distinct fractions of fine particulate matter.[10]

2. Fate and Transport

Fine particles and coarse particles exhibit different behavior in the atmosphere. Coarse particles can settle rapidly from the atmosphere with lifetimes from a few seconds to hours, and their spatial impact is limited because they tend to fall out of the air in the downwind area near their emission point.[11] On the other hand, fine particles are kept suspended by normal air motions, low surface deposition rates, and can be transported great distances like a thousand miles or more and remain in the

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7. *Id.*
8. *Id.*
9. *Id.*
10. PARTICULATE MATTER SCIENCE FOR POLICY MAKERS—A NARSTO ASSESSMENT (Peter H. McMurry, Marjorie F. Shepherd & James S. Vickery eds., 2005).
11. OFFICE OF AIR QUALITY PLANNING AND STANDARDS, U.S. ENVTL. PROT. AGENCY [EPA], STAFF REPORT: REVIEW OF THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER: POLICY ASSESSMENT OF SCIENTIFIC AND TECHNICAL INFORMATION 2, 2-9 (2001), *available at* http://www.epa.gov/ttn/oarpg/t1/reports/pmstdrft.pdf [hereinafter OAQPS STAFF REPORT]. *See also* AIR RES. BD. & THE OFFICE OF ENVTL. HEALTH HAZARD ASSESSMENT, CAL. EPA, STAFF REPORT: PUBLIC HEARING TO CONSIDER AMENDMENTS TO THE AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER AND SULFATES 1 (2002), *available at* ftp://ftp.arb.ca.gov/carbis/research/aaqs/std-rs/pm-final/PMfinal.pdf.

atmosphere for days to weeks.[12]

Atmospheric deposition refers to the removal of these, and other, pollutants from the air to soil, water, and other surfaces.[13] The three major processes in atmospheric deposition are wet deposition, dry deposition, and air-water exchange or intermediate transport.[14] Wet deposition refers to the incorporation of both gases and particles into all types of precipitation like rain, fog, or snow.[15] Dry particle deposition is defined as "the transport of particles onto surfaces," where particles are removed by gravity or impaction and gases adhere to surfaces where they are absorbed or adsorbed.[16] Air-water exchange, or intermediate transport, refers to the transfer of chemicals between the gas phase in the air and the dissolved phase in the water.[17]

Ultrafine particles may be removed by dry deposition or by their growth into fine particles. Because the rate of growth varies with the concentration of fine particles, it is assumed that the concentration of ultrafine particles would increase since the fine particle mass has decreased.[18] Moreover, once ultrafine particles are emitted into the atmosphere, their transport, fate, physical, and chemical properties are strongly related to the atmospheric processes—meteorological, aerosol, transport, gas, and radiative processes.[19]

3. Atmospheric Concentration

Federal standards for ambient air and, in some cases, for industrial emissions are expressed in terms of mass concentrations. Atmospheric aerosol mass concentrations range from about 20 $\mu g/m^3$ for unpolluted air to 200 $\mu g/m^3$ for polluted air.[20] For example, and as previously noted, in 1997, EPA revised the primary NAAQS for PM and added both daily and yearly standards for $PM_{2.5}$ at 65 $\mu g/m^3$ and 15 $\mu g/m^3$, respectively.

Total PM emissions for 2003 were 4.1 million tons.[21] More

12. OAQPS STAFF REPORT, *supra* note 11.

13. *See* THE DELTA GROUP, ATMOSPHERIC DEPOSITION OF TOXICS TO THE GREAT LAKES: INTEGRATING SCIENCE AND POLICY 1 (2000), *available at* http://www.delta-institute.org/publications/airtoxics.pdf.

14. *Id.*

15. OAQPS STAFF REPORT, *supra* note 11.

16. *Id.*

17. George D. Leikauf, *Hazardous Air Pollutants and Asthma*, 110 ENVT'L HEALTH PERSP. 505, 510 (2002 Supp. 4).

18. NAT'L CTR. FOR ENVTL. ASSESSMENT-RTP OFFICE, OFFICE OF RESEARCH AND DEV. U.S. EPA, AIR QUALITY CRITERIA FOR PARTICULATE MATTER 2, 2-36 (2004), *available at* http://cfpub.epa.gov/ncea/cfm/partmatt.cfm.

19. *Id.*

20. *Id.*

21. U.S. EPA, THE PARTICLE POLLUTION PROBLEM- CURRENT UNDERSTANDING OF AIR QUALITY AND EMISSIONS THROUGH 2003 at 22 (2004), *available at*

specifically, PM_{10} emissions were 2.3 million tons and $PM_{2.5}$ emissions were 1.8 million tons.[22] In addition, for 2003, $PM_{2.5}$ annual average ambient concentrations for the select following cities were for Los Angeles - 20 $\mu g/m^3$, Chicago - 16 $\mu g/m^3$, and Washington, D.C. - 15 $\mu g/m^3$.[23]

Since airborne PM concentrations are expressed in terms of mass concentration per unit volume, the sampled mass is often dominated by the largest particles that reach the collector. Therefore, the concentration of TSP is numerically larger than that for PM_{10} which, in turn, is larger than that for $PM_{2.5}$. The $PM_{2.5}$ contains the accumulation mode of the atmospheric aerosol that extends from $PM_{2.5}$ down to approximately 0.1 μm. It has been noted that this mode includes most of the mass of the secondary aerosols formed in the atmosphere from gaseous pollutant precursors by chemical reactions, including sulfuric acid and its ammonium salts; ammonium nitrate; and photochemically-formed organics.[24] The $PM_{2.5}$ fraction also includes the short-lived, rapidly coagulating ultrafine aerosol mode that extends from approximately 0.1 μm down to 0.01 μm, but the mass of this mode makes little contribution to the overall mass of $PM_{2.5}$.[25] However, in terms of the particle number concentration of the ambient aerosol concentration, the ultrafine mode is the prominent fraction.[26] For instance, in the number of particles in 1 g of particulate matter could measure as high as 15×10^{15} particles.[27] This demonstrates that particle number concentration is a more representative depiction of air quality than mass concentration.

There have been a number of recent national and international studies related to concentrations of ultrafine particles in the atmosphere.[28] A published report that monitored the ambient air in

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http://www.epa.gov/airtrends/pmreport03/pmexplain_2405.pdf.

22. *Id.*

23. THE PARTICLE POLLUTION PROBLEM, *supra* note 21.

24. *Id.*

25. Annette Peters et al., *Respiratory Effects are Associated with the Number of Ultrafine Particles*, 155 AM. J. RESPIRATORY & CRITICAL CARE MED. 1376 (1997).

26. *Id.*

27. David Kittleton, *Engines and Nanoparticles: A Review*, 29 J. AEROSOL SCI. 575 (1998).

28. *See* Meng-Dawn Cheng & Roger L. Tanner, *Characterization of Ultrafine and Fine Particles at a Site Near the Great Smoky Mountains National Park*, 36 ATMOSPHERIC ENV'T 5795, 5799 (2002) (where the median concentration of ambient concentrations of ultrafine particles were 407, 932, 1440, 2418, 9354, 11049, 6350, and 1445 particles/cm^3 respectively). *See also* Juhani Ruuskanen et al., *Concentrations of Ultrafine, Fine and $PM_{2.5}$ Particles in Three European Cities*, 35 ATMOSPHERIC ENV'T 3729, 3733 (2001) (where total ultrafine number concentrations were simultaneously measured in Alkmaar, The Netherlands, Erfurt, Germany, and Helsinki, Finland between November 1996 and March 1997, and the mean ultrafine number concentrations were 18,300, 17,700, and 16,200, particles/cm^3, respectively).

Atlanta, Georgia found 89 percent of the number of particles was in the ultrafine mode, but that 83 percent of the particle volume was greater than 0.1 μm.[29] In another study, on-road particulate matter concentrations on Minnesota highways have measured between 10^4 and 10^6 particles/cm^3 with the majority of the particles being less than 50 nanometers (nm.)[30] Another study did continuous measurements of particle size distribution in El Paso, Texas for a 21-day period in the winter of 1999, and the mean ultrafine particle number concentration was 14,400 particles/cm^3.[31] Similarly another study found that average ultrafine particle concentrations 17 meters from a busy highway measured 1.8×10^5 to 3.5×10^5 particles/cm^3.[32] To help determine the dispersion of ultrafine particles from highway activity, ambient measurements were taken upwind from Interstate 405 at the Los Angeles National Cemetery, where the results of this investigation indicate that the ultrafine particle number concentration decreased the further away measurements were taken from the highway.[33] Lastly a study conducted in southwest Detroit characterized ambient ultrafine particles, and examined the effect of local sources and meteorological parameters on the ultrafine number concentration and size distribution, where on average, ultrafine particles ranged from 1.4×10^4 to 2.5×10^4 particles/cm^3, with significant daily variations, and accounted for approximately 89 percent of the total number concentration.[34]

4. Surface Area

A corresponding physical feature of particle number is surface area.[35] The high surface area of ultrafine particles is a dominant factor in its physical properties. This is a concern because particles may carry toxic materials on their surface, so small particles in high number

29. K.S. Woo et al., *Measurement of Atlanta Aerosol Size Distributions: Observations of Ultrafine Particle Events*, 34 AEROSOL SCI. AND TECH. 75 (2001).

30. David B. Kittelson et al., *Nanoparticles Emissions on Minnesota Highways*, 38 ATMOSPHERIC ENV'T 9, 10 (2004).

31. Christopher A. Noble et al., *Continuous Measurement of Fine and Ultrafine Particulate Matter, Criteria Pollutants and Meteorological Conditions in Urban El Paso, Texas*, 37 ATMOSPHERIC ENV'T 827, 827 (2003).

32. Yifang Zhu et al., *Study of Ultrafine Particles Near a Major Highway With Heavy-Duty Diesel Traffic*, 36 ATMOSPHERIC ENV'T 4323, 4333 (2002).

33. Lidia Morawska et al., *A Study of the Horizontal and Vertical Profile of Submicrometer Particles in Relation to a Busy Road*, 33 ATMOSPHERIC ENV'T 1261 (1999).

34. Li-Hao Young and Gerald J. Keeler, *Characterization of Ultrafine Particle Number Concentration and Size Distribution During a Summer Campaign in Southwest Detroit*, 54 J. AIR & WASTE MGMT. ASS'N 1079 (2004).

35. GUNTER OBERDOSTER, EFFECTS OF ULTRAFINE PARTICLES IN THE LUNG AND POTENTIAL RELEVANCE TO ENVIRONMENTAL PARTICLES (1996).

concentrations, which gives a high total surface area, may potentially carry more toxic materials into the lungs. For instance, a particle with a diameter of 2.5μm contains 1.2 particles in l/cm^3 of air with a total particle surface area of 24 $\mu m^2/cm^3$.[36] In contrast a particle with a diameter of 0.02 μm contains 2,400,000 particles in l/cm^3 of air with a total particle surface area of 3016 $\mu m^2/cm^3$.[37]

C. Chemical Characteristics and Source Distribution

Particles that make up ambient aerosol vary in their chemical composition.[38] The composition of an individual particle depends on its source and its subsequent atmospheric history. In addition, particles are considered either primary or secondary. Those emitted directly to the atmosphere are primary and may be either coarse or fine. The ultrafine fraction, which is part of the primary fine mode, originates from combustion sources and from homogeneous nucleation of low vapor pressure compounds. Constituent components like sulfate, nitrate, ammonium, metals, elemental carbon, and organic carbon compounds characterize the fine primary fraction.[39]

Secondary particles result from condensation or the deposition of gaseous precursors onto a particle. The major precursors of secondary fine particles include SO_2, nitrogen oxides (NO_x), which includes nitrogen oxide NO and nitrogen dioxide (NO_2), volatile organic compounds (VOCs), ammonium (NH_3), hydrogen ions and particle-bound water.[40] All four of these precursors singularly or combination with each other or with other factors have a significant impact on the formation of PM. Atmospheric PM also contains a large number of elements in various compounds and concentrations. As a result, under Section 302(g) of the CAA, these PM precursors may be regulated to reduce PM emissions, thereby making them subject to the air quality planning and control requirements of the CAA.[41]

Because PM is composed of complex mixtures of chemicals, from a wide number of sources, it is considered to be strongly dependent on source characteristics. As a result, a source inventory is important to determine what sources must be regulated to reduce ambient particulate pollution. For example, SO_2 emissions are a major source of fine

36. *Id.*
37. *Id.*
38. CAL. AIR RES. BD., STAFF REPORT: PUBLIC HEARING TO CONSIDER AMENDMENTS TO THE AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER & SULFATES (2002), *available at* ftp://ftp.arb.ca.gov/carbis/research/aaqs/std-rs/pm-final/exesum.pdf.
39. *Id.*
40. *Id.*
41. *See* 42 U.S.C. § 7602(g) (2000).

particles and result primarily from stationary fuel combustion at 85 percent, on-road and off-road engines and vehicles at 9 percent, and metals processing at 2 percent.[42] NO_x emissions result primarily from on-road and non-road engines and vehicles at 53 percent and stationary fuel combustion at 42 percent.[43] VOC emissions, which are precursors of secondarily-formed particles, include solvent utilization at 47 percent, on-road and non-road engines and vehicles at 29 percent, and storage and transport at 10 percent.[44] NH_3 is also listed as a major precursor of secondary particles, and its major source categories include livestock and fertilizer at 85 percent, on-road and off-road engines and vehicles at 5 percent, chemical and allied products at 3 percent, and waste disposal and recycling at 2 percent.[45]

In addition to these precursors, a variety of trace metals and hazardous air pollutants (HAPs) have been identified in fine particles.[46] Identified elements with more than 75 percent of their mass associated with fine particles include sodium (Na), cesium (Cs), chloride (Cl), bromide (Br), copper (Cu), arsenic (As), silver (Ag), cadmium (Cd), lead (Pb), indium (In), tin (Sn), and antimony (Sb).[47] Concentrations of trace elements such as As, Cd, nickel (Ni), Pb, vanadium (V), zinc (Zn), chorium (Cr), iron (Fe), mercury (Hg), and manganese (Mn) are typically orders of magnitude higher in urban areas compared to those in remote areas in the United States, and several times orders of magnitudes higher in rural areas compared to urban areas.[48]

1. Regional and Seasonal Distribution of Chemical Composition

An overlooked aspect of this PM inventory is the regional and seasonal nature of the chemical composition of PM.[49] Since the chemical speciation of PM differs in parts of the United States, regional, rather than uniform, control strategies maybe necessary to reduce PM at all concentration levels. For example, sulfate compounds comprise the major portion of the fine particle mass collected in the ambient air of many urban areas in North America with more than 40 percent to

42. *See* OAQPS STAFF PAPER, *supra* note 11.
43. *Id.*
44. *See* OAQPS STAFF PAPER, *supra* note 11.
45. *Id.*
46. THAD GODISH, AIR QUALITY 61 (4th ed. 1997).
47. *Id.*
48. *Id.*
49. *See* OAQPS STAFF PAPER, *supra* note 11, at S-13. *See also* Shao-Hang Chu et al., *PM Data Analysis—a Comparison of Two Urban Areas: Fresno and Atlanta*, 38 ATMOSPHERIC ENV'T 3155 (2004) (where the analytical results reveal that differences in meteorology and emissions have a significant impact on the observed seasonality in chemical contribution concentrations in these two cities).

50 percent of the mass found in the eastern United States.[50] Therefore high PM concentrations driven by sulfate concentrations in summer, may point to the need for additional SO_x reductions strategies in the eastern part of the country.

In contrast, nitrate concentrations are low in the eastern United States with approximately 1 percent of the fine particle mass, but much higher concentrations are found in the western United States with approximately 25 percent of fine particle mass in some cities.[51] While summer nitrate concentrations in the eastern United States are low in comparison with other PM components, higher winter nitrate concentrations occur in eastern urban areas. High levels of PM occurring in the Los Angeles Basin and San Joaquin Valley in California are dominated by winter ammonium nitrate so strategies to reduce in NO_x and VOCs may be appropriate in these areas.

In addition, the time of year also influences daily fine particle patterns.[52] Unlike daily ozone levels, which are typically elevated in the summer, daily $PM_{2.5}$ values at some locations can be high at any time of the year. For example, EPA notes that fine particles can be elevated in the fall and winter, while ozone is elevated only in the summer.[53] However, urban areas like Chicago experience elevated $PM_{2.5}$ levels year-round.[54]

2. Ultrafine Particles

Unlike the other pollutants examined in this article, there is no official U.S. emissions inventory of ultrafine particles. However, there are a number of local emission inventories that extend down to the ultrafine range.[55] For example, the emissions inventory for ultrafine particles constructed for the Los Angeles area indicates a mass emissions rate at 13 tons per day in particle sizes smaller than 0.1 μm.[56] The largest

50. *Id.*

51. NAT'L CTR. FOR ENVTL. ASSESSMENT, U.S. EPA, AIR QUALITY CRITERIA FOR PARTICULATE MATTER. Vol. II. (1996).

52. U.S. EPA, *supra* note 18.

53. *Id.*

54. *Id.*

55. *See* Glen R. Cass et al., *The Chemical Composition of Atmospheric Ultrafine Particles*, 358 PHIL. TRANS. R. SOC. LOND. 2581 (2000) (where in the United Kingdom vehicle road transportation accounts for 60 percent of the ultrafine particles emissions inventory, combustion processes related to energy production, industrial, commercial, and residential activities account for 26 percent of the inventory, non-combustion processes account for 13 percent of the inventory, and the remaining 4 percent is divided equally between waste treatment/disposal practices and machinery use).

56. Michael J. Kleeman et al., *Sources Contributing to the Size and Composition Distributions of Atmospheric Particles: Southern California in September 1996*, 33 ENVTL. SCI. TECH. 4331 (1999).

sources are on-road motor vehicles at 43 percent; stationary source fuel combustion at 32 percent; non-highway mobile sources at 10 percent; and other industrial processes at 7 percent.[57]

Measurements of ultrafine particle mass concentration made in seven Southern California cities show that ultrafine particle concentrations in the size range 0.056 to 0.1 μm aerodynamic diameter average 0.55 to 1.16 $\mu g/m^3$.[58] A source emissions inventory constructed for the South Coast Air Basin that surrounds Los Angeles shows a primary ultrafine particle emissions rate of 13 tons per day.[59] Those ultrafine particle primary emissions arise principally from mobile and stationary fuel combustion sources and are estimated to consist of 65 percent for organic compounds, 7 percent for elemental carbon, 7 percent for sulfate, 4 percent for trace elements, and negligible quantities of sodium, chloride and nitrate.[60]

Studies of ultrafine particle measurements for the Pittsburgh region were conducted during the summer of 2001 and winter of 2002.[61] On a number basis, the particle size distribution in the Pittsburgh region was dominated by ultrafine particles.[62] Overall number concentrations went from less than 20,000 particles/cm^3 to over 100,000 particles/cm^3 due to nucleation events, which were defined as those corresponding days with bright sun and low concentrations of preexisting particles. The authors found nucleation events the single biggest factor in determining the number concentration of particles at its urban monitoring site, followed by traffic intensity, local combustion, and regional transport as contributing factors.[63]

In the United States researchers set out to study number concentrations of fine and ultrafine particles containing metals in the ambient air around Baltimore, MD.[64] Number concentrations of ambient particles containing these metals exceeded 10,000 particles/cm^3 at the measurement site. These researchers identified V is a primary marker for fuel oil combustion, Fe as a marker from a variety of sources including

57. *Id.*
58. CAL. AIR RES. BD., STAFF REPORT, *supra* note 38.
59. *Id.*
60. *Id.*
61. *See* Ann E. Wittig et al., *Pittsburgh Air Quality Study Overview*, 38 ATMOSPHERIC ENV'T, 3107 (2004). *See also* ALLEN L. ROBINSON ET AL., CARNEGIE MELLON UNIV., DEP'T OF MECH. ENG'G, CHARACTERISTICS AND SOURCES OF $PM_{2.5}$ IN THE PITTSBURGH REGION (2002), *available at* http://www.netl.doe.gov/publications/proceedings/02/air_q3/CMU.pdf.
62. *Id.*
63. *Id.*
64. Michael P. Tolocka, Derek A. Lake, Murray V. Johnston, & Anthony S. Wexler, *Number Concentrations of Fine and Ultrafine Particles Containing Metal*, 38 ATMOSPHERIC ENV'T 3263 (2004).

incinerators, smelters and boilers, and as as a marker from smelter emissions. The exact sources for Pb were difficult to identify among the power plants, steel mills, and specialty chemical manufacturers.

In addition to these inventory studies, EPA has identified numerous theoretical and laboratory studies have shown that the typical size of metals from combustion are ultrafine particles.[65] The presence of metals in a combustion process such as incineration of biological and chemical wastes or treatment of contaminated soils poses a problem.[66] It is suggested that raising the temperature of combustion high enough to affect a more than 99.99 percent destruction rate for biological and chemical species will also enhance the volatilization of metallic compounds in the feed stock, requiring more efficient removal methods for ultrafine metals.[67]

After issuing its revised PM standards in 1997, EPA developed the PM Supersites project, a monitoring research program to address a number of scientific issues associated with PM.[68] EPA selected eight locations for "Supersites"—Atlanta; Los Angeles; St. Louis; Pittsburgh; Fresno; Houston; Baltimore; and New York. Atmospheric measurements at the Los Angeles site between October 2002 and September 2003 show that coarse, fine, and ultrafine particles have different compositions. For instance, over 80 percent of the ultrafine particle fraction is made up of carbon with organic carbon being the dominant contributor.[69] These Supersite findings are consistent with independent studies conducted in two urban areas of southern California, Downey and Riverside, which examined the effect of different sources and formation mechanisms on the size distribution of ultrafine particles.[70] In that study 64 percent and 73 percent of the ultrafine particles were composed of organic carbon in Downey and Riverside, respectively.

3. Diesel Particulate Matter

When studying ultrafine particles, it is important to look at diesel particulate matter ("DPM"), which is a prominent part of the ultrafine

65. AIR QUALITY CRITERIA FOR PARTICULATE MATTER, *supra* note 51.
66. *Id.* at 6-190.
67. *Id.*
68. U.S. EPA, PM SUPERSITE PROJECTS (PHASE I AND II INFORMATION), *available at* http://www.epa.gov/ttn/amtic/ssprojec.html.
69. U.S. EPA, *supra* note 18.
70. Kim Seongheon et al., *Size Distribution and Diural and Seasonal Trends of Ultrafine Particles in Source and Receptor Sites of the Los Angeles Basin*, 52 J. THE AIR & WASTE MGMT. ASS'N 297 (2002).

particle fraction.[71] For instance, approximately 50 percent to 90 percent of the number of particles in diesel exhaust is in the ultrafine size range, with the majority of diesel particles ranging in size from 0.005 to 0.05 μm and with a mode at about 0.02 μm.[72] These aerosol particles are formed from exhaust constituents and consist of sulfuric acid droplets, ash particles, condensed organic material, and primary carbon spherules. Although it accounts for the majority of particles, ultrafine DPM accounts for only 1 percent to 20 percent of the mass of DPM.[73]

Approximately 80 percent to 95 percent of diesel particle mass is in the size range from 0.05 to 1.0 μm, with a mean particle diameter of about 0.2 μm.[74] The elemental carbon core has a high specific surface area of approximately 30 to 50 m^2/g, and after the removal of adsorbed organic material, the surface area of the diesel particle core is approximately 90 m^2/g.[75] Because these particles have a very large surface area, it has been noted that this characteristic makes them excellent carriers for adsorbed inorganic and organic compounds, which may enhance penetration of such compounds to lower portions of the respiratory tract upon inhalation.[76]

Diesel exhaust is also a complex mixture of hundreds of constituents in the form of either a gas or particle. Gaseous components of diesel exhaust include CO_2, O_2, N, water vapor, CO, nitrogen compounds, sulfur compounds, and low-molecular-weight hydrocarbons. Among the gaseous hydrocarbon components of diesel exhaust that are individually known to be toxic are the aldehydes, like formaldehyde, acetaldehyde, and acrolein, benzene, 1,3-butadiene, and PAHs and nitro-PAHs.[77]

Diesel exhaust is emitted from a variety of sources, both on-road sources, like motor vehicles, and nonroad sources, like construction equipment, farm equipment, railway locomotives, or marine uses.[78] Moreover, environmental exposure to diesel exhaust is higher in urban areas than in rural areas. The concentration of diesel exhaust in the air also varies within a geographic area depending on the number and types of diesel engines in the area and the atmospheric patterns associated with air dispersal. As previously noted, diesel exhaust is emitted from "on-road" diesel engines, like vehicle engines, or "nonroad" diesel engines,

71. U.S. EPA, HEALTH ASSESSMENT DOCUMENT FOR DIESEL ENGINE EXHAUST (2002), *available at* http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=29060.
72. *Id.* at 1-3.
73. *Id.*
74. *Id.*
75. *Id.*
76. *Id.*
77. *Id.* at 2-1.
78. *Id.*

like locomotives, marine vessels, and heavy-duty equipment. EPA nationwide data, from 1998, indicated that diesel exhaust as measured by DPM made up about 6 percent of the total ambient $PM_{2.5}$ inventory and about 23 percent of the inventory, if natural and miscellaneous sources of $PM_{2.5}$ are excluded.[79] Estimates of the DPM percentage of the total inventory in urban centers are higher. For example, estimates range from 10 percent to 36 percent in certain urban areas in California, Colorado, and Arizona.[80]

The EPA Emissions Trends Report from 2000 indicates that annual nationwide emissions of on-road and non-road diesel $PM_{2.5}$ in 1998 were 77 percent of all mobile-source emissions, 23 percent of the total $PM_{2.5}$ inventory excluding natural and miscellaneous sources, and 6 percent if the natural and miscellaneous sources are included.[81] Some geographic areas have a higher percentage of DPM in ambient $PM_{2.5}$ because of differences in the number and types of diesel engines present in the area. For example, in Manhattan, New York, on-road diesel PM was reported to contribute about 53 percent of ambient PM_{10} during 3 days in 1993, whereas 1996 to 1997 studies in the Phoenix and Denver areas showed diesel PM to be 10 percent to 15 percent of total $PM_{2.5}$ mass and gasoline PM accounted for an average of 50 percent of ambient PM.[82]

III. Health Effects of Ultrafine Particles

A. Introduction

The adverse effects of inhaled pollutants have been of public health and regulatory concern for over the past 50 years starting with some particularly severe episodes in Donora, Pennsylvania in 1948, Pozo Rico, Mexico in 1950, and London, England in 1952.[83] In London it was generally agreed that about 4,000 excess deaths resulted from the 1952 episode.[84] It has been said that the development of epidemiology initiated from the London episode, but it was not until 1965 that acceptable scientific methods were developed to study disease occurrence in human populations, including a description of the occurrence of the disease, and identification of the causes of disease.[85]

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79. *Id.*
80. *Id.*
81. U.S. EPA, NATIONAL AIR POLLUTANT EMISSION TRENDS, 1990-1998 (2000).
82. *See, e.g.*, ARIZ. DEP'T OF ENVTL. AIR QUALITY, THE 1989-1990 PHOENIX PM_{10} STUDY, VOLUME II: SOURCE APPORTIONMENT, FINAL REPORT (1991).
83. *See* Geneva H. Heimann, *Effects of Air Pollution on Human Health*, AIR POLLUTION 159 (1961).
84. *Id.*
85. *Id.*

Since that time substantial investigative efforts have been directed at not only understanding mechanisms of disease, but also at providing direct evidence on risks to human populations, which are needed to develop regulatory and other risk management strategies. The resulting evidence of adverse health effects of air pollution, derived from population-based studies, toxicological studies, and other scientifically valid methods, have assisted in the development of environmental regulatory programs and served to guide the development of standards for pollutant emissions and concentrations in ambient air.

It is well settled that there is a clear association between increased levels of ambient PM and morbidity and morality in people with preexisting respiratory or cardiopulmonary conditions.[86] It is also well settled that PM levels have dropped significantly since EPA began its regulatory regime in 1971.[87] The national trend in annual mean PM_{10} concentration from 1989-1998 has dropped 25 percent from 31.7 $\mu g/m^3$ to 23.7 $\mu g/m^3$. However, recent epidemiological studies indicate adverse health effects on the general population when air particulate mass concentrations are below existing air quality standards. These studies indicate that increases in human mortality and morbidity are associated with levels of air particulate pollution significantly lower than were previously thought to affect human health.[88]

A number of hypotheses have been proposed to explain which particle characteristics might be responsible for the adverse health effects.[89] However there is a growing body of evidence to suggest that ambient ultrafine particles, which are generally associated with the PM number concentration, may be the characteristic that represents the greatest risk to human health.[90] In general, this evidence suggests that on an equal mass basis, ultrafine particles may be more potent than accumulation mode particles in inducing airway injury and inflammation.[91] This may be due in part to a much higher number concentration and surface area. For instance, to achieve a low airborne

86. *Id.*

87. OAQPS STAFF REPORT, *supra* note 11.

88. *Researchers Call for Studies to Determine Why Asthma Rate Up While Emissions Down*, DAILY ENV'T REPORT, Oct. 21, 2004.

89. *See* Mark J. Miller, Identification of Factors and Properties of Airborne Particulate Matter That Contribute to Adverse Health Effects (May 2002) (unpublished Master thesis, Penn State Harrisburg) (on file with author) for a comprehensive discussion on the particle characteristics that correlate with human health effects. These characteristics include PM mass concentration; PM surface area; PM number concentration; transition metals; acids; organics compounds; bioaerosols; sulfate and nitrate compounds; peroxides and free radicals that can accompany and help form PM; and soot or EC).

90. DAILY ENV'T REPORT, *supra* note 88.

91. Miller, *supra* note 89.

concentration of 10 $\mu g/m^3$, 19,100 particles/cm^3 with a diameter of 0.1 μm are needed.[92] In contrast, only 1 particle /cm^3 with a diameter of 2.5 μm is needed to reach the same concentration. As will be discussed, inhaled ultrafine particles have a very high deposition rate in the pulmonary region. Moreover, it will be noted that ultrafine particles also have a high propensity to penetrate the epithelium, or lung tissue, and reach extrapulmonary sites. Finally ultrafine particles are biologically more reactive than larger sized particles and therefore elicit adverse health effects at lower concentrations.[93]

In addition to ultrafine particles generally, diesel exhaust contains several substances that are known, likely, or possible human or animal carcinogens, or that has serious noncancer health effects. As note earlier, these substances include, but are not limited to, benzene, formaldehyde, acetaldehyde, 1,3-butadiene, acrolein, dioxin, PAH, and nitro-PAH. Furthermore, diesel exhaust creates DPM of which the greatest fraction is in the ultrafine mode.

B. Ultrafine Particle Deposition in the Respiratory Tract

Depending on particle size, inhaled particles are deposited in different parts of the respiratory tract. As a result, the epidemiological concern for the ultrafine particle fraction is in the structure of the human respiratory system, and the fate and transport of ultrafine particles in the human body. The human respiratory system can be classified into three regions each covering one or more anatomical regions.[94] These regions differ in structure air flow patterns, function, and sensitivity to deposited particles. The first is the head region, or extrathoracic region, which includes the nose, mouth, and pharynx.[95] Inhaled air is warmed and humidified in this region. The second is the tracheobronchial region, which includes the airways from the larynx to the terminal bronchioles.[96] This region resembles an inverted tree with a single trunk, the trachea, subdividing into smaller and smaller branches. Finally beyond the terminal bronchioles is the pulmonary or alveolar region where gas exchange takes place.[97] A fully developed lung is estimated to have approximately 300 million alveoli or air sacs, which have a large surface area to facilitate the efficient exchange of CO_2 and O_2 between the lung and the blood capillaries that cover the alveoli. Moreover, the deposition

92. THE PARTICLE POLLUTION PROBLEM, *supra* note 21.
93. *Id.*
94. W.C. HINDS, AEROSOL TECHNOLOGY (1982).
95. *Id.*
96. *Id.*
97. *Id.*

probability of ultrafine particles is high in the alveolar region.[98]

The respiratory system is protected from foreign substances, like PM, by a variety of defense mechanisms.[99] In the nasal region, for example, large particles may be removed by the stiff nasal hairs or by striking the mucus layer. Cilia clean the mucus layer and entrapped particles move toward the back of the mouth where they are swallowed or expectorated.[100]

Within the alveoli and bronchioles of the pulmonary region, specialized absorbing cells called phagocytes ingest deposited PM.[101] These phagocytes and the matter they contain are normally transported out of the lungs in mucus by the respiratory cilia. However, the PM may also penetrate the alveolar membrane and enter either the lymphatic or circulatory systems and move toward and embed in certain organs other than the lungs.

The fate and transport of ultrafine particles within the lung and body is also a very important factor related to health effects.[102] Because of changes in flow patterns in the tracheobronchial zone, particles tend to be deposited at or near airway intersections. Nerve endings are concentrated at these sites, and deposited particles often lead to reflex couching and bronchoconstriction, which results in increased breathing rates and increased stress on the heart.[103]

Deposition of particles is not only influenced by particle size but also by mass concentration, molecular composition, pH, and solubility.[104] For instance, if particles are relatively insoluble they may be retained in the lung for months or years and exhibit effects over a long period of time.[105] If particles are more soluble, their residence time in the lung may be minutes or hours and their effects are likely to be either at or near the original deposition site, or in other organs after being transported via blood to those other organs.[106]

After particles have been deposited, their retention may be a function of the rate of clearance, which varies greatly among different regions of the respiratory tract.[107] For instance, clearance effects for

98. INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, HUMAN RESPIRATORY TRACT MODEL FOR RADIOLOGICAL PROTECTION (1994).
99. GODISH, *supra* note 46.
100. *Id.*
101. *Id.*
102. M.B. Snipes, *Long-term Retention and Clearance of Particles Inhaled by Mammalian Species*, 20 CRIT. REV. TOXICOL. 175 (1989).
103. *Id.*
104. *Id.*
105. *Id.*
106. *Id.*
107. OAQPS STAFF REPORT, *supra* note 11, at 6-1.

larger particles are usually described in terms of effects on upper airway clearance that takes place over hours, and long-term clearance for ultrafine particles in the alveolar region takes place over weeks to years.[108]

Particles in the range of 0.1 to 2.5 μm usually settle within the alveolar region.[109] The toxicity of these small particles may be greater than that of larger particles, because concentrations of toxic substances like Pb, Zn, Cr, Hg, sulfates, and nitrates increase with decreasing particle size.[110] In addition the large surface area of small particles allows for high reaction and dissolution rates for toxic chemical species.[111] Their relatively long retention in the alveolar region permits substances such as Pb to be extracted and transported to other parts of the body.[112]

C. *Epidemiological Studies in Air Quality Management and Ultrafine Particles*

Epidemiological studies gather the evidence of the adverse public health effects from air pollution exposure in a designated community.[113] The results of these studies can document the occurrence of adverse effects of air pollution, describe the relationship between exposure and response, and characterize effects on susceptible groups within the population like persons with preexisting respiratory illnesses like asthma, the elderly, and children. In general, these studies are carried out to determine if air pollution or a source of air pollution poses a hazard to human health, to characterize the relationship between the level of exposure and response, and to examine responses of potentially susceptible populations to pollutant exposures.[114] Moreover, these objectives relate to the information needed by regulators and policymakers to determine if the pollutant poses a hazard to human health, the level of acceptable risk of that pollutant, and which groups, if any, need special consideration because of susceptibility.[115] These

108. *Id.*
109. *Id.*
110. *Id.*
111. *Id.*
112. *Id.*
113. *See* AIR POLLUTION AND HEALTH (Holgate et al. eds., 1999).
114. *Id.*
115. For a fulsome discussion on the interaction between epidemiology and public policy decision making, *see* J.M. Samet & N.L. Lee, *Bridging the Gap: Perspectives on Translating Epidemiologic Evidence into Policy*, J.V. Rodricks, *Some Attributes of Risk Influencing Decision-making by Public Health and Regulatory Officials*, M. Szklo, *The Evaluation of Epidemiologic Evidence for Policy-making*, L. Goldman, *Epidemiology in the Regulatory Arena*, and G.M. Matanoski, *Conflicts between Two Cultures:*

epidemiology studies are necessary for regulatory agencies, like U.S. EPA, which, under the CAA, is required to set standards for criteria pollutants, like PM, that protect against adverse effects with an "adequate margin of safety," regardless of susceptibility.[116]

As previously noted, in 1971, 1987, and 1997 EPA revised the NAAQS for PM. The rationale for the new 1997 standards was to provide increased protection against a wide variety of health effects related to PM.[117] This action was based primarily on epidemiological studies finding an association between PM and morbidity and mortality and other endpoints associated with daily exposure to PM in large, long-term cohort studies.[118] This EPA decision is the most recent action in an ongoing debate on epidemiological studies on PM-related healthy effects, and on the public health policy actions to be implemented based on those studies.[119] However, this regulatory action has not ended the matter since EPA, as required under the CAA, must review the standard every five years, and the continuing debate and interest has generated further study on this issue.[120]

1. Mortality Studies and Exposure to Ultrafine Particles

The most widely cited epidemiological study on mortality and ultrafine particles is a Health Effects Institute (HEI) report where investigators characterized the sizes of particles in the ambient air of Erfurt, Germany, to determine whether size ranges related to changes in daily mortality.[121] In this study, data were collected over a three-year period, from 1995-1998. Death certificates were collected for 6,091 individuals from the local health authorities, and aggregated to daily time-series of total counts or counts for subgroups like age at death and cause of death, which were then compared with particle data. Particles

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Implications for Epidemiologic Researchers, in Communicating with Policy-Makers, 12 AM. J. EPIDEMIOLOGY (2001 Supp. 154).

116. *See infra* notes 206 and 207. Section 108 and Section 109 of the CAA govern the establishment, review, and revision of the NAAQS. 42 U.S.C. § 7408; 42 U.S.C. § 7409.

117. *See generally* 62 Fed. Reg. 38,652, *supra* note 5.

118. NAT'L CTR. FOR ENVTL. ASSESSMENT, U.S. EPA, AIR QUALITY CRITERIA FOR PARTICULATE MATTER, VOL. III (1996).

119. *See* Daniel S. Greenbaum et al., *Particulate Air Pollution Standards and Morbidity and Mortality: Case Study*, 154 AM. J. EPIDEMIOLOGY S78-S90(1) (2001) (for a discussion on the role of epidemiology in public policy matters).

120. Section 109(d)(1) of the Clean Air Act requires periodic review and, if appropriate, revision of the existing air quality criteria and NAAQS. 42 U.S.C. § 7409(d)(1) (2000).

121. H-Erich Wichmann et al., *Daily Mortality and Fine and Ultrafine Particles in Erfut, Germany*, 98 HEALTH EFFECTS INSTITUTE RESEARCH REPORT 1 (2000), *available at*: http://www.healtheffects.org/Pubs/Wichmann.pdf.

smaller than 0.1 μm were classified as ultrafine particles with three size classes, and particles between 0.1 and 2.5 μm were classified as fine particles with three size classes.

The daily average total number concentration was 18,000 particles/cm^3 with 88 percent of particles below 0.1μm and 58 percent below 0.03μm in diameter.[122] In the study period, fine particle mass decreased, but the ultrafine particle number was unchanged.[123] Moreover, the proportion of ultrafine particles below 0.03 μm diameter increased compared with the proportion of other particles.

Mortality increased in association with ambient ultrafine particle numbers after adjustment for season, influenza epidemics, day of the week, and meteorology. As a result, the authors concluded that both fine particles, represented by particle mass, and ultrafine particles, represented by particle number, showed independent effects on morality at ambient concentrations.[124] Because this is the first study that links ultrafine particle numbers and mortality, comparisons with other studies could not be made.

2. Morbidity Studies and Exposure to Ultrafine Particles

There have been a number of morbidity studies related to ultrafine particles, as well. The first such study was conducted in the winter of 1991 to 1992, on asthmatic adults living in Erfurt, Germany.[125] Twenty-seven asthmatics recorded daily peak expiratory flow (PEF) and respiratory symptoms. It was determined that both ultrafine and fine particles were associated with a decrease of PEF and an increase in cough and illness during the day. Furthermore, health effects from ultrafine particles were more pronounced than those associated with the mass of fine particles.

In another study the effects of daily variations in particles of different sizes on PEF were investigated during a 57-day follow-up of 39 asthmatic children in 1994.[126] These children were age 7 through 12 years and resided in Koupio, Finland. In addition to PM_{10} concentrations, particle number concentrations in the size range of 0.01 to 10 μm were also measured. The authors concluded that all of these

122. *Id.*
123. *Id.*
124. *Id.*
125. A. Peters et al., *Respiratory Effects Are Associated with the Number of Ultrafine Particles*, 155 AM. J. RESPIR. CRIT. CARE MED. 1376 (1997), *available at* http://ajrccm.atsjournals.org/cgi/content/abstract/155/4/1376.
126. J. Pekkanen et al., *Effects of Ultrafine and Fine Particles in Urban Air on Peak Expiratory Flow among Children with Asthmatic Symptoms*, 74 ENVTL. RES. 24 (1997).

measured pollutants tended to be associated with declines in morning PEF and increased respiratory symptoms.

Another study identified a group of 78 adults that were followed to assess PEF measurements and symptoms, and examine medication diaries for six months in the winter and spring on 1996-1997 in Helsinki, Finland.[127] The associations between daily health endpoints and indicators of air pollution were examined. Daily mean number concentration, but not particle mass, was negatively associated with daily PEF deviations. The authors found the strongest association was seen for particles in the ultrafine range.

Lastly, another study focused on adult asthmatics in Erfurt Germany.[128] Daily asthmatic medication use was reported in 58 asthmatics from October 1996 to March 1997. The authors analyzed the overall prevalence of medication use controlling for trend, temperature, weekend, and holidays. The authors concluded that asthmatic medication use increased as cumulative exposure to ultrafine and fine particles increased over a five-day period.

D. Toxicological Studies on Ultrafine Particles

Toxicological or controlled biological studies may be conducted on humans or animals to determine the functional, structural, and biochemical effects of toxic substances.[129] However, toxicological studies of humans usually provide the best scientific evidence in establishing a cause-effect relationship between a pollutant and adverse health effects. But most controlled biological studies are conducted on animals due to ethical considerations related to human studies.[130] Nevertheless, animal studies have limitations since studies must be extrapolated to humans and exposure concentrations are in excess of the ambient concentrations, to name a few.[131]

There are three common experimental approaches for studying the toxicological or biological effects of PM—inhalation; *in vivo*; and *in vitro*.[132] Inhalation studies are thought to be physiologically more

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127. Pasi Penttinen et al., *Ultrafine Particles in Urban Air and Respiratory Health Among Adult Asthmatics*, 17 EUROPEAN RESPIRATORY J. 28 (2001), *available at*: http://erj.ersjournals.com/cgi/reprint/17/3/428.

128. Stephanie von Klot et al., *Short-Term Effects of Ultrafine and Fine Particles on Medication use in Asthmatic Adults*, 160 AM. J. RESPIRATORY CRITICAL CARE MED. A130 (2000).

129. GODISH, *supra* note 46.

130. *Id.*

131. *Id.*

132. NAT'L CTR. FOR ENVTL. ASSESSMENT, *supra* note 18, at 6-64; *see also* PAUSTENBACH, HUMAN AND ECOLOGICAL RISK ASSESSMENT—THEORY AND PRACTICE (2002).

realistic and more applicable to human risk assessment.[133] *In vitro* studies use live cells, but are carried out in isolation from a living organism.[134] *In vivo* studies take place within the living organism.[135]

1. Human Studies

There are a number of studies related to the deposition rates of inhaled ultrafine particles, which focus on pulmonary and extrapulomonary effects.[136] These studies are important from a dosimetric point of view, because a greater deposition dose poses a greater risk to health.

In 1995 a number of authors presented evidence that ultrafine particles are responsible for associations between particle matter and health outcomes at current low concentrations of ambient particles in the elderly and evaluated this hypothesis by evaluating the breathing patterns of healthy elderly volunteers and used ultrafine particles of Teflon® fume with diameters of 10 to 26 nm.[137] The author concluded that certain ultrafine particles when inhaled as single particles can be highly toxic and that there is a need to study more closely environmentally occurring ultrafine particles.

In 1999, researchers recruited healthy adults, 11 men and 11 women, ranging in ages from 20 to 40 to measure the total deposition fraction of ultrafine aerosols between 0.04 to 0.1 μm at six different breathing patterns.[138] The authors concluded that the results suggest that the total deposition fraction of ultrafine particles increases with a decrease of particle size and with deeper breathing patterns, which is consistent with diffusion deposition of ultrafine particles.[139]

In another study, to assess to what extent and how rapidly inhaled pollutant particles pass into the human body's circulatory system, a group of researchers measured, in five healthy male volunteers, the distribution of radioactivity after the inhalation of a manufactured

133. *Id.*
134. *Id.*
135. *Id.*
136. *See, e.g.*, GUNTER OBERDORSTER, EFFECTS OF ULTRAFINE PARTICLES IN THE LUNG AND POTENTIAL RELEVANCE TO ENVIRONMENTAL PARTICLES (1996) (on file with the University of Rochester Department of Environmental Medicine).
137. Aerosol Inhalation, Recent Research Frontiers: Proceedings of the International Workshop on Aerosol Inhalation, Lung Transport, Deposition, and the Relation to the Environment—Recent Research Frontiers, Warsaw, Poland, Sept. 14-16, 1995 (J.C.M. Marijnissen & L. Gradon, Kluwer eds., 1996).
138. Peter Jacques and K. S. Chong, *Measurement of Total Lung Deposition of Inhaled Ultrafine Particles in Healthy Men and Women*, 12 INHALATION TOXICOLOGY 715 (2000).
139. *Id.*

aerosol consisting mainly of ultrafine carbon particles. The researchers concluded that inhaled ultrafine carbon particles pass rapidly into the systemic circulation, and this process could account for the extrapulmonary effects of air pollution.[140]

Medical researchers in Taiwan conducted a study on two panels of human subjects—nine young adults and ten elderly patients with lung function impairments—to evaluate whether ultrafine particle air pollution was associated with heart rate variability (HRV) and measured these subjects' electrocardiography and personal exposure to number concentrations of ultrafine particles in the size range of 0.02 to 1 μm continuously during the 16-hour monitoring period.[141] For the young adult panel, a 10,000 particle/cm^3 increase in ultrafine particles showed across the board decreases in HRV parameters, and similarly, for the elderly panel, a 10,000 particle/cm^3 increase in ultrafine particles showed an even greater decrease in the HRV parameters. This is the first study to demonstrate that personal measurements of environmental exposure to ultrafine particles can affect HRV in human subjects.

In one of the more intriguing inhalation studies, a research group set out to determine whether translocation of inhaled ultrafine particles to regions of the brain takes place.[142] It is estimated in this study that 20 percent of the inhaled ultrafine particles can be translocated to the olfactory bulb of the brain. The research group concluded that the central nervous system can be targeted by airborne ultrafine particles and that the most likely mechanism is from deposits on the olfactory mucosa of the nasopharyngeal region of the respiratory tract and subsequent translocation via the olfactory nerve.

These and other studies have identified a number of potential mechanisms that can contribute to increased toxicity of ultrafine particles.[143] Ultrafine particles, as well as fine particles, can act as a carrier to the deep lung for adsorbed reactive gases, transition metals, or organic compounds with the larger surface area of ultrafine particles transporting more toxic, surface-adsorbed materials.[144] Deposition of

140. *Id.*

141. Chang-Chuan Chan et al., *Personal Exposure to Submicrometer Particles and Heart Rate Variability in Human Subjects*, 112 ENVIRONMENTAL HEALTH PERSPECTIVES 10 (2004), *available at* http://www.ehponline.org/members/2004/6897/6897.pdf.

142. Gunter Oberdorster et al., *Translocation of Inhaled Ultrafine Particles to the Brain*, 16 INHALATION TOXICOLOGY 437 (2004).

143. H-Erich Wichmann & A. Peters, *Epidemiological Evidence of the Effects of Ultrafine Particle Exposure*, 358 PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY 2751 (2000).

144. W. MacNee et al., *How Can Ultrafine Particles be Responsible for Increased Mortality?*, 55 MONALDI ARCHIVES FOR CHEST DISEASE 135 (2000).

inhaled ultrafine particles is very high in the respiratory tract.[145] After deposition, ultrafine particles penetrate more rapidly into interstitial sites.[146] Because of these and other effects, lung defense mechanisms that are normally effective for coarse and fine particles are less effective for ultrafine particles.[147]

In addition to these studies, there are a number of other data available that have investigated the association between morbidity and ultrafine particles.[148] Collectively the data present ultrafine/morbidity associations in adults with asthma. A summary of this data indicates that while the associations of ultrafine and fine particles were observed generally, the associations of ultrafine particles were slightly stronger.

2. In Vivo Studies

In a Health Effects Institute-funded study, a research team focused its efforts on researching the principles of ultrafine particle toxicity, generating these particles to characterize their number, size, and mass for animal inhalation studies, and determining any pulmonary effects.[149] This team, in part, concluded that ultrafine particles cause pulmonary inflammatory responses in rodent models when inhaled at concentrations that are predicted to occur in people living in cities and being exposed to episodic increases of ultrafine particles.

A different group of researchers studied the hypothesis that linked ultrafine particles and blood coagulation with an increase in cardiovascular mortality and morbidity.[150] It was determined that the instillation of ultrafine carbon black in the lungs of rats does increase the

145. P.J. Anderson et al., *Respiratory Tract Deposition of Ultrafine Particles in Subjects with Obstructive or Restrictive Lung Disease,* 97 CHEST 1115 (1990).

146. Mark J. Utell & Mark W. Frampton, *Acute Health Effects of Ambient Air Pollution: The Ultrafine Particle Hypothesis*, 13 J. AEROSOL MEDICINE 355, 355-359 n.2 (2000).

147. Ken Donaldson et al., *Ultrafine Particles: Mechanisms of Lung Injury*, 358 PHIL. TRANS. R. SOC. LONDON A. 2741 (2000), *available at* http://erj.ersjournals.com/cgi/content/full/21/40_suppl/47S.

148. A. Peters et al., *Respiratory Effects are Associated with the Number of Ultrafine Particles*, 155 AM. J. RESP. & CRITICAL CARE MED. 1376 (1997); A. Peters et al., *Comparison of the Number of Ultrafine Particles and the Mass of Fine Particles with Respiratory Symptoms In Asthmatics*, 41 ANN. OCCUP. HYG. 19 (Supp. 1 1997); JUHA PEKKANEN ET AL., EXPOSURE AND RISK ASSESSMENT FOR FINE AND ULTRAFINE PARTICLES IN AMBIENT AIR, (1999); H-Erich Wichmann et al., *Epidemiological Evidence of the Effects of Ultrafine Particle Exposure*, PHILOS. R. SOC. B. BIOL. SCI. (2000).

149. Gunter Oberdörster et al., Abstract, *Acute Pulmonary Effects of Ultrafine Particles in Rats and Mice*, 96 HEALTH EFFECTS INST (2000), *available at* http://www.healtheffects.org/Pubs/Oberdorster.pdf.

150. Xiao Yang Li et al., *Short-term Inflammatory Responses Following Intratrachael Instillation of Fine and Ultrafine Carbon Black in Rats*, 11 INHALATION TOXICOL. 709 (1999).

level of coagulation factor. This study also determined that smaller particles of black carbon induced more lung inflammation.

Another group of investigators looked exclusively at the link between lung inflammation and particle size.[151] The conclusion reached with this study is that low concentrations of ultrafine carbon black particles at 1 $\mu g/m^3$, with a 14 nm diameter caused severe inflammation effects in rats, whereas fine carbon black particles with a 260 nm diameter showed no effect.

A different set of investigators conducted a group of studies in rats with different types and sizes of ultrafine particles, which suggest that some ultrafine particles, like carbon black, have extra toxicity.[152] This group concluded that effect may be explained by the greater surface area of the ultrafine material, which could deliver oxidative stress because of a greater surface release of transition metals.

Lastly a group conducted a pulmonary retention study of ultrafine and fine particles in rats to determine if primary particle size affects the fate of particles after these particles are deposited.[153] According to the group, the studies showed that ultrafine particles at equivalent masses access the pulmonary tissue to a larger extent than fine particles. The translocation of the particles to the tissue appeared to be a function of the number of particles, and was related to particle size, the delivered dose, and the rate of delivered dose.

3. In Vitro Studies

A research team from southern California set out to determine whether there was a link between ultrafine composition and biological effects.[154] Two cell lines were used to mimic oxidative stress response of the pulmonary alveolar macrophages in response to particle exposure. Their data indicate that the ultrafine particle mode is capable of producing greater stress on a microgram basis than fine and coarse particles, and concluded that enhanced tissue penetration and the ability to generate oxidative stress render ultrafine particles more damaging at the cellular level than other particle sizes.

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151. W. MacNee et al., *Effects of Short-term Low Exposure to Carbon Black*, AM. J. RESP. AND CRITICAL CARE MEDICINE (2000).

152. Ken Donaldson et al., The Toxicology of Ultrafine Particles, *in* PARTICULATE MATTER: PROPERTIES AND EFFECTS UPON HEALTH 115 (R.L. Maynard & C.V. Howard eds., 1999).

153. Juraj Ferin et al., *Pulmonary Retention of Ultrafine and Fine Particles in Rats*, 6 AM. J. RESP. CELL AND MOLECULAR BIOLOGY 535 (1992).

154. Ning Li et al., *Ultrafine Particulate Pollution Induce Oxidative Stress and Mitochondrial Damage*, 111 ENVT'L HEALTH PERSPECTIVES 393 (2003), *available at* http://www.ehponline.org/members/2003/6000/6000.html.

In another study the team investigated whether slowed clearance after exposure to ultrafine particles was due to a failure in alveolar macrophage phagocytosis, which is a defense mechanism to protect the respiratory system from foreign substances.[155] Because of the large size and smaller surface area of fine particles, a much greater mass of phagocytosed particles at 0.78 $\mu g/mm^2$ was required to impair macrophage phagocytosis compared to their ultrafine counterparts at 0.39 $\mu g/mm^2$. As a result, the authors concluded that slowed clearance of ultrafine particles can in part be attributed to particle-mediated impairment of macrophage phagocytosis.

Based on the results of these and other toxicological studies there are a number of patterns of reactivity that are specific for ultrafine particles: there is evidence that ultrafine particles have a greater inflammatory effect than larger particles;[156] it has been suggested that the large surface area of ultrafine particles may react with target cells like macrophages and epithelial cells that could be important in priming and activating cells for inflammatory reactions;[157] particles may exert adverse biological effects by the presence and/or release of toxic free radicals on and/or from their surfaces, respectively;[158] ultrafine particles are less well phagocytized by alveolar macrophages than larger particles;[159] there is also evidence that ultrafine particles have the ability to inhibit phagocytosis;[160] and at the same mass concentration, ultrafine particles are more toxic than larger particles with the same chemical composition.[161]

E. Diesel Particulate Matter Studies

The combined human and animal evidence indicates that diesel exhaust can induce irritation to the eye, nose, and throat, as well as

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155. *Id.*

156. Juraj Ferin, *Pulmonary Retention and Clearance of Particles*, 72 TOXICOL. LETT. 121 (1994); G. Oberdörster et al., *Role of Alveolar Macrophage During Lung Injury: Studies with Ultrafine Particles*, 97 ENVIRONMENTAL HEALTH PERSPECTIVES 193 (1992).

157. Anthony Seaton et al., *Particulate Pollution and Acute Health Effects*, 345 LANCET 176 (1995).

158. Peter Stone & John Godleski, *First Steps Toward Understanding the Pathophysiologic Link Between Air Pollution and Cardiac Mortality*, 138 AM. HEART J. 804 (1999), *available at* http://www2.us.elsevierhealth.com/inst/serve?action=get-media&id=a99146&trueID=pdf_99146&location=jhj991385&type=pdf&name=x.pdf.

159. Wolfgang Kreyling & Rudolf Scheuch, *Clearance of Particles Deposited in the Lungs*, PARTICLE LUNG INTERACTIONS 323 (2000).

160. Kenneth Donaldson et al., *Ultrafine Particles*, 58 J. OCCUPATIONAL & ENVTL. MED. 211 (2000).

161. David M. Brown, *Increased Inflammation and Intracellular Calcium Caused by Ultrafine Carbon Black is Independent of Transition Metals or Other Soluble Components*, 57 J. OCCUPATIONAL & ENVTL. MED. 10, 685 (2000).

inflammatory responses in the airways and the lung following acute and/or short-term exposure to high concentrations.[162] Acute exposure to diesel exhaust has been associated with irritation of the eye, nose, and throat, respiratory symptoms, and neurophysiological symptoms such as headache, lightheadedness, nausea, vomiting, and numbness or tingling of the extremities.[163] Moreover, there also is evidence for possible immunological and allergenic effects of diesel exhaust.[164]

Based on animal data, EPA has also concluded that diesel exhaust is judged to pose a chronic respiratory hazard to humans. For instance, chronic-exposure, animal inhalation studies show a host of dose-dependent inflammation and histopathological changes in the lung in several animal species like rats, mice, hamsters, and monkeys.

A few human studies in various diesel occupational settings suggest that diesel exhaust exposure may impair pulmonary function, because of increases in respiratory symptoms and reductions in pulmonary function, which is consistent with restrictive airway disease.[165] Animal studies also provide evidence that prolonged inhalation exposure to high concentrations of diesel exhaust can result in pulmonary injury.[166] EPA has now determined that since long-term exposure to diesel exhaust has been shown to induce exposure-dependent chronic respiratory effects in a wide range of animal species, there is a sufficient scientific basis to support a conclusion that humans also could be at hazard for these effects under a chronic exposure condition.[167]

EPA has further concluded that diesel exhaust is "likely to be carcinogenic to humans by inhalation" and that this hazard applies to environmental exposures.[168] Moreover, EPA notes, there is considerable evidence demonstrating an association between diesel exhaust exposure

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162. *See generally* DIESEL EMISSIONS REFERENCE LIST: HEALTH EFFECTS, MEASUREMENTS AND CONTROL, TECHNICAL REPORT (2002).

163. *Id.*

164. U.S. EPA, HEALTH ASSESSMENT DOCUMENT FOR DIESEL ENGINE EXHAUST (2000).

165. David De Marini et al., *Bioassay—Directed Fractionation and Salmonella Mutagenicity of Automobile and Forklift Diesel Exhaust Particles*, 112 ENVTL. HEALTH PERSP. 814 (2004).

166. *See* Michael Bérubé et al., *Physiocochemical characterization of diesel exhaust particles: Factors for Assessing Biological Activity*, 33 ATMOSPHERIC ENV'T 1599 (1999) (where in addition to mass, the authors recommend that of parameters of toxicological significance such as particle number, surface area, shape, size, crystallinity, surface reactivity, and chemistry are of importance for characterizing and/or interpreting the results of biological assays). *See also* HEALTH EFFECTS INST. PROGRAM SUMMARY, RESEARCH ON DIESEL EXHAUST AND OTHER PARTICLES (2003) (for an assessment of exposure to diesel exhaust and health effects like lung cancer, asthma exacerbation, and immune response).

167. NAT'L CTR. FOR ENVTL. ASSESSMENT, *supra* note 118.

168. *Id.*

and increased lung cancer risk among workers in varied occupations where diesel engines historically have been used.[169]

The carcinogenic potency of diesel particles is related to their small size and convoluted shape, which results in a large specific particle surface area. For example, studies[170] have shown that ultrafine titanium dioxide particles, which are approximately 0.2 μm diameter, are much more toxic than particles that have diameter 10 times greater of the same composition used in an earlier study.[171] This increase in toxicity has been noted in even smaller particles than 0.2 μm diameter. Additionally, carbon black particles 20 nm in diameter were shown to be significantly more toxic than 50 nm particles.[172] The relationship between particle size and toxicity is a public health concern because, as previously noted, approximately 50 percent to 90 percent of the number of particles in diesel exhaust are in the size range from 5 to 50 nm.

All of the highlighted epidemiological and toxicological studies related to ultrafine particles have significant implications for the current air quality regulatory structure. While all of these studies demonstrate a link between ultrafine particles and human health effects, the most significant study came out of the Erfurt, Germany investigation, which effectively links ultrafine particles and mortality. Given the indications that ultrafine particles may be relevant for human health, it is insufficient to study and regulate fine particle mass only. Early regulatory effects sought to reduce TSP, but epidemiological and toxicological studies using PM_{10} and now $PM_{2.5}$ benchmarks now show clearer health effects for fine particles than for coarse particles. In turn, these most recent regulatory efforts now show clearer adverse health effects for particle number than for particle mass.

IV. Dosimetry Modeling as a Basis to Determine the Particle Metric for Regulatory Action

A. Introduction

Understanding the health effects of inhaled PM also requires an

169. *Id.*

170. U. Heinrich et al., *Chronic Inhalation Exposure of Wistar Rats and Two Different Strains of Mice to Diesel Engine Exhaust, Carbon Black, and Titanium Dioxide,* 7 INHALATION TOXICOL. 533 (1995).

171. K.P. Lee et al., *Pulmonary Response to Impaired Lung Clearance in Rats Following Excessive TiO_2 Dust Deposition,* 41 ENVTL. RES. 144 (1986).

172. S.A. Murphy et al., *Bioreactivity of carbon black and diesel-exhaust particles to primary clara and type II epithelial cell cultures,* 56 J. OCCUPATIONAL & ENVTL. MED. 813 (1999).

understanding of the dosimetry of these particles.[173] This understanding is necessary because the proximate cause of any response is due to the dose of particles delivered to, and retained at the target site, rather than the exposure concentration.[174] The proximate cause of any health effect response to PM is not due to ambient air exposure. Rather the proximate cause of any health effect response to PM is due to the dose deposited at the target site whether that target site is the respiratory tract, generally, or some other internal organ. Moreover, the dose of inhaled particles to a target tissue also depends on the initial deposition and later retention of particles within the respiratory tract.

Models for deposition, clearance, and dosimetry of the respiratory tract of humans have been available for the past four decades.[175] One of the most common is the Human Respiratory Tract Model for Radiological Protection that was adopted by the International Commission on Radiological Protection.[176] This model estimates regional deposition for a wide range of particle sizes from approximately 0.0005 μm to 100 μm. The model also takes into account body size, gender, age, and the level of physical exertion.

B. Factors that Influence Particle Deposition

1. Deposition Mechanisms

Particles may deposit within the respiratory tract by five mechanisms—inertial impaction, sedimentation, diffusion, electrostatic precipitation, and interception.[177] In inertial impaction, particles impact and adhere to airway surfaces because sudden changes in airstream direction and velocity cause the particles to move outside the streamlines of airflow. In sedimentation, particles acquire a settling velocity when equilibrium is achieved between the gravity acting on the particle and the resistance of the air, which takes the particle into contact with airway surfaces. Particles that have diameters of less than 1 μm are subject to diffusive deposition because of random bombardment by air molecules, which results in contact with air surfaces. Interception is deposition by physical contact with airway surfaces. Electrostatic precipitation is deposition related to the charge of a particle.

Besides particle size, breathing pattern, which includes tidal

173. NAT'L CTR. FOR ENVTL. ASSESSMENT, *supra* note 118, at 6-105.
174. *Id.*
175. *Id.*
176. INT'L COMM'N ON RADIOLOGICAL PROT., HUMAN RESPIRATORY TRACT MODEL FOR RADIOLOGICAL PROTECTION (1993).
177. NAT'L CTR. FOR ENVTL. ASSESSMENT, *supra* note 18, at 6-1.

volume, breathing frequency, route of breathing, is the most important factor affecting lung deposition.[178] Total lung deposition increases as tidal volume increases at a given flow rate, and as the flow rate increases at a given respiratory time. Therefore, the total deposition fraction (TDF) of ultrafine particles increases with a decrease of particle size and with breathing patterns of longer respiratory time.[179]

2. Particle Clearance

As previously noted, the respiratory tract is divided into three sections—head, or extrathoracic; tracheobronchial; and alveolar.[180] Each region has particular particle clearance and displacement mechanisms. For the head region these mechanisms include mucociliary transport; sneezing; nose wiping and blowing; and dissolution and adsorption into blood. For the traecheobronchial region these mechanisms include mucociliary transport; endocytosis, or incorporation into the cell, by macrophages, which act as phagocytic cells; epithelial cells; couching; and dissolution and adsorption into blood/lymph. For the alveolar region these mechanisms include - macrophages; epithelial cells, which protect other parts of the body; and dissolution and absorption into blood/lymph.

3. Particle Retention

Particles that are not removed by the lungs clearance mechanisms are retained in the lung tissue.[181] Particles deposited in the alveolar region are retained longer than are those deposited in airways cleared by mucociliary transport. Some particles can bind to epithelial cell membranes, to macromolecules, or to cell components, which can delay their clearance from the lungs. There are several interesting studies that have examined particle retention in humans, which note that ultrafine particles are more likely to be retained in the lungs than other sized particles.[182]

4. Gender

Males and females physiologies differ in body size, conductive airway size, and ventilatory parameter distributions. As a result, gender differences in deposition are normally expected in studies and modeling

178. *Id.*
179. *Id.*
180. *See* Chart 1 for a pictorial representation of these sections.
181. *Id.*
182. *See* Andrew Churg & Markus Brauer, *Human Lung Parenchyma Retains $PM_{2.5}$*, 155 AM. J. RESPIR. CRIT. CARE MED. 2109 (1997). *See also* Markus Brauer et al., *Air Pollution and Retained Particles in the Lungs*, 109 AM. HEALTH PERSP. 1039 (2001).

exercises.[183]

5. Age

Airway structure and physiological function vary with age and health status of the respiratory tract.[184] Such variations may alter the deposition patterns for inhaled particles.

6. Lung Disease

The presence of respiratory tract disease can affect airway structure and ventilatory parameters, which alter deposition compared to that in healthy individuals.[185] Studies show that people with chronic obstructive pulmonary disease had very heterogeneous deposition patterns and differences in regional deposition compared to healthy individuals.[186]

7. Anatomical Variability

As indicated above, variations in anatomical parameters between genders and between healthy people and others with obstructive lung disease can affect deposition patterns. However, it has been noted that previous analyses have overlooked the effect on deposition of normal individual variability in airway structure in healthy individuals.[187]

8. Exercise

Exercise may also increase the potential health risks of inhaled particles because exercise increases the rate of O_2 consumption and changes ventilatory parameters.[188] The switch from nose breathing to mouth breathing, which occurs as exercise intensity increases, leads to an increase in deposition of particles in the tracheobronchial and alveolar regions.

C. Dosimetry Models and Modeling Runs

The model used for the dosimetry modeling portion of this paper is entitled PDRT—"Particle Deposition inside the Respiratory Track." The spreadsheet includes not only the particle deposition and first-order

183. *See, e.g.*, John Pritchard et al., *Sex Differences in the Regional Deposition of Inhaled Particles in the 2.5 μm to 7.5 μm Range*, 17 J. AEROSOL. SCI. 385 (1986).

184. NAT'L CTR. FOR ENVTL. ASSESSMENT, *supra* note 118, at 6-107.

185. *Id.*

186. James Brown et al., *Ultrafine Particle Deposition and Clearance in Healthy and Obstructed Lung*, 166 AM. J. RESPIR. CRIT. CARE MED. 1240 (2002).

187. NAT'L CTR. FOR ENVTL. ASSESSMENT, *supra* note 118, at 6-107.

188. *Id.*

clearance particulate calculations, but extends to include chemical components present within the particles as well. This model calculates particulate deposition profiles in the respiratory tract on a continuum ranging from ultrafine to coarse aerodynamic particle sizes.

As a starting point for this exercise, particle speciation data from the Pittsburgh Pennsylvania $PM_{2.5}$ nonattainment area was reviewed and analyzed. Representative data was selected from the Pennsylvania Department of Environmental Protection database for a typical day, which was identified as May 15, 2004. The analysis found that sulfate was the dominant substance found with a mass of 39 g. and a volume of 18.902 cm^3. Based on this data particle density was determined to be 2.334.

Modeling runs with the PDRT model were taken for both male and female engaging in light exercise with an atmospheric particle concentration of 100 $\mu g/m^3$. Particle sizes ranges were 10 μm, 2 μm, 1 μm, 0.1 μm, 0.01 μm, and 0.001 μm, respectively.

1. Females

As demonstrated under Chart 2, for females inhaling 100 $\mu g/m^3$ of air particles in the ranges of 10 μm, 2 μm, and 1μm showed the greatest exposure in the upper extrathoracic regions of ET1 and ET2. Particles in the range of 0.1μm range showed the greatest exposure in alveolar interstitial region (Al). This shows that ultrafine particles within this size range penetrate the deepest area of the respiratory tract and can remain there for extended periods of time. As a result, this may cause serious health effects including, but not limited to, particle overload, which is excess lung burden of insoluble particles. Particles in the 0.01 μm range, showed the greatest exposure within the lower respiratory tract regions of the bronchiolar (bb) and the alveolar interstitial region (Al). This shows that ultrafine particles within this size range penetrate the deepest area of the respiratory tract and can remain there for extended periods of time. As a result, this may cause serious health effects including, but not limited to, particle overload. However, for the smallest particles in the 0.001μm range most of the particle settled within the upper extrathoracic regions (ET1 and ET2). This shows that the upper extrathoraric regions are excellent filters of ultrafine particles within this smallest size range. Moreover, it is very likely that these smallest particles may act as a gas and pass through the respiratory track into the circulatory system.

2. Males

As demonstrated under Chart 3 for males inhaling 100 $\mu g/m^3$ of particles in the ranges of 10 μm, 2 μm, and 1μm, most exposure was in

the upper extrathoracic regions (ET1 and ET2). Particles in the 0.1μm range showed the greatest exposure in alveolar interstitial region (Al). This shows that ultrafine particles within this size range penetrate the deepest area of the respiratory tract and can remain there for extended periods of time. As a result, this may cause serious health effects including, but not limited to, phagocytosis inhibition. In comparison to the female model runs, the males have a slightly larger deposition rate, but similar clearance rates. Particles in the 0.01 μm range showed the greatest exposure within the lower respiratory tract regions of the bronchiolar (bb) and the alveolar interstitial region (Al). This shows that ultrafine particles within this size range penetrate the deepest area of the respiratory tract and can remain there for extended periods of time. As a result, this may cause serious health effects including, but not limited to, phagocytosis inhibition. In comparison to the female model runs, the males have a slightly larger deposition rate. Particles in the 0.001 μm range showed most of the particles settled within the upper extrathoracic regions (ET1 and ET2). This shows that the upper extrathoraric regions are excellent filters of ultrafine particles within this smallest size range. Moreover, in comparison to the female model runs, the males have a slightly larger deposition rate, but similar clearance rates.

As a result of these modeling runs, it seems the ultrafine fraction of concern is within the 0.1 to 0.01 μm range. Most of the particles within this range settle in the deepest regions of the respiratory tract. Moreover, there is very little, if any, clearance of particles once they are lodged in these regions. These characteristics may have a number of adverse health effects. First, there is evidence that ultrafine particles have a greater inflammatory effect than larger particles. It has been suggested that the large surface area of ultrafine particles may react with target cells like macrophages and epithelial cells that could be important in priming and activating cells for inflammatory reactions. Particles may exert adverse biological effects by the presence and/or release of toxic free radicals on and/or from their surfaces, respectively. Ultrafine particles are less well phagocytized by alveolar macrophages than larger particles. There is also evidence that ultrafine particles have the ability to inhibit phagocytosis.

V. The Legal Foundations for Establishing the PM NAAQS

The statutory scheme established by Congress under the CAA is based primarily on nationwide air quality goals that are set established on the desired concentrations of specific pollutants in the ambient air. These goals, in the form of the NAAQS, establish the maximum concentrations for the ambient pollutant that are not to be exceeded

anywhere in the United States. Section 108 of the federal CAA requires the EPA to promulgate a list of air pollutants from numerous and diverse sources and whose presence in the atmosphere "may reasonable to anticipated to endanger public health or welfare."[189] EPA must also issue air quality criteria for the listed air pollutant that includes the latest scientific knowledge in indicating the kind and extent of all identifiable effects on public health and welfare. As a result, these listed pollutants are known as "criteria pollutants" and the document containing the scientific information is a "criteria document." A scientific review process of the criteria documents and revisions to the standards are required under Section 109(d) and any promulgation or revision on a NAAQS is subject to the rulemaking process under Section 307(d) of the Act.[190] As previously mentioned there are six pollutants that are criteria pollutants—NO_2, SO_2, O_3, CO, and PM. Moreover, all criteria pollutant concentrations are expressed in the form of mass or weight of pollutant per volume of air (i.e., $\mu g/m^3$) or as "x" parts pollutant per million (ppm). However, there is no statutory prohibition from regulating a criteria pollutant on the basis of some other air quality metric.

Section 109 of the CAA requires EPA to promulgate regulations to establish a national primary ambient air quality standard and a secondary ambient air quality standard for each of the criteria pollutants identified under Section 108.[191] The primary standard is set to protect public health with an adequate margin of safety, while the secondary standard is set to protect the public welfare. In practice, EPA sets the secondary standard at the same level as the primary standard for most criteria pollutants, including PM, since a standard set to protect public health will always protect public welfare. Moreover, this statutory section requires periodic review at five-year intervals, and if appropriate, revision of the existing air quality criteria and NAAQS.

The CAA calls for the appointment of "an independent scientific review committee," the Clean Air Scientific Advisory Committee ("CASAC"), which periodically reviews the NAAQS and advises EPA of any need for new standards or for the revision of existing standards.[192] The CAA directs the CASAC to advise the agency on areas in which additional knowledge is required to appraise the adequacy and basis of existing, new, or revised standards, and to describe the research efforts necessary to provide the required information. Under Section 307(d)(3), when EPA proposes to issue new or revise existing NAAQS, it must set

189. 42 U.S.C. § 7408 (2000).
190. 42 U.S.C. §§ 7409(d), 7607(d) (2000).
191. 42 U.S.C. § 7409 (2000).
192. 42 U.S.C. § 7409(d)(2)(A) (2000).

forth or summarize and provide a reference to any pertinent findings, recommendations, and comments by the CASAC.[193]

Decisions on the NAAQS involve consideration of the four basic elements of a standard—indicator; averaging time; form; and level.[194] The indicator defines the pollutant to be measured in the ambient air to determine compliance with the standard. The averaging time defines the time period over which air quality measurements are to be obtained and averaged. The form of the standard defines the air quality concentration that is to be compared to the concentration of the standard, which determines if an area is in attainment with the standard. The level of the standard specifies the air quality measurements that are used for compliance purposes, the monitors used to record measurements, and whether the standard is to be averaged across multiple time periods. These four elements taken together determine the degree of public health and welfare protection afforded by the NAAQS.[195]

Once EPA establishes a NAAQS for a particular pollutant, the standard becomes the centerpiece of a complex statutory regime aimed at reducing that pollutant's atmospheric concentration. EPA and the States must first designate areas of the country that fail to meet the standard because the atmospheric concentrations of that pollutant exceed allowable levels.[196] Each State must then adopt a plan that provides for the implementation, maintenance, and enforcement of the primary NAAQS.[197] States generally regulate emissions from sources like power plants, manufacturing and industrial facilities, and in-use motor vehicles, in order to implement the NAAQS.

In addition to the congressional mandate set forth in the CAA, the federal courts have addressed EPA's responsibilities in establishing the requirements of the NAAQS, as well. The cases confirm the premise that the NAAQS are health-based standards.[198] Economic and technological considerations are subordinated to the goal of protecting public health by precluding any consideration of such factors.[199] Air quality standards must also protect individuals who are particularly sensitive to the effects of pollution and be set at a level at which there is

193. 42 U.S.C. § 7607(d)(3) (2000).
194. NAT'L CTR. FOR ENVTL. ASSESSMENT, *supra* note 18, at 3-1.
195. *Id.*
196. 42 U.S.C. § 7407(d)(1)-(2) (2000).
197. 42 U.S.C. §7 410(a)(1) (2000).
198. *See* Lead Indus. Ass'n v. EPA, 647 F.2d 1130, 1148 (D.C. Cir.1980). *See also* Whitman v. Am. Trucking Assoc., 531 U.S. 457 (2001); Am. Lung Ass'n v. EPA, 902 F.2d 962, 973 (1990), *vacated in part*, 921 F.2d 326 (1991); Am. Petroleum Inst. v. Costle, 65 F.2d 1176, 1185 (1981).
199. Lead Indus. Ass'n v. EPA, 647 F.2d at 1148.

"an absence of adverse effect" on these sensitive individuals.[200] Moreover, the CAA specifically directs EPA to allow an adequate margin of safety in setting primary air quality standards in order to provide some protection against effects that research has not yet uncovered.[201]

Courts have previously noted that some uncertainty about the health effects of air pollution is inevitable and that certainty in the complexities of environmental science may be achievable only after the fact.[202] As a result, requiring EPA to wait until it can conclusively demonstrate that a particular effect is adverse to health before it acts is inconsistent with both the CAA's precautionary and preventive orientation and the nature of the agency's statutory responsibilities. This preventive approach articulated in the CAA and by the court is reminiscent of the precautionary principle where the lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.[203]

While the court's role in reviewing EPA actions, like establishing or revising air quality standards, is limited, the court does not serve as a mere rubber stamp for agency decisions. Rather the function of judicial review is to ensure that the scientific judgments of an agency are based on certain minimal standards of rationality.[204] However, the court must undertake a "substantial inquiry" into the facts which may require it to delve into scientific literature to understand the underlying decisions of an agency, in order to satisfy itself that the agency has exercised a reasoned discretion, with reasons that do not deviate from or ignore legislative intent.[205] Nevertheless, judicial review of the evidence is not designed to second-guess the agency, since Congress has entrusted the agency with the responsibility for making these scientific judgments.

While EPA first established a NAAQS for PM in 1971, the agency significantly revised the standards in 1987 when it changed the indicator for particles from TSP to PM_{10}.[206] This is also the first time the courts

200. *Id.*

201. *Id.*

202. Ethyl Corp. v. EPA, 541 F.2d 1 (D.C. Cir. 1976).

203. *See* JOHN C. DERNBACH, STUMBLING TOWARDS SUSTAINABILITY (John C. Dernbach, ed., 2002) (comprehensive analysis of sustainable development law and the role of the precautionary principle).

204. *See* Citizens to Preserve Overton Park Inc. v. Volpe, 401 U.S. 402 (1971). *See also* Am. Trucking Ass'n et al., v. EPA, 283 F.3d 355, 375 (D.C. Cir., 2002) (where the court reviews scientific judgments of an agency not as a chemist, biologist, or statistician that it is qualified neither by training nor experience to be, but as a reviewing court exercising its narrowly defined duty of holding agencies to certain minimal standards of rationality).

205. *Ethyl Corp.*, 541 F.2d at 36.

206. National Ambient Air Quality Standard for Particulate Matter, 52 Fed. Reg.

were afforded the opportunity to review the new standard.[207] The dispute did not center around the PM_{10} particle size fraction used as the indicator, but rather, the numerical levels for the 24 hour and annual standards at 150 and 50 $\mu g/m^3$. The petitioners in this case, the American Iron and Steel Institute, claimed that the only reliable scientific evidence showed that standards could only be set at the highest levels, which were 250 and 65 $\mu g/m^3$.[208] In essence, the petitioners asked the court to give greater weight to those studies that supported their claim as opposed to studies that supported EPA's claim.

In reviewing this claim, the court noted that EPA may apply its expertise to draw conclusions from suspected, but not completely substantiated, relationships between facts, from trends among facts, from theoretical projections from imperfect data, and from probative preliminary data not yet certifiable as fact. Given that EPA was able to distinguish between the competing studies and explain its decision, the court held that the agency made a reasoned decision based on reasonable extrapolations from some reliable evidence. Therefore, the court upheld that NAAQS as promulgated by EPA.[209]

EPA again revised the PM NAAQS in 1997 and determined that the fine and coarse fractions of PM_{10} should be regulated separately.[210] New standards were added, using $PM_{2.5}$ as the indicator for fine particles and the PM_{10} was retained for the purpose of regulating coarse-fraction particles. EPA established two new $PM_{2.5}$ standards—an annual standard of 15 $\mu g/m^3$, based on the 3-year average of annual arithmetic mean $PM_{2.5}$ concentrations from single or multiple community oriented monitors; and a 24-hour standard of 65 $\mu g/m^3$, based on the 3-year average of the 98th percentile of 24-hour $PM_{2.5}$ concentrations at each population-oriented monitor within an area.[211]

As with the revisions of 1987, the 1997 revisions were challenged in federal court. In the initial decision, the court upheld EPA's decision to establish a $PM_{2.5}$ standard since there was growing empirical evidence demonstrating a relationship between fine particle pollution and adverse health effects.[212] Moreover, the court also held that the identification of a biological mechanism for a particular pollutant's relationship to adverse health effects is not a requirement under the CAA.[213]

24,634 (July 18, 1987).

207. Natural Res. Def. Council, Inc. v. EPA, 902 F.2d 962 (D.C. Cir. 1990), *cert. denied,* 498 U.S. 1082 (1991).

208. *Id.* at 968.

209. *Id.* at 976.

210. Fed. Reg. 24,634, *supra* note 206.

211. *Id.*

212. Am. Trucking Ass'n v. EPA, 175 F.3d 1027, 1056 (D.C. Cir. 1999).

213. *Id.* at 1057.

The court got a second look at the standard to resolve some unanswered questions.[214] In setting the final $PM_{2.5}$ standard, the court that found EPA considered all public comments, the CASAC's recommendations, the agency's staff review of the latest scientific information, and various epidemiological studies on PM-related health risks.[215] The court also found that EPA provided a lengthy explanation of its selection of the new standards relative to the need to revise the old standards, the reasons for adopting both annual and daily standards, and the rationale behind the new standards.[216]

In justifying the chosen levels for the new NAAQS, EPA emphasized that considerable uncertainty remains about whether $PM_{2.5}$ is a threshold pollutant where there is a concentration below which $PM_{2.5}$ is harmless.[217] However, the court noted that this inability to guarantee the accuracy of the $PM_{2.5}$ NAAQS did not undermine the standards' validity. These limitations, the court said, indicate only that significant scientific uncertainty remains about the health effects of fine PM. Since EPA's decision to revise the NAAQS was rational and supported by the record, the court upheld the standards.

As part of its statutory duty, under the CAA, to review the NAAQS at 5 -year intervals, EPA released its "Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information (OAQPS Staff Paper—First Draft).[218] This report notes that the schedule for completion of the five year review is governed by a consent decree resolving a lawsuit filed in March 2003 by a group of plaintiffs representing national environmental organizations. The lawsuit alleged that EPA had failed to perform its mandatory duty, under Section 109(d)(1), of completing the current review within the 5-year period provided by statute.[219] The consent decree provides that EPA will issue a final PM Criteria Document no later than December 19, 2003, and that EPA will sign for publication notices of proposed and final rulemaking concerning its review of the PM NAAQS no later than March 31, 2005 and December 20, 2005,

214. In addition to the $PM_{2.5}$ standard, the 8-hour ozone standard was also challenged. The Court of Appeals for the District of Columbia Circuit decision was appealed to the U.S. Supreme Court, which ultimately upheld EPA's interpretation of the CAA in Whitman v. Am. Trucking Ass'n, 531 U.S. 457 (2001). The U.S. Supreme Court then remanded the case back to the Court of Appeals in Am. Trucking Ass'n v. EPA, 83 F.3d 355 (D.C. Cir. 2002).

215. Am. Trucking Ass'n, 83 F.3d at 365.

216. *Id.*

217. *Id.* at 368.

218. OFFICE OF AIR QUALITY PLANNING AND STANDARDS, U.S. EPA, REVIEW OF THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER, FIRST DRAFT (2003).

219. *See* Am. Lung Assoc. v. Whitman, No. 1:03CV00778 (D.D.C. Mar. 2003).

respectively.

This staff paper concluded that it remains appropriate to use undifferentiated particle mass as the basis for the indicator of fine particle standards.[220] Further conclusions are that there is no adequate basis for supplementing mass-based fine particle standards with standards for any specific fine particle component or subset of fine particles. As a result, this staff paper concluded that 2.5 μm remains an appropriate cut point for including the larger accumulation-mode particles of the fine fraction while limiting intrusion of coarse fraction particles, and recommended that $PM_{2.5}$ be retained as the indicator for fine-fraction particles.[221]

Interesting though, a second draft paper prepared by EPA staff and released on February 1, 2005 recommends that EPA consider tightening its air quality standard for fine particles.[222] The second draft "Review of the National Ambient Air Quality Standards for Particulate Matter" states that "[w]hile the limitations and uncertainties in the available evidence suggest caution in interpreting the epidemiologic studies at the lower levels of air quality observed in the studies, staff concludes that the evidence now available provides strong support for considering fine particle standards that would provide increased protection from that afforded by the current $PM_{2.5}$ standards."[223] The report further states that "[m]ore protective standards would reflect the generally stronger and broader body of evidence of associations with mortality and morbidity now available in this review, at lower levels of air quality and at levels below the current standards, and with more understanding of possible underlying mechanisms."[224]

The staff paper recommended EPA consideration of two alternative approaches for revising the fine particle standard. Under one option, EPA would retain the current annual fine particle standard but lower the 24-hour standard to between 25 and 35 $\mu g/m^3$. Under the second approach, EPA would consider an annual standard between 12 and 14 $\mu g/m^3$, along with a revised 24-hour standard of 35 to 40 $\mu g/m^3$.

The staff paper also recommended a new standard for "thoracic coarse particles," which is for those particles between 10 and 2.5 μm in diameter. This recommendation includes particles larger than 2.5 μm but smaller than 10 μm, expressed as $PM_{10\text{-}2.5}$.

220. NAT'L CTR. FOR ENVTL. ASSESSMENT, *supra* note 18, at 6-12.

221. *Id.*

222. OFFICE OF AIR QUALITY PLANNING AND STANDARDS, U.S. EPA, REVIEW OF THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER, SECOND DRAFT (2005).

223. *Id.*

224. *Id.*

The staff paper said EPA should consider a setting a 24-hour standard for these thoracic coarse particles at 65 to 85 $\mu g/m^3$. The current standard for coarse particles is 150 $\mu g/m^3$. In addition, the paper said, some evidence exists to support consideration of a standard set between 30 and 35 $\mu g/m^3$. The CASAC reviewed this second draft of the staff paper at a meeting in April 2005 and concurred with this assessment.

A scientific advisory review panel endorsed an EPA staff recommendation to significantly tighten the air quality standards for fine particulate matter in a final report released on June 10, 2005.[225] The report from the CASAC Particulate Matter Review Panel said most panel members favored setting a standard for fine particles, those less than 2.5 μm in diameter, at between 30 and 35 $\mu g/m^3$ of air averaged over a 24-hour period as opposed to the current standard of 65 μg. The panel also favored a standard of 13 to 14 μg, averaged over one year as opposed to the current annual standard of 15 μg. The panel was unable to agree on a recommendation for thoracic coarse particles. Because thoracic coarse particles occurring in urban areas appear to be more toxic than those occurring in rural areas, the panel said EPA should consider limiting a standard to urban areas only.

On January 17, 2006, EPA published a proposed rule with regard to primary standards for fine particles, and proposes to revise the level of the 24-hour $PM_{2.5}$ standard to 35 micrograms $\mu g/m^3$, which is consistent with the CASAC recommendation.[226] However, the agency decided to retain the level of the annual $PM_{2.5}$ standard at 15 $\mu g/m^3$. Written comments on this proposed decision must be received by April 17, 2006.

As the previous survey of epidemiological and toxicological studies demonstrate, there is a growing body of scientific evidence that ultrafine particles seem to be the particle metric most responsible for the adverse respiratory health effects experienced by certain populations. Moreover, ultrafine particles can only be effectively regulated on a number-based concentration standard since the current mass-based approach allows this fraction to remain uncaptured. It would seem then that EPA could make a strong legal argument that a number-based standard should be implemented to protect public health. Furthermore, because the CAA is preventive in nature, and the role of the judicial branch is to ensure that EPA's scientific judgments are rational, a number-based standard is likely to pass judicial muster. Lastly, such a standard would drive PM

225. Steven D. Cook, *EPA Advisory Panel's Final Report Endorses Reduction in Fine Particle Standard*, DAILY ENV'T REP., June 13, 2005, *available at* http://www.awma.org/pubs/envirowire/article.asp?id=912.

226. National Ambient Air Quality Standards for Particulate Matter, 71 Fed. Reg. 2620 (Jan. 17, 2006) (to be codified at 40 C.F.R. pt. 50).

emissions down significantly since technologies would need to be more efficient. As a result, EPA could do away with a piecemeal approach to PM regulation that revises the standard on a periodic basis.

VI. Form of the Revised PM NAAQS Based on a Number Concentration

A. Introduction

As previously noted, since the inception of the 1970 CAA, EPA has continued to make the PM NAAQS more stringent when the available scientific evidence links exposures to ambient PM to adverse health and welfare effects at levels allowed by the PM standards in place at that time. PM mass concentrations vary significantly on both temporal and spatial scales. For instance, coarse particles, like PM_{10}, are more of a regional pollutant, fine particles, like $PM_{2.5}$, are more of a continental pollutant, and ultrafine particles, like $PM_{0.1}$ are more of a local pollutant.[227] Recent health effects data points to ultrafine particles as a pollutant of concern that should be regulated. As a result the regulation of ultrafine particles on a number-concentration basis is the "missing link" in developing a PM NAAQS that would be fully protective of public health.

B. Urban Air Quality

This reference to a "missing link" is particular apt for urban air quality and other "microenvironments." In urban areas, PM in general, and ultrafine particles in particular, raise concerns because sources of emissions and people are concentrated in the same geographic area, leading to large numbers of people exposed to the emissions of ultrafine particles from many sources. The concentration of activities in urban areas leads to the presence of multiple emission sources and proportionately higher emissions of ultrafine particles. Many of these emission sources are area or mobile sources, and their emissions are more likely to be released at ground level, where people are more likely to be exposed to them.[228] Because approximately 80 percent of the U.S. population lives in metropolitan areas, exposures resulting from urban ultrafine particle emissions may pose a significant risk to public health. Additionally, the prevalence of minority and low income communities in urban industrial and commercial areas, where ambient concentrations of

227. PARTICLE MATTER SCIENCE FOR POLICY MAKERS: A NARSTO ASSESSMENT pt. 2 1-7 (Peter H. McMurry et al., eds., 2003).

228. *See* Samet et al., *supra* note 115.

ultrafine particles may be greater, increases the likelihood of elevated ultrafine particle exposures among these subgroups.[229] The potential for ultrafine particles in urban areas, either directly or indirectly, to contribute to elevated health risks among these and other subgroups, including children, the elderly and persons with existing illness or other potential vulnerability, demonstrates the need to assess risk distributions across urban populations in order to address disproportionate impacts of air hazards.

Living, working, or attending school close to a heavily traveled highway has been linked by a number of epidemiological studies to adverse human health consequences.[230] According to the panelists, who addressed the 2005 Health Effects Institute annual conference, evidence exists of health risks posed by particles emitted primarily by diesel engines and by ground-level ozone hotspots.[231] In particular, one EPA researcher noted that his year-long study of 233 Los Angeles-area homes located various distances from freeways found asthmatic children clustered in homes closer to the highways, where higher levels of NO_x and PM are found.[232] These findings are not unusual if associated with previously mentioned studies which showed measured concentrations of vehicle-related pollutants, including ultrafine pollutants, drop dramatically within approximately 300 meters of selected freeways.[233]

In one study an association was found between exposure to traffic and the onset of a myocardial infarction within one day after exposure.[234] The time the subjects spent in cars, on public transportation, or on motorcycles or bicycles was consistently linked with an increase in the risk of myocardial infarction. The subject's use of a car was the most common source of exposure to traffic, but the study notes there was also an association between time spent on public transportation and the onset of a myocardial infarction.

In addition to vehicular pollution, urban centers have a high concentration of a number of industrial and commercial sources that emit

229. *See, e.g.*, Poverty Fact Sheet Series—The Urban Poor, http://ohioline.osu.edu/hyg-fact/5000/5710.html (last visited Apr. 15, 2006).

230. *See* The Health Effects Institute Annual Conference 2005, http://www.healtheffects.org/Archives/AnnConf2005.htm (last visited Apr. 15, 2006) (presentations and handouts related to PM traffic exposure available for downloading). *See also* H.S. Adams et al., *Fine Particle ($PM_{2.5}$) Personal Exposure Levels in Microenvironments*, 279 SCI. TOTAL ENV'T 29 (2001).

231. *Agencies 'Grapple' With Health Threats of Localized Pollution in High-Traffic Areas*, DAILY ENV'T REPORT, Apr. 25, 2005.

232. *Id.*

233. Kleeman, *supra* note 56.

234. Annette Peters et al., *Exposure to Traffic and the Onset of Myocardial Infarction*, 351 NEW ENG. J. MED. 1721 (2004).

PM.[235] Distribution centers, rail yards[236] maritime ports[237] municipal waste combustors and medical waste incinerators[238] and older coal-fired power plants[239] are a significant source of ambient PM pollution in urban areas.

With the advent of deregulated electric markets, the structure of the electric utility market has shifted to one in which power is sold on exchange at real-time market prices.[240] In this market end users have opportunities to buy power for less than fixed utility rates, but they assume the risk of price increases during times of high demands. As a result, end users now have an incentive to deploy distributed generation (DG) technology. However, the air quality implications related to these DG units is significant.[241] With locations largely in urban areas, existing DG unit emissions lack proper air dispersion because of the high building structures. High demand periods in the summer often coincide with unhealthy air quality due to ozone pollution. Increased operating hours, especially for peak shaving or load curtailment will also produce substantial air emission increases. Moreover, the use of DG diesel technology can result in emissions of large concentrations of ultrafine particles. Therefore, these largely unregulated existing sources of emissions would need to be regulated if a number-based concentration were promulgated. Additionally, the majority of DG is diesel-fueled and has little or no emission controls and it exhibits emission profiles that are many times greater than even older fossil-fueled central power generation.[242] Unlike conventional power stations, which are large and centralized, DG sources are smaller and scattered across metropolitan areas.[243] Moreover, as noted throughout this article, while most of the

235. *See* CAL. AIR RES. BD., CAL. ENVTL. PROT. AGENCY, AIR QUALITY AND LAND USE HANDBOOK: A COMMUNITY HEALTH PERSPECTIVE (proposed March 2005).

236. *Id.*

237. *Id. See also* CAL. AIR RES. BD., DIESEL PARTICULATE MATTER EXPOSURE ASSESSMENT STUDY FOR THE PORTS OF LOS ANGELES AND LONG BEACH (2005), *available at* http://www.arb.ca.gov/msprog/offroad/marinevess/documents/100305draftexposrep.pdf (draft report finding that DPM emissions from ports are a major contributor to DPM in the South Coast Air Basin).

238. U.S. EPA, SOLID WASTE DISPOSAL (1993), *available at* http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s00.pdf.

239. U.S. EPA, BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION (1998), *available at* http://www.epa.gov/ttn/chief/ap42/ch01/final/c01s01.pdf.

240. *See* Michael A. Devine, *The DG Equation Changes*, POWER, Dec. 1, 2004, at 56.

241. *Id.*

242. ERIC WILLIAMS ET AL., CTR. FOR CLEAN AIR POL'Y, DISTRIBUTED GENERATION AND A FORECAST OF ITS GROWTH & EFFECTS ON THE NEW YORK STATE ELECTRIC SYSTEM FROM 2001 TO 2020 (2003) (where 1996 emissions from diesel generators are over 296,000 tons of NO_x or comparable to the combined power plant emissions from New Jersey, New York, and Pennsylvania.)

243. *See* NANCY E. RYAN ET AL., ENVTL. DEFENSE, SMALLER, CLOSER, DIRTIER—

mass diesel particle matter ranges from 0.1 to 1.0 μm, the majority of the number of particles is in the ultrafine range.

EPA notes that DPM concentrations reported from CMB and dispersion modeling studies in the 1980s suggest that in urban and suburban areas of Phoenix and Southern California, the annual average DPM concentration ranged from 2 to 13 $\mu g/m^3$.[244] In nonurban and rural areas in the 1980s, DPM concentrations were reported to range from 1.4 to 5 $\mu g/m^3$. In the 1990s, annual or seasonal average DPM concentrations in suburban or urban locations have ranged from 1.2 to 4.5 $\mu g/m^3$. In the 1990s, nonurban air basins in California were reported to have DPM concentrations ranging from 0.2 to 2.6 $\mu g/m^3$.

In addition, there is data available that characterizes DPM concentrations in "hotspots" such as near heavily traveled roadways, bus stations, train stations, and marinas. One CMB study attempted to apportion PM measured in an urban hotspot.[245] Researchers reported results of conventional CMB performed on PM samples collected in the spring of 1993 over a 3-day period at a site adjacent to a major bus stop on Madison Avenue in midtown Manhattan. Buses in this area can idle for as long as 10 minutes, and PM emissions are augmented by the elevated levels of DPM emitted during acceleration away from the bus stop. DPM concentrations reported from this study ranged from 13.0 $\mu g/m^3$ to 46.7 $\mu g/m^3$. This study attributed, on average, 53 percent of the PM_{10} to diesel emissions.[246]

C. *Shape of the Standard*

In selecting a NAAQS, EPA focuses on the indicator, averaging time, the form of the standard, and the level.[247] Since most data points to concerns related to ultrafine particles in the urban environment, the focus of a number-based standard should be for urban areas. A number-based standard would not replace the current PM standard, but rather would be in addition to the current standard. Moreover, because modeling results show that the greatest fraction of concern is with the 0.1 to 0.01 μm range, the indicator should be targeted to this range.

DIESEL BACKUP GENERATORS IN CALIFORNIA (2002) (where these DG diesel generators are under close scrutiny in California because as previously noted they are an attractive alternative source of power and a significant threat to air quality. CARB estimates there are over 11,000 generators in the State and the average size is about 600 horsepower (hp), but some are as large as 2,000 to 4,000.)

244. NAT'L CTR. FOR ENVTL. ASSESSMENT, *supra* note 118, at 2-94.

245. Wittorff et al., *The Impact of Diesel Particulate Emissions on Ambient Particulate Loadings*, Air & Waste Management Association 87th Annual Meeting (June 19-24, 1994).

246. *Id.*

247. 62 Fed. Reg. 38,652, *supra* note 5.

A 24-hour averaging time may be appropriate for a number-based standard since it would be consistent with the majority of epidemiological studies which have reported associations of health effects with 24-hour concentrations of various PM indicators, including ultrafine particles. However, serious consideration should be given to developing a shorter averaging time over an eight-hour timeframe. This "sub-daily standard" for a number-based standard could certainly be greatly protective of sensitive populations as well as urban populations. Additionally, it may give a more complete picture of ultrafine particle exposure because these particles are of shorter atmospheric duration than other PM fractions. Since continuous PM monitors are now available, measuring concentrations on a real time basis is technologically feasible. Regardless of whether EPA moves to a sub-daily standard, continuous PM monitors can be used to study real-time increases of just a few hours and use those to compare with epidemiology studies, such as hospital admissions based on cardiac arrest or breathing difficulties.[248]

In addition to a 24-hour averaging time, spatial averaging may also be appropriate since a number of epidemiology studies used this approach. This may be more representative of community-wide exposures or "microenvironments," like neighborhoods or business districts when multiple monitoring sites are used to characterize area-wide exposure levels and the associated health risks.

Many of the community-based epidemiological studies examined in this paper use ultrafine concentrations. As a result a concentration-based standard would be the appropriate form of a number-based standard. Moreover, a concentration-based form would be more directly related to the ambient ultrafine PM concentrations that are associated with health effects.

The level of the standard is more difficult to recommend. In a follow-up to their mortality study in Erfurt, Germany,[249] researchers recorded the daily average particle concentrations in Erfurt from September 1995 to December 1998.[250] In the Erfurt Germany study, 87.5 percent of the ambient number concentration is between the 0.1 to 0.01 μm range. The median ambient concentration is 14,769 particles/cm^3. Because the authors of the Erfurt study concluded that both fine particles, represented by particle mass, and ultrafine particles, represented by particle number, showed independent effects on mortality at ambient concentrations, it is likely that the level of an

248. *New Research May Point To Need For Stricter Fine Particle Standard*, INSIDE FUELS AND VEHICLES, Nov. 7, 2002.

249. H-ERICH WICHMANN ET AL., *supra* note 121.

250. H-ERICH WICHMANN ET AL., SOURCES AND ELEMENTAL COMPOSITION OF AMBIENT PARTICLE IN ERFURT, GERMANY (2002).

ultrafine standard would be less than the ambient ultrafine number-concentrations represented in their follow-up study. However, these results may not be easily transferred to the United States since the mix of ultrafine sources may be markedly different. Nevertheless, this study provides a good starting point for an ambient level of ultrafine PM.

A review of other atmospheric concentration data studies conducted in the United States have been documented in this paper and reveal ultrafine concentrations in the ranges of 14,400 particles/cm^3,[251] 1.8 x 10^5 to 3.5 x 10^5 particles/cm^3,[252] and 1.4 x 10^4 to 2.5 x 10^4 cm^3.[253] These ambient levels may be more representative of the United States, but they were not done in conjunction with an epidemiology study. However, as noted earlier, medical researchers in Taiwan found lung impairment within the ultrafine particle range of 10,000 particle/cm^3.[254] Linking this study in Taiwan with the Erfurt Germany and United States studies, it is likely a PM number-based concentration standard would be in the general range of 10,000 to 15,000 particle/cm^3. However as alluded to previously, more work would need to be conducted in order to give a more precise range. Moreover, additional research may need to be done to see if this level is sufficiently protective of susceptible populations.

VII. Development and Implementation of an Ambient PM Number-Based Standard

A. Introduction

The NAAQS addresses air pollution that endangers public health and welfare. The scientific literature shows ambient ultrafine particles are important in regard to respiratory health effects. There is a growing body of scientific data to support the regulation of ultrafine particles, but there are a number of data gaps in the epidemiology arena that would need to be filled before the CASC could make a recommendation that the PM NAAQS be revised to regulate that pollutant on a number-based standard. Nevertheless, based on current research trends in this area, it is completely plausible that these gaps could be filled within the next five to eight years to allow the CASC to make such a recommendation and allow EPA to regulate on a PM number-based standard. Were EPA to develop a PM number-based standard, the current regulatory scheme related to PM would need to be revised.

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251. David B. Kittelson et al., *supra* note 30.
252. Christopher A. Noble et al., *supra* note 31.
253. Lidia Morawska et al., *supra* note 33.
254. Chang-Chuan Chan et al., *supra* note 141.

B. Implementation of the Number-based NAAQS

Each time EPA promulgates a new NAAQS, it sets off a number of requirements mandated by the CAA. The law requires EPA and the States to identify and designate areas that attain the new standards, fail to attain them, or cannot be designated based on current information. EPA makes these designations after it assesses pollution data and considers the designation recommendations made by the States. These designations must be made no later than three years after promulgation of the new NAAQS. In conjunction with the designation process, States must begin working to develop state implementation plans ("SIPs"). Section 110 of the CAA requires each State to submit, within three years after promulgation of a new NAAQS, a plan providing for "implementation, maintenance, and enforcement" of the standards in all areas of the State.[255] Once EPA finalizes designations of nonattainment areas, States may need to add further requirements to their SIPs for nonattainment areas. Under the CAA, a nonattainment area is any area that does not meet, or that contributes to ambient air quality in a nearby area that does not meet, the national primary or secondary ambient air quality standard for any pollutant. Subpart D of the CAA, requires that SIPs for nonattainment areas must demonstrate that an area will attain the standard "as expeditiously as practicable," but no later than specified deadlines after the date of designation.[256] Lastly SIPs are due within three years of final designations. EPA has identified a number of key factors that it looks at in making designation decisions, and that States should look at when making designation recommendations.[257]

C. SIP Development for the New PM NAAQS

When the designation process is complete, the next formal step required under the CAA is for States to develop and submit SIPs, which demonstrate how they meet the new NAAQS by the required

255. 42 U.S.C. § 7410 (2000).

256. 42 U.S.C. §§ 7501-7515 (2000).

257. Memorandum from Jeffrey R. Holmstead, EPA Assistant Administrator, Office of Air and Radiation, to EPA Regional Administrators (Apr. 1, 2003). These factors include emissions in areas potentially included versus excluded from nonattainment areas; air quality in potentially included versus excluded areas; population density and degree of urbanization, including commercial development in included versus excluded areas; traffic and commuting patterns; expected growth, which includes extent, pattern, and rate of growth; meteorology; geography and topography; political jurisdictional boundaries, like counties; location of emission sources; and level of control of emission sources. *See also,* Wegman & Sasser, *The Path Toward Clean Air—Implementing New Standards for Ozone and Fine Particles*, EM MAGAZINE, Apr. 2005.

deadlines.[258] In addition to requiring an attainment plan, the CAA mandates certain programs or control strategies for nonattainment areas. These include transportation conformity; new source review; and reasonably available controls on certain industrial sources.[259] To develop SIPs, States must have a clear understanding of the amount, composition, and sources of pollution in or near the designated nonattainment areas. In order to remedy air quality problems in these areas, States must employ a combination of control strategies aimed at correcting both local and transported pollution.

Control requirements necessary to attain and maintain the NAAQS are a central part of the SIPs developed by States for nonattainment areas.[260] In the case of a number-based PM standard, like in the case of previous PM standards, attainment is expected for all areas of the country as expeditiously as practicable, but not later than five years after the effective date of designations.[261] Depending on the severity of nonattainment and the availability and feasibility of pollution control measures, EPA may extend this attainment date by up to an additional one to five years based upon the severity of the nonattainment problems or feasibility of implementing control measures.[262]

Section 172(c) of the CAA, requires States with nonattainment areas to submit an attainment demonstration.[263] An attainment demonstration consists of technical analysis that locate, identify, and quantify sources of emissions that are contributing to violations of the PM NAAQS; analyses of future year emissions reductions and air quality improvement resulting from already adopted national and local programs, and from potential new local measures to meet reasonably available control technology, reasonably available control measures, and reasonable further progress requirements in the area; adopt emission reduction measures with schedules for implementation and other means and techniques necessary and appropriate for attainment; and contingency measures required under Section 172 (c)(9) of the CAA.[264]

Section 172(c)(1) of the CAA requires sources located in nonattainment for PM to contain reasonably available control measures (RACM).[265] This section provides that RACM for nonattainment areas shall include "such reductions in emissions from existing sources in the

258. 42 U.S.C. §§ 7501-7515.
259. 42 U.S.C. § 7502(c).
260. 42 U.S.C. § 7502(a)(2)(A).
261. *Id.*
262. 42 U.S.C. § 7410(a)(2)(B).
263. 42 U.S.C. § 7502(c).
264. 42 U.S.C. § 7502(c)(9).
265. 42 U.S.C. § 7502(c)(1).

area as may be obtained through the adoption, at a minimum of reasonably available control technology." However, it should be noted that while RACM includes stationary source control measures, it is not limited to these measures and can include mobile source measures, and area source measures as well. For example, a stationary source control measure could be new pollution control technology, a mobile source control measure could be an inspection and maintenance program, and an area source control measure could be solvent substitution. Moreover, under Section 189(c) of the CAA, PM nonattainment areas SIPs must include quantitative emission reductions milestones which are to be achieved every three years which demonstrate reasonable further progress, as defined under Section 171(1),[266] until the area is redesignated attainment.[267] Because automobiles are a major source of ultrafine particles, the reasonable further progress plan should include a motor vehicle budget for each milestone year.

For PM nonattainment area all SIPS must include contingency measures consistent with Section 172(c)(9) of the CAA.[268] Contingency measures are additional control measures to be implemented in the event that an area fails to meet reasonable further progress or fails to attain the standard by its attainment date. These contingency measures must be fully adopted rules or control measures that are ready to be implemented promptly upon failure to meet reasonable further progress or failure of the area to meet the standard by its attainment date.

Sections 107 and 110 of the CAA give each state primary responsibility for assuring that air quality within its borders is maintained at a level consistent with the NAAQS.[269] This is achieved through the establishment of source specific requirements in SIPs. The stringency of the substantive requirements depends upon whether an area attains or does not attain the level of air quality specified in the NAAQS. Were EPA to promulgate a number-based concentration standard, States would be required to make revisions to their SIPs. For instance, emission limits would need to be established which reflected a change to a PM number-based concentration standard. Air quality data, monitoring and emissions information would need to be collected on a number-based concentration format. Permit revisions would be needed to reflect the addition of a PM number-based concentration standard. SIP revisions would be necessary related to the nonattainment new source review and prevention of significant deterioration programs relating to the

266. 42 U.S.C. § 7501(1).
267. 42 U.S.C. § 7513a(c).
268. 42 U.S.C. § 7502(c)(9).
269. 42 U.S.C. §§ 7407, 7410.

construction of new sources and the operation of existing sources in areas that are in nonattainment as well as attainment areas. Moreover, prevention of significant deterioration increments and major source thresholds would need to be revised in order to take a number-based concentration standard into account.

D. Technology-Forcing Requirements of SIPs

After EPA revises the PM NAAQS to a number-based concentration, each State must develop and adopt a SIP and submit it to EPA for approval for each attainment and nonattainment area in the State. The basic requirements for the SIP are set forth under Section 110(a)(2)(A)-(M) of the CAA.[270] Those requirements include, but are not limited to the following: enforceable emission limitations and other control measures; an appropriate monitoring and data analyzing program to provide data to EPA; an enforcement program; adequate provisions to prevent interstate pollution; adequate funding under state law to carry out the SIP; requirements for stationary sources to monitor, report, and make emissions data available; procedures for revision of the SIP if necessary in order to meet additional requirements established under the CAA; provisions to meet additional requirements for nonattainment areas; provisions to meet the requirements relating to prevention of significant deterioration of air quality; and provisions for the performance of air quality modeling as prescribed by EPA.[271] In essence, a SIP is a compilation of regulations and programs that a State uses to carry out its responsibilities under the CAA, including the attainment, maintenance, and enforcement of the NAAQS.

There are 87 areas that were either classified as nonattainment or maintenance for the PM_{10} NAAQS as of May 17, 2004.[272] In contrast, on June 29, 2004, EPA announced there are 243 areas classified as nonattainment with the $PM_{2.5}$ NAAQS.[273] While the exact number of nonattainment areas for a number-based PM NAAQS would be difficult to estimate, the stringency of such a standard compared to the current mass-based approach, it is likely to exceed the current 243 $PM_{2.5}$ nonattainment areas simply because these particles are ubiquitous. As a result, a number based standard would have a strong technology forcing effect.

The U.S. Supreme Court has recognized that the CAA is a

270. 42 U.S.C. §§ 7410(a)(2)(A)-(M).
271. *Id.*
272. U.S. EPA, Green Book, http://www.epa.gov/oar/oaqps/greenbk/pnc.html (last visited Apr. 15, 2006).
273. *Id.*

"technology-forcing" statute that sets ambitious goals to protect public health and welfare.[274] As this name suggests, a regulatory standard that cannot be met with currently available technology "forces" government, industry, and other stakeholders to develop and implement a compliance strategy. Technology forcing measures can take one of two forms.[275] The first is a technology standard that specifies a process to be used and is usually based on an existing technology that has been adopted and developed. The second is a performance standard that requires companies to meet a mandated target, but the standard does not specify the use of any particular technology. Technology forcing can be consistent with either technology or performance standards because it can either be a mandate to meet performance levels that are not currently technologically feasible or a specific technology that is not currently viable. A regulatory agency can also identify a preferred technology and set performance standards that are likely to force development of that technology.

It is likely that technologies needed to reduce particle number emissions may be different than the ones currently used to reduce mass emissions. This is because under the current mass-based regime technologies focus on capturing the high end of the PM fraction. However, in this case, both the regulatory agencies and industry will be seeking to employ advanced technologies to implement and achieve a standard based on a number concentration.

VIII. Development and Implementation of PM Number-Based Standard Ambient Monitoring Program

A. Introduction

The CAA requires ambient air quality monitors to define nonattainment areas, evaluate progress toward achieving the NAAQS, and to report data to EPA to document a State's air quality status.[276] In addition, sources subject to the Prevention of Significant Deterioration regulations of the New Source Review Program are subject to preconstruction ambient air quality monitoring requirements.[277] To satisfy these statutory requirements, EPA promulgated regulations,

274. *See* Train v. Natural Res. Def. Council, Inc., 421 U.S. 60, 91 (1975).

275. *See, e.g.*, D. GERARD & L.B. LAVE, CTR. FOR THE STUDY & IMPROVEMENT OF REGULATION, CARNEGIE MELLON UNIV., IMPLEMENTING TECHNOLOGY-FORCING POLICIES: THE 1970 CAA AMENDMENTS AND THE INTRODUCTION OF ADVANCED AUTOMOTIVE EMISSION CONTROLS (2003).

276. 42 U.S.C. § 7711d(b)(2) (2000); 42 U.S.C. § 7511e; 42 U.S.C. § 7512(b)(2)(A).

277. *See* 42 U.S.C.§§ 7475(a)(7), (e). *See also* 40 C.F.R. § 51.166(m), 51.21(m).

which provides detailed requirements for air quality siting and data reporting of all criteria pollutants.[278] Assessing the ambient air quality of an area takes a wide range of tools, like monitoring systems, models, and emission inventories.

B. Air Monitoring Stations

State and local government monitoring stations across the nation collect direct measurements of pollutants in the air and submit this data to EPA's Aerometric Information Retrieval System (AIRS). The vast majority of these measurements are representative of the country's heavily populated urban areas.

The CAA requires every State to establish a network of air monitoring stations for criteria pollutants, using criteria set by EPA for their location and operation. The monitoring stations in this network are called the State and Local Air Monitoring Stations (SLAMS).[279] To obtain more timely and detailed information about air quality in strategic locations across the nation, EPA established an additional network of monitors called the National Air Monitoring Stations (NAMS).[280] A third type of monitor, the Special Purpose Monitor (SPMS), is used by State and local agencies to fulfill very specific or short-term monitoring goals.[281] The 1990 Amendments to the CAA also requires a fourth category of a monitoring station, the Photochemical Assessment Monitoring Station (PAMS), which measures ozone precursors.[282]

To assess ambient air monitoring instruments, EPA uses the Ambient Air Monitoring Reference and Equivalent Methods regulatory procedure.[283] Procedures for testing performance characteristics of methods for PM_{10} and $PM_{2.5}$ are found in these regulations.[284] Each SLAMS must employ reference or equivalent methods and meet the siting requirements before its data can be used for regulatory purposes. The operating schedule for SLAMS, PAMS, and other sampling programs are found in the regulations.[285] In addition, monitoring

278. 40 CFR pt. 58.

279. 40 C.F.R. § 58.20 (1997). The SLAMS consist of a network of about 4,000 monitoring stations whose size and distribution is largely determined by the needs of State and local air pollution control agencies to meet their respective SIP requirements.

280. 40 C.F.R. § 58.1(c) (1997). The NAMS, which has 1,080 stations, are a subset of the SLAMS network with emphasis being given to urban and multi-source areas.

281. 40 C.F.R. § 58.1 (1997). SPMS provide for special studies needed by the State and local agencies to support SIP and other air program activities.

282. 40 C.F.R. § 58.40 (1997). A PAMS network is required in each ozone nonattainment area that is designated serious, severe, or extreme.

283. 40 C.F.R. pts. 50, 53 (1997).

284. 40 C.F.R pt. 53, subpts. D and E (1997).

285. 40 C.F.R. § 58.13 (1997).

methods are specified[286] and the requirements for locating monitoring stations are specified in the regulations.[287]

C. *Spatial Monitoring Requirements*

Currently EPA spatial monitoring requirements are classified into five categories for SLAMS—micro; middle; neighborhood; urban; and regional.[288] Movement to a number-based PM standard would have the effect of requiring EPA to revise its air quality monitoring program. For example, and as previously indicated, a number of studies demonstrate that there is significant generation of and exposure to ultrafine particles in urban areas, in general, and around major highways, in particular. As a result, EPA may seek to place more emphasis on microscale and neighborhood scale PM monitoring networks since much of the ultrafine particle exposure would be expected to be associated with this scale of measurement.

A microscale would typify areas such as downtown canyons and traffic corridors where the general public would be exposed to maximum concentrations from mobile sources. Monitoring sites should be located near inhabited buildings or locations where the general public can be expected to exposed to ultrafine PM pollution. Emissions from stationary sources such as power plants and other large industrial processes may, under certain plume conditions, likewise result in high ground level concentrations at the microscale level.

A neighborhood scale is generally thought of as a homogenous urban subregion. Such a geographical scale could be no more than a few kilometers. This type of scale can provide good information about trends and compliance with a number-based standard since it represents conditions in areas where people live and work. Moreover, this category may also include industrial and commercial neighborhoods in districts of mixed land use where residences are interspersed.

D. *Continuous Monitoring Requirements*

In addition, to revising site requirements, EPA would also need to revise Ambient Air Monitoring Reference and Equivalent Methods requirements under 40 CFR Parts 50 and 53. At this time, EPA has listed 21 PM_{10} samplers and 15 of these samplers are manual or filter-based methods.[289] EPA has listed 14 $PM_{2.5}$ samplers as designated reference

286. 40 C.F.R. pt. 58, app. C (1997).
287. 40 C.F.R. pt. 58, apps. D, E (1997).
288. *See* 40 C.F.R. pt. 58, app. D (1997).
289. OFFICE OF RESEARCH & DEV., U.S. EPA, LIST OF DESIGNATED REFERENCE AND EQUIVALENT METHODS 2-5 (2005), *available at* http://www.epa.gov/ttn/amtic/files/

and equivalent methods, all of which are filter-based. The filter-based sampling and analytical methods are labor-intensive because they require laboratory weighing of the filters before and after sampling.[290] Each sample is collected during a 24-hour period, and one sample typically is taken every six days throughout the year at each monitoring station. There are also calibration and quality assurance/quality control requirements. Moreover, there is a time lag of days to weeks from the date of sampling to the time results are available.

However, continuous monitoring for PM has many advantages over traditional filter based sampling techniques.[291] A continuous monitoring method is an in-situ, automatic measurement of suspended particle mass with varied averaging time from minutes to hours, which provides instantaneous results. The 24-hour a day, 7 days a week sampling schedule of this technique can track PM emission patterns and exposure, and can be used to enhance public health research into short-term peak exposure. Two of the more common continuous monitoring methods for PM_{10} and $PM_{2.5}$ are the Tapered Element Oscillating Microbalance (TEOM) and the beta attenuation monitors (BAM).[292]

E. Ultrafine Monitoring Devices

All of these ambient monitoring devices mentioned above would be made obsolete if EPA moved to a number-based concentration system. There are not many ambient monitoring devices, which measure ultrafine particle concentrations because, at this time, there is no regulatory need for such devices. However, TSI, Inc., has developed Scanning Mobility Particle Sizer (SMPS) systems, which are technologically advanced instruments for measuring ultrafine particles in the range from three to 1000 nm in diameter.[293] Moreover, a number of ultrafine ambient air

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ambient/criteria/ref1005.pdf.

290. 40 C.F.R. pt. 50, app. B (1997).

291. OFFICE OF RESEARCH & DEV., U.S. EPA, GUIDANCE FOR USING CONTINUOUS MONITORS IN $PM_{2.5}$ MONITORING NETWORKS (1998).

292. CAL. AIR RES. BD., CAL. ENVTL. PROT. AGENCY, AIR QUALITY MANUAL (2003), *available at* http://www.arb.ca.gov/aaqm/qmosqual/qamanual/vol4/Chapter5.pdf.

293. The product description and technical discussion related to SMPS systems is found at http://www.tsi.com/Product.aspx?Pid=85. In addition, there are a number of studies that discuss ambient measurement technologies for ultrafine particles. *See* Jeremy A. Sarnat et al., *Measurement of Fine, Coarse, and Ultrafine Particles*, 39.3 ANN IST SUPER SANITÀ 351 (2003); Pasi Aalto, *Atmospheric Ultrafine Particle Measurements*, 64 REP. SERIES IN AEROSOL SCI. 1 (2004), *available at* http://ethesis.helsinki.fi/julkaisut/mat/fysik/vk/aalto/atmosphe.pdf; S.P. Bell et al., AEA TECH., EXPERIMENTAL ASSESSMENT OF PARTICULATE MEASUREMENT INSTRUMENTATION (1999); PHILIP HOPKE ET AL., CAL. ENERGY COMM'N AND THE N.Y. STATE ENERGY RESEARCH & DEV. AUTH., A SURVEY OF MONITORING INSTRUMENTS FOR MEASUREMENTS OF AIRBORNE POLLUTANTS (2002). Periodic reports for the Los Angeles Supersite Project, which discuss ambient

concentration studies, that have been cited in this article and elsewhere, commonly use ultrafine monitoring equipment manufactured by TSI, Incorporated.[294]

F. Modeling Requirements

Air quality can be either monitored or modeled.[295] Monitoring gives a picture of air quality only at the point in time and space in which the monitor operates. However, models enjoy certain advantages that monitors do not. They can measure the contribution of atmospheric contribution to atmospheric pollution made by different sources or locations. They can also be adjusted to account for future increases in emissions, and they allow alternative control strategies to be evaluated and can be used to aid in cost/benefit analysis.[296]

EPA has developed new data systems and processing software to expedite emissions estimating and data processing.[297] Moreover, U.S. EPA is developing a new modeling system termed the Motor Vehicle Emissions Simulator (MOVES) that will estimate emissions for both onroad and offroad sources.[298] While many if not most of the models EPA uses would need to be modified to account for ultrafine particles, only source and receptor models will be discussed.

Under the CAA, modeling is used for, among other things, to determine nonattainment and attainment areas under Section 107;[299]

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ultrafine monitoring techniques, may be found at http://www.epa.gov/ttn/amtic/laprog.html.

294. *See* Roy M. Harrison et al., *Measurement of the Physical Properties of Particles in the Urban Atmosphere*, 33 ATMOSPHERIC ENV'T 309 (1999); Galina Gramotnev & Zoran Ristovski, *Experimental Investigation of Ultrafine Particle Size Distribution Near a Busy Road*, 38 ATMOSPHERIC ENV'T 1767 (2004); Lidia Morawska et al., *A Study of the Horizontal and Vertical Profile of Submicrometer Particles in Relation to a Busy Road*, 33 ATMOSPHERIC ENV'T 1261,(1999); M.D. Keywood et al., *Relationship Between Size Segregated Mass Concentration Data and Ultrafine Particle Number Concentrations in Urban Areas*, 33 ATMOSPHERIC ENV'T 2907 (1999); L. Gidhagen et al., *Simulation of NO_x and Ultrafine Particles in a Street Canyon in Stockholm, Sweden*, 38 ATMOSPHERIC ENV'T 2029 (2004); Ji Ping Shi et al., *Sources and Concentrations of Nanoparticles (10 nm diameter) in the Urban Atmosphere*, 35 ATMOSPHERIC ENV'T 1193 (2001).

295. ARNOLD REITZE, AIR POLLUTION LAW, ch. 3 (1995).

296. *Id.*

297. *See* Clearinghouse for Inventories and Emissions Factors, U.S. EPA, Tech Transfer Network, http://www.epa.gov/ttn/chief/software (last visited Apr. 15, 2006).

298. Office of Transportation and Air Quality, U.S. EPA, http://www.epa.gov/otaq/hwy.htm; http://www.epa.gov/nonroad (last visited Apr. 15, 2006). Some of those models and tools include SPECIATE, which contains more than 1000 speciation profiles for total organic carbon and PM emissions; FIRE, which contains EPA's recommended emission factors for criteria and hazardous air pollutants; and NONROAD, which predicts criteria pollutant emissions from non-road equipment ranging from lawn mowers and heavy duty commercial vehicles.

299. 42 U.S.C. § 7407 (2004).

develop transportation plans under Section 108;[300] develop SIPs including transportation control plans under Section 110;[301] ultilize innovative technology under Section 111;[302] develop conformity plans under Section 176;[303] develop nonattainment plans under section 182;[304] and Prevention of Signification Deterioration preconstruction permitting requirements.[305] As a result, movement towards a PM number-based concentration standard will require EPA to revisit its guidelines on air quality modeling.

Source and receptor-oriented models play central roles in developing, evaluating, and implementing national air pollution policies and regulations.[306] Source-oriented models use emission-inventory data as the input and incorporate various meteorological and atmospheric chemistry processes to provide estimates of ambient PM concentrations. Receptor-oriented models, on the other hand, use ambient air quality data to arrive at quantitative estimates of the contributions of the specific sources of the PM pollution. Additionally, receptor-oriented models provide information on the sources contributing to air pollution problems. This information allows regulators to develop control strategies that target the most significant sources of air pollution and assists those regulators to better understand the near and long term effects of their decisions.

In implementing the PM NAAQS source and receptor-oriented models provide States with air quality mechanisms to develop SIPs.[307] In preparing SIPs, source-oriented models are used to design and evaluate alternative strategies for meeting regulatory requirements and to demonstrate that the SIP requirements will result in attainment and maintenance of a specific NAAQS.[308] Receptor-oriented models are

300. 42 U.S.C. § 7408.
301. 42 U.S.C. § 7410.
302. 42 U.S.C. § 7411.
303. 42 U.S.C. § 7506.
304. 42 U.S.C. § 7511a.
305. *See* Ming-Dong Cheng & Roger L. Tanner, *Characterization of Ultrafine and Fine Particles at a Site Near the Great Smoky Mountains National Park*, 36 ATMOSPHERIC ENV'T 5795 (2002) (where the mean concentration of ambient concentrations of ultrafine particles were 407, 932, 1440, 2418, 9354, 11049, 6350, and 1445 particles/cm^3 respectively). *See also* J. Ruuskanen et al., *Concentrations of Ultrafine, Fine and $PM_{2.5}$ Particles in Three European Cities*, 35 ATMOSPHERIC ENV'T 3729 (2002), (where total ultrafine number concentrations were simultaneously measured in Alkmaar, Netherlands, Erfurt, Germany, and Helsinki, Finland between November 1996 and March 1997, and the mean ultrafine number concentrations were 18,300, 17,700, and 16,200, particles/cm^3, respectively).
306. OFFICE OF RESEARCH & DEV., U.S. EPA, PARTICULATE MATTER RESEARCH PROGRAM—FIVE YEARS OF PROGRESS (2004).
307. *Id.* at 49.
308. REITZE, *supra* note 295.

used to identify the most significant sources contributing to air pollution problems in order to develop SIP strategies that can effectively control that pollution. Moreover, receptor modeling provides checks on the emission inventories utilized in the source models to develop SIPs and can also be used to evaluate progress in reaching attainment with the NAAQS.

The promulgation of ambient air quality standards for $PM_{2.5}$ has prompted the use of 3-dimensional (3-D) Eulerian air quality models to demonstrate how the NAAQS can be attained.[309] A number of these models provide a more detailed representation of the particle size distribution using either a modal or sectional representation, which could assist in modeling the ultrafine particle fraction in the ambient air.[310]

The Community Multiscale Air Quality (CMAQ) model provides a more detailed representation of the particle size distribution by using either a modal or sectional representation.[311] This particular model, which is a source-oriented model, can characterize PM subdivisions, like ultrafine particles, and may be a useful tool to demonstrate that SIP requirements will result in attaining for maintaining a number-based concentration NAAQS.

The CIT-UCD model, which is a source-oriented 3-D Eulerian model has 15 discrete particle sizes ranging in initial diameter from 10 nm to 10 μm.[312] This model is urban-scaled using sectional representation treating a number of particle formation processes.[313]

Currently EPA has focused on model development in the area of receptor-oriented models for $PM_{2.5}$ SIP development.[314] Two models that have received the most interest from EPA are the Chemical Mass Balance (CMB) and UNMIX, which is multivariate in nature.[315] Both of these models are able to extract major use profiles used to create a simulated data set for both outdoor[316] and indoor exposure.[317]

309. Christian Seigneur, *Current Status of Air Quality Models for Particulate Matter*, 51 AIR & WASTE MGMT ASS'N 1508 (2001).

310. *Id.* at 1515.

311. *Id.*

312. Tony Held et al., *Modeling Particulate Matter in the San Joaquin Valley with a Source-Oriented Externally Mixed Three-Dimensional Photochemical Grid Model*, 38 ATMOSPHERIC ENV'T 3689 (2004).

313. Seigneur, *supra* note 309, at 1515.

314. OFFICE OF AIR QUALITY AND PLANNING STANDARDS, U.S. EPA, REVIEW OF THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER: POLICY ASSESSMENT OF SCIENTIFIC AND TECHNICAL INFORMATION (2005), *available at* http://www.epa.gov/ttn/naaqs/standards/pm/data/pmstaffpaper_20051221.pdf.

315. Shelly L. Miller et al., *Source Apportionment of Exposures to Volatile Organic Compounds. I. Evaluation of Receptor Models Using Simulated Exposure Data*, 36 ATMOSPHERIC ENV'T 3629 (2002).

316. *Id.*

In addition to source and receptor-oriented models, EPA also uses an emissions factor model for estimating pollution from on-road motor vehicles in States outside of California, which is known as MOBILE.[318] MOBILE is used to calculate current and future inventories of motor vehicle emissions at the national and local level, in order to make decisions about air pollution policies and programs at the local, State, and national level. Inventories based on MOBILE are also used to meet the federal CAA's SIP and transportation conformity requirements.

The previous version of MOBILE, known as MOBILE6, calculated emissions of VOCs, NO_x, and CO, from passenger cars, motorcycles, buses, and light-duty and heavy-duty trucks. EPA recently updated this version, to MOBILE6.2, which added the capability to estimate direct PM emission factors for PM_{10} and $PM_{2.5}$ and emission factors for particulate precursors.[319] Were EPA to move from a mass based standard to number based standard it would likely require a revision to this model.

Modeled estimates of population exposures to DPM integrate exposure in various indoor and outdoor environments, account for the demographic distribution and time-activity patterns, and DPM concentrations in various environments, like job-related exposures. Two models have been developed to determine DPM exposures in the general population—the Hazardous Air Pollutant Exposure Model for Mobile Sources, version 3 (HAPEM-MS3); and the California Population Indoor Exposure Model.[320] EPA has also developed version 4 of the HAPEM, which provides State-specific average exposures for DPM and 32 other urban air toxic compounds.[321]

There has been extensive modeling research relating to ultrafine particles from motor vehicles.[322] One group of researchers developed a

317. Melissa J. Anderson, *Source Apportionment of Exposures to Volatile Organic Compounds: Application of Receptor Models to Team Study Data*, 36 ATMOSPHERIC ENV'T 3643 (2002).

318. *See* Clearinghouse for Inventories and Emissions Factors, U.S. EPA, *supra* note 297.

319. Official Release of the MOBILE6.2 Motor Vehicle Emissions Factor Model and the December 2003 AP-42 Methods for Re-Entrained Road Dust, 69 Fed.Reg. 28,830 (May 19, 2004).

320. *See,* NAT'L EXPOSURE RESEARCH LAB., U.S. EPA, FINAL TECHNICAL REPORT, ANALYSIS OF CARBON MONOXIDE EXPOSURE FOR FOURTEEN CITIES USING HAPEM-MS3 (1998), *available at* http://www.epa.gov/otaq/regs/toxics/hapem-co.pdf.

321. *Id.*

322. *See, e.g.,* L. Morawska et al., *A study of the horizontal and vertical profile of submirometer particles in relation to a busy road*, 33 ATMOSPHERIC ENV'T 1261 (1999). *See also* A. Kristensson et al., *Real-world traffic emission factors of gases and particles measured in a road tunnel in Stockholm, Sweden*, 38 ATMOSPHERIC ENV'T 657 (2004) (where real-world traffic emission factors where derived for a number of gaseous and particle pollutants including 49 different polycyclic aromatic hydrocarbos, CO, NO_x, benzene, toluene, xylenes, aldehydes, elements and inorganic carbon contained in

model to review the evolution of particle number distribution near roadways for regulatory purposes.[323] This group analyzed the aerosol dynamics near roadways and proposed a structure for a mechanistic roadway air quality model that provides a tool for evaluating the impact of transportation on ambient air quality and serves as a grid model for mobile sources. This same group of researchers also introduced a multi-component sectional aerosol dynamic model, simulating only the most important particulate processes in measuring ultrafine particles from the tailpipe to the ambient air.[324] The researchers believe that this multi-component sectional aerosol dynamic model was better able to capture the aerosol dynamics during this particulate evolution process.

G. Emission Factors

Emission factors are a fundamental tool for air quality management and affects operating permit fees, compliance assessments, and SIP attainment emission inventories.[325] According to EPA, "an emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant."[326] An emission factor then, according to the agency, is generally expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant.[327] These factors facilitate estimation of emissions from various sources of air pollution. As it relates to PM pollution, AP-42 contains emission factors for pollutants that are expected to be primary PM.[328] Because these emission factors are mass-based estimates, they would need to be revised to reflect a more stringent number-based standard.

There are a number of broad industrial sources that are responsible for PM or PM precursor emissions, like external combustion sources, solid waste disposal processes, the petroleum industry, organic and inorganic chemical process industry, the wood processing industry, the mineral extraction and processing industry, and stationary internal

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particles, the sub-micrometer aerosol number size distribution, $PM_{2.5}$, and PM_{10}).

323. K. Max Zhang & Anthony S. Wexler, *Evolution of Particle Number Distribution Near Roadways—Part I: Analysis of Aerosol Dynamics and its Implications For Engine Emission Measurement,* 38 ATMOSPHERIC ENV'T 6643 (2004).

324. K. Max Zhang et al., *Evolution of Particle Number Distribution Near Roadways. Part II: The 'Road-to-Ambient' Process,* 38 ATMOSPHERIC ENV'T 6655 (2004).

325. 42 U.S.C. § 7430 (2005) (Section 130 of the CAA discusses the EPA's authority to establish and revise emission factors to estimate the quantity of emissions from air pollution sources).

326. Clearinghouse for Inventories and Emissions Factors, U.S. EPA, *supra* note 297.

327. *Id.*

328. *Id.*

combustion engines.[329] Currently there are no emission factors for these sources that are based on number concentration.[330] However, since vehicles have been extensively linked with the generation of ultrafine particles, studies have been done to present a size dependent road traffic emission factor for particle number.[331] Reseachers believe that there is a need for such studies since ultrafine particles do not correlate with larger particles in on-road studies and therefore cannot be used for information on concentrations of ultrafine particles.

H. Inventory Updates

Concomitantly with modeling, EPA and the States and local governments would also need to revise their emission inventories to identify source of ultrafine particles. For example, EPA produces a comprehensive National Emissions Inventory (NEI) every three years, along with trends for emissions for the intervening years.[332] The NEI is designed to - provide input to national and regional modeling; used as the basis for air toxics risk analyses; serve as a starting point for regulatory development; provide trends and Government Performance and Results Act tracking; and provide readily accessible information for the public.[333] The emission inventory includes data on all criteria pollutants, including ozone and fine PM precursors and all 188 HAPs. In addition to national inventories, regional, State, and local inventories are developed periodically to meet SIP development requirements.[334] While it is unlikely that interstate regional inventories would need to revised, it is likely that all State and local inventories would need to revised in order to identify ultrafine pollution sources.

As note previously, there is no official U.S. emissions inventory of

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329. *Id.*

330. *See, e.g.*, Gregory E. Muleski et al., *Particulate Emissions from Construction Sites*, 55 J. AIR & WASTE MGMT. ASS'N 772 (2005) (where the authors presented the first directly measured PM_{10} and $PM_{2.5}$ emission factors for individual construction operations at actual construction sites).

331. *See* Adam Kristensson et al., *Real-World Traffic Emission Factors of Gases and Particles Measured in a Road Tunnel in Stockholm, Sweden*, 38 ATMOSPHERIC ENV'T 657 (2004). *See also* Matthias Ketzel *et al., Particles and Trace Gas Emission Factors Under Urban Driving Conditions in Copenhagen Based on Street and Roof-Level Observations*, 37 ATMOSPHERIC ENV'T 2735 (2003); Sara Janhäll et al., *Size Resolved Emission Factors of Submicrometer Particles*, 38 ATMOSPHERIC ENV'T 4331 (2004).

332. National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data, U.S. EPA, http://www.epa.gov/ttn/chief/trends/ (last visited Apr. 15, 2006).

333. *Id.*

334. *See* Regional Planning Organizations, U.S. EPA, http://www.epa.gov/air/visibility/regional.html (last visited Apr. 15, 2006). *See also* 42 U.S.C. §§ 7491-92 (200) (visibility requirements); 42 U.S.C. § 7506a (interstate transport commissions); Ozone Transport Commission, http://www.otcair.org/index.asp (last visited Apr. 15, 2006).

ultrafine particles. However, there are a number of local emission inventories that extend down to the ultrafine range.[335] For example, the emissions inventory for ultrafine particles constructed for the Los Angeles area indicates a mass emissions rate of 13 tons per day in particle sizes smaller than 0.1 μm. The largest sources are on-road motor vehicles at 43 percent; stationary source fuel combustion at 32 percent; non-highway mobile sources at 10 percent; and other industrial processes at 7 percent. As a result, it is likely that the numbers reached in this inventory would be similar to local inventories throughout the United States.

335. M.J. Kleeman et al., *Sources Contributing to the Size and Composition Distributions of Atmospheric Particles: Southern California in September 1996*, 33 ENVTL. SCI. TECH. 4331 (1999).

IX. Development and Implementation of PM Number-based Standard Stationary Source Regulatory Program

A. Introduction

There are three sets of regulatory requirements that subject new, reconstructed, and modified sources to more stringent levels of control—new source performance standards (NSPS), the prevention of significant deterioration (PSD) and nonattainment new source review (NNSR) requirements under the New Source Review (NSR) preconstruction permitting program.

Under Section 111 of the CAA, the NSPS is a set of emission standards that reflect the degree of emission reduction achievable through the best technology that EPA determines has been adequately demonstrated.[336] Once set, the NSPS serve as the minimum level of control that must be achieved by new as well as "reconstructed" sources. Many of these standards have specific emission limits for PM on a mass basis.[337] As a result, if EPA moves to a number-based concentration standard it will need to revise these standards for new and reconstructed sources.

As part of a number-based concentration standard, existing operating permits may need to be revised to reflect this new metric. Moreover, as part of this new standard, EPA would need to select emission threshold amounts for major sources of PM that would trigger, among other things, NSR.[338] The NSR program subjects major new or "modified" sources of air pollution to preconstruction review and permitting requirements.[339] The purpose of this program is to ensure that the proposed source meets all applicable air quality requirements before it is constructed. The nature of the NSR preconstruction requirements depends upon whether the source is to be located in an area the meets or fails to meet the applicable ambient air quality standards.

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336. 42 U.S.C. § 7411(a)(1). *See also* 40 C.F.R. § 60.1 (2005).

337. REITZE, *supra* note 295, at Ch. 4.

338. The PSD program applies to sources that have the potential to emit at least 250 tons per year (TPY) of a regulated pollutant, or at least 100 TPY of a regulated pollutant if the source falls within a listed source category. 40 C.F.R. § 52.21(b)(1) (2005). The non-attainment program applies to sources that have the potential to emit at least 100 tons per year (TPY) of a regulated non-attainment pollutant. 42 U.S.C. § 7602(j) (2000).

339. There are two sets of regulatory requirements that subject new and modified sources to more stringent levels of control—the Prevention of Significant Deterioration (PSD) under Title I, Part C, of the CAA, 42 U.S.C. §§ 7470-7479 and nonattainment New Source Review (NNSR) requirements under Title I, Part D, of the CAA, 42 U.S.C. §§ 7501-7515, under the NSR preconstruction permitting program.

Sources located in an area that meet the relevant health-based ambient air quality standard are subject to the PSD preconstruction permitting requirements.[340] Among other things, a source must employ the "best available control technology" (BACT) for each pollutant regulated under the CAA that it will emit in significant amounts.[341] BACT must be at least as stringent as any applicable NSPS, but is typically more stringent than NSPS.

Sources located in an area that fail to meet the relevant ambient air quality standard are subject to the NNSR preconstruction permitting requirements.[342] Among other things, a source must commit to achieve the "lowest achievable emission rate" (LAER) for each applicable pollutant regulated under the CAA that it would emit in significant amounts.[343] LAER is always more stringent than either NSPS or BACT. In addition, the proposed emission increases must be offset at ratios based on the nonattainment classification of the area in which the new or modified major source is located.

For PM nonattainment areas, the CAA establishes a minimum offset ratio of 1:1 under Part D Subpart 1.[344] Were EPA to implement a PM number-based concentration standard, it would need to determine how to implement this provision of the CAA.

A major source subject to PSD review, either as a new source or a major modification, must determine that BACT will be applied to each emissions unit or other pollution emitting activity from which there will be any net increase in a pollutant that the facility will emit or have the potential to emit in significant amounts.[345] The BACT determination is required for each pollutant emitted by the source for which there will be a significant increase in emissions.[346]

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340. 42 U.S.C. §§ 7470-7479 (2000).

341. *See* 40 CFR § 52.21(b)(12) (where BACT is defined as "an emissions limitation (including a visible emission standard) based on the maximum degree of reduction for each pollutant subject to regulation under [the Clean Air] Act which would be emitted from any proposed major stationary source or major modification which the Administrator, on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs").

342. 42 U.S.C. §§ 7501-7515 (2000).

343. *See* 42 U.S.C. § 7501(3) (Section 171(3) of the CAA defines LAER as the most stringent emission limitation which is contained in the implementation plan of any State for such class or category of source, unless the owner or operator of the proposed source demonstrates that such limitations are not achievable; or the most stringent emission limitation which is achieved in practice by such class or category of source).

344. 42 U.S.C. § 7503(c).

345. For a complete discussion of the operating permit process, *see generally* AM. BAR ASS'N, THE CLEAN AIR ACT HANDBOOK 121 (1998).

346. Because the PM PSD increments for annual geometric mean and 24-hour maximum are in $\mu g/m^3$, it may be necessary for the agency to establish a number-based concentration increment in certain cases. 42 U.S.C. § 7475(d)(2)(c)(iv). *See also* 42

There are two basic types of pollution control technologies—emission control technologies and emission control techniques. To identify these potential control options, the source can consult a number of information sources including EPA's RACT/BACT/LAER Clearinghouse and Control Technology Center; technology vendors; federal, State, and local NSR permits and associated inspection and performance test reports; technologies or emission control practices required under other CAA programs; environmental consultants; technical journals, reports, and newsletters; and pollution control seminars. The final result of the BACT process is an enforceable BACT emissions limits and control standard or practice for each pollutant subject to PSD review and for all affected emissions units for which control options must be applied.[347]

The technology selection under a NNSR analysis differs from the BACT selection. Sources subject to NNSR must select technology that satisfies the more stringent LAER standard for covered pollutants. Applicants select LAER technology in a similar manner as BACT, except that there is no consideration of economic, energy, or environmental factors. After choosing a LAER limit, the limit is, if possible, expressed as a numerical emissions limit, like lb/MMBtu, and as an emission rate, like lb/hr.

As previously noted, Section 172(c)(1) of the CAA requires sources located in nonattainment for PM to contain RACM, which includes reasonably available control technology (RACT). Because it is likely that there would be a large number of nonattainment areas under a number-based concentration standard, existing sources would be required to install RACT. RACT is defined as "the lowest emissions limitation that a particular source is capable of meeting by the application of control technology that is reasonably available, considering technological and economic feasibility."[348] States would need to analyze whether or not RACT controls would assist an area in meeting the reasonable further progress requirements to bring an area into attainment with the standard.

The CAA also requires EPA to regulate emissions of 188 air toxics, also known as known as hazardous air pollutants. Specifically, Section 7412(d) of the CAA requires EPA to establish emission limits for major source categories emitting air toxics, commonly referred to as "maximum achievable control technology" (MACT) standards.[349] The

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U.S.C. § 7476(f) (where EPA is authorized to substitute maximum allowable increases in PM with an aerodynamic diameter smaller than or equal to 10 μm).

347. AM. BAR ASS'N, *supra* note 345, at 121.

348. Proposed Rule, National Ambient Air Quality Standards for Particulate Matter, 71 Fed. Reg. 10,2620 (Jan. 17, 2006) (to be codified at 40 C.F.R. pt. 50).

349. 42 U.S.C. § 7412(d) (2000).

MACT standard is to require the maximum degree of reductions achievable for the source category, taking into consideration cost and any non-air quality health and environmental impacts. The emission limitation achieved by the best performing 12 percent of sources is referred to as the "MACT floor."

Under Section 112(d), once EPA defines the floor of the proposed MACT standard, it examines possible standards that are more stringent than the floor. In evaluating these options, the CAA provides that EPA shall determine what reduction in emissions constitute MACT, taking into account the cost of achieving the reductions, any non-air quality health and environmental impacts, and energy requirements. In looking at standards "beyond the floor," cost of controls is the determining factor. If the costs are deemed reasonable for a particular source category, EPA might adopt a standard that goes beyond the floor. Whether EPA promulgates MACT floor or beyond the floor standards, PM emission rates are on a mass basis.[350]

B. Ultrafine Particle Technology Overview

Emission control devices are used in end-of-the-pipe type of applications or as post-combustion techniques and most often are an added cost to the industrial process.[351] The major factors of particle collection efficiency are the collection principle and particle size. As a result, some collection techniques are more efficient than others. Through control technologies, pollutant concentrations may be reduced through several methods.[352] First, a pollutant may be adsorbed on the surface of a solid. Second, a pollutant may be absorbed by a liquid. Third, a pollutant may be oxidized by a catalytic or direct incineration to another chemical form. And fourth, the pollutant concentration may be reduced by restricting the quantity of the pollutant formed in the original chemical process.

Particulate control equipment falls into five classes—gravity settling chambers; cyclone separators; wet collectors; fabric filters; and electrostatic precipitators.[353] Typical efficiencies in the 0-2.5 μm particle range are 90 percent for a wet scrubber, 80 percent for a centrifugal collector, 95 percent for a electrostatic precipitator, 90 percent for a packed-gas absorption column, 99 percent for a fabric filter, and

350. *See* 40 C.F.R. pt. 63 (2005).
351. AIR & WASTE MGMT. ASS'N, EPA SPECIALTY COURSE HANDBOOK: AIR QUALITY (2002).
352. *Id.*
353. KENNETH W. AYERS ET AL., ENVIRONMENTAL SCIENCE AND TECHNOLOGY HANDBOOK ch.5 (1994).

90 percent for a venturi scrubber.

There are a number of new technology developments that are focused on removing ultrafine particles from industrial gas streams.[354] As a result, there may be a number of proven technologies available, to assist in meeting emission limitations under the NSPS, BACT, LAER, RACT, and MACT, if EPA regulates PM on a number concentration basis. For example, a research team looked at the removal efficiency of granular filters packed with lava rock and sand that studied collection of airborne particles 0.05 to 2.5 μm in diameter.[355] According to this team of researchers, the results of this study suggest that development of biological filters for ultrafine particles is possible.

In another study, a laboratory-scale ESP was designed and constructed where the grounded collector plate was substituted by a set of wire screens placed perpendicularly to the gas flow.[356] A preliminary experimental evaluation of this filtering device showed that submicrometer particles with diameters down to a few nanometers can be collected with number efficiencies greater than 99 percent.

In another study, the owner and operators of a medical waste incinerator decided to replace their woven fiberglass filter bags with catalytic filters that simultaneously destroy dioxins and furans and collect PM in order to come into compliance with new dioxin/furan regulations.[357] The catalytic filter system employed was a REMEDIA D/F Catalytic Filter System. The owners/operators of this incinerator report an overall PM efficiency for this device at 99.95 percent.

The "Cloud Chamber Scrubber" has been identified as an emerging technology that is highly effective in removing submicron particles.[358] The Cloud Chamber Scrubber has been shown to more than 99.99 percent efficient for the collection of all types of particles from 0.1 to 300 μm.[359]

A group of researchers carried out a two-stage ESP experiment for

354. *See, e.g.*, U.S. EPA, STATIONARY SOURCE CONTROL TECHNIQUES DOCUMENT FOR FINE PARTICULATE MATTER (1998) (where a number of emerging technologies related to fabric filters, ESPs, scrubbers, and combination technologies are discussed that may be useful for ultrafine particle control as well).

355. Fethiye Ozis et al., *Removal of Ultrafine and Fine Particulate Matter from Air by a Granular Bed Filter*, 54 J. AIR & WASTE MGMT. ASS'N 935 (2004).

356. Manuel Alonso & F.J. Alguacil, *Electrostatic Precipitation of Ultrafine Particles Enhanced by Simultaneous Diffusional Deposition on Wire Screens*, 52 J. AIR & WASTE MGMT ASS'N 1342 (2002).

357. Keith J. Fritsky et al., *Combined PCDD/F Destruction and Particulate Control in a Baghouse: Experience with a Catalytic Filter System at a Medical Waste Incineration Plant*, 51 J. AIR & WASTE MGMT ASS'N 1642 (2001).

358. *See* Cloud Chamber Wet Scrubber is Superior to an ESP, http://www.tri-mer.com (last visited Apr. 15, 2006).

359. *Id.*

particles in the submicron size range.[360] Based on their experiment and model, they concluded that the collection efficiencies of the two-stage ESP under nominal operation conditions fall within a 93 to 98 percent for particles within 0.03 to 0.2 μm.

Another research group has tried to remedy this intrinsic particle charging effect by proposing a new-type ESP to elevate the collection efficiency for submicron sized particles in exhausted gas from a fine-grained coal-burning boiler.[361] According to the authors this new type of ESP is expected to increase the collection efficiency from 95 to 98 percent due to a calculation of the collection efficiency using the measured agglomeration particle size distribution in the range of 0.06 to 12 μm.[362]

Another engineering group designed an efficient venturi scrubber system making use of heterogeneous nucleation and condensational growth of particles and tested it to remove fine particles from the exhaust of a local scrubber where residual silane (SiH_4) gas was abated and where fine silicone dioxide (SiO_2) particles were generated.[363] With fine-water mist for nucleation and growth, test results show that the maximum removal efficiency achieved for particles at 478 nm is 96 percent.

Another report looked at the capabilities of condensation scrubbers technology, or wet scrubbers.[364] The authors note that collection efficiencies of greater than 99 percent have been reported for PM emissions.

Electrostatically Stimulated Fabric Filtration (ESFF) is a technology where particles are charged with a corona discharge and collected on a fabric filter under the influence of an electric field. Pilot-scale performance data shows collection rates of PM_1 with ESFF of 0.05

360. Kyung Hoon Yoo et al., *Charging and Collection of Submicron Particles in Two-Stage Parallel-Plate Electrostatic Precipitators*, 27 J. AEROSOL SCIENCE & TECH. 308 (1997). For other studies on ESPs and ultrafine particle penetration *see,* S.I. Ylätalo & J. Hauntanen, *Electrostatic Precipitator Penetration Function for Pulverized Coal Combustion*, 29 AEROSOL SCIENCE & TECH. 17 (1998) (where ultrafine particle penetration is a function of size, ESP performance, firing process, and coal grind). *See also* Mohr et al., *Submicron Fly Ash Penetration Through Electrostatic Percipitators at Two Coal Power Plants*, 24 AEROSOL SCIENCE & TECH. 191 (1996) (where the minimum collection efficiency of ESPs for particles is in the size range between 200 and 400 nm).

361. T. Watanabe et al., *Submicron particle agglomeration by an electrostatic agglomerator*, 34 J. ELECTROSTATICS 367 (1995).

362. *Id.*

363. Chuen-Jinn Tsai et al., *An Efficient Venturi Scrubber System to Remove Submicron Particles in Exhaust Gas*, 55 J. AIR & WASTE MGMT. 319 (2005).

364. Sun et al., *A Method to Increase Control Efficiencies of Wet Scrubbers for Submicron Particles and Particulate Metals*, 44 J. AIR & WASTE MANAGEMENT 2 (1994). *See also* U.S. EPA, AIR POLLUTION CONTROL TECHNOLOGY FACT SHEET.

mg/m^3, and a collection rate of PM_1 without ESFF of $0.17mg/m^3$.

An emerging technology for mechanical collectors is the "Core Separator" that has been developed by LSR Technologies, Inc. for use with PM from coal combustion.[365] According to the company, this system removes 80 percent of what usually penetrates a conventional cyclone to give 95 to 98 percent overall PM control.

Powerspan Corporation has pilot tested a multi-pollutant control system named Electro-Catalytic Oxidation (ECO) to reduce NO_x, SO_x, PM, and air toxics.[366] Pilot scale testing of a condensing wet ESP on a coal-fired gas stream was performed by the company and removal rates for fine PM was 95 percent. Moreover, the company claims the average removal efficiencies for metals like As, Cr, and Ni all exceeded 99 percent.

C. *Revised Stationary Source Air Quality Sampling and Testing Requirements*

As previously noted, particles in combustion exhaust come from mineral matter and other impurities in the fuel, carbonaceous particles formed during combustion, condensation of inorganic and organic vapors, and chemical reactions. After leaving the stack, hot exhaust is rapidly cooled and mixed with ambient air, resulting in vapor species nucleating homogeneously and heterogeneously, or condensing on pre-existing particles. Source test methods that determine PM emissions for stationary sources have been promulgated on mass basis.[367] However, if a number-based concentration standard were developed, these sampling and testing methods would need to be refined.

Stationary sources are normally subject to stack testing and emissions monitoring. Source or stack tests consist of taking quantitative air samples from exhaust stacks and analyzing these samples in a laboratory to determine pollutant concentrations.[368] In addition, the pollutant emission rate established by a source test must be less than the

365. AirQualityWeb.com, Yellow Pages - LSR Technologies Incorporated, http://www.airqualityweb.com/yellow/control_equip/lsr_technologies.shtml (last visited Apr. 15, 2006).

366. McLarnon & Jones, Address at Electric Power 2000 Cincinnati Convention Center: Electro-Catalytic Oxidation Process for Multi-Pollutant Control at First Energy's R.E. Burger Generating Station (Apr. 5, 2000).

367. *See, e.g.*, 40 C.F.R. 60 subpt. PPP (1985) (where the test method emission rate for PM is in lb/yr for wool fiberglass insulation manufacturing plants).

368. *See* U.S. EPA, Technology Transfer Center Emission Measurement Center, http://www.epa.gov/ttn/emc/promgate.html (last visited Apr. 15, 2006). Stack test methods have been promulgated by EPA and are set forth in the Federal Code of Regulations. Some of the PM stack methods include: Method 5, 5A, 5B, 5D, 5E, 5F, 5G, 5H, and 5I.

allowable rate specified in the facility's permit to operate. Furthermore, testing determines compliance with emission rates listed in permits, establishes permit terms and conditions, and sets operating parameters for the source and air pollution control equipment.[369]

In addition to stack testing, some emission units are required to operate Continuous Emission Monitors (CEMs) to measure opacity, PM, SO_2, and NO_x, and to indicate on-going compliance with permit limits.[370] CEMs were originally developed to support the allowance trading programs developed by EPA to comply with the Acid Rain Requirements under Title IV of the CAA.[371]

In the mid-1970s, EPA dictated the use of transmissometers for CEMs monitoring of the opacity of emissions from stationary sources.[372] Opacity is used as a surrogate for PM emissions and provides qualitative information on the operation and maintenance of PM control equipment. However, EPA has moved to mandating the use of PM CEMs.[373] On January 12, 2004, EPA it has finalized its performance specification (PS)-11, "Specifications and Test Procedures for Particulate Matter Continuous Emission Monitoring Systems in Stationary Sources," to evaluate the acceptability of a PM CEMS.[374] PS-11 is used for evaluating the acceptability of a PM CEMS at the time of or soon after installation, and whenever specified in the source's applicable regulation.

There are a number of PM CEMs that are currently on the market[375] and other technologies that are in development.[376] In addition to CEMs,

369. Muleski, *supra* note 330 at Ch. 18.

370. *See* 40 C.F.R. pt. 75 (1999). CEMs are permanently installed devices, which extract and analyze samples of stack gases several times each hour for concentrations of compounds such as NO_x and SO_2. When these monitors are combined with flow monitors, emission tonnages can be calculated, and compliance can be determined. These monitors are checked frequently with gases of known concentrations to ensure the system is calibrated and the emissions data produced is accurate.

371. *See* 42 U.S.C. § 7651k(a) (2000).

372. U.S. EPA, CURRENT KNOWLEDGE OF PARTICULATE MATTER CONTINUOUS EMISSION MONITORING (2000).

373. National Emission Standards for Hazardous Air Pollutants for Source Categories; Portland Cement Manufacturing Industry, 64 F.R. 31898 (1999) (where EPA has mandated the use of a PM CEM for the Portland Cement Manufacturing sector, but not until PS-11 was finalized).

374. *See* 69 Fed. Reg. 1785 (2004).

375. *See infra* note 419 at Chapter 4. *See also,* PEELER & SHIGEHARA, PORTLAND CEMENT ASSOCIATION, CURRENT STATUS OF PARTICULATE MATTER, MULTI-METALS, MERCURY, HYDROGEN CHLORIDE, AND AMMONIA CONTINUOUS EMISSION MONITORS (2003).

376. *See* Seltzer, *Performance Testing of a Multimetals Continuous Emission Monitor*, 50 J. AIR & WASTE MANAGEMENT 1010 (2000). *See also* S.S. Woskov, *Stack Moutable Calibrated Microwave Plasma for Sensitive Real Time Calibrated Metals and Particle Monitoring,* PROCEEDINGS, May 2000.

predictive emission monitoring systems (PEMS)[377] could also be used to measure ultrafine particle emissions.[378] In addition, PEMS is a feasible and accurate alternative to CEMS.[379] Moreover, progress is also being made in the development stack testing methods that measure ultrafine particles.[380]

D. Land Use Restrictions Related to Industrial Air Emissions Effects

The California Air Resources Board (CARB) has produced a handbook on the air quality impacts that certain types of facilities have when sited near residences, schools, day car centers, playgrounds, and medical centers.[381] CARB notes that these land uses deserve special attention because susceptible populations like children, pregnant women, the elderly, and those with existing health problems are especially vulnerable to the non-cancer effects of air pollution. Moreover, focusing attention on these siting situations is an important preventive and sustainable measure for public health and the environment. For instance, some industrial sources projects that are sited very close to homes, schools, and other public places can result in elevated air pollution exposure even if they are fitted with state-of the-art pollution controls. In addition, siting a new school or home too close to an existing source of air pollution can pose a public health risk. Avoiding these incompatible land uses is an important measure that can reduce localized air pollution exposures and minimize adverse health impacts, especially to sensitive individuals. As a result of the analysis by CARB, States may want to use industrial land use restrictions as RACM to reduce ultrafine particle emissions.

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377. PEMS is a technology that uses the operating parameters of combustion equipment through thermodynamic or statistical methods to construct a mathematic model that can predict emissions by a computer program.

378. U.S. EPA, Clean Air Markets—Programs and Regulations, Predictive Emission Monitoring Systems, http://www.epa.gov/airmarkets/monitoring/pems.html (last visited Apr. 15, 2006).

379. Chien et al., *A Feasibility Study on the Predictive Emission Monitoring System Applied to the Hsinta Power Plant of Taiwan Power Company*, 53 J. AIR & WASTE MANAGEMENT 1022 (2003) (where research showed that the comparative figures of the predicted values of NOx closely match the values of CEMS).

380. Chang et al., *Measurements of Ultrafine Particle Size Distributions from Coal, Oil, and Gas Fired Stationary Combustion Sources*, 54 J. AIR & WASTE MANAGEMENT 1494 (2004) (where the average distribution of particle number concentrations show modes of particle size at 40-50 nm, 70-100 nm, and 15-25 nm, respectively for coal, No. 6 fuel oil, and natural gas combustion).

381. CAL. ENVTL PROT. AGENCY, CAL. AIR RESOURCES BOARD, AIR QUALITY AND LAND USE HANDBOOK: A COMMUNITY HEALTH PERSPECTIVE (2005).

X. Development and Implementation of PM Number-based Mobile Source and Diesel Engine Regulatory Program

A. Introduction

Researchers have summarized a number of studies which measured number emission rates from both diesel and spark-ignition engine powered vehicles.[382] These researchers found that number emission rates from the spark-ignition vehicles were much lower than from the diesel vehicles under most operating conditions, but were similar under high-speed highway cruising conditions. At these cruising conditions they observed rates of about 1×10^{14} and 1 to 1.5×10^{14} particles for spark-ignition and diesel vehicles respectively. These high rates were observed even for a spark-ignition vehicle equipped with a three-way catalyst.

One of the most interesting findings in this study was the number to volume ratio for the engines.[383] For the diesel engine, the number to volume ratio was much higher at light loads where high number concentrations were produced by nucleation. Researchers theorize that this indicates the newer engines were emitting smaller particles. In addition, the number weighted geometric mean diameter is also much smaller at 0.011 μm, compared to 0.043 μm. This finding, the researchers note, collaborates the suspicions of many researchers that newer model engines are emitting fewer larger particles, but more smaller particles to assist in meeting a mass-based NAAQS for PM.

In a European study researchers separated out five categories of engine classes to measure the emission of ultrafine particles—spark ignited engine; spark ignited turbo charged; spark engine direct injection; diesel; and diesel with a particle filter.[384] The spark ignited turbo engines emitted smaller particles compared to those emitted by diesel engines. The number of particles emitted by diesel engines was unaffected by load, excess air, and driving style. The tests also showed that particle filters are very effective at removing ultrafine particles from exhaust. Based on their findings, the authors concluded that circumstances argue in favor of regulating particle emissions on a number concentration basis for both spark ignited and diesel engines.

382. Cheng & Tanner, *supra* note 28.
383. *Id.*
384. FÄRNLUND ET AL., SWEDISH NAT'L RD. ADMIN. EMISSIONS OF ULTRAFINE PARTICLES FROM DIFFERENT TYPES OF LIGHT DUTY VEHICLES (2001).

B. Spark Engines Regulation

1. Regulatory Programs

Under the CAA, EPA generally sets vehicle emission standards.[385] While the CAA prohibits States from setting standards for new vehicles or engines,[386] it exempts any State that adopted standards before March 30, 1966.[387] However, only California meets that exemption requirement. But, under the CAA, States other than California may adopt the California vehicle emission standards in lieu of those established by EPA so long as those standards are identical to California's and a two-year lead time is provided for after adoption of the standards.[388]

a. EPA's Tier 2 Standards

On February 10, 2000, EPA took a significant step in reducing air pollution from motor vehicles with the establishment of a regulatory program, commonly known as the Tier 2 standards.[389] This program treats vehicles and fuels as a system by promulgating more stringent emission standards and increasing the effectiveness of control technology by reducing the sulfur content of gasoline. The program targets new passenger cars, and light trucks, including pickup trucks, vans, minivans, and sport-utility vehicles. The program is designed to focus on reducing the emissions most responsible for O_3 and PM impacts from these vehicles—NO_x, and non-methane organic gases (NMOG).[390] However, it is unlikely that the Tier 2 standards would have much, if any, effect on reducing the number of particles coming from the tailpipe of a conventional motor vehicle.[391] As a result, it is likely that EPA may need

385. 42 U.S.C. § 7521 (2000).
386. 42 U.S.C. § 7543(a).
387. 42 U.S.C. § 7543(b).
388. 42 U.S.C. § 7507.
389. Control of Air Pollution From New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements, 65 Fed. Reg. 6698 (2000).
390. *Id.*
391. *See* Cadle et al., *Real-World Vehicle Emissions: A Summary of the 14th Coordinating Research Council On-Road Vehicle Emissions Workshop*, 55 J. AIR & WASTE MGMT. 13-146 (2005) (where the objectives of the workshop were to present the most recent results from research on: portable emissions and activity measurement systems; EPA Motor Vehicle Emissions Simulator (MOVES) model; mobile source modeling; on-road gasoline and diesel vehicle emissions; fuel effects on vehicle emissions; emission inventories; measurement methods; and unregulated emissions, like ultrafine particles).

to increase the stringency of its emission standards if it implements a number-based PM standard. Areas designated nonattainment with a number-based PM standard may look to advanced automobile technology as RACM.

b. Cal LEV II Standards

The Cal LEV II program builds on the initial Cal-LEV program and affect passenger cars, light-duty trucks, and medium-duty vehicles.[392] These regulatory amendments revised the Cal-LEV program is a number of significant ways.[393] First, it extended the passenger car emission standards to heavier sport utility vehicles and pickup trucks. Second it extended and tightened the fleet average emission standards during 2004 to 2010. Third it created a new super-ultra low emission vehicle category for light-duty vehicles. Fourth it increased emission control durability standards from 100,000 miles to 120,000 miles for passenger cars and light trucks.

The differences in emission standards between Cal LEV II and Tier 2 are significant.[394] By Model year 2010, NMOG is reduced by an additional 50.5 percent with Cal LEV II than with Tier 2; NO_x is reduced by an additional 20.3 percent with Cal LEV II than with Tier 2; and PM is reduced by an additional 3.0 percent with Cal LEV II than with Tier 2. Therefore, greater reductions that would be achieved by adopting the Cal LEV II program rather than the Tier 2 program.

2. Advanced Spark Engine Technology

Even though there will be substantial reductions under the Cal-LEV II program, PM emissions can further be reduced through a zero-emission vehicle (ZEV) program like the one established by California in 1990, which required auto manufacturers to produce and offer ZEVs for sale beginning in 1998.[395] However, due to cost and technical issues, CARB, in 2001, amended its regulatory program to allow manufacturers to meet their ZEV requirements with a mix of pure ZEVs that have zero tailpipe emissions, partial zero emitting vehicles (PZEVs), and hybrid electric and other advanced technology PZEVs.

392. CAL. CODE REGS. tit. 13, § 1900 *et seq.* (2006).

393. Low-Emission Vehicle Program, Exhaust Emission Standards for Cars, Light Trucks, and Medium-Duty Vehicles, http://www.arb.ca.gov/msprog/levprog/levii/factsht.htm (last visited Apr. 15, 2006).

394. Coralie Cooper, NESCAUM, California Low Emission Vehicle (LEV II) Program in the Northeast Connecticut, Adress Before SIPRAC (Mar. 11, 2004).

395. CARB, ZEV Program, http://www.arb.ca.gov/msprog/zevprog/zevprog.htm (last visited Apr. 15, 2006).

a. ZEV technology

ZEV technology is essentially electric vehicles (EVs) that run on electricity stored in batteries.[396] EVs are the only truly zero emission car available because they have no tailpipe exhaust and no evaporative emissions from fuel systems. For example, Nissan has developed and offers for sale the Navarra pickup truck.[397] This truck is a fuel cell/electric hybrid. The batteries run the electric motor, which in turn powers the truck. The batteries are charged using the fuel cell and the regenerative brakes also are used to charge the batteries. This model has a top speed of 75 mph and a maximum range of 250 miles. Moreover, it has zero emissions.

b. Hybrid

Hybrid electric vehicles (HEVs) commercially available today combine an internal combustion engine with a battery and electric motor.[398] This technology combination provides the extended range and rapid refueling of a conventional vehicle, while reducing energy requirements and emissions of the vehicles. The practical benefits of HEVs include improved fuel economy and lower emissions compared to conventional vehicles.

ISE Corporation has developed a unique gasoline-hybrid bus, which it calls the ThunderVolt® drive system, which results in PM emissions of less than 0.01 g/mile.[399] Moreover, Hybrid Cars.com has done a comparison for a number of traditional gasoline powered engine and hybrid cars and has found significant PM emission reductions realized through hybrid vehicles.[400]

c. Fuel Cells

Fuel cells, which are powered by clean hydrogen and other sources, are a technology that was considered for motor vehicle as a result of the

396. *See* http://www.driveclean.ca.gov/en/gv/driveclean/vtype_electric.asp (last visited Apr. 15, 2006).

397. Zero Emission Vehicles LTD, http://www.zevltd.com/pickup.htm (last visited Apr. 15, 2006).

398. *See* http://www.driveclean.ca.gov/en/gv/driveclean/vtype_hybrid.asp (Apr. 15, 2006).

399. *See* Versatile Hybrid Electric Alternative for Large Transit Buses, http://www.isecorp.com/ise_products_services/gasoline_hybrid_drive_system/pdf/TB40-HG.pdf (last visited Apr. 15, 2006).

400. *See* HybridCar.com, Pollutants, http:// www.hybridcars.com/pollutants.html (last visited Apr. 15, 2006).

ZEV regulations.[401] CARB helped establish the California Fuel Cell Partnership in 1999 to explore ways that vehicles can be powered by fuel cell technology and to develop ways to overcome obstacles to commercialization.[402] Moreover, President Bush announced $350 million in nationwide funding, through the U.S. Department of Energy (DOE), for science and research projects to establish a hydrogen economy.[403] Vehicles that run on pure hydrogen are true zero-emission vehicles, while hydrocarbon fuel cells vehicles would result in tailpipe air pollutant emissions.[404]

d. Alternative Fuel Vehicles

Alternative fuel vehicles (AFVs), as defined by the Energy Policy Act of 1992, include any dedicated, flexible-fuel, or dual-fuel vehicle designed to operate on at least one alternative fuel.[405] Alternative fuel vehicles come in a variety of vehicle models such as sedans, pickup trucks, sport utility vehicles, vans, shuttle buses, medium-duty vehicles, heavy-duty buses, and heavy-duty trucks.[406] There are a number of alternative fuel vehicles.[407] One study shows that while overall, PM emissions from AFV technology were low, they were also comparable to those of similar technology gasoline vehicles.[408] For example, the average Federal Test Procedure (FTP) PM emissions for CNG and M85 fueled vehicles were 1.40 and 0.70 mg/mi, respectively.

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401. CARB, *supra* note 395.

402. *See* California Fuel Cell Partnership, http://www.driveclean.ca.gov (last visited Apr. 15, 2006).

403. *See* U.S. Dept. of Energy, Hydrogen, Fuel Cells & Infrastructure Technologies Program, http://www.eere.energy.gov/hydrogenandfuelcells/presidents_initiative.html (last visited Apr. 15, 2006).

404. *See* Union of Concerned Scientists, Clean Vehicles, http://www.ucsusa.org/clean_vehicles/advanced_vehicles/page.cfm?pageID=208 (last visited Apr. 15, 2006).

405. *See* James J. Winebrake & Michael L.Deaton, *A Comparative Analysis of Emissions Deterioration for In-Use Alternative Fuel Vehicles*, 47 J. AIR & WASTE MGMT. ASS'N 1291 (1997) (where emissions data from 70 alternative fuel vehicles (AFV) and 70 conventional vehicles (CV) were analyzed to determine whether AFV emissions deterioration differs significantly from CV emissions deterioration. An analysis is conducted on three alternative fuel types—natural gas, methanol, and ethanol—and on four pollutants—CO, THC, NMHC, and NO_x. The results indicate that for most cases studied, deterioration differences are not statistically significant.).

406. For model types and fuels, s*ee, e.g.*, http://www.eere.energy.gov/afdc/afv/hd_vehicles.html (last visited Apr. 15, 2006).

407. *See* http://www.fueleconomy.gov/feg/current.shtml (last visited Apr. 15, 2006).

408. Particulate Measurements and Emissions Characterization of Alternative Fuel Vehicle Exhaust, Submitted to: National Renewable Energy Laboratory October 1998, Center for Environmental Research and Technology College of Engineering University of California Riverside, CA 92521, http://www.cert.ucr.edu/research/project.asp?project=117 (last visited Apr. 15, 2006).

C. *Diesel Engine Regulation*

1. Introduction

Diesel engines present unique challenges if PM were to be regulated on a number concentration basis, since these engines are used in both on-road and off-road settings. Diesel engine exhaust is emitted from "on-road" diesel engines or "nonroad" diesel engines, like locomotives, marine vessels, and heavy-duty equipment. Nationwide data in 1998 indicated that diesel exhaust as measured by DPM made up about 6 percent of the total ambient $PM_{2.5}$ inventory and about 23 percent of the inventory, if natural and miscellaneous sources of $PM_{2.5}$ are excluded.[409] Estimates of the DPM percentage of the total inventory in urban centers are higher. For example, estimates range from 10 percent to 36 percent in some urban areas in California, Colorado, and Arizona.[410] Available data from this same source indicate that over the years there have been significant reductions in DPM emissions from the exhaust of on-road diesel engines, whereas limited data suggest that exhaust emissions from nonroad engines have increased. Areas designated nonattainment with a number-based PM standard may look to advanced diesel technology as RACM in order to come into attainment for on-road and non-road sources, and as RACT for stationary sources.

Because of their durability and fuel economy, the use of diesel engines, particularly in long-distance transportation, has increased over the years.[411] This trend towards more diesel vehicles on the road is of great concern.[412] First, diesel trucks have historically been driven more miles per truck than gasoline trucks. Second, diesel trucks are more durable and stay on the road longer than gasoline vehicles. The longevity of diesel trucks is an important factor because older vehicles are subject to less stringent regulations and may remain in use for several decades after their manufacture.

EPA recognizes the serious human effects that diesel engine pose and has advanced a two-part program to reduce emissions from these engines. The first program reduced emissions from on-road heavy-duty engines. The second program reduced emissions from non-road diesel engines.

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409. Health Assessment Document For Diesel Engine Exhaust, *supra* note 164 at 1-2.
410. *Id.*
411. Health Assessment Document For Diesel Engine Exhaust, *supra* note 164 at 2-4.
412. C. DAVID COOPER & F.C. ALLEY, AIR POLLUTION CONTROL: A DESIGN APPROACH ch. 18 (3rd ed. 2002).

a. Onroad Diesel Engine Regulations

On October 6, 2000, U.S. EPA finalized an emission reduction program related to on-road heavy-duty engines and vehicles.[413] As with the Tier 2 Standards, this on-road program was put in place to ensure that certain areas met the one-hour ozone and PM_{10} standards.[414] Although this rule does not require reductions in direct PM emissions, the standards are expected to result in significant reductions in the concentrations of secondary PM. As a result, EPA did not present an estimate of the tons of PM reduction that can be expected from this program. However, it is unlikely that these standards would have much, if any, effect on reducing the number of particles coming from the tailpipe of a conventional diesel motor vehicle.

b. Nonroad Diesel Engine Regulations

Diesel engines are used in such diverse industries as construction, farming, and mining and are a significant source of PM pollution on a local and national scale. While PM pollution measured on a mass basis from most mobile and stationary has trended downward, PM pollution measured on a mass basis from construction, surface mining, and industrial equipment is three times greater than it was in 1970.[415] EPA recently adopted new emission standards for nonroad diesel engines and sulfur reductions in nonroad diesel fuel, which is known as the Tier 4 standards.[416] The nonroad standards cover mobile nonroad diesel engines of all sizes used in a wide range of construction, agricultural and industrial equipment. The EPA definition of the nonroad engine is based on the principle of mobility and portability, and includes engines installed on self-propelled equipment; on equipment that is propelled while performing its function; or on equipment that is portable or transportable, as indicated by the presence of wheels, skids, carrying handles, dolly, trailer, or platform.[417] In other words, nonroad engines are all internal combustion engines except motor vehicle engines, stationary engines, which remain at one location for more than 12 months, engines used solely for competition, or engines used in aircraft.

413. Emissions Control, Air Pollution From 2004 and Later Model Year Heavy-Duty Highway Engines and Vehicles; Light-Duty On-Board Diagnostics Requirements, Revision; Final Rule, 65 Fed. Reg. 59895 (Oct. 10, 2000).

414. *Id.*

415. U.S. EPA, EMISSIONS FACTORS AND INVENTORY GROUP, 1970-2001 TIERED LEVEL NON-ROAD SUMMARIES (2001), *available at* http://www.epa.gov/ttn/chief/trends/01/trends2001.pdf.

416. Control of Emissions of Air Pollution From Nonroad Diesel Engines and Fuel, 69 Fed. Reg. 38958 (June 29, 2004).

417. 40 CFR § 1068.30 (2000).

As with the Tier 2 standards, this program regulates nonroad diesel engines and diesel fuel as a system.[418] The program adopts standards for nonroad diesel engines of all horsepower ratings. Those classes of engines include all land-based nonroad, locomotive, and marine engines. These standards are technology neutral in that manufacturers are the responsible party in determining which emission control technologies will be needed to meet the requirements. In addition, by 2012, the sulfur content for all diesel fuels must be 15 ppm in order to ensure that the control technologies operate at optimum efficiency.

Unlike the Tier 2 standards, EPA promulgated the Tier 4 standards to assist areas in meeting the 8-hour O_3 NAAQS and $PM_{2.5}$ NAAQS.[419] As a result, there will be a significant reduction of $PM_{2.5}$ and PM precursors when this rule is fully implemented. It is uncertain if such a regulatory approach would have a significant impact on the number of particles emitted from these types of engines. However, an analysis on the difference between onroad and nonroad emission standards shows that a medium-sized construction engine manufactured in 2007 will still be allowed to release 30 times as much PM pollution as a large diesel onroad engine manufactured in the same year.[420]

The first emission regulation for railroad locomotives was adopted by the EPA on April 16, 1998.[421] Planned future emission standards for locomotives were outlined in the Advance Notice of Proposed Rulemaking published by the EPA.[422] The emission standards would be modeled after the 2007 to 2010 highway engine program and the Tier 4 nonroad rule, with an emphasis on achieving large reductions in PM emissions through the use of advanced emission control technology.

c. Diesel Stationary Sources Regulations

A diesel engine that is moved more than once in one year is regulated under EPA's nonroad regulations, but if that same engine remains in place at a site for more than one year is considered a stationary source and has not been traditionally regulated by EPA.[423] However, EPA has recently proposed standards of performance for

418. Health Assessment Document For Diesel Engine Exhaust, *supra* note 164 at 2-4.
419. *Id.*
420. DECKER ET AL., ENVT'L DEFENSE, CLOSING THE DIESEL DIVIDE (2003).
421. Emission Standards for Locomotives and Locomotive Engines, Final Rule, 63 Fed. Reg. 18978 (Apr. 16, 1998.)
422. Control of Emissions of Air Pollution From New Locomotive Engines and New Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder, 69 Fed. Reg. 39275 (June 29, 2004.)
423. *See* U.S. EPA, EMISSION REGULATIONS FOR STATIONARY AND MOBILE ENGINES (2001).

stationary compression ignition (CI) internal combustion engines (ICE) under the NSPS provision of Section 111(b) of the CAA.[424] An IC ICE is a stationary internal combustion engine that is not a spark engine. These new standards would apply to new, modified, and reconstructed IC ICE to use the best demonstrated technology. Existing IC ICE would remain unregulated by EPA. These standards would also set emission limits for NO_x, NMHC, CO, and PM. Moreover, these standards would be output-based in units of emissions mass per unit work performed or grams per HP-hour. This output-based standard is different than current regulations, which traditionally has established emission standards on a heat input basis. The latter compares emissions from the stack and the former compares thermal efficiency. EPA estimates that in 2015 the proposed standards would reduce NO_x by 38,000 tons per year, SO_2 by 9,000 tons per year, NMHC by 600 tons per year, carbon monoxide by 18,000 tons per year, and PM by 3,000 tons per year.[425]

As previously noted, deregulation in the energy market and associated economic forces have led to growth in smaller, more dispersed sources of electrical power referred to as "distributed generation." DOE has established its Advanced Reciprocating Engine Systems (ARES) program, which aims to develop cleaner, more-efficient lean-burn gas engines specifically designed for the DG market.[426] Under ARES, DOE and a consortium of North American engine manufacturers are cooperating in a 10-year effort to produce a new generation of gas engines with thermal efficiency of 50 percent and NO_x emissions of 0.1 g/bhp-hr. or less.

Combined heat and power (CHP) is a technology application that can increase more environmentally friendly DG usage.[427] CHP offers opportunities to increase thermal efficiencies of electric generation by utilizing its waste heat in applications that range from heating office space, to preheating boiler combustion air, to use for in-process applications.[428] In addition, in 1998, DOE and EPA have teamed up to establish the "CHP Challenge" to double CHP in the U.S. economy by 2010.[429]

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424. Standards of Performance for Stationary Compression Ignition Internal Combustion Engines, 70 Fed. Reg. 39870 (July 11, 2005).

425. *Id.*

426. *See* http://www.eere.energy.gov/de/pdfs/reciprocating.pdf (last visited Apr. 15, 2006).

427. *See* United States Combined Heating and Power Association, http://www.uschpa.org (last visited Apr. 15, 2006).

428. John Jimison & Doug Hinrichs, *Operating in Parallel With End Users*, POWER, Nov. 2004.

429. *See* http://www.eere.energy.gov/femp/pdfs/chp_prog_overvw.pdf (last visited Apr. 15, 2006).

3. Diesel Technologies

There are a number of available technologies that can further reduce PM emissions and possibly have an impact on reducing ultrafine emissions for both new and existing diesel engines. This is particularly important for existing engines since, as previously noted, they are more durable than standard engines and therefore are likely to be in use for longer periods of time.

Diesel particulate filters also known as "traps" remove PM from diesel exhaust.[430] These filters are very durable and rely on some means of external regeneration or self-cleaning such as a burner or electrical heater to periodically burn off accumulated PM.[431] Catalyzed filters can provide in excess of 90 percent reductions in PM emissions when combined with low sulfur diesel fuel.[432]

Manufacturers of heavy-duty diesel engines analyzed the cost-effectiveness of catalyzed diesel particulate filter (CDPF) technology to reduce diesel fuel emissions.[433] The objective of this study was to perform a detailed characterization of exhaust emissions from school buses powered by conventional diesel, (CD) low-emitting diesel, (LED) and CNG. The study's results show that emissions of PM, NO_x, NO, CO, total hydrocarbons (THCs), and NMHCs were all significantly lower for the LED-powered bus than for either the CD or CNG powered buses.[434]

In another research evaluation, ultrafine particle measurements were taken of a diesel powered Peugeot with a particle filter, which showed every low ultrafine emissions.[435] The particle count concentration in the

430. *See* Retrofitting Emission Controls on Diesel-powered Vehicles, http://www.meca.org (last visited Apr. 15, 2006). *See also, California Plan to Cut Diesel Emissions Includes Requirement for Particle Traps*, DAILY ENV'T, July 17, 2000.

431. *See* Bretecher et al., *Evaluation of Catalyzed and Electrically Heated Filters for Removal of Particulate Emissions from Diesel-A and JP-8-Fueled Engines*, 54 J. AIR & WASTE MGMT. 83 (2004) (where a study evaluated the effects of an Engelhard catalyzed soot filter (CSF) and a Rypos electrically heated soot filter on the emissions from in-service diesel engines in terms of PM mass, black carbon concentration, particle bound polycyclic aromatic hydrocarbon concentrations and size distribution. Generally, the CSF removed at least 90 percent of the total PM and the removal efficiency improved or remained constant after several months of operation. In contrast, the electrical filters removed 44 to 69 percent of PM mass.)

432. *See*, U.S. EPA, Environmental Technology Verification Program (where Lubrizol Engine Control Systems Purifilter Particulate Filter was certified at 95percent removal efficiency of PM with the use of ultra-low sulfur diesel fuel).

433. William B. Bunn et al., *Reducing Diesel Engine Emissions Using Catalyzed Diesel Particulate Filter Technology*, EM—AIR & WASTE MANAGEMENT ASS'N MAGAZINE FOR ENVTL. MANAGERS, 2004.

434. *Id.*

435. Jan Czerwinski et al., *Nanoparticles Emissions from Particle Filter Equipped Diesel Cars*, DIESELNET TECHNICAL REPORT, http://www.dieselnet.com/

exhaust gas is about 18 times lower than the dilution air.

The effectiveness of particle filters for large diesel engines located at construction sites was tested.[436] The authors concluded the results of a four-year investigation of construction site engines on test rigs demonstrate a filtration rate of more than 95 percent for ultrafine particles. A two-year field test, with subsequent trap inspection, confirmed the results related to the filtration rate for ultrafine particles.

In addition to particulate filters there are a number of available control technologies for upgrading existing diesel engines in order to further reduce PM emissions and their precursors. The most common after treatment technologies include oxidation catalysts; selective catalytic reduction; and low NOx catalysts.[437] In addition, exhaust gas recirculation shows some promise as well.

Oxidation catalysts initiate a chemical reaction in the exhaust stream, oxidizing pollutants into water vapor and other gases, such as SO_2 and CO.[438] Manufacturers report that flow-through oxidation catalysts can reduce total PM by 20 to 50 percent.[439] Moreover, these catalysts have been used in both on-road and off-road diesel engines.

EPA's Environmental Technology Verification program, conducted verification testing for Clean Diesel Technologies' diesel retrofit emission control system of a platinum/cerium fuel-borne catalyst.[440] Exhaust emissions measured during tests included HC, CO, NOx, and PM. Emission reductions were 59 percent, 64 percent, 7.4 percent, and 53 percent, respectively.

Several different oxidation catalysts were tested to determine the potential emission reductions that could be achieved with 368 ppm, 54 ppm, and zero ppm sulfur diesel fuels.[441] The catalysts reduced transient emissions of PM by 23 to 29 percent, 27 to 32 percent and 47 percent, respectively.

Selective Catalytic Reduction (SCR) is another technology that may

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papers/0209czerwinski (last visited Apr. 15, 2006).

436. A. Mayer et al., *Effectiveness of Particulate Traps on Construction Site Engines: VERT Final Measurements*, DIESELNET TECHNICAL REPORT, http://www.dieselnet.com/papers/9903mayer (last visited Apr. 15, 2006).

437. *See* Allen Schaeffer, *Clean Diesel Technology—Progress and Potential*, EM MAGAZINE, May 2004.

438. *Id.*

439. *Id.*

440. U.S. EPA Environmental Technology Verification, Test Report of Mobile Source Emissions Control Devices, Clean Diesel Technologies Fuel-Borne Catalyst with Clean Air System's Diesel Oxidation Catalyst, at http://www.epa.etv/verifications (last visited Apr. 15, 2006).

441. MANUFACTURERS OF EMISSION CONTROLS ASS'N, DEMONSTRATION OF ADVANCED EMISSION CONTROL TECHNOLOGIES ENABLING DIESEL-POWERED HEAVY-DUTY ENGINES TO ACHIEVE LOW EMISSION LEVELS FINAL REPORT (1999).

have potential for vehicle retrofit applications.[442] SCR has been used to reduce NO_x emissions from stationary sources for more than 15 years. More recently, this technology has been applied in retrofit projects for mobile sources, including trucks, marine vessels, and locomotives. SCR has been found to produce simultaneous reductions of NO_x, HCs, and PM.[443]

As part of its test program on advanced diesel emission control technologies, the Manufacturers of Emission Controls Association (MECA) tested SCR.[444] All tests were run using a 46 percent urea solution and two fuel sulfur levels of 368 ppm and 54 ppm. Incorporating a catalyst into the systems when testing with 368 ppm sulfur fuel reduced PM emissions to 0.052 g/bhp-hr were achieved. Using 54 ppm sulfur fuel reduced and a more active catalyst further reduced PM emissions to 0.042 g/bhp-hr.

DaimlerChrysler unveiled an ultra-low-emissions, high-efficiency diesel passenger vehicle that uses direct fuel injection, along with SCR technology to achieve 70 m/gal. fuel efficiency.[445] The concept car also complies with EPA emissions standards set to go into effect in 2007 for passenger diesel vehicles, which will require reductions of 95 percent or more in emissions of PM and NO_x.

There are two low NO_x catalyst that are being developed to reduce NO_x emissions by up to 70 percent.[446] The first technology, the so-called "low-NOx catalyst," works like SCR in that it adds a reducing agent to the exhaust stream to facilitate catalytic conversion. The second technology, known as the NO_x adsorber, operates in two stages. First, the NO_x is converted and adsorbed into a chemical storage site within the system, and then when the NO_x absorber becomes saturated, it is regenerated by adding extra diesel fuel to the exhaust stream. The addition of the fuel causes the NO_x adsorber to work like a low-NO_x catalyst, which converts the collected NO_x into N and O_2 that is emitted from the system.

Exhaust Gas Recirculation (EGR) reduces NO_x by reducing the

442. *Id.*

443. C. DAVID COOPER, *supra* note 412. SCR is similar to an oxidation catalyst in that it initiates chemical reactions to eliminate pollutants without itself being changed or consumed. However, SCR goes beyond catalytic activity by adding a reducing agent, like urea or NH_3, to the exhaust stream that converts NO_x to N and O_2. As the exhaust gases, along with the reducing agent pass over a catalyst-coated substrate, NOx, HCs, and PM are converted to less harmful emissions.

444. *Id.*

445. *DaimlerChrysler Diesel Concept Car Meets Tougher EPA, California Emission Standards*, DAILY ENVT., June 8, 2005.

446. *See* MANUFACTURERS OF EMISSION CONTROLS ASS'N, *supra* note 441.

temperature at which fuel burns in the combustion chamber.[447] There is concern that this technique could increase PM emissions, because a lower peak temperature results in less complete combustion. However, one study suggests that EGR increases the mean particle size in diesel exhaust, and the number of accumulation mode particles increases with EGR, while the total mass of particles decreases and the number of nuclei mode particles decreases with increasing EGR.[448]

4. Diesel Engine Design Factors

There is the suggestion that the DPM emission size distribution from newer technology engines, which is from 1991 and later, may be shifted to a much higher number concentration of nuclei-mode particles, independent of fuel sulfur content.[449] Preliminary results show that, despite a substantial reduction in the weight of total PM, the total number of particles in emissions from the more advanced 1991-model engine was 15 to 35 times greater than the number of particles from the 1988 engine when both engines were operated without emission control devices.[450] Apparently this finding was due to a 30- to 60-fold increase in the number of small, primary particles. Nuclei-mode particles made up 40 percent to 60 percent of the number fraction of DPM emissions for the 1988 engine and 97 percent of the DPM from the 1991 and 1995 engines. Moreover, this research suggests that number concentrations were roughly two orders of magnitude higher for the newer engines.

Because of these results, it may be necessary for diesel engines to be re-engineered through combustion management in order to reduce ultrafine particle emissions.[451] By altering parameters such as fuel injection timing, injection pressure, or combustion gas temperature, automotive engineers are developing ways of reducing the levels of NO_x and PM before the exhaust reaches the after-treatment system. For

447. KLIESCH & LANGER, AMERICAN COUNCIL FOR AN ENERGY EFFICIENT ECONOMY, DELIBERATING DIESEL: ENVIRONMENTAL, TECHNICAL, AND SOCIAL FACTORS AFFECTING DIESEL PASSENGER VEHICLE PROSPECTS IN THE UNITED STATES (2003). Engines employing EGR technology recycle a portion of engine exhaust back to the engine air intake. The oxygen-depleted exhaust gas is mixed into the fresh air that enters the combustion chamber, which, in turn, dilutes the oxygen content of the air in the combustion chamber and the reduction in O_2 produces a lower temperature burn and reduces NO_x emissions by as much as 40 percent.

448. A.M. Kresco et al., *A Study of the Effects of Exhaust Gas Recirculation on Heavy-Duty Engine Emissions*, 107 J. FUELS AND LUBRICANTS 665 (1998).

449. SUSAN T. BAGLEY ET AL., THE HEALTH EFFECTS INSTITUTE, EFFECTS OF FUEL MODIFICATION AND EMISSION CONTROL DEVICES ON HEAVY-DUTY DIESEL ENGINE EMISSIONS (2004), *available at* http://www.healtheffects.org/Pubs/st76.htm.

450. *Id.*

451. NAT'L CTR. FOR ENVTL. ASSESSMENT *supra* note 18, at 2-49.

instance, while the use of exhaust driven turbochargers has been in use for over 40 years, there may be additional opportunities to reduce DPM emissions. Turocharging permits the use of higher initial injection rates, which can reduce particle emissions.[452]

A group of researchers identified the various factors, like timing strategies, affect the amount of emissions produced by a diesel engine.[453] The researchers concluded that knowing the effect of each aspect of engine and vehicle operation on the emissions from diesel engines is useful in determining methods for reducing these emissions.

In addition to turbocharging and timing intervals, another group of researchers have identified aftercooling, optimizing combustion chamber design, and high-pressure fuel injection as ways to reduce diesel emissions generally.[454] For instance, modifications to the shape of the combustion chamber, location of the injection swirl, crevice volumes, and compression ratios optimize multipollutant reductions. Moreover, electronic computer control has also improved emissions.

5. Diesel Hybrids

General Motors has developed the Opel Astra Diesel Hybrid car.[455] This diesel front-wheel drive concept vehicle is equipped with a two-mode full hybrid and the 1.7-liter CDTI engine, and delivers up to 25 percent improved fuel economy.

Isuzu Motors Limited has added a new diesel hybrid truck.[456] The system achieves fuel economy improvement of 35 percent. PM emissions are reduced by 85 percent and NO_x is reduced by 25 percent over previous models.

In addition to gasoline hybrid buses, ISE Corporation has developed a diesel hybrid bus.[457] The diesel hybrid system developed by ISE has a number of unique features like a smaller diesel engine, which helps to reduce fuel consumption, emissions, and noise.

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452. KENNETH WARK ET AL., AIR POLLUTION: ITS ORIGIN AND CONTROL (3d ed. 1998).

453. N.N. Clark et al., *Factors Affecting Heavy-Duty Diesel Vehicle Emissions*, 52 J. AIR & WASTE MGMT. ASS'N 84 (2002).

454. Alan C. Lloyd & Thomas A. Cackette, *Diesel Engines: Environmental Impact and Control*, 51 J. AIR & WASTE MGMT. ASS'N 809 (2001).

455. General Motors, Opel Astra Diesel Hybrid Concept Demonstrates Easy Scalability of Innovative Two-Mode Full Hybrid System, January 10, 2005, http://www.gm.com/company/gmability/adv_tech/100_news/astra_011005.html (last visited Apr. 15, 2006).

456. Isuzu Motors Limited, Isuzu to Release new Elf Diesel Hybrids, April 18, 2005, http://www.isuzu.co.jp/world/press/2005/p_0418.html (last visited Apr. 15, 2006).

457. ISE Corporation, Diesel Hybrid Drive System, http://www.isecorp.com/ise_products_services/diesel_hybrid_drive_system/ (last visited Apr. 15, 2006).

One of the more unique diesel hybrids is the "Green Goat" which is a locomotive engine designed to reduce DPM emissions that result from idling.[458] The hybrid locomotives are remanufactured from aging diesel-electric switchers by replacing the large diesel engine, generator, and analog controls above the frame with a small generator set, a battery pack, and a computerized control module.[459]

The Northeast Advanced Vehicle Consortium ran some emission tests on diesel hybrid heavy-duty vehicles.[460] PM emissions from the hybrid vehicles were generally 50 to 70 percent lower than a conventional diesel.[461] Moreover, three of the six vehicles in the study had PM emissions near or below the detection limit of the measuring equipment, which is approximately 0.01 to 0.02 g/mi.

6. Diesel Fuels

EPA has broad authority under the CAA to regulate fuels. For example, Section 211(a) of the CAA was expanded to allow EPA to regulate included fuel and fuel additives used in nonroad engines and vehicles.[462] Section 211(b)(2)(B) provides for testing of these fuels and fuel additives.[463] Section 211(g)(2) regulates the sulfur content of diesel fuel introduced into an engine.[464] Sections 241 through 245 introduce a new program for clean alternative fuels.[465] While ultrafine particles are an issue for both gasoline and diesel engines, recent focus has been centered on diesel fuels because of their higher sulfur content and high PM emissions.

Diesel fuel used in highway engines currently cannot contain more than 500 ppm of sulfur.[466] Under new federal regulations, this limit will fall to 15 ppm in 2006.[467] By contrast, the sulfur content of diesel fuel

458. As previously noted, locomotives are a major contributor of PM emissions in urban airsheds, Section 213(a)(5) of the CAA specified that EPA establish emission standards for "new locomotives and new engines used in locomotives." 42 U.S.C. § 7547(a)(5) (2000).

459. Railpower Technologies Corp., http://www.railpower.com/products_hl_howitworks.html. (last visited Apr. 15, 2006).

460. Hybrid-Electric Drive Heavy-Duty Vehicle Testing Project—Final Emissions Report, Northeast Advanced Vehicle Consortium, http://www.navc.org/index.html (last visited Apr. 15, 2006).

461. *Id.*

462. 42 U.S.C. § 7545(a) (2000).

463. 42 U.S.C. § 7545(b)(2)(B).

464. 42 U.S.C. § 7545(g)(2).

465. 42 U.S.C. §§ 7581-7585.

466. Regulation of Fuels and Fuel Additives: Fuel Quality Regulations for Highway Diesel Fuel Sold in 1993 and Later Calendar Years, 55 Fed. Reg. 34120 (Aug. 21, 1990).

467. Control of Air Pollution From New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, 66 Fed. Reg.

for nonroad engines averages 3,300 ppm[468] and 45,000 ppm for marine vessels.[469] The 15 ppm sulfur limit is designed to reduce primary and secondary PM, and reduce the fouling of emission control technology.

Researchers have identified and summarized a number of findings related to PM reductions from reformulated and alternative diesel fuels.[470] Atlantic Richfield Company has developed a reformulated diesel fuel called "EC-D" that has demonstrated emission reductions of PM relative to low-sulfur fuel.

Synthetic diesel fuel, produced by a gas-to-liquid chemical conversion process known as Fischer Tropsch, apparently is the cleanest burning of the reformulated diesel fuels with demonstrated average emission reductions of 26 percent for PM over low-sulfur diesel fuel. Lubrizol has produced a fuel known as "PuriNO_x" which has shown emission reductions of 63 percent for PM.

Biodiesel is a monoalkyl ester-based oxygenated fuel made from vegetable oil or animal fats.[471] It contains 11 percent oxygen by weight and no sulfur or aromatic compounds and can be blended into conventional diesel fuel at any ratio. Pure biodiesel (B100) reduces PM emissions by 30 percent over conventional diesel fuels.[472] B35 reduces PM emissions in nonmodified engines by 25 percent.[473] B20, a blend of 20 percent biodiesel with conventional diesel, is the most common biodiesel blend and reduces PM emissions.[474]

The use of rapeweed oil as a liquid fuel either by constructing special engines or by transesterifying it into rapeweed oil methyl ester (RME) or more commonly biodiesel has gained considerable attention in Europe.[475] Laboratory tests showed that biodisel fuel emitted significantly fewer particles that conventional diesel fuel.[476]

In another study three diesel fuels, an oil sand-derived diesel

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5001 (Jan. 18, 2001).

468. Control of Air Pollution From New Motor Vehicles: Proposed Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements, 64 Fed. Reg. 26142 (May 13, 1999).

469. Control of Emissions From New Marine Compression Ignition Engines at or Above 30 Liters Per Cylinder, 68 Fed. Reg. 9745 (Feb. 28, 2003).

470. *See* A.C. Lloyd & T. A. Cackette, *Diesel Engines: Environmental Impact and Control*, 51 J. AIR & WASTE MGMT. ASS'N 809 (2001). *See also* A.J. Kean & R. F. Sawyer, *A Fuel-based Assessment of Off-Road Diesel Engine Emissions*, 50 J. AIR & WASTE MGMT. ASS'N 1939 (2000).

471. W.G. Wang et al., *Emissions from Nine Heavy Trucks Fueled by Diesel and Biodiesel Blend without Engine Modification*, 34 ENVTL. SCIENCE & TECH. 933 (2000).

472. *Id.*

473. *Id.*

474. *Id.*

475. M. Bahadir et al., Biodiesel, http://www.chemsoc.org/networks/learnnet/green/docs/biodiesel.pdf (last visited Apr. 15, 2006).

476. *Id.*

serving as base fuel, one cetane-enhanced base fuel, and one oxygenate-blended base fuel, which contained the oxygenate diethylene glycol dimethyl ether (DEDM), were tested for their emission characterizations in vehicle exhaust on a light-duty diesel truck.[477] Cetane-enhanced and oxygenated fuel runs for PM showed an overall reduction of 40 percent, respectively.

Danish researchers measured particle number concentration and size distributions in a Copenhagen street canyon in January 1999 and again in January 2000.[478] Their measurement revealed a steep decline in the number of particles in the ultrafine range. The researchers concluded that the change was probably due to the reduction of the sulfur content in diesel fuel from approximately 0.05 percent to less than 0.005 percent implemented in Denmark of July 1999.

7. Combined Diesel Technologies

Studies have been conducted on combined diesel technologies to determine the amount of PM emission reductions. For instance, the Association for Emissions Control by Catalyst (AECC) has preformed a test program to support the European Commission review process of the technical feasibility of Europe's 2008 heavy-duty diesel emission standards.[479] A combined emission control system of catalyst-based diesel particulate filter and urea-based SCR catalyst with an NH_3 clean-up catalyst has been applied to a series production EU 3 medium sized diesel engine. The authors concluded that no major changes in particle size distribution were observed with the applied technologies and significant reductions in particle emissions of both mass and number were demonstrated.

MECA has also run PM emission tests on combined technologies.[480] SCR was tested on 368 ppm sulfur fuel alone and in conjunction with diesel oxidation catalyst controls as well as in combination with two different diesel particle filter technologies. Tests showed that replacing the diesel oxidation catalyst with two different diesel particle filter technologies resulted in NO_x and HC emissions in the range of 1.10 to

477. Jiping Zhu, Xu-Liang Cao, Rene Pigeon, & Ken Mitchell, *Comparison of Vehicle Exhaust Emissions from Modified Diesel Fuels*, 53 J. AIR & WASTE MGMT. ASS'N 67 (2003).

478. P. Wåhlin et al., *Pronounced Decrease of Ambient Particle Number Emissions From Diesel Traffic in Denmark After Reduction of the Sulphur Content in Diesel Fuel*, 35 ATMOSPHERIC ENV'T 3549 (2001).

479. Jon D Andersson et al., *Particle Emissions from a EU 3 Heavy-duty Diesel Engine with Catalyst-based Diesel Particle Filter and Selective Catalytic Reduction System: Size, Number, Mass & Chemistry*, 11 AACHENER KOLLOQUIUM FAHRZEUG-UND MOTORENTECHNIK 1 (2002).

480. *Id.*

1.17 g/bhp-hr and PM emissions of 0.002 to 0.01 g/bhp-hr.

D. Additional Mobile Source and Diesel Engine Regulatory Considerations

1. New and In-Use Vehicle Regulatory Programs

Moving from a mass basis to a number concentration basis for regulating PM emissions would require EPA to revisit two methods it uses to regulate emissions from motor vehicles—the FTP and the inspection and maintenance (I/M) program. Every new motor vehicle or engine introduced into commerce for sale is required to have a certificate of conformity.[481] In order to acquire that certification, vehicles must pass the FTP where, among other things, the vehicle is tested on a chassis dynamometer that simulates road conditions and wind resistance in order to see if the vehicle meets the established emission standard for that class of vehicle.[482] Although neither light duty cars nor trucks have a PM emission standard,[483] both are, as previously discussed, significant sources of ultrafine particles, and as such, would need ultrafine particle emission standards in order to reduce their ambient concentrations. Moreover, while there is a mass-based PM emission standard for heavy-duty diesel trucks and engines,[484] there would need to be a number concentration standard as well, since diesel vehicles and engines are also a prime emission source of ultrafine particles.

Under the CAA, all states with O_3 or CO nonattainment areas are required to revise their SIPs to include either a "basic" on an "enhanced" vehicle I/M program, depending on population classification.[485] The basic test measures exhaust emissions with the vehicle in neutral gear and the engine at idle. The enhanced test requires testing under load during cycles of acceleration and deceleration. The purpose of the I/M program is to identify and ensure the repair of in-use vehicles that emit excessive pollutants on a mass basis.[486]

Vehicle I/M program requirements under the CAA are being updated to reflect more protective air quality standards for ground-level O_3, according to a proposed rule EPA published in the Federal Register.[487] Since vehicles are a major source of ultrafine PM, it is likely

481. U.S.C. § 7522(a)(1) (2000).
482. *See* 40 C.F.R. pt. 86 (2005).
483. *See* 40 C.F.R. § 86.001.
484. 40 C.F.R. § 86.007-11.
485. 42 U.S.C. §§ 7511a(a)(2)(B), (b)(4), (c)(3)(d) and (e).
486. *See* 40 C.F.R. pt. 51.
487. Amendments to Vehicle Inspection Maintenance Program Requirements To

that a number-based standard would require an I/M program for PM number nonattainment areas as well. Moreover, States could adopt an I/M program as RACM to control ultrafine particle emissions.

There is technology that would allow EPA to measure new and existing vehicle emissions on a number concentration basis. TSI, Inc. has developed an engine exhaust particle sizer spectrometer.[488] This spectrometer measures ultrafine particles in the range from 5.6 to 560 nm and has the ability to measure the behavior of particle emissions that occur during transient test cycles.

EPA has published a rule required testing for in-use for heavy-duty engines and vehicles.[489] It requires in-use measurement of the following pollutants from heavy-duty diesel engines: NMHC; THC; CO; NO_x; and PM.

EPA is currently evaluating prototype portable units for measuring PM.[490] The agency is looking at a laboratory-scale quartz crystal microbalance (QCM) measurement procedure versus a laboratory PM measurement procedure. EPA believes that the QCM is a viable technology that should be implemented. Because QCM technology can measure "nano-gram" levels of PM, EPA thinks it may be sufficiently sensitive to measure 30-second samples of PM.[491] As a result, it is likely States would adopt such a program as RACM to control ultrafine particle emissions from diesel engines.

2. Transportation Conformity Requirements

Section 176(c) of the CAA requires federal agencies to determine that a proposed action it wishes to take will not interfere with the SIP or a State's ability to attain and maintain the NAAQS.[492] EPA has developed two sets of regulations to implements Section 176(c)—the transportation conformity regulations, which deal with the approval and funding of highway and mass transit projects; and the general conformity regulations, which deal with all other federal actions.[493] Only the transportation conformity regulations will be discussed in this article,

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Address the 8-Hour National Ambient Air Quality Standard for Ozone, 70 Fed. Reg. 1314 (Jan. 6, 2005) (to be codified at 40 C.F.R. pt. 51).

488. For a full description of Model 3090 Engine Exhaust Particle Sizer Spectrometer, *see* TSI_Engine Exhaust Particle Sizer Spectrometer Model 3090, http://www.tsi.com/Product.aspx?Pid=82 (last visited April 15, 2006).

489. Test Procedures for Testing Highway and Nonroad Engines and Omnibus Technical Amendments, 70 Fed. Reg. 40420-1 (July 13, 2005) (to be codified at 40 C.F.R pt. 85).

490. *Id.*

491. *Id.*

492. 42 U.S.C. § 7506(c) (2000).

493. *See generally* 40 C.F.R. pt. 93.

because of the significant emissions of ultrafine particles from mobile sources. Conformity to a SIP means that a transportation activity will not cause or contribute to new air pollution violations, worsen existing violations, postpone expeditious implementation of TCMs, or delay timely attainment of federal air quality standards.[494] In essence, conformity requires that transportation projects contribute to improved air quality.

These transportation related conformity requirements are meant to encourage long-range planning to improve air quality. Any transportation project not part of an EPA approved SIP or Federal Highway Administration approved transportation program must be evaluated by the recipient of federal transportation funds and must be found to be in conformity with the SIP or program before the project can proceed.[495] The project review must use updated air quality information. If the project does meet applicable air quality requirements, it may not be federally approved or receive federal funds unless it is modified.[496]

As previously noted, on-road motor vehicles are the largest source of ultrafine particles.[497] Therefore, regulation of particles on a number concentration basis will have a significant impact on conformity determinations.

On July 1, 2004, EPA promulgated revisions to the transportation conformity regulations for the new eight-hour O_3 and $PM_{2.5}$ NAAQS.[498] The final rule describes in general terms how conformity will apply to new nonattainment and maintenance areas under the new eight-hour O_3 and $PM_{2.5}$ standards. The transportation conformity rule outlines the procedures for determining whether federally-funded or approved highway and transit projects are consistent with, or conform to, State air quality goals.[499]

On December 13, 2004, EPA published a supplemental notice of proposed rulemaking, requesting further comment on five options for consideration of localized emission impacts of individual transportation projects in both $PM_{2.5}$ and PM_{10} nonattainment and maintenance areas.[500]

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494. *Id.*
495. *Id.*
496. Reitze, *supra* note 295, at Chapter 15.
497. Kleeman et. al., *supra* note 56.
498. Transportation Conformity Rule Amendments for the New 8-hour Ozone and $PM_{2.5}$ National Ambient Air Quality Standards and Miscellaneous Revisions for Existing Areas; Transportation Conformity Rule Amendments: Response to Court Decision and Additional Rule Changes, 69 Fed. Reg. 40004 (July 1, 2004) (to be codified in 40 C.F.R. pt. 93).
499. 42 U.S.C. § 7506(c) (2000).
500. Options for $PM_{2.5}$ and PM_{10} Hot-Spot Analyses in the Transportation Conformity Rule Amendments for the New $PM_{2.5}$ and Existing PM_{10} National Ambient Air Quality Standards, 69 Fed. Reg. 72140 (Dec. 13, 2004) (to be codified in 40 C.F.R. pt. 93).

In general, a quantitative or qualitative hot-spot analysis must show that a given project does not cause or contribute to any new violations of the air quality standard or increase the frequency or severity of existing violations. A hot-spot analysis assesses impacts on a scale smaller than an entire nonattainment or maintenance area, including for example, congested roadway intersections and highways or transit terminals.[501] Because ultrafine particles are found in large concentrations near highways, hot spot analyses would figure prominently, if EPA were to move to a number-based concentration standard.

One research team set out to demonstrate a methodology for quantification of high emissions hot spots along roadways based upon real-world, on-road vehicle emission measurements.[502] One of the main objectives of this study was to investigate factors that contribute to hot spots. According to this study, factors that affect vehicle emissions include vehicle characteristics; vehicle operating conditions; fuel characteristics; and vehicle operating environment.

Another important consideration related to transportation conformity is the National Environmental Policy Act[503] ("NEPA"). The essential purpose of NEPA is to ensure that environmental factors are given the same consideration as other factors in decision making by federal agencies. The effectiveness of NEPA stems from its environmental impact statement or EIS requirement where federal agencies must consider the environmental effects of, and any alternatives to, all proposals for major federal actions that significantly affect the quality of the human environment. Until fairly recently, Federal Highway Administration environmental impact statements on proposed roads examined only localized CO levels.[504] Studies of near-road exposures to PM are now incorporated on a case-by-case basis, while the Department of Transportation considers adding them as a standard feature in NEPA reviews of proposed road projects.[505]

Moreover, federal environmental justice mandates also play a role in the urban or microenvironment PM pollution issue for conformity. Executive Order No. 12898, which was signed by President Bill Clinton, in February of 1994, requires all federal agencies, like the Department of Transportation, to take into account their projects' impact on low-income

501. *Id.*

502. A. Unal et al., *Quantification of Highway Vehicle Emission Hot Spots Based upon On-Board Measurements*, 54 J. AIR & WASTE MGMT. ASS'N 130, 140 (2004).

503. *See* 42 U.S.C. §§ 4321-4370c (2000).

504. FED. HIGHWAY ADMIN., THE CONGESTION MITIGATION AND AIR QUALITY IMPROVEMENT PROGRAM UNDER THE TRANSPORTATION EQUITY ACT FOR THE 21ST CENTURY—PROGRAM GUIDANCE (1999), *available at* http://www.fhwa.dot.gov/environment/cmaq99gd.pdf.

505. *Id.*

and minority communities since these communities are located disproportionately near heavily traveled highways.

3. Transportation Control Measures

When a State prepares or revises its SIP for ozone nonattainment areas, it is required to adopt all of the control measures listed under Section 108(f) of the CAA or it may select other measures considered appropriate.[506] A lists of 16 TCMs, is found under Section 108(f)(1)(A) and includes, but is not limited to, public transit; exclusive bus and high-occupancy vehicle roads; traffic flow improvement plans; programs to restrict or limit vehicle use in downtown areas; and programs to control extended idling of vehicles. Because vehicles are a prime source of ultrafine particle emissions, a number-based PM standard may require states with PM nonattainment areas to adopt similar TCMs as RACM to reduce ultrafine ambient air concentrations. For example, congestion pricing is a relatively new TCM that is often referred to as "value pricing." This TCM, operates in one of two ways.[507] It either provides a disincentive to drive on highly-used roadways by imposing fees in congested areas that vary depending on location, time or vehicle occupancy, or it offers a priced alternative to a congestion roadway that enables the motorist to reach his or her destination more quickly. These fees are intended to reduce congestion and improve air quality by encouraging people to change their travel patterns by shifting to off-peak periods, less congested travel routes, higher occupancy vehicles, or a different mode of transportation, like public transit. There are several congestion pricing measures, which may be implemented such as variable tolls, high occupancy vehicle lane permits, vehicle miles traveled fees, and parking fees.[508]

A technology-based TCM is truck stop electrification (TSE), which harnesses an electrical system to provide truck drivers with electricity for air conditioning and heating for their sleeper compartments and to run appliances eliminating the need to run their engines.[509] Such an approach would completely eliminate ultrafine PM emissions from idling diesel-powered trucks.

On March 9, 2005, EPA announced an effort to develop a model

506. 42 U.S.C. § 7408(f) (2000).

507. U.S. EPA, ENVIRONMENTAL UPDATE: AIR QUALITY OPPORTUNITIES IN THE TRANSPORTATION EQUITY ACT FOR THE 21ST CENTURY (1999), *available at* http://www.epa.gov/otaq/transp/40f99001.pdf.

508. *Id.*

509. *See* IdleAire Technologies, http://www.idleaire.com/technology (last visited April 15, 2006).

anti-idling State law through a voluntary initiative.[510] EPA estimates that unnecessary idling consumes 1 billion gallons of diesel fuel each year, producing 12 million tons of CO_2 and 200,000 tons of NO_x. This effort will undoubtedly lead to reduced ultrafine PM emissions, as well. Moreover, anti-idling laws could also be enacted as a transportation control measure.

In addition to this effort, EPA and major freight railroads announced a voluntary agreement to reduce locomotive emissions and fuel consumption under the SmartWay initiative.[511] This initiative aims to reduce emissions of CO_2 by as much as 66 million metric tons, NO_x by 200,000 tons, and annual fuel consumption by as much as 150 million barrels of oil by 2012. Reduction of fuel consumption and emissions would come from using new technologies that can curb engine idling at truck stops, ports, rail yards, and distribution hubs, as well as from the use of hybrid and liquid natural gas locomotive engines.

Studies by the South Coast Air Quality Management District indicate emissions from activities at the Los Angeles port and its sister port across the harbor in Long Beach are a major stumbling block to the region's ability to attain federal air quality standards.[512] As a result, California had developed a draft plan, which comprises about 65 control measures to reduce emissions from oceangoing vessels, harbor craft, cargo handling equipment, railroads, and heavy-duty diesel vehicles. More than half have already been adopted or proposed by either the port or state, federal, and international regulatory agencies. Public concern over harmful emissions of NO_x and PM at the ports, increasing port traffic, and planned expansion projects prompted the State to assemble the No Net Increase Air Quality Task Force in mid-2004.

4. Land Use Restrictions Related to Transportation Air Emissions Effects

The CAA specifically provides that nothing in the legislation constitutes and infringement on the existing authority of counties and cities to plan or control land use, and nothing in the legislation transfers authority over such land use.[513] Land use planning is considered in almost every metropolitan area in the country for such reasons as to reduce traffic congestion, promote economic vitality, preserve

510. *See EPA Plans to Develop Model State Law to Limit Idling by Heavy-Duty Diesel Trucks*, DAILY ENV'T REP., Mar. 14, 2005.

511. *See EPA, Railroads Aim to Reduce Emissions, Fuel Use through Voluntary Partnership*, DAILY ENV'T REP., June 6, 2005.

512. *See Plan for Cutting Los Angeles Port Emissions Includes Controls for Ships, Trucks, Trains*, DAILY ENV'T REP., Mar. 7, 2005.

513. 42 U.S.C. § 7431 (2000).

recreational space and agricultural lands, and protect endangered species. However, land use planning also plays a significant role in air quality impacts, as well.[514] For instance, in 1920, the average density of America's urbanized areas was 6,160 persons per square mile or about ten persons per acre. Since 1990, the average density of urbanized areas is about 2,589 persons per mile or about four persons per acre.[515] As this decentralization or sprawl continues, Americans must use their automobiles to travel longer distances. In fact, motor vehicle use in the United States has doubled from one to two trillion miles per year between 1970 and 1990.[516] As a result, a connection between sprawling land use and increased driving contributes to, among other things, increased air pollution.

Several regional air agencies in California use a software tool known as URBEMIS7G to estimate the emissions impact of particular land use projects.[517] Such models would need to be developed and made available for State agencies that would want to get SIP credit for land use measures.

Were EPA to regulate PM emissions on a number concentration basis, it is likely that the agency would finalize a scheme to grant air quality credits in SIPS for land use measures that reduce ultrafine emissions.[518] Therefore, these measures could be identified as RACM. Land use, however, has been the traditional domain of local governments. Therefore, economic incentives may need to be enacted to ensure that local governments establish programs that shape land use in such a way that it changes travel patterns that reduce vehicle miles, which will reduce emissions.

In addition to these land use strategies, there are a number of other strategies that reduce emissions.[519] These include street design, parking pricing, traffic calming measures, and improved bicycle and pedestrian facilities. For instance, throughways as opposed to cul-de-sacs should be used. Increased parking pricing would discourage car ridership in favor of public transportation. Traffic calming measures reduce speed and certain types of motor vehicle emissions. Lastly improved bike and

514. *See* F. KAID BENFIELD ET AL., ONCE THERE WERE GREENFIELDS: HOW URBAN SPRAWL IS UNDERMINING AMERICA'S ENVIRONMENT, ECONOMY, AND SOCIAL FABRIC (1999).

515. *Id.* at 12.

516. *Id.*

517. URBEMIS7G Computer Program User's Guide, Version 3.1 was prepared for San Joaquin Valley Unified Air Pollution Control District by Jones & Stokes Associates, August 1998.

518. U.S. EPA, GRANTING AIR QUALITY CREDIT FOR LAND USE MEASURES: POLICY OPTIONS (1999).

519. *Id.*

pedestrian would encourage those modes of transportation in lieu of the automobile.

5. Tax Policy to Reduce Automobile Related Emissions

Taxes have been suggested as a means to reduce fuel consumption and increase fuel efficiency for automobiles.[520] One co-benefit of such an approach would be the reduction of PM emissions from automobiles. The two types of taxes most often mentioned are a carbon tax and fuel tax. A carbon tax aims at internalizing the cost of carbon emissions in the price of fuel. From the perspective of economic efficiency, an economy wide carbon tax would be the most effective method of reducing greenhouse gas emissions. In the case of light-duty vehicles, such a tax may be incorporated as a part of the fuel tax.

XI. Enhanced Pollution Prevention Requirements

A. Introduction

In enacting the Pollution Prevention of Act of 1990, Congress declared it to be the national policy of the United States that "pollution should be prevented or reduced at the source whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner, whenever feasible; pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner."[521] Regulation of PM on a number-based concentration standard may force a number of industries to move toward proactive pollution prevention strategies in the areas of process modifications or pre-combustion techniques to avoid the generation of particles or particle precursors by either excluding the pollutant from the process or conducting the industrial process in a manner that the pollutant is not released into the gaseous effluent. Moreover, States with nonattainment areas may also identify pollution prevention as RACM in order to come into compliance with the standard.

B. Renewable Energy Technologies

Wind, solar, biomass, and geothermal technologies are the most

520. ANUP BANDIVADEKAR & JOHN B. HEYWOOD, COORDINATED POLICY MEASURES FOR REDUCING THE FUEL CONSUMPTION OF THE U.S. LIGHT-DUTY VEHICLE FLEET (2004), *available at* http://lfee.mit.edu/public/LFEE_2004-001_RP.pdf.

521. *See* 42 U.S.C. § 13101(b) (2000).

common renewable energy sources. While each of these technologies has it place as electricity-generating technologies, the greatest strides in emission-free industrial application seem to focus around solar and wind energy, which is available throughout the United States.[522]

The National Renewable Energy Laboratory (NREL) has been working on a number of renewable technologies suitable for industrial and power generation application.[523] The first renewable technology for industrial application relates to solar energy generally, and concentrated solar energy, in particular.[524] NREL notes that another option is concentrating solar power systems, which use the sun as a heat source. In addition to this application for power generation, commercial and industrial buildings may also use the same solar technologies, like photovoltaics, passive heating, and water heating that are used for residential buildings.[525]

In addition to solar power, wind power has taken on increasing prominence as a renewable energy source.[526] Wind turbines use wind to make electricity.[527] NREL has contracted with companies like Global Energy Concepts (GEC), Northern Power Systems (NPS), and Clipper Windpower to pursue different approaches to reduce the costs of drivetrain components, like generators, gearboxes, shafts, and bearings, for 1.5-MW turbines.[528] In addition to drivetrain components, research on new blade designs is also being pursued. Because the amount of energy a wind turbine generates depends on the amount of energy captured by its blades, longer blades capture more energy.[529]

As part of its research and development on distributed wind systems in 2003, DOE awarded $1.5 million in grants to ten firms to enhance the cost-effectiveness of small wind turbines.[530] The goal for distributed wind technology is to reduce the cost of electricity from distributed wind systems to $0.10–$0.15/kWh by 2007.[531]

While the greatest strides in renewable energy centers around solar and wind power, new mapping and drilling technologies and additional

522. *See* JAMES A. FAY & DAN S. GOLOMB, ENERGY AND THE ENVIRONMENT (2002).
523. *See generally* National Renewable Energy Laboratory, http://www.nrel.gov/ (last visited April 19, 2006).
524. *Id.*
525. *Id.*
526. FAY & GOLOMB, *supra* note 522.
527. National Renewable Energy Laboratory, *supra* note 523.
528. FAY & GOLOMB, *supra* note 522.
529. *Id.*
530. Energy Efficiency and Renewable Energy: Wind and Hydropower Technologies Home Page, http://www.eere.energy.gov/windandhydro/ (last visited April 15, 2006).
531. U.S. DEP'T OF ENERGY, WIND POWER TODAY AND TOMORROW—THE ADVANCING INDUSTRY, ENERGY EFFICIENCY AND RENEWABLE ENERGY (2003), *available at* http://www.nrel.gov/docs/fy04osti/34915.pdf.

research, show that the size and scope of U.S. geothermal resources suitable for electric generation are much larger than once believed.[532] Drilling advances that allow companies to drill as deep as 15,000 feet could make thermal energy feasible in every state. The two most common processes for harnessing geothermal energy to produce electricity involve the use of dry plants and binary-cycle plants.[533]

C. Green Chemistry

The CAA like all other federal environmental statues, with the exception of the Pollution Prevention Act of 1990, deal with pollution after the fact. These laws are in general focused on the treatment or abatement of pollution and have become know as "command and control" laws. While these laws have reduced pollution, there is still a significant amount of pollution that is released into the environment. For example under the Toxic Release Inventory, which is part of the Emergency Planning and Community Right to Know Act,[534] companies are required to report the use and/or release of certain hazardous substances. In 2002, U.S. industry released or disposed 4.79 billion pounds of reportable substances from a total of 24,379 U.S. facilities.[535]

In the last decade a new paradigm has emerged at the EPA, ushered in, in part by the Pollution Prevention Act of 1990.[536] In 1991 Green Chemistry became a formal focus of EPA.[537] The aim of Green Chemistry is to design chemical products and processes in order to reduce or eliminate the use and generation of hazardous substances. Instead of limiting risk by controlling exposure to hazardous chemicals, green chemistry attempts to reduce and preferentially eliminate the hazard which negating the necessity to control exposure.

An example of green chemistry, in the context of PM pollution is ultra-deep fuel desulfurization. Ultra-deep desulfurization of fuel oils has also been studied in an attempt to not only meet new emission controls standards, but also for producing sulfur-free hydrogen used in fuel cell systems.[538] The sulfur level of the desulfurized diesel can be lowered from about 500 ppm to 0.1 ppm without changing the properties

532. Ken Wicker, *Geothermal: Hotter Than Ever*, POWER, Feb. 2005.
533. FAY & GOLOMB, *supra* note 522.
534. *See* 42 U.S.C. §§ 11001-11050 (2000).
535. *See* U.S. EPA, Toxics Release Inventory (TRI) Program, http://www.epa.gov/tri/ (last visited April 15, 2006).
536. *See* 42 U.S. §§ 13101-13109 (2000).
537. *See* U.S. EPA, http://www.epa.gov/greenchemistry/index.html (last visited April 15, 2006).
538. Dr. Can Li et al., *Ultra-Deep Desulfurization of Diesel: Oxidation with a Recoverable Catalyst Assembled in Emulsion*, 10 CHEM. EUR. J. 2277 (2004).

of the diesel fuel.

Another example of green chemistry would be reduced solvent usage or solvent substitution. EPA identifies organic compounds with seven atoms or more like toluene, xylene, and trimethyl benzene as compounds that could be reduced or substituted.[539]

D. Advanced Fossil Fuel Technology

One of the more impressive ways that industry is advancing green chemistry principles is through the use of integrated gasification combined cycle, (IGCC) which results substantially reduced air emissions. IGCC technology can help meet an extremely stringent emission standard like a number-based PM concentration standard, since it removes emission-forming constituents like sulfur, NH_3, and PM before power generation.[540]

The first demonstration of IGCC was a 100-MW plant located at the Cool Water Station of Southern California Edison, which was operated from 1984 to 1989.[541] The Tampa Electric Polk County IGCC plant, based on the Texaco technology, started operations in 1996 and completed its DOE demonstration period in 2001. The Wabash Repowering IGCC project in Indiana based on the Dow technology, started operations in 1995 and completed its DOE demonstration period in 2000. These plants can achieve an efficiency between 50 and 60 percent, and in some case 75 percent. Moreover, this technology also has extraordinary low emissions of SO_x, NO_x, and PM.[542]

E. Stationary Source Fuel Cells

In addition for use in the transportation sector, stationary source fuel cells have also been developed to generate electricity. For example, Fuel Cell Energy, Inc. has developed direct fuel cell technology that allows the cell to operate at a temperature of about 1,200° F, which allows a catalyst to extract hydrogen internally within the fuel cell module itself.[543] This direct cell technology is available from the company in

539. U.S. EPA, *supra* note 537; *see also* WASH. STATE DEP'T OF ECOLOGY, ALTERNATIVES TO CHLORINATED SOLVENTS—SOLVENT SUBSTITUTION OPTIONS, *available at* http://www.ecy.wa.gov/pubs/96420.pdf.

540. Gary J. Stiegel & Massood Ramezan, *The Case for Gasification*, *in* EM MAGAZINE—COAL GASIFICATION AND IGCC TECH., THE CASE FOR CLEANER ENERGY (2004).

541. A.H. Neville et al., *IGCC Technology—Status, Opportunities, and Issues*, *in* EM MAGAZINE—COAL GASIFICATION AND IGCC TECH., THE CASE FOR CLEANER ENERGY (2004).

542. *Id.*

543. Andy Skok & Steven P. Eschbach, *Fuels Cells Reach MW Class*, POWER,

sizes ranging from 250 kW to 2 MW. Operation at these high temperatures means that these fuel cells have the ability to be powered by a variety of fuels, including anaerobic digester gas, natural gas, propane, coal gases, and diesel fuel. Compared with combustion-based generators, this technology puts out 99.96 percent less NO_x, 99.99 percent less SO_2, and 59 percent less CO_2.[544]

F. Pollution Prevention Techniques

Corporations are increasingly using environmental management systems (EMS) and other techniques as a means to achieve pollution prevention goals. An EMS is generally that aspect of an organization's overall management structure that addresses the immediate and long term impact of a company's products, services, and processes on the environment.[545] It also allows a company to monitor its impact on the environment and to ensure compliance with environmental regulations. Other pollution prevention techniques include industry or government sponsored standards.[546] For example, a study of pollution prevention techniques at a petroleum refinery, was undertaken based on a combination of technology and operating guidelines.[547] Several energy integration techniques also helped to optimize fuel consumption and atmospheric emissions.[548] This energy integration plan also produced real reductions in atmospheric pollutants as follows: SO_2 to 14.5 kg/hr; NO_x to 4.2 kg/hr; CO_2 to 2134 kg/hr; and PM to 0.9 kg/hr.

In a similar vein, a research group set out to measure ultrafine particle size distributions from coal-, oil-, and gas-fired stationary combustion sources.[549] This study reports experimental results to determine the minimum aging time and dilution air ratio required to achieve stable number distributions of ultrafine particles and the dependence of ultrafine particle size distributions on combustion fuel types, like coal, oil, and natural gas, and temperatures.

One particular barrier that that reduces pollution prevention opportunities is the existing air quality regulatory structure, which traditionally has established emission standards on a heat input basis

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Jan./Feb. 2005.

544. *Id.*

545. Robert Anthony Reiley, *The New Paradigm: ISO 14000 and Its Place in Regulatory Reform—Part I,* THE ENVT'L COUNSELOR, Apr. 15, 1998.

546. Robert Anthony Reiley, *The New Paradigm: ISO 14000 and Its Place in Regulatory Reform—Part II,* THE ENVT'L COUNSELOR, May 15, 1998.

547. Encarnacion Rodríguez & Jose-Luis Martinez, *Pollution Prevention and Control Procedure Case Study: An Application for Petroleum Refineries*, 55 J. AIR & WASTE MGMT. ASS'N 792 (2005).

548. *Id.*

549. Chang et. al., *supra* note 380.

(i.e., lbs/MMBtu) or on a pounds per hour basis. Comparing technologies using these traditional tools, the one with the lowest emissions out of the stack has been determined to be the "best available control technology" regardless of how much fuel is combusted or its thermal efficiency. However, EPA is in the process of addressing this bias and has established emission standards on an output basis (i.e., lbs./MW generated).[550] Moreover, as previously noted, the proposed NSPS for IC ICE is on a output-basis. This regulatory change may make CHP a more attractive and competitive energy source.

The primary benefit of out-put based standards is that they as a form of pollution prevention in that they encourage energy efficiency.[551] More energy efficient technologies reduce fossil fuel consumption and concomitantly reduce adverse environmental impacts. In addition, output-based standards permit sources to use energy efficiency as a part of their emission control strategy, which can reduce compliance costs and lower emissions.

G. Co-Benefits

Lastly, in addition to reductions in pollution that contribute to ultrafine pollution, there are a number of co-benefits from adopting renewable energy strategies as well. These co-benefits include reduced ozone, and other criteria pollutants, regional haze, and visibility. Moreover, there are significant reductions in green house gases, like CO_2. Lastly such an approach will foster energy independence.

XII. Conclusion

As noted at the beginning of this article, the regulatory process under the federal CAA is an iterative one designed to result in continuing improvements over time and is driven by the NAAQS. In theory, goals like the NAAQS are established after public health, and other scientific inquiries, demonstrate adverse affects from certain pollution concentrations. Next emission reductions are determined through monitoring, emission inventories, and modeling. Finally, pollution control programs are developed and implemented to reduce pollution to levels where they will no longer adversely affect public health and the environment.

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550. Notice of Availability for Draft Guidance on Source Determinations for Combined Heat and Power Facilities Under the Clean Air Act New Source Review and Title V Programs, 66 Fed. Reg. 52,403, (Oct. 15, 2001).

551. Prevention of Significant Deterioration, Nonattainment New Source Review, and New Source Performance Standards: Emission Test for Electric Generating Units, 70 Fed. Reg. 61081, (Oct. 20, 2005) (to be codified at 40 C.F.R. pts. 51 and 52).

From 1970 until its most recent revision, the PM NAAQS standard has focused on a mass concentration basis. However, recent epidemiological studies indicate health effects on the general population at air particulate mass concentrations that lie significantly below the existing PM NAAQS. The main topic of interest related to these studies is the effect that ultrafine particles. If ambient ultrafine particles can induce such adverse responses, the question posed at the beginning of this article was whether a mass concentration standard was sufficiently protective of human health or whether a particle number concentration standard should be implemented instead. This article has set forth a convincing argument that the latter is more appropriate for adequately addressing the number concentration of ultrafine particles and should be implemented as the more protective regulatory standard in conjunction with a mass based concentration standard.

This article has cited a number of recent epidemiological and toxicological studies, which show the ultrafine fraction to be of most concern related to adverse health effects. Among other things, these studies show that ultrafine particles can act as a carrier to the deep lung for adsorbed reactive gases, transition metals, or organic compounds with the larger surface area of ultrafine particles transporting more toxic surface adsorbed materials. Deposition of inhaled ultrafine particles is very high in the respiratory tract. After deposition, ultrafine particles penetrate more rapidly into interstitial sites. Moreover, lung defense mechanisms that are normally effective for coarse and fine particles, are less effective for ultrafine particles.

Modeling runs, conducted as a part of this article show that the ultrafine fraction of concern is within the 0.1 to 0.01 range. Most of the particles within this range settle in the deepest regions of the respiratory tract. Moreover, there is very little, if any, clearance of particles once these particles are lodged in these regions.

The CAA is preventive in nature, and any NAAQS must provide a margin of safety for susceptible populations. Moreover, the case law demonstrates that EPA's decisions will be upheld if the agency's EPA's scientific judgments are rational. Given that the scientific community finds ultrafine particles to be a significant health concern, a number-based standard could to pass judicial scrutiny.

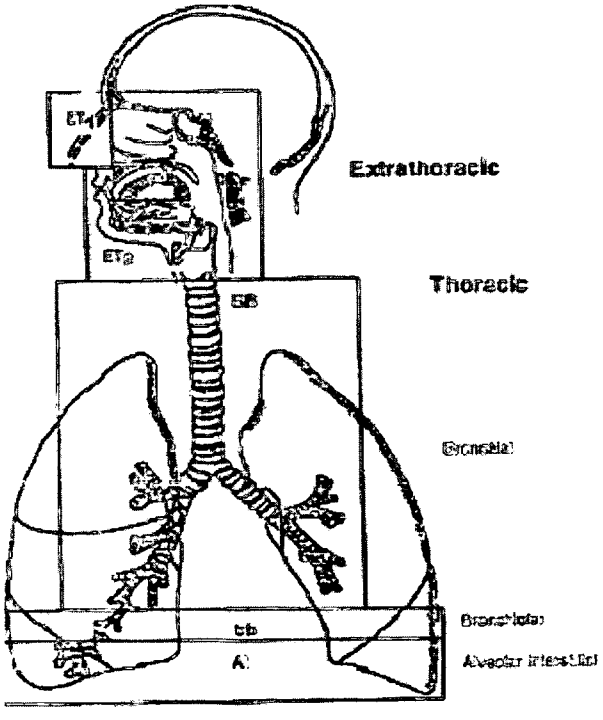
In selecting a NAAQS, a number-based standard would not replace the current PM standard, but rather would be in addition to the current standard. Since most data points to concerns related to ultrafine particles in the urban environment, the focus of a number-based standard should be for urban areas.

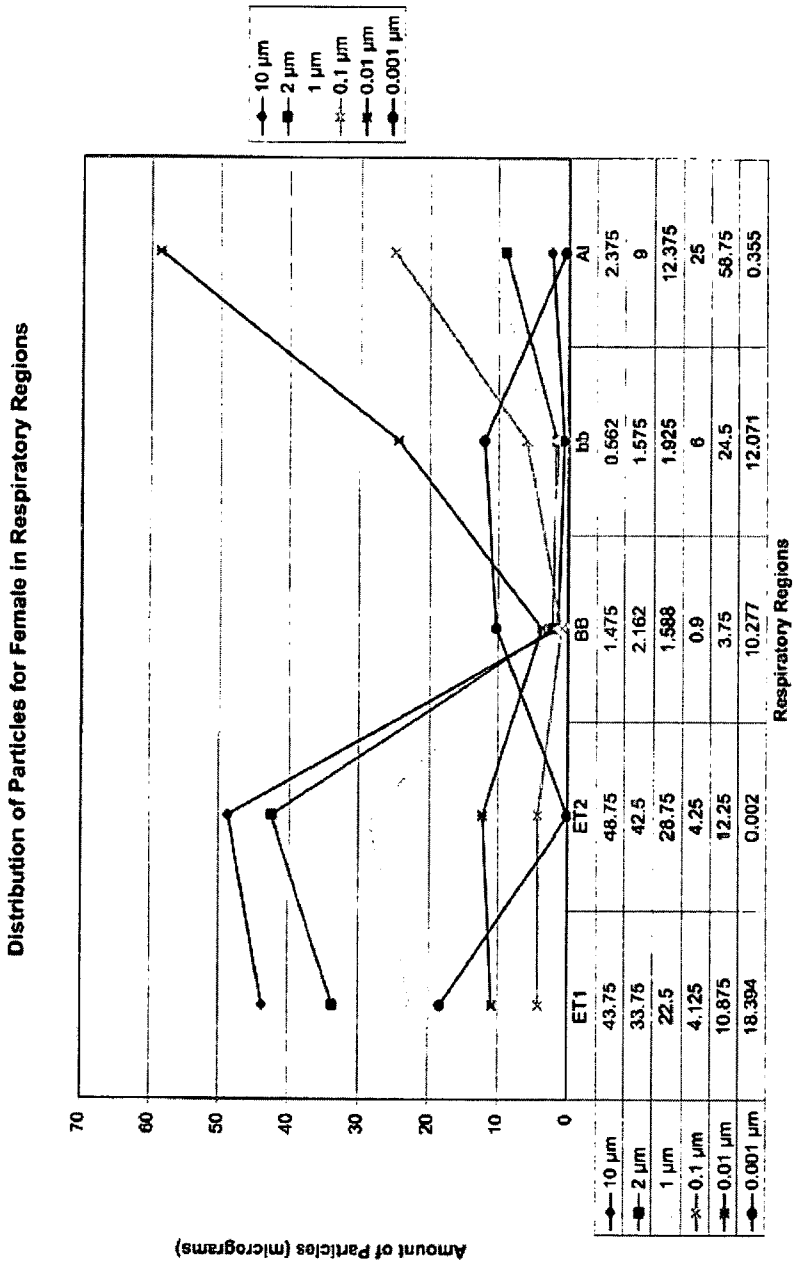
There are a large number of monitoring and modeling technologies that are now available to measure ultrafine ambient particle

concentrations. Therefore, the implementation of a number-based concentration standard from a planning and enforcement perspective won't be as difficult since some of these technologies are already available.

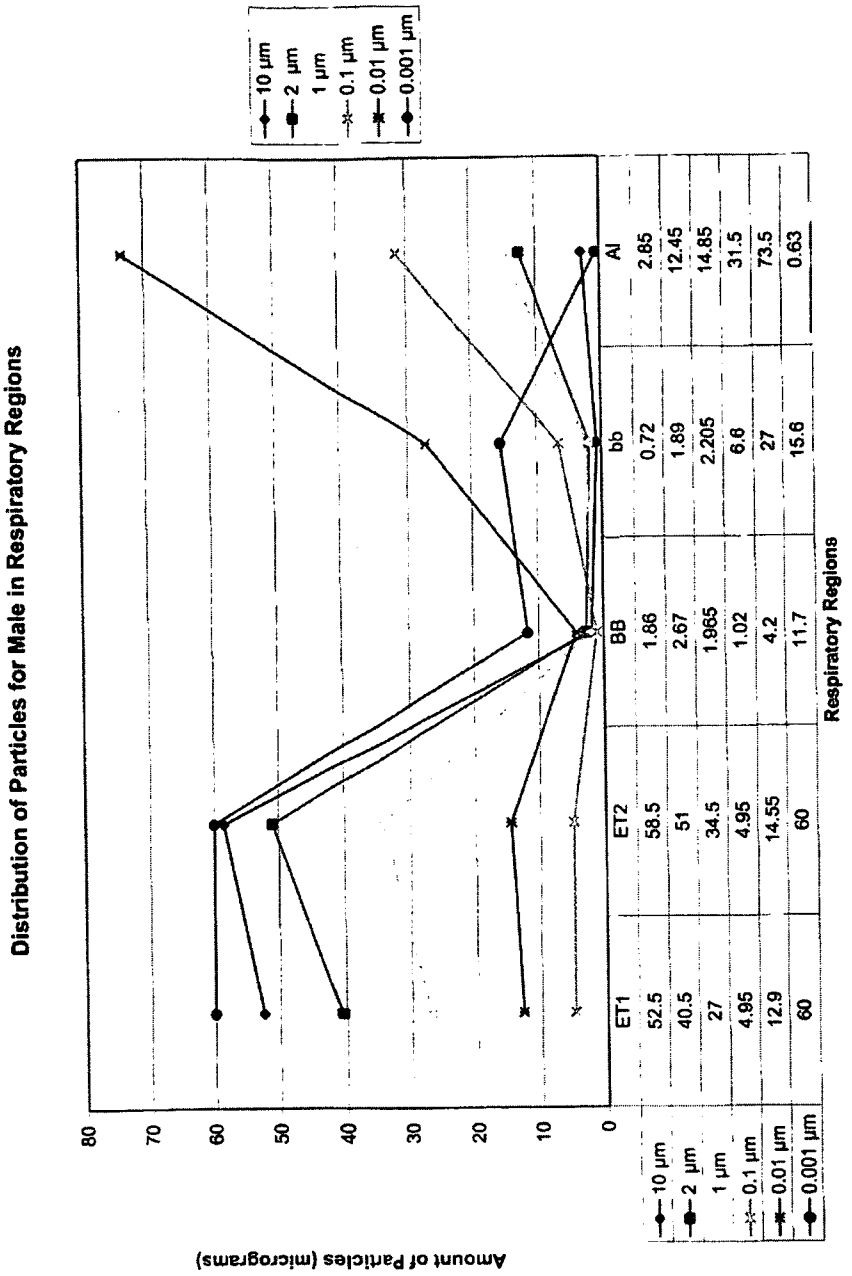
The largest sources of ultrafine particles are on-road motor vehicles, stationary source fuel combustion, non-highway mobile sources, and other industrial processes. There are a number of current technologies, which are available to reduce ultrafine emissions from these source categories. In addition, enhanced pollution prevention techniques may also play a vital role in reducing ambient particle concentrations.

Lastly, EPA could dispense with the piecemeal approach to regulating PM on a mass-based standard. As a result, a number-based standard would drive PM emissions down significantly and technologies would become more efficient.





	ET1	ET2	BB	bb	Al
10 µm	43.75	48.75	1.475	0.662	2.375
2 µm	33.75	42.5	2.162	1.575	9
1 µm	22.5	28.75	1.588	1.925	12.375
0.1 µm	4.125	4.25	0.9	6	25
0.01 µm	10.875	12.25	3.75	24.5	58.75
0.001 µm	18.394	0.002	10.277	12.071	0.355


Distribution of Particles for Male in Respiratory Regions
10 µm
2 µm
1 µm
0.1 µm
0.01 µm
0.001 µm
80
70
60
50
40
30
20
10
0
ET1
ET2
BB
bb
Al
52.5
58.5
1.86
0.72
2.85
40.5
51
2.67
1.89
12.45
27
34.5
1.965
2.205
14.85
4.95
4.95
1.02
6.6
31.5
12.9
14.55
4.2
27
73.5
60
60
11.7
15.6
0.63
Amount of Particles (micrograms)
Respiratory Regions