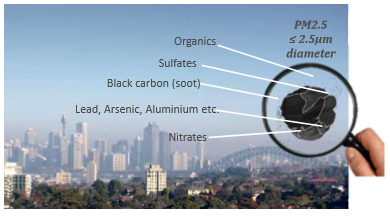
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| Fine Particle Pollution: Combustion |
| Information Processing and Data Analysis |
| **Student Worksheet**  This document and its accompanying Excel workbook provide the opportunity to process and analyse authentic scientific data created at ANSTO.  The authentic data provides records from 1998 to 2019 of the concentration of 12 elements present in fine airborne particulate matter, from an air sampling station located in Mayfield in Newcastle, NSW.  Students will:   * construct graphs using Excel * analyse their graphs to determine the trends of fine particle pollution in Newcastle * process information from suggested videos and background information to determine the source/s of the fine particle pollution and answer the questions provided   **The activities address these Australian Curriculum Science Understanding and Inquiry Skills.**  **Students:**   * understand that chemical reactions, including combustion and the reactions of acids, are important in both non-living and living systems and involve energy transfer [(ACSSU179)](http://www.scootle.edu.au/ec/search?accContentId=ACSSU179) * analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies [(ACSIS169/ 203)](http://www.scootle.edu.au/ec/search?accContentId=ACSIS169) * critically analyse the validity of information in primary and secondary sources and evaluate the approaches used to solve problems [(ACSIS172/ 206)](http://www.scootle.edu.au/ec/search?accContentId=ACSIS172) * communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations [(ACSIS174/ 208)](http://www.scootle.edu.au/ec/search?accContentId=ACSIS208)   **These activities are suitable for students in Years 9 to 12.** |
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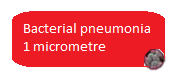
# The dirty facts of fine particle pollution

The presence of atmospheric particulate matter (APM) pollution in high concentration is generally referred to as haze or smog because of their effect on visibility. The particles range in size, but those with a diameter of 2.5 micrometres or less (PM2.5), which is about half the diameter of a red blood cell, are classified as fine particles.

Fine particle pollution is generated by urbanisation, industrial processes, motor vehicles, coal-fired power stations, wood burning heaters and other man-made sources. Fine particles are also generated by natural events such as volcanic eruptions, bushfires and dust storms, produced when strong winds lift large amounts of sand and dust from bare, dry soils into the atmosphere. Bushfires are most common in the summer months in NSW, but tinder-dry, warmer-than-usual conditions can mean that the bushfire danger period can start as early as August and extend through to April. The small size of fine particles means they can remain suspended in the atmosphere for days, even weeks, and can be easily transported over long distances across international borders and around the globe by winds and air currents.







High concentrations of fine particles in the atmosphere are a significant contributor to reduced visibility because they are very efficient in either scattering or absorbing light, depending on the particle. This visual degradation is sometimes called haze or smog. When the visual degradation is influenced by high concentrations of salts particles (such as sea spray, sulfates and nitrates) which strongly scatter light, it appears as a white coloured haze. On the other hand, a dark visual degradation typically seen across urban skylines is often referred to as smog (a descriptive term combining the words *smoke* and *fog*), and is strongly influenced by the presence of **black carbon** (BC), which is an efficient light absorber. Other terms later coined include “sulfurous smog” and “photochemical smog”. Sulfurous smog is associated with high concentration of sulfur oxides (SOx) and humidity in the air which react to form fine sulfate particles. Photochemical smog is associated with large amounts of nitrogen oxides (NOx) and volatile organic compounds (VOC) primarily emitted from vehicles, particularly diesel-fuelled vehicles, which react in the presence of sunlight to form ground level ozone, nitrogen dioxide and nitrate particles. The combination of these secondary reaction products with primary BC particles co-emitted from the same vehicles produces the brown coloured smog synonymous with many traffic-congested city skylines.

The photographs below show Sydney, Australia, on clear and polluted days.





In addition, the light absorbed by black carbon particles is re-radiated as heat which can contribute to environmental warming effects in a number of ways. If there is a lot of black carbon in the air at the altitude where clouds are forming, it can cause premature cloud evaporation which contributes to global warming, as clouds are needed to reflect a significant amount of solar radiation back to space. The premature evaporation of clouds also impacts our environmental climate by modifying weather patterns. Atmospheric particles are known as short-lived climate pollutants, because unlike greenhouse gases such as carbon dioxide, they can only remain suspended in the atmosphere for up to a few weeks before falling to earth with either gravity or rain. Black carbon particles that fall out of the atmosphere onto regions of snow and ice, darken the surface reducing their albedo (the reflecting power of a surface) which can accelerate melting.

Measuring the black carbon (BC) concentration gives an indication of the amount of soot present in the atmosphere. Black carbon is mainly produced by biomass burning and incomplete or inefficient combustion processes in motor vehicles, especially diesel powered vehicles. Incomplete combustion occurs when there is not enough oxygen present. So for the incomplete combustion of hydrocarbon fuels, such as petrol and diesel, water is still produced, but carbon monoxide and carbon are produced instead of carbon dioxide. Domestic wood (biomass) burning heaters are a major source of black carbon (BC) fine particle pollution in wintertime.

Biomass burning also contributes to a fine particle source known as **smoke**, which typically contains BC and potassium (K) as two key elemental components. Smoke is often produced by bushfires in summer and hazard reduction burning, as well as wood burning heaters used for domestic heating in winter. During these colder months, once the sun goes down, the ground loses heat very quickly and this cools the air that is in contact with the ground. However, the air above remains warm, known as an inversion layer, and acts like a lid trapping the cooler air at the surface instead of dispersing it higher in the atmosphere. So on a still, cold winter’s night, smoke particles from wood burning heaters become trapped in the cold air close to ground level making the air we breathe much more polluted.

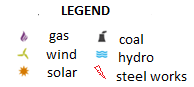
Many fine particles form in the atmosphere as a result of complex chemical reactions. One such particle is **ammonium sulfate**. These particles originate from sulfur dioxide gas which is released into the atmosphere when fossil fuels containing sulfur are burned, and from [metal smelting](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/metal-smelting) and other industrial processes. High concentrations of sulfur dioxide are created through burning coal and oil for electricity generation in power stations.Sulfur dioxide is also present in motor vehicle emissions as the result of fuel (petrol and diesel) combustion. In January 2002, the Australian Government introduced a fuel quality standard for petrol, limiting the amount of sulfur in unleaded petrol (ULP) to 500 mg/kg and 150 mg/kg in premium unleaded petrol (PULP). The sulfur standard in ULP was adjusted to 150 mg/kg in 2005 and, in 2008, the sulfur standard in PULP became 50 mg/kg. This is still much greater than the European fuel sulfur standard which has been capped at 10mg/kg since 2009. In the atmosphere, sulfur dioxide gas reacts with other chemicals forming [sulfuric acid](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/sulphuric-acid). The sulfuric acid then undergoes a neutralisation reaction with ammonia present in the atmosphere to produce fine particle ammonium sulfate. If there is not enough ammonia in the atmosphere to fully neutralise the sulfuric acid, ammonium hydrogen sulfate (also known as ammonium bisulfate) is formed.

Fine PM2.5 particles pose a hazard to human health because their small size means they easily bypass our body’s natural defences, where they can enter deep into the lungs and have direct access to the bloodstream, as fine particles are about half the size of a red blood cell. There is a growing body of evidence strongly linking the inhalation of fine particle air pollution to a range of serious human health problems including respiratory disease and infection, cardiovascular disease and stroke. Fine particle pollution has also been linked to premature death. This has led to the Australian National Environment Protection Council (NEPC) recommending goals of an annual average mass of fine particle pollution of 8μg/m3 (1 μg = one millionth of a gram) and a maximum mass over any 24 hour period of 25μg/m3.

# Method and study site

The data for this activity (Fine Particle Air Pollution Mayfield Data Excel Workbook) were collected at an air sampling station located in Mayfield, one of Newcastle’s older suburbs, between 1998 and 2019. Newcastle is situated on the east coast of NSW, about 150 km north of Sydney. This region was developed as an area for heavy industry, specifically for iron and steel making and steel products, non-ferrous metal manufacture, chemical and fertiliser manufacture, petroleum and coal-tar products. Significant tonnes of coal are also exported annually from Australia to Asia through the port of Newcastle. Mayfield is close to the highly industrialised areas and the port of Newcastle.

Newcastle is also in the vicinity of five coal-fired power stations. Two of these, Vales Point and Eraring, are located near Lake Macquarie on the central coast, Bayswater and Liddell power stations are located near Muswellbrook, and Mt Piper power station is located near Portland (close to Wallerawang) (Figure 1).



|  |  |
| --- | --- |
| 1996 | 2001 |
|  |  |
| 2012 | 2019 |
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Figure 1. Maps showing changes in energy production and industrialisation around the Newcastle area (<https://www.aemc.gov.au/energy-system/electricity/changing-generation-mix/nsw>)

Many changes have occurred in the area around Newcastle over the time of the data sampling. In October 1999, a major industrial iron and steel works plant in Newcastle closed, shutting down its blast furnaces. There were also closures of three coal-fired power stations in the vicinity of Newcastle. In July 2012 the coal-fired generators of the Munmorah power station, located near Doyalson in NSW, were permanently shut down. The Redbank power station, which began operating near Singleton in 2000, closed in August 2014, and Wallerawang C power station closed down in November 2014 after operating for around 56 years. The ageing 50 year old Liddell plant, is due to shut during the 2022-23 summer months.

Some extreme natural events such as dust storms and bushfires have also taken place over the sampling period. During September 2009, winds swept millions of tonnes of red dust from inland NSW to the coast. Severe bushfires occurred in the Hunter region around Newcastle in January 1998, December 2001 and January 2002, from July 2002 to February 2003 (which produced 151 days of severe fire activity), and most recently throughout December 2019 and January 2020. These bushfires significantly increased smoke and black carbon fractions of fine particle pollution, with these extreme events being observed as individual spikes above long-term seasonal trends in the data.

A team of scientists at ANSTO, Prof David Cohen, Dr Armand Atanacio and Dr Madhura Manohar, have been measuring and characterising fine particle pollution from key sites around Australia, including Mayfield, for more than 30 years. They collect the fine particulate matter on thin Teflon filters and then analyse them using ion beam analysis (IBA) techniques on the STAR accelerator, a 2 million volt tandem accelerator. The STAR accelerator is a super sensitive instrument that can measure parts per million concentrations of elements in the very small microgram samples collected. It can simultaneously determine 21 key air pollution elements collected on each filter. Ion beam analysis is non-destructive and requires no additional sample preparation. It takes only 5 minutes per filter for the IBA analysis to be completed, making it an ideal technique for the hundreds of samples collected each month as part of the ongoing research program. Using powerful statistical analysis techniques on the IBA elemental data, the scientists can identify the sources of these fine particles.



*Exposed stretched Teflon*

*filter, specifically designed*

*for IBA analysis*

All values given in the spreadsheet (Fine Particle Air Pollution Mayfield Data Excel Workbook) are the concentrations of PM2.5 fine particle pollution and are measured in nanograms (1 ng = one billionth of a gram) per cubic metre of air sampled (ng/m3). The air was sampled over a 24 hour period (from midnight to midnight) every Wednesday and Sunday. Each filter was analysed for the concentration of key elements. The concentrations provided in the table are averaged over the month for each key element examined. The data presented are the mean absolute concentrations of PM2.5 atmospheric particles for each month.

# Fu**rther background reading for students**

Before beginning the information and data analysis tasks, read the background information provided (“*The dirty facts of fine particle pollution”* and “*Method and study site”*) and view the videos listed below.

Use the information presented in these sources to assist you in answering the questions in the tasks.

1. <https://www.ansto.gov.au/research/programs/other/aerosol-sampling-program>

* a video of Prof David Cohen introducing fine particle pollution and revealing the sources of Sydney's air pollution
* a video on how fine particle samples are collected

1. <https://www.ansto.gov.au/2mv-star-tandem-accelerator>

* ANSTO STAR accelerator animation
* SBS The Crew learn about ANSTO's STAR Accelerator video

1. <https://www.ansto.gov.au/ion-beam-analysis>

* Ion beam analysis simulation
* particle induced X-ray emission (PIXE) and particle induced gamma ray emission (PIGE) simulation

1. <https://www.youtube.com/watch?v=CcPJjlQpl8Y>

# Smoke Pollution Levels in Sydney 2019: Prof David Cohen

# Fine Particle Pollution: The effect of combustion

1. Fine particle pollution consists of particles having a diameter of 2.5 micrometres or less. How many fine particles of size 2.5 micrometres would line up across the diameter of a human hair shown below?



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1. Describe how the process of Ion Beam Analysis is used to determine the key air pollution elements collected on each filter.

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1. When analysing the filter samples, those with incorrect exposure time, excessively high or low air flow rates or those damaged during handling were rejected.

In terms of scientific method, explain why this was done.

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1. Sulfur dioxide gas is released into the atmosphere due to emissions from coal burning, industry and cars. In the atmosphere, sulfur dioxide reacts with other chemicals to form [sulfuric acid](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/sulphuric-acid), which undergoes a neutralisation reaction with ammonia present in the atmosphere forming fine particle ammonium sulfate.

Write a word equation (or a completely balanced chemical equation) to represent the chemical reaction that produces particulate ammonium sulfate, and explain why this reaction is classed as a neutralisation reaction.

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1. Write a word equation (or a completely balanced chemical equation) for the reaction that occurs when there is not enough ammonia in the atmosphere to fully neutralise the sulfuric acid.

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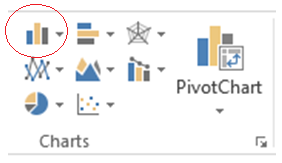
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1. Construct a 2D clustered column graph to show the concentration of ammonium sulfate in sampled air from 1998 to 2019.

Label your axes and include units. Give your graph a title.

**HINT:** You can use the following steps to create your chart:

1. Highlight all the data in **column A ‘1998-2019’**, by moving the cursor to the first date, Feb-98 (cell A8) and clicking and dragging the cursor down to the last date, Dec-19 (cell A267).
2. Hold down the control button and highlight all the data in **column C ‘(NH4)2SO4’** highlighting from cell C8 to cell C267.
3. On the **Insert** tab, in the **Charts** group, click the **column graph** symbol.



1. Choose **2D clustered column graph** (first graph under 2D column heading).
2. Add axes titles and chart title. Add the title *Month-Year* for Primary Horizontal axis and the title *mean monthly concentration of PM2.5 ammonium sulfate (ng/m3)* for the Primary Vertical axis.

Add the chart title *Ammonium sulfate PM2.5 concentration in air sampled at Mayfield from 1998 to 2019*

(For Excel 2013, click on your scatter graph and then click on **Design** tab in **Chart Tools**. **Add Chart Elements** appears on left hand side of tool bar. Click here for **Axis Titles** and **Chart Title**.)

1. Right-click the **x axis labels** (horizontal axis) and select **Format Axis** in the dialog box. For **Axis position** choose **On tick marks**. Click on **LABELS** select **specify interval unit** and type 6 in the box. Press **ENTER**.
2. To remove decimal points from y axis scale, right-click the **y axis labels** (vertical axis) and select **Format Axis** in the dialog box. Click on **NUMBER** and for **decimal places** type 0 in the box.
3. Consider the concentration of PM2.5 ammonium sulfate over the last decade, from Jan 2009 to Jan 2019. Suggest a possible reason for the observed seasonal variations.

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1. Account for any observed trend in the concentration of PM2.5 ammonium sulfate from 1998 to 2019.

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1. Smoke is produced when biomass is burned. What is meant by the term ‘biomass’?

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1. Construct a 2D clustered column graph to show the concentration of **smoke** in sampled air from 1998 to 2019.

Label each of your axes and include units. Give your graph a title.

**HINT:** Follow the instructions on pages 9 and 10, but for step 2 hold down the **control** button and highlight all the data in **column H ‘smoke’**, highlighting from cell H8 to cell H267.

Add appropriate axes titles and a chart title.

1. Identify the times when smoke concentrations around Mayfield are highest, above 50 ng/m3. Provide a possible explanation to account for the presence of significant smoke during these times.

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1. Black carbon concentration gives an indication of the amount of soot that is present in the atmosphere. Soot is mainly produced by motor vehicles and biomass burning.

Explain how soot is produced by motor vehicles. Include a word equation (or a completely balanced chemical equation) in your answer.

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1. Construct a 2D clustered column graph to show the concentration of Black Carbon (BC) in sampled air from Jan 2015 to Dec 2019.

Label your axes and include units. Give your graph a title.

**HINT:** You can use the following steps to create your chart:

1. Highlight the required data in **column A ‘1998-2019’** by moving the cursor to the date Jan-15 (cell A208) and clicking and dragging the cursor down to the last date, Dec-19 (cell A267).
2. Hold down the control button and highlight the required data in **column F BC** highlighting from cell F208 to cell F267.
3. On the **Insert** tab, in the **Charts** group, click the **column graph** symbol and choose **2D clustered column graph** (first graph under 2D column heading).
4. Add appropriate axes titles and a chart title.
5. Right-click the **x axis labels** (horizontal axis) and select **Format Axis** in the dialog box. For **Axis position** choose **On tick marks**. Click on **LABELS** select **specify interval unit** and type 2 in the box. Press **ENTER**.
6. To remove decimal points from y axis scale, right-click the **y axis labels** (vertical axis) and select **Format Axis** in the dialog box. Click on **NUMBER** and for **decimal places** type 0 in the box.
7. Account for any seasonal variations in the concentration of Black Carbon from 2015 to 2019.

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1. You have been appointed as a consultant to the Pollution Management Committee for the City of Newcastle.

What recommendations would you make in order to reduce fine particle pollution and improve the air quality in the Newcastle region? Justify your recommendations.

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1. Why should ANSTO continue to monitor the fine particle pollution in the Newcastle area as well as other urban areas?

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