AIR POLLUTION: Particulate Matter

Before Black Lung, The Hawks Nest Tunnel Disaster Killed Hundreds

The construction of the Hawks Nest Tunnel, West Virginia in 1930

...almost 90 years ago, thick clouds of dust blurred the eyes and choked the lungs of workers inside the tunnel. The project attracted thousands of men, hoping to find work during the Great Depression. Three-fourths were African-Americans fleeing the South. Hundreds of workers would die after working in the tunnel from exposure to toxic silica dust, a mineral that slices the lung like shards of glass.
Bad Science Underlies EPA’s Air Pollution Program

The agency itself admits most emission factors are unreliable: It rates about 62 percent as “below average” or “poor.” Nearly 22 percent are not rated at all. About 17 percent earned grades of “average” or better and only one in six has ever been updated. There is a slew of common problems, such as poor accounting for emissions from aging equipment.

https://www.scientificamerican.com/article/bad-science-underlies-epa-s-air-pollution-program/


Particulate Matter

Particulate matter is the term used for a complex mixture of solid particles and liquid droplets found in the air.

TSP – Total Suspended Particles in air

- Air pollution regulations address two size categories of particles, PM10 and PM2.5.
- PM10 refers to particles less than ten microns in diameter (an average human hair is about 70 microns in diameter).
- PM2.5 refers to particles less than 2.5 microns in diameter, sometimes referred to as fine particles.

- Coarse particles mainly result from the break up of larger ones, fine particles are mainly formed by chemical reactions between gases and coagulation of even smaller particles and molecules.
- Most ultrafine particles in the urban area are anthropogenic origin
- Organic content of fine particles is generally greater than that of the coarse one.

World Business: Cement: A Global Pollutant
New York Times

- China produces and consumes 45 percent of the global output of cement.
- Cement plants account for 5 percent of global emissions of carbon dioxide.

Heavy dust from nearby cement factories fills the air in Daluotai Village in China's Liaoning province.  
Laborers transport cement powder at a freight dock

10 Worst Cities

Emission Density tons/square mile

- > 4
- > 3
- > 2
- > 1
- > 0

Source: Environmental Protection Agency

"Where Does Tread Rubber Go?"

"It is estimated that more than 600,000 metric tons of tire tread are worn off American vehicles every year. Instead of leaving black smudges on the highways, tiny particles of tread are worn off tires and are released into the air."

by Peggy J. Fisher President of Fleet Tire Consulting, Rochester Hills, MI

Particle and Fiber Toxicology Volume 2
Research Impact of tire debris on in vitro and in vivo systems
by Maurizio Gualtieri* et al
http://www.particleandfiberotoxicology.com/content/2/1/1

Over 80% of respirable particulate matter (PM_{10}) in cities comes from road transport and that tire and brake wear are responsible for the 3-7% emission of it.

TD has been investigated for its impact on human cell lines and on *X. laevis* embryos. TD eluates contain zinc, and we have demonstrated that this metal can accumulate in cells, and affect *X. laevis* embryos.
Road traffic has been highlighted as a major source of metal emissions in urban areas. Brake linings and tires are known emission sources of particulate matter to air; the aim of the current study was to follow the development of metal emissions from these sources over the period 1995/1998−2005, and to compare the emitted metal quantities to other metal emission sources. Stockholm, Sweden was chosen as a study site. The calculations were based on material metal concentrations, traffic volume, particle emission factors, and vehicle sales figures. The results for metal emissions from brake linings/tire tread rubber in 2005 were as follows: Cd 0.061/0.47 kg/year, Cu 3800/5.3 kg/year, Pb 35/3.7 kg/year, Sb 710/0.54 kg/year, and Zn 1000/4200 kg/year. The calculated Cu and Zn emissions from brake linings were unchanged in 2005 compared to 1998, indicating that brake linings still remain one of the main emission sources for these metals. Further, brake linings are a source of antimony. The results also showed that tires still are one of the main sources of Zn and Cd emissions in the city.

Gasoline consumption gets all the publicity, but in truth, cars use up a lot more than fuel. Tire treads and brake linings, for example, wear down over time, their component materials ending up in the environment in the form of tiny particles. -NY Times

Sizes of common airborne particles

- Rain
- Mist/Fog/Clouds
- Smog
- Coal dust
- Tobacco smoke
- Atmospheric dust
- Foundry dust
- Agriculture sprays
- Oil smoke
- Pollen
- Bacteria
- Viruses

Particle diameter in micrometers (\(\mu m\))
**Sources of fine particles**

- Primary fine particles are anthropogenic origin – tires, brakes, metal smelting etc.
- Soot particles from **incomplete combustion** also contribute (*Take a closer look at a diesel engine next time*) Most of this soot consists of organic compounds – much more than carbon particles.
- Aromatic hydrocarbons with at least seven carbon atoms that enter atmosphere (e.g. evaporation gasoline) form aerosols.
- The **organic content** of smaller particles is greater than the coarse ones
- Because of their small size their settling velocity is very small. Most of them remain suspended in air.

Settling velocity increases with square of particle radius

**Stoke’s Law**

If the particles are falling in the viscous fluid by their own weight, then we can derive their settling velocity by equating this frictional force with the gravitational force:

\[ V = \frac{d^2 g (\rho_p - \rho_f)}{18 \eta} = \frac{d^2 g (\Delta \rho)}{18 \eta} \]

where: \( V \) is the particles settling velocity, \( d \) is the diameter, \( g \) is the acceleration of gravity, \( \rho_p \) is the density of the particles, and \( \rho_f \) is the density of the medium (\( \Delta \rho = \rho_p \) since density of air is too small)

Note: \( V \) is proportional to density of particle and square of diameter
\( V \) increases with increasing diameter of the particle
Aerosol

(Aerosol: A dispersion of microscopic solid or liquid particles dispersed in gaseous medium)

- Sulfate aerosol from volcano eruption, fuel combustion and microbial activities.
- Sea salt aerosol from sea spray and bubble bursting
- Soot from fuel combustion
- Secondary organic aerosol from volatile organic compounds

Typical composition of fine aerosol

Aerosol Radiative Forcing: direct effect

The effect of aerosol on the energy flux of the atmosphere depends on particle size and composition.
- Dark particles (soot-containing) tend to absorb light, thus warming Earth’s atmosphere.
- Small particles tend to scatter light, thus increasing the albedo of the atmosphere.

Aerosol and cloud condensation nuclei (CCN)

- Cloud Condensation Nuclei (CCN) are particles that can become activated to grow to fog or cloud droplets in the presence of a supersaturation of water vapor.
- If the Earth’s atmosphere were totally devoid of particles, clouds could not form!
Mt. Pinatubo eruption made 1992 one of the coolest year

Largest eruption since 1912

Red line: modeled temperature changes
Blue line: temperature changes observed from meteorological ground stations

http://www.ngdc.noaa.gov/seg/hazard/stratoguide/pinfact.html
http://vulcan.wr.usgs.gov/Volcanoes/Philippines/Pinatubo/description_pinatubo.html

Sulfate aerosol

- Large amount of \( \text{SO}_2 \) is injected into the atmosphere from the force of the volcano eruption. (Also from the burning of sulfur rich fossil fuels)
- \( \text{SO}_2 \) can be converted to sulfate in gas and aqueous phase.
  \[
  \text{SO}_2 + \text{OH} + \text{M} \rightarrow \text{HOSO}_2 + \text{M}
  \]
  \[
  \text{HOSO}_2 + \text{O}_2 \rightarrow \text{HO}_2 + \text{SO}_3
  \]
  \[
  \text{SO}_3 + \text{H}_2\text{O} + \text{M} \rightarrow \text{H}_2\text{SO}_4 + \text{M}
  \]

Sulfate formation from biogenic gases

- Dimethylsulfide (DMS): \( \text{CH}_3\text{SCH}_3 \)
  - Marine origin
  - Oxidation of DMS \( \rightarrow \text{SO}_2 \rightarrow \) sulfate
- \( \text{H}_2\text{S} \)
  - Terrestrial origin
  - Produced by sulfate-reducing bacteria.

Neutralization of acids by ammonia results in the conversion of nitrates and sulfates

For example: \( \text{H}_2\text{SO}_4(aq) + 2\text{NH}_3(g) \rightarrow (\text{NH}_4)_2\text{SO}_4(aq) \)
Distribution of numbers of aerosol particles in a typical urban area

**Nuclei Mode:** Small particles (0.01 μm) are formed by the condensation of vapors of pollutants (Condensation of H₂SO₄ and soot particles)

**Accumulation Mode:** These small particles serve as nuclei and undergo coagulation followed by deposition of gaseous molecules. (Distribution peak 0.1 μm)

**Coarse Particle Mode:** Particles with distribution peak around 1 μm are mainly soot or materials produced from mechanical grinding. Larger particles quickly settle.

Distribution of numbers of aerosol particles in a typical urban area

Substances that dissolve into the body of the particle are said to be absorbed.

Those that simply stick to the surface are said to be adsorbed.
The average residence time for an aerosol particle

Distribution of Particle Volume (based on mass) for a typical urban model aerosol

- Number of particles does not represent the actual mass
- Both mass and volume are proportional to \((\text{radius})^3\)
- The mass distribution shows two peaks one centered around 0.3 \(\mu\text{m}\) and the other one at 7 \(\mu\text{m}\). These two peaks correspond to accumulation mode and Coarse Particle mode respectively. (Because of the small size, peak corresponding to nuclei mode is not seen.)
Air Quality

TSP Index: Total suspended particulates. It refers to total particulates suspended in air.

PM Index: Amount of particulate matter that is present in a given volume. Usually expressed as micrograms/m$^3$ ($\mu$g/m$^3$).

PM$_{10}$ (particles with diameters less than 10 microns) are considered inhalable. In urban air, a typical value for PM$_{10}$ is 20-30$\mu$g/m$^3$.

Since most of the fine particles in urban air are secondary, their number can only be controlled by reducing primary pollutants (NO, VOCs, and SO$_2$).

Haze

- Particles whose diameter is about that of the wavelength of visible light (0.4-0.8 $\mu$m) scatter light, thus reducing the visibility and amount of light reaching the ground. Indeed haziness can be used to measure the particulate pollution of air.
- Sulfate aerosols contribute to the winter haze in Russia and Europe (burning of coal) and summer haze in North America.

For more information see http://airnow.gov/

http://airnow.gov/
AQI: It measures how clean or polluted air is and informs the public to be aware of associated health concerns.

http://www.cbsnews.com/htdocs/dirty_airframesource_quality.html

Rooftops of Beijing's Forbidden City, obscured by thick smog, in Beijing, China.

http://www.theatlantic.com/infocus/2013/01/chinas-toxic-sky/100449/
Extensive studies have shown that particulate matter contributes to serious cardiovascular and respiratory problems, such as asthma and pulmonary dysfunction.

"With particle air pollution and greenhouse gas buildup, we're getting a double hit—we're in double jeopardy." ...Devra Lee Davis, director of the World Resources Institute's Health, Environment, and Development Program,


Atmospheric particles increase the risk of cardiovascular diseases and mortality.
- Particles penetrate the lungs, blocking and irritating air passages.
- Particles themselves could exert toxic effects. (toxic substances present in the particles) [Polycyclic Aromatic Hydrocarbons.]

Relation between PM2.5 and daily deaths in six US cities

Fine particles that originated from auto emissions and sulfate from burning of coal are responsible for increased mortality rate.

Cities with high PM$_{2.5}$ (~20mg/m$^3$) had 1.4% higher death rate than cities with 10mg/m$^3$.

A reduction in the particle level will result in 36000 fewer earlier deaths per year.

The shaded area represents uncertainty in data points.

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**TABLE 2-2: Air Quality Standards for Gaseous Pollutants**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Time Span to Average</th>
<th>U.S. EPA Standard</th>
<th>EU Standard$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO$_2$</td>
<td>1 day</td>
<td>140 ppb</td>
<td>47 ppb</td>
</tr>
<tr>
<td></td>
<td>1 year</td>
<td>30 ppb</td>
<td>8 ppb</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>1 hour</td>
<td></td>
<td>105 ppb</td>
</tr>
<tr>
<td></td>
<td>1 year</td>
<td>53 ppb</td>
<td>21 ppb</td>
</tr>
<tr>
<td>CO</td>
<td>1 hour</td>
<td>35 ppm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8 hour</td>
<td>9 ppm</td>
<td></td>
</tr>
<tr>
<td>O$_3$</td>
<td>1 hour</td>
<td>120 ppb</td>
<td>90–180 ppb</td>
</tr>
<tr>
<td></td>
<td>8 hour</td>
<td>80 ppb (proposed)</td>
<td>55 ppb</td>
</tr>
</tbody>
</table>

$^a$Some European Union standards allow exceedance of these values several times per year. E.U. values are for 20°C.
10,000 die from air pollution each year

2 February 2006

BRUSSELS — Alarming figures indicated on Thursday that more than 10,000 Belgians die prematurely each year due to fine particles in the air.

The revelations came as Belgium confronted its second day in succession of poor air quality due to high concentrations of fine particles.

The high level of pollution is being caused primarily by the current unusual weather situation, which is characterised by temperature inversions and low wind speeds.

The weather pattern has led to a reduced dilution of air pollution at various locations across the country. This has resulted in high concentrations of nitrogen oxides, carbon monoxide, benzene and fine particles.
WASHINGTON - Health problems linked to aging coal-fired power plants shorten nearly 24,000 lives a year, including 2,800 from lung cancer, and nearly all those early deaths could be prevented if the U.S. government adopted stricter rules, according to a study released Wednesday.

http://www.msnbc.msn.com/id/5174391/

WASHINGTON -- Trains and boats powered by diesel-fueled engines cause about 4,400 premature deaths, nearly 5,700 nonfatal heart attacks and more than 73,000 asthma attacks in children, says a study by associations representing air pollution control officials.

The study by the trade groups - the State and Territorial Air Pollution Program Administrators and the Association of Local Air Pollution Control Officials - is an attempt to prod the Environmental Protection Agency to make good on its promise of new regulations.

"These are among the largest and most dangerous under-regulated sources of pollution in the United States," Bill Becker, the executive director for both groups, said Thursday. "It is within EPA's power to avoid most of these premature deaths as well as most of the other adverse health consequences." The groups used an EPA formula for calculating health and economic impacts.

http://seattlepi.nwsource.com/health/1500AP_Diesel_Pollution.html
If the world community does nothing to reduce the combustion of fossil fuels, particulate matter could cause up to 8 million avoidable deaths between the years 2000 and 2020.


Some problems still persists……..

- Emission from diesel engines continue to emit – catalytic converters do not function well because of low temperature.
- Traps remove 90% of PM$_{10}$ emissions.
- Other measures are underway to reduce particle emission
WASHINGTON - The Environmental Protection Agency said Friday that marine and locomotive engines must meet tougher pollution controls, hoping for dramatic cuts in the amount of smog-causing chemicals and soot coming from trains, cargo ships, tugboats and passenger ferries.

The EPA regulation would require that new diesel engines used on ships and locomotives produce **90 percent less soot and 80 percent less smog-causing nitrogen oxide** beginning within six or seven years.

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**EPA orders ship, train pollution cuts**

**Environmentalists praise move to slash soot, smog emissions**

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**Heavy Duty Diesel Program**

**Since 2007, the pollution from new heavy-duty highway vehicles are reduced by more than 90%**.

**Lowering of Sulfur in diesel fuel**

**EPA now requires a 97 percent reduction in the sulfur content of highway diesel fuel from 500 ppm (low sulfur diesel) to 15 ppm (ultra-low sulfur diesel).**
Heavy Duty Diesel Program

Fully implemented plan:

• 2.6 million tons of smog-causing nitrogen oxide emissions will be reduced each year.

• **Soot or particulate matter will be reduced by 110,000 tons a year.**

• An estimated 8,300 premature deaths, 5,500 cases of chronic bronchitis and 17,600 cases of acute bronchitis in children will be prevented annually.

• An estimated 360,000 asthma attacks and 386,000 cases of respiratory symptoms in asthmatic children will also be avoided every year.

• 1.5 million lost work days, 7,100 hospital visits and 2,400 emergency room visits for asthma will be prevented.

http://www.epa.gov/otaq/highway-diesel/index.htm

The case for clean air


Dirty air really can shorten your life. A drop of just 10 micrograms per cubic metre in the concentration of airborne particulate matter less than 2.5 micrometres in diameter extends human life by an average of almost 7.5 months, according to a team led by Arden Pope of Brigham Young University in Provo, Utah.

Comparing data from surveys carried out in 1979–1983 and 1999–2000, the researchers charted improvements in pollution levels in 51 US cities. They then correlated that data with changes in life expectancy over the same period, using census and health survey data to factor out other variables such as population density, income and smoking.

http://today.msnbc.msn.com/id/28779476/
• Pollen, dust, dirt and other toxins can be present in the air inside a home which can make the simple task of breathing a hard feat for any allergy or asthma sufferer.
• The exposure to particles in the air can cause the symptoms of many respiratory conditions, even if a person does not normally suffer from any of these conditions.
• One of the easiest ways to keep a home’s indoor air clean and contaminant-free is with an air cleaner.
• Many products are able to fit snugly inside an air conditioning unit or a furnace.

….. Ways to avoid breathing of particles

Filters Out:
Hydrocarbons including Benzene & Pyrene, Nitrogen Oxides, Sulphur Dioxide, Lead Oxide and Black Smoke,
PM 10’s including Pollen Dust and Building Dust

Masks help breath cleaner air
- popular among cyclists in major cities

http://www.icanbreathe.com/
A combination photograph shows people wearing masks on a heavy smog day in Beijing, on January 29, 2013. (Reuters/Jason Lee)

As the Nanotechnology advances.............new environmental concerns arise

Toxic Potential of Materials at the Nanolevel

Andre Nel,1,2* Tian Xia,1 Lutz Mädler,3 Ning Li1

Nanomaterials are engineered structures with at least one dimension of 100 nanometers or less. These materials are increasingly being used for commercial purposes such as fillers, opacifiers, catalysts, semiconductors, cosmetics, microelectronics, and drug carriers. Materials in this size range may approach the length scale at which some specific physical or chemical interactions with their environment can occur. As a result, their properties differ substantially from those bulk materials of the same composition, allowing them to perform exceptional feats of conductivity, reactivity, and optical sensitivity. Possible undesirable results of these capabilities are harmful interactions with biological systems and the environment, with the potential to generate toxicity. The establishment of principles and test procedures to ensure safe manufacture and use of nanomaterials in the marketplace is urgently required and achievable.

SCIENCE 3 FEBRUARY 2006 VOL 311, p 622 www.sciencemag.org
Orbiting Junk, Once a Nuisance, Is Now a Threat

By WILLIAM J. BROAD  
Published: February 6, 2007  
New York Times

- There are more than 1300 spacecrafts orbiting earth -2/3 are inactive  
- 7000 pieces are large enough to be tracked  
- Satellite recently destroyed by China created more than 900 pieces.

Early this year, after a half-century of growth, the federal list of detectable objects (four inches wide or larger) reached 10,000, including dead satellites, spent rocket stages, a camera, a hand tool and junkyards of whirling debris left over from chance explosions and destructive tests.
Coke producers in East Chicago, Indiana, were fined $5 million by the Environmental Protection Agency this week for air pollution violations. US Army Corps of Engineers, Chicago District

A facility like a chemical plant or a factory is classified as “major” by the Clean Air Act if it has the potential to emit more than 10 tons of an individual toxic chemical or 25 tons of a combination of toxics into the air per year. Those that cross this line have to deploy the “maximum achievable control technology” (MACT) to reduce pollution as much as possible with the best hardware that’s available.


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March 23, 2006 – Carbon Cloud Over A Green Fuel by Mark Clayton – Christian Science Monitor – An Iowa corn refinery, open since December, uses 300 tons of coal a day to make ethanol.