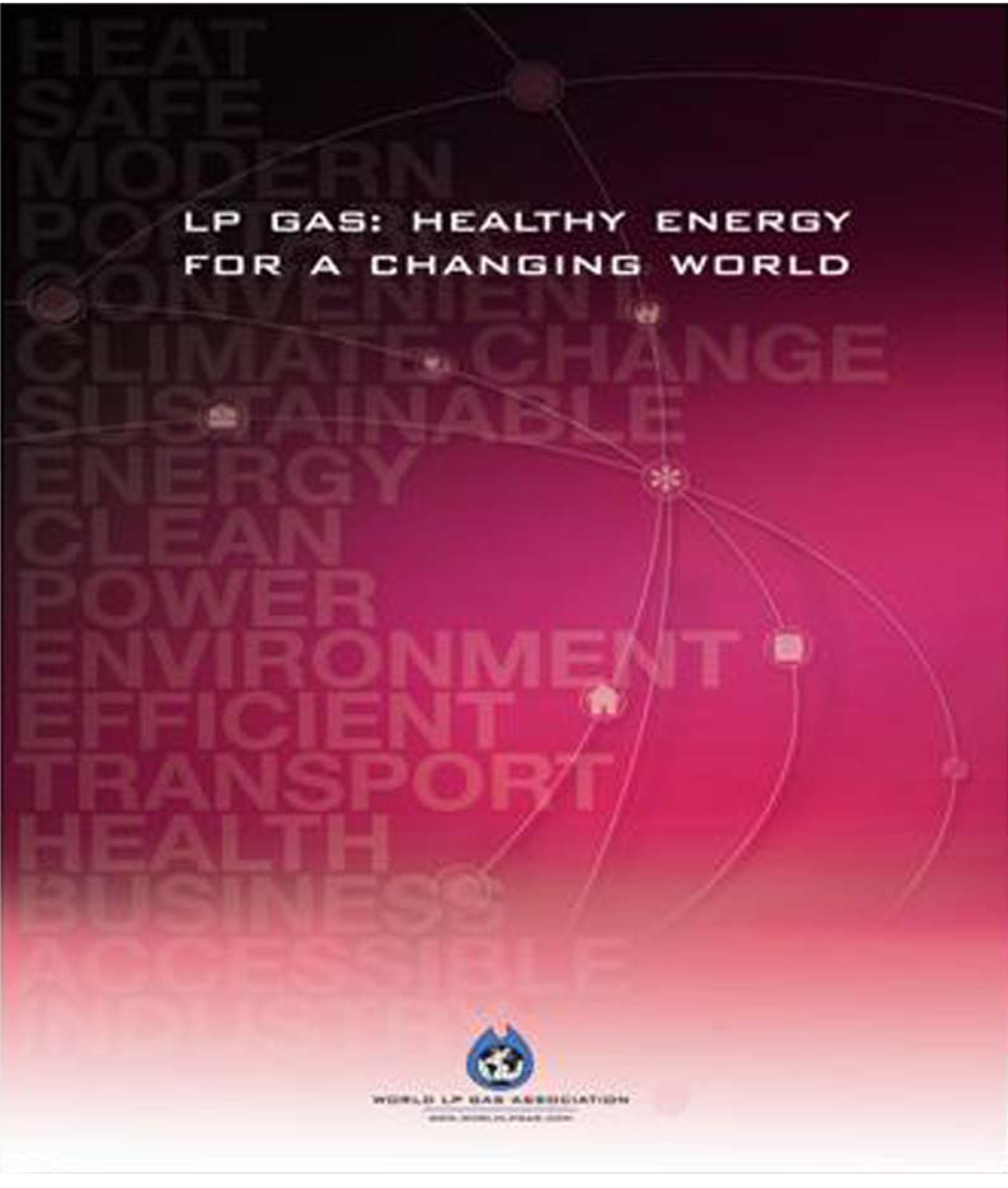


LP GAS: HEALTHY ENERGY FOR A CHANGING WORLD

WORLD LP GAS ASSOCIATION
www.worldlpgas.com

LP GAS: HEALTHY ENERGY FOR A CHANGING WORLD

FOREWORD BY THE WORLD LP GAS ASSOCIATION (WLPGA)

Energy is essential for our very existence, yet for all the invaluable benefits that energy brings, its consumption can generate harmful pollutants which affect the air we breathe, our waterways and the soil which provides our food. But not all energy sources have the same potential to affect our health, so it is important that consumers are informed and able to choose cleaner fuels to meet their energy needs.

This study, which draws on data from a wide range of independent studies into the impact of energy-related pollution on human health, demonstrates that Liquefied Petroleum Gas (LP Gas) can help to reduce human exposure to many of the most harmful pollutants, in many applications and regions around the world today.

LP Gas is a clean-burning and efficient fuel. It is also a vital source of energy for hundreds of millions of people throughout the world today. It is a modern and safe fuel, providing heat and power to both urban and rural consumers. LP Gas can be used anywhere and is available now, without large investments in technology and infrastructure. It is a multi-purpose energy with literally thousands of applications. It is portable; and so can be transported, stored and used virtually anywhere in the world, with sufficient reserves to last for many decades.

The World LP Gas Association (WLPGA) is the global voice of the LP Gas industry. Granted consultative Status with the United Nations Economic and Social Council in 1989, the WLPGA promotes the use of LP Gas worldwide to help foster a cleaner, healthier and more prosperous world.

This report complements two other WLPGA publications which address Energy Efficiency and Climate Change issues.

Acknowledgements

The author extends special appreciation to David Tyler of the WLPGA for his excellent advice, diligence and his patience as the coordinator of this project.

Thanks are also due to the following members of WLPGA's Expert Panel, for their guidance and most useful feedback during the course of drafting this document.

Joaquim Cardigos	Repsol
Kimball Chen	Energy Transportation Group
Tony Dale	Ferrellgas
Arnaud Duvielguerbigny	AEGPL
Mauricio Jarovsky	Ultragaz
Sunil Kakar	BP
Greg Kerr	PERC
Ian Maloney	ELGAS
Ian McCracken	SHV Gas

This study was authored by Peter Anyon

April 2009

Table of Contents

Overview 6

Key Findings 9

1 What is LP Gas? 10

2 Policy and Economic Overview 11

2.1 Pricing Policy 11

2.2 Public Health 12

2.3 Climate Change 12

3 How Pollutants Can Affect Human Health 14

3.1 Health Effects of Individual Pollutants 15

3.1.1 Which Pollutants are Most Important? 15
3.1.2 Particulate Matter (PM) 15
3.1.3 Nitrogen Oxides (NOx) 16
3.1.4 Hydrocarbons (HC) (also referred to as Volatile Organic Compounds (VOC) 17
3.1.5 Ozone (O_3) 17
3.1.6 Carbon Monoxide (CO) 17
3.1.7 Sulphur Dioxide (SO_2) 17
3.1.8 Which Fuels? 18
3.1.9 Air Toxic Compounds 19

4 Quantifying Health Impacts 20

4.1 Background 20

4.2 Health Cost Impacts 22

5 LP Gas in Key Applications 25

5.1 Road Transport 26

5.2 Cooking 36

5.3 Residential Space and Water Heating 38

5.3.1 Indoor Air Quality 38
5.3.2 Outdoor Air Quality. 39

5.4 Electrical Power Generation 41

5.4.1 Medium Capacity Generator Sets 42
5.4.2 Small Generator Sets 44

5.5 Other LP Gas Applications 45

6 Conclusions 48

7 Annex A1 - Pollutants and their Health Effects 50

7.1 Regulated (Criteria) Pollutants 50

7.1.1 Particulates (PM) 50
7.1.2 Oxides of Nitrogen (NOx) 51
7.1.3 Volatile Organic Compounds (VOCs), including Hydrocarbons (HC) 52
7.1.4 Ozone (O_3) 52
7.1.5 Carbon Monoxide (CO) 53
7.1.6 Fuel Sulphur Content and Sulphur Dioxide (SO_2) 54

7.1.7 Lead (Pb) 56
7.2 Air Toxic Compounds 56
7.2.1 Benzene 58
7.2.2 1,3-Butadiene 59
7.2.3 Polycyclic Aromatic Hydrocarbons 59
7.2.4 Toluene 59
7.2.5 Xylenes 60

8 Annex A2 - Ambient Air Quality Standards 61

8.1 Background 61
8.2 Air Quality Standards and Regulations 61

9 Annex A3 –Particle Emissions from Current Technology Engines 64

10 References 66

11 Glossary of Terms 68

Overview

Energy brings life to the world. Every person on this planet, wherever they live, depends every day on energy to feed and nurture their families, to provide heat and light, and to transport goods and people to their destinations. But generating energy can also generate pollution which can be very harmful to human health. Fortunately, some fuels burn much more cleanly and have greatly reduced potential to affect human health.

Liquefied Petroleum Gas (LP Gas) is one of these fuels. The World Health Organisation, in a recent report which evaluates strategies to avoid the devastating health consequences of exposure to wood-fire cooking in poorer countries, had this to say about the value of switching to LP Gas:

> *"...**investing US$13 billion per year to halve, by 2015, the number of people worldwide cooking with solid fuels by supplying them with liquefied petroleum gas, shows a payback of US$91 billion per year."*** (WHO, 2006)

One of the most dangerous pollutants from combustion sources is fine particulate matter (PM), which can penetrate deep into human lungs, causing respiratory illnesses, heart disease and neurological problems. Reducing exposure to PM is the highest air quality priority for most countries in both developed and developing regions. A recently completed study by the Harvard School of Public Health and Brigham Young University (Pope, 2009) emphasises this point, when they found that:

> *"**...for every decrease of 10 micrograms per cubic meter of particulate pollution in a city, its residents' average life expectancy increased by more than seven months."***

To put this in context, Paris has an ambient PM concentration of around 15 micrograms per cubic metre ($\mu g/m^3$). In some Asian cities the level can rise to above 100 $\mu g/m^3$, and in a dwelling where indoor wood fire cooking takes place, the level can be an order of magnitude higher again. PM emissions from combustion of LP Gas are typically around 1000 times lower than wood burning, and can be 100 times lower than combustion of diesel fuel.

This independent report, commissioned by the World LP Gas Association (WLPGA), explores and compares the health impacts on society caused by pollutants emitted by a range of commonly used fuels. Where it is feasible and relevant to do so, estimates are also made of the direct and indirect economic costs associated with these health effects. As part of a trilogy of related documents, this report complements two other WLPGA publications which address Energy Efficiency and Climate Change issues.

In these more enlightened times we now recognise that the fuels we use to provide this energy must also respect the environment and the well-being of people living on this planet, as well as satisfying our energy needs.

Our understanding of how air pollutants affect human health has greatly improved. With this understanding we can estimate the economic costs associated with medical care, lost productivity and the provision of social services to support those affected.

Hundreds of pollutants have potential to damage human health. Of these, the United States Environmental Protection Agency (EPA) has identified six, referred to as "criteria pollutants" as being the highest priority. The pollutants are:

- ground-level ozone (O_3)
- sulphur oxides (SOx)
- carbon monoxide (CO)
- nitrogen oxides (NOx)
- lead (Pb)

- particulate matter (PM)

Because of their role in the formation of ground level ozone, volatile organic compounds (VOCs) are also widely regulated. Many dangerous compounds classed as “air toxics” are also categorised as VOCs.

Health damage caused by exposure to these pollutants generates a huge social and economic burden for society, running into hundreds of billions of dollars every year.

For PM alone, an extensive European Union research project on the health impacts of airborne particles, completed in 2005 by the World Health Organisation (WHO), emphasises this point. The researchers’ findings are both clear and very disturbing:

> ***“Air pollution from particulate matter (PM) claims an average of 8.6 months from the life of every person in the European Union (EU)”*** *(WHO, 2005-1)*

The same WHO report concluded that exposure to fine particles in the EU resulted in avoidable economic costs in the range €58 billion to €161billion annually.

Sources of energy-related pollution are numerous. In terms of human activity transport, industry, power generation, domestic cooking/heating and deforestation burning are the most prevalent. Volcanic activity and naturally occurring forest/grassland fires can also be the cause of major pollution episodes, but society has only very limited ability to mitigate the consequences of these events.

In many poorer countries, cooking over an open fire using wood, charcoal, crop waste or even animal dung has a devastating impact on human health. Exposure to the extremely high levels of pollutants emitted by these fires is reported by the WHO and other independent researchers to cause the premature deaths of more than 1.5 million people every year. Women and young children are those most greatly affected.

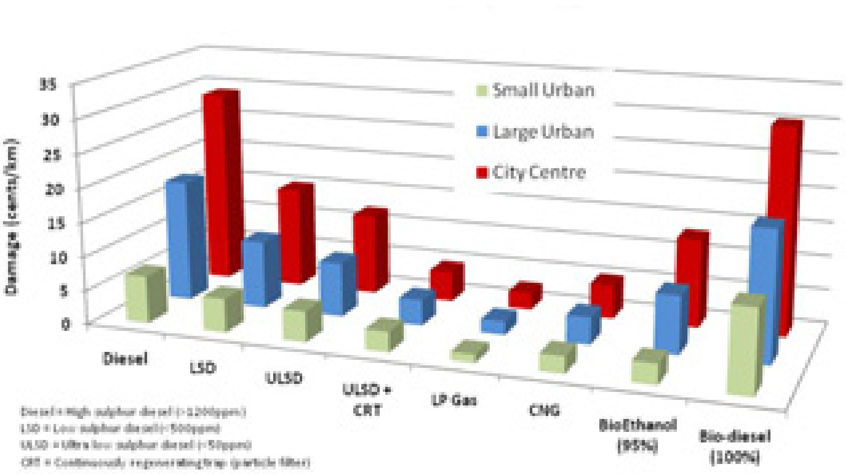
On a broader front, traditional liquid fuels such as gasoline (petrol), diesel and kerosene, have complex chemical structures. When burned, these fuels can release a range of harmful compounds; some of which are linked to serious and frequently life-threatening illnesses.

The types of fuel used and the way they are employed may vary from one region to another but the pollution they produce, and the health consequences that follow, exist at every level of society, in the poorest to the richest nations.

Reflecting this growing awareness, governments around the world have introduced or encouraged a wide range of measures to reduce pollutant emissions through regulation, education and incentive-based programs.

Switching to cleaner burning gaseous fuels has been an important element of these measures. Gaseous fuels such as LP Gas have a very simple chemical structure which promotes clean burning, with greatly reduced levels of combustion by-products.

The following chart (BIC, 2001) provides a graphic picture of the overall damage to society caused by a number of widely used existing transport fuels, together with some emerging alternative fuels, when used in an urban bus application. The value of switching to LP Gas is self-evident.



Impacts of Urban Bus Pollution by Fuel Type and Locality (AU cents/km)

As well as being an exceptionally good transport fuel for passenger cars and many types of commercial vehicles, LP Gas is a proven and practical alternative energy source for a wide range of domestic, commercial, industrial, agricultural and transport applications, including:

- Cooking
- Residential space and water heating
- Distributed electrical power generation
- Industrial appliances (e.g. compressors, water blasters, pumps, etc)
- Industrial processes(e.g. flame cutting, dryers, process heaters)

.....and many more

From a purely practical standpoint, of all the gaseous fuels, LP Gas excels through its ability to be liquefied at low pressure then safely transported in bulk to almost any location. LP Gas can then be dispensed as easily as gasoline or diesel for use in a wide range of domestic, commercial, industrial, agricultural and transport applications.

So, no matter whether you are a cosmopolitan city dweller or living in a remote village, fuelling a car or cooking a simple meal, choosing LP Gas will benefit you and the people around you.

To Summarise:

The availability of controllable energy for cooking, warmth, production and transport is essential for human existence.

Selecting the optimum fuel for a given task can benefit society, not only by reducing human exposure to harmful pollutants, but also in direct monetary terms by reducing the burden of providing medical care and social services for those affected.

For businesses, a healthier workforce means enhanced productivity and a lower risk of economic trauma from the loss of a vital team member.

The benefits do not end with its contribution to the wellbeing of society. Viewed from almost any perspective, LP Gas stands out as the cleanest, most convenient and accessible alternative to the traditional fuels, as well as having among the lowest greenhouse gas emissions. In many instances it can also be the lowest cost option.

Key Findings

This report has evaluated LP Gas alongside a range of other liquid, solid and gaseous fuels, using data drawn from a broad base of independent studies. In many applications and regions, LP Gas has been found to rank as one of the cleanest and most energy efficient of the available fuels. Some of the key findings are summarised below.

Transport The traditional transport fuels: diesel and gasoline, are identified as a primary source of air pollution and ill-health, including the incidence of respiratory diseases and cancers. Much of the European Union's particle pollution comes from motor vehicle exhaust, and the health consequences are estimated to impact on the EU economy by up to €161 billion annually (WHO, 2005-1). For example, diesel cars manufactured prior to the introduction of the "Euro 4" emission regulations (in 2005 for Europe and later in some other regions) have a health cost impact of around €11.70 for every 1000km travelled, compared with €0.90 for a car powered by LP Gas. From 2005 onwards, most diesel cars have been fitted with diesel particle filters, but even with the latest technologies to reduce particle emissions, the health impact of currently manufactured diesel cars is still around €3.50 per 1000km.

Cooking Over half of the world's population still relies on wood, crop waste, or even dried dung to provide the energy for cooking. Exposure to the pollutants released by these fuels is the direct cause of premature death for more than 1.5 million people, every year. Providing the means to cook with LP Gas greatly reduces this exposure, often by a factor of 100 or more, delivering enormous community health benefits.

Residential Space Heating Without adequate ventilation, or if heating appliances and associated flues or chimneys are faulty, the concentration of some pollutants can build up to levels which may be harmful to human health. So many variables influence actual exposure levels that it is difficult to make meaningful comparisons, but measurements of total pollutant emissions produced by burning wood and coal show that these fuels produce around 150 times more carbon monoxide (CO) than LP Gas, per gigajoule of energy produced. Liquid fuels, such as kerosene, produce levels around 50% higher. The picture is similar for residential boilers.

Residential Water and Space Heating (Outdoor Air Quality) In many locations solid fuel heaters and boilers produce enough pollution to directly affect the health of people in the community. Australian research clearly shows that cities where wood burning heaters are prevalent can have much higher ambient particle levels (43 to 65µg/m^3) compared with other cities (20 to 25µg/m$^{3)}$, even though the non wood-burning cities had much lower population and traffic densities. The recommended WHO exposure limit (24 hour mean) is 25µg/m^3.

Distributed Electricity Generation Unless they are fitted with sophisticated emission control technologies, generator sets can produce very high levels of high particle (PM) and oxides of nitrogen (NOx) emissions, with commensurably high health impacts. For a typical mid-size generator, running for 12 hours a day with an average load of 80kW, the annual health impact cost can be in the order of €47,000 for a diesel fuelled unit, compared with less than €2,000 for an equivalent generator set powered by LP Gas. Small, domestic size generator sets also benefit from using LP Gas. Small 4-stroke gasoline powered generators have a health impact cost around 1.5 times higher than LP Gas, and for a similar 2-stroke version the relative health impact factor rises to over 4.5.

1 What is LP Gas?

Liquefied Petroleum Gas (LP Gas) is the generic name for mixtures of hydrocarbon gases, mainly propane and butane, (although small amounts of other compounds, such as propylene and butylenes may also be present in the mixture). Depending on the climate and availability LP Gas can be made up of propane, butane or a range of different mixtures of these gases. LP Gas contains only trace of sulphur compounds. Since LP Gas is naturally odourless, for safety purposes, as in the natural gas industry, a sulphur-based odorising agent is added in very limited quantities to the product in the distribution chain to allow leaks to be more easily detected.

LP Gas can be obtained from several sources. Two of the most common are extraction directly from the mixture of “wet” gases recovered from naturally occurring oil and gas fields, and as a product of the petroleum refining process.

Because of its high volatility, LP Gas is unlikely to cause ground or water pollution. It is biodegradable in air, soil and water.

According to European oil industry research (CONCAWE, 1992), an extensive literature search failed to identify any references to the ecotoxycological effects of LP Gas or their primary constituents.

When lightly compressed (to approx. 800 kPa or 120 psi), the gases change from a gaseous state to a liquid. When the pressure of LP Gas is reduced (for example, prior to being fed into a burner), the liquid boils, turns into gas and expands to about 270 times the liquid volume. LP Gas is therefore very convenient and economical to transport and store, making it a practical and cost effective alternative to many of the traditional fuels for a wide range of applications.

In locations where the infrastructure required to bring grid-based energy is not available, the ease of storage and transportability of LP Gas make it an excellent alternative to natural gas. The two energy sources are highly complementary, sharing the same clean burning and naturally occurring credentials.

From a climate change perspective, neither Propane nor Butane is on the Intergovernmental Panel on Climate Change (IPCC) list of greenhouse gases. LP Gas released into the environment rapidly disperses into the atmosphere where it undergoes photochemical degradation.

Additionally, the greenhouse gas emissions from the combustion of LP Gas are also low compared with most other fuels, giving LP Gas the lowest carbon footprint for many applications. (*For more information on the comparative greenhouse gas emissions of LPG and other fuels, please consult the companion WLPGA publication* “LP GAS: AN ENERGY SOLUTION FOR A LOW CARBON WORLD”).

It has low reactivity at normal temperatures, yet readily burns in the presence of air and its energy content per kilogram is similar to gasoline and diesel.

These characteristics have made LP Gas a popular fuel for domestic, commercial, industrial, agricultural and transport applications.

2 Policy and Economic Overview

In an ideal world we would satisfy all our energy needs from natural sources such as the sun, the wind or the oceans and rivers. Indeed, as mankind becomes more aware of the damage caused to our environment and wellbeing through pollution and climate-impacting activities, many avenues are now being pursued to harness energy from these clean natural sources.

Despite these endeavours, energy from renewable sources will for the forthcoming decades continue to satisfy only a very limited fraction of global energy demand. The overwhelming majority of our energy needs will continue to be met by a range of fossil fuels.

Making the right decisions about which fuels to use can deliver environmental and health benefits on both a local and a regional scale. As we will see later in this document, fuel choice can significantly reduce the incidence of respiratory ailments, heart disorders and other illnesses, which place such a burden on the fabric of developed and developing countries alike.

Most governments now recognise at a macro level the financial and social benefits of reducing human exposure to pollution – but they must also send the right signals to business and the community at large, either through economic policies, education/awareness programs or through regulation.

2.1 Pricing Policy

Fuel taxation remains a contentious issue in many countries, but it nevertheless provides a very convenient mechanism for governments to generate revenues on one hand, and on the other to influence fuel selection and purchasing patterns.

The following table (2.2) illustrates some current examples of these pricing policies in the transport sector.

Average Pump Price (per litre) in Local Currencies*

Country	LP Gas	Gasoline	Diesel
UK (£Stg)	0.52	0.89	1.00
Australia (AU$)	0.52	1.20	1.22
France (€)	0.69	1.13	1.08

** Typical pump prices, February 2009*

Table 2.2: Typical LP Gas, Gasoline and Diesel Pump Prices

In some cases the incentives are even more direct. The UK government, for instance, waives the London Congestion Charge of £8 per day for most LP Gas fuelled commuter vehicles (a saving of £2000 per annum for daily commuters), as well as levying a lower company car tax and discounting the vehicle excise duty (annual car tax) by around £35 for a typical mid-sized car.

By exempting LP Gas from the excise fuel tax, the Australian Federal Government provides direct financial incentives for people to use LP Gas for a wide range of energy needs. In addition to saving the 38 cents per litre tax applied to gasoline and diesel fuel, car owners purchasing a factory-built LP Gas car (purchased on or after 10 November 2008), or converting a gasoline car to LP Gas operation, also receive a cash rebate of A$2000.

Although social and health cost impacts are the principal driving force behind policies and measures to reduce energy-related pollution, there is a move around the world to also take account of a broader range of external factors, including climate change, infrastructure deterioration, soil degradation, water quality and lost productivity. Some of the data presented in this study include some of these factors (examples are Figure 5.2 and Table 4.3).

New taxation and fiscal frameworks are now integrating, or will be based on, life cycle analysis of fuels, and will inevitably reshape the future global energy picture.

2.2 Public Health

Although residents of cities in the wealthier countries may rightly consider themselves fortunate to live in relatively pleasant and comfortable surroundings, this does not mean that they are necessarily spared the health consequences of breathing pollution-laden air.

In 2005 the WHO completed an intensive study into the health impacts of human exposure to airborne particles (mostly combustion generated) in the European Union. The research concluded that exposure to particles reduces the life expectancy of every person in the European Union (EU) by an average of nine months, and has a direct economic impact of up to €161 billion (US$220 billion) every year (WHO 2005-1).

A 2006 cost-benefit study (WHO, 2006) performed by the World Health Organisation concluded that investing US$13 billion a year to provide LP Gas access worldwide to halve the number of people cooking with solid fuels by 2015 would generate a return of US$91 billion in health and other community benefits.

In numerous poorer countries many inhabitants are living in dire circumstances. Malnutrition robs whole populations of a healthy and productive life. But the problems lie not just in a lack of food. The way food is cooked also represents a major health hazard in its own right. The seriousness of the problem has been summarised by the World Health Organization as follows:

> *"More than half of the world's population rely on dung, wood, crop waste or coal to meet their most basic energy needs. Cooking and heating with such solid fuels on open fires or stoves without chimneys leads to indoor air pollution. Exposure is particularly high among women and young children, who spend the most time near the domestic hearth. Every year, indoor air pollution is responsible for the death of 1.6 million people - that's one death every 20 seconds".* (WHO 2005-3)

So, whether the focus is on vehicles in city streets, or the preparation of a simple meal, fuel choice has a critical influence on human health and is a decision which should be made with care.

In fact, for almost every application that involves converting a fuel into energy for heat or power, LP Gas can do the job cleanly, efficiently and economically.

2.3 Climate Change

From a global warming perspective, fuel selection can play a significant role in reducing emissions of carbon dioxide and other greenhouse gases.

For many applications, including transport, cooking, heating, industrial processes and local power generation there is a major role in small and medium scale applications for alternative low carbon fuels, such as LP Gas, which have a smaller carbon footprint than traditional fuels.

LP Gas and CNG are often compared from a global warming perspective. On one hand, the lower carbon content of CNG results in lower CO_2 emissions from combustion. However, considerable energy is expended in compressing natural gas for storage, and any unburned gas released to the atmosphere has a global warming potential 23 times higher than CO_2, whereas unburned LP Gas is greenhouse neutral. These factors tend to narrow the difference between the two fuels. In practice, both LP Gas and natural gas share the same clean burning, low-carbon attributes and both compare extremely favourably with the traditional liquid fuels.

For a comprehensive discussion on greenhouse gas emissions from LPG and other fuels, please consult WLPGA publication “LP GAS: AN ENERGY SOLUTION FOR A LOW CARBON WORLD”.

3 How Pollutants Can Affect Human Health

Relationships between exposure to pollutants and the consequent health effects have been extensively researched over several decades and have resulted in the introduction of numerous standards, targets and guidelines aimed at minimising risk at both local and regional levels.

The success of these measures continues to be very mixed. In some regions considerable progress has been made to introduce cleaner fuels and reduce overall emissions from transport vehicles and industry. In most cases this has resulted in a beneficial impact on air quality.

Other parts of the world still face an uphill battle, and may be held back by a number of factors including poverty, reliance on dirty energy sources, broad-acre burning or ineffectual government administration.

The interactions between airborne pollutants and human health are complex and are influenced by exposure levels, duration of exposure and the inherent toxicity of individual pollutants. In many situations the youngest and oldest sections of the population are most vulnerable.

An unavoidable consequence of global population growth has been increased urbanisation. Regardless of how rich or how poor the cities might be, high population densities result in a commensurately higher incidence of sickness from air pollution. In many cities, a combination of high polluting vehicles, street cooking and proximity of heavy industry can take a heavy toll.

But wealthier regions are not immune to the problems. The cost of providing health care, social services and the direct economic cost of lost productivity can impact on a region's economy to the tune of tens or even hundreds of billions of dollars annually.

In regions where income levels and national budgets are much lower, many decisions are driven by necessity rather than choice, and often these decisions can have a serious health downside.

Exposure to a cocktail of particles and toxic chemicals, generated when wood or other biomass material is used for indoor cooking, is responsible for widespread sickness and greatly reduced life expectancy for many people living in poorer communities.

Approximately one half of the world's population relies on burning biomass, that is wood, crop residues, dung, and charcoal, as their primary source of domestic energy.

Exposure to indoor air pollution resulting from biomass burning is the cause of widespread respiratory and eye infections. Putting this into perspective, respiratory infections account for over 10% of the total disease burden in developing countries, leading to an estimated 1.6 million deaths annually in these countries.

Programs aimed at improving food supply and medical care are of paramount importance, but the value of practical measures to support and encourage healthier cooking practices should not be overlooked. Switching to a simple, clean LP Gas burner can go a long way towards avoiding the tragedy of an incapacitated parent, a chronically ill child, or worse, and should be an important consideration for aid agencies and government assistance programs.

3.1 Health Effects of Individual Pollutants

This section briefly reviews the six most prevalent pollutants generated by commonly used fuels. It should be noted that several fuels do not emit all of these pollutants, either through their removal from the fuel (for example the addition of lead to gasoline is no longer permitted in most countries), or because of the intrinsically clean composition of the fuel (for example LP Gas contains no lead and very limited amount of sulphur compounds).

3.1.1 Which Pollutants are Most Important?

Literally hundreds of pollutants have potential to damage human health, but the United States Environmental Protection Agency (EPA) has identified six pollutants, referred to as "criteria pollutants" as being the highest priority. Standards for the criteria pollutants are regulated under the Clean Air Act. The pollutants are:

- particulate matter (PM)
- nitrogen oxides (NOx)
- hydrocarbons (HC)
- carbon monoxide (CO)
- sulphur oxides (SOx)
- ground-level ozone (O_3)
- lead (Pb)

Because of their role in the formation of ground level ozone, volatile organic compounds (VOCs) are also widely regulated. Many dangerous compounds classed as “air toxics” are also categorised as VOCs (see Section 3.1.9). VOCs are also often referred to simply as hydrocarbons (HC).

Most countries recognise the same pollutants as being the highest priority health related pollutants in their regulations and emission abatement programs.

There are still some highly populated regions where fuels with high sulphur and/or lead contents continue to be sold.

In addition to the criteria pollutants listed above, another very large and important group of hazardous chemicals (generally referred to as “**air toxics**”) are released to the atmosphere during combustion of most fuels. The more significant of these pollutants are discussed briefly in Section 3.1.9, with more detailed information in Annex A1.

3.1.2 Particulate Matter (PM)

Particulate matter (PM) from fuel combustion is a mixture of solid particles and liquid droplets suspended in the air. A high proportion of these particles are extremely small, mostly less than 10 microns (about 10 times smaller than the thickness of a human hair). The smallest particles can go down to 10 nanometers (one nanometer is one millionth of a millimetre or 0.000001mm) in diameter), which is around 10,000 times smaller than the thickness of a human hair.

Particulate Matter is probably the most dangerous of all fuel-related pollutants because of its known toxicity and the high exposure levels experienced by large sections of the world’s population. It is emitted directly as a product of combustion from virtually every burning process, though the rate at which it is emitted by different fuels can vary by a factor of 100 or more. Gaseous products of combustion can also form into particles through chemical reactions in the atmosphere.

From a regulatory perspective, transport sources of PM emissions have received most attention, but it is likely that other sources generate comparable or even higher atmospheric particle concentrations in some regions or localised instances. Some of these include: wood-fire cooking, coal-fired industrial processes, electricity generation, vegetation and naturally occurring wildfires.

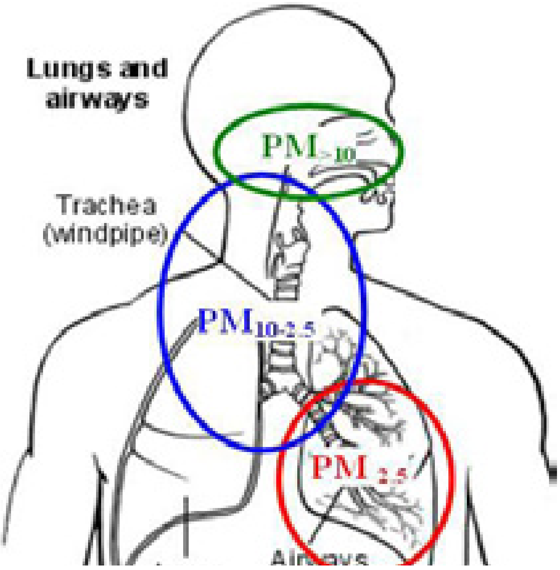


Figure 3.1: Deposition Zones by Particle Size

Combustion-generated particles range in size from ten microns or more, down to a few nanometers. As can be seen in Figure 3.1, the smaller particles can reach the deepest and most sensitive areas of the lung. Those in the nanometer range may even pass through the *lung tissue directly into the bloodstream. Over* 90% of particles in the exhaust of internal combustion engines are smaller than one micron ($PM_{1.0}$), ranging down to as little as 10 nanometers (0.00001mm).

In 1998 the California Air Resources Board (CARB) determined diesel particulates to be a Toxic Air Contaminant. In 2002, after much research, the US EPA concluded that PM in diesel exhaust causes acute throat and bronchial irritation, poses a chronic respiratory hazard to humans, and is a likely carcinogen. Particles may also adsorb potentially health-threatening organic “air toxics” found in engine exhaust.

Gasoline and diesel exhaust particles pose a higher risk than those of LP Gas, as not only do these fuels generate higher particle concentrations, but the exhaust from liquid fuelled vehicles contains much higher levels of air toxics, which can be adsorbed onto the surface of particles and carried into the most sensitive lung areas.

This can lead to severe lung problems and increased susceptibility to respiratory infection, such as pneumonia, aggravation of acute and chronic bronchitis, and asthma. Moreover, the very smallest particles can even pass through the lung tissue directly into the bloodstream, where they have been linked to a number of neurological and heart disorders.

There are large differences between the particle emissions associated with different fuels. Diesel engines and burning of wood and other biomass materials generate the highest levels of PM. Gaseous fuels, notably LP Gas, have the lowest emissions of this pollutant.

3.1.3 Nitrogen Oxides (NOx)

Several oxides of nitrogen, all of which can be produced in fuel combustion, have significant environmental and health impacts. The principal compounds of concern are nitrogen dioxide (NO_2), nitrous oxide (N_2O) and nitric oxide (NO). Collectively these compounds are referred to simply as NOx.

Photochemical smog is formed when NOx and volatile organic compounds (VOCs) react in the presence of sunlight to form ozone. Smog severely irritates the mucous membranes of the nose and throat, which can lead to coughing and even choking. It also impairs normal functioning of the lungs and long-term exposure may cause permanent damage. Ozone can also reduce crop yields

NOx and sulphur dioxide react with other substances in the air to form acids which can fall to earth as “acid rain”, damaging property and, in some areas causing lakes and streams to become sterile. Through a reaction with ammonia or other compounds NOx can be transformed from a gas into tiny nitric acid particles which, when inhaled can affect breathing, damage lung tissue, and even lead to premature death.

Nitrous oxide (N_2O) is a very powerful greenhouse gas. Its influence as a greenhouse gas is more than 298 times greater than carbon dioxide (CO_2), but fortunately is generally produced in relatively small amounts. There is concern that chemical reactions in the catalytic converters fitted to motor vehicles to reduce other pollutants emissions may in fact increase emissions of N_2O.

3.1.4 Hydrocarbons (HC) (also referred to as Volatile Organic Compounds (VOC)

Hydrocarbons are compounds containing only hydrogen and carbon atoms. They are present in the air both as naturally occurring gases and as the product of incomplete combustion of carbon-based fuels. As well as being emitted during combustion, hydrocarbons are also released to the atmosphere through evaporation from paints and solvents, industrial processes, and from gasoline fuelled vehicles during refuelling or through failures in their on-board vapour recovery systems.

They comprise a large range of gaseous organic compounds, many with complex chemical structures, which react with NOx in the presence of sunlight to form ground level ozone – a precursor of photochemical smog.

A number of hydrocarbon compounds, classified as **"air toxics"** are extremely hazardous to humans, but are only generated in very small quantities from motor vehicles.

Some air toxics are known to be carcinogenic and this group of chemicals is also suspected to play a role in the rapid growth of a number of "20th century" illnesses, including asthma. However, because their ambient concentrations are extremely low, it has not yet been possible to reliably establish dose response characteristics, nor to place a direct monetary cost on their exposure effects (see Section 3.1.9).

3.1.5 Ozone (O_3)

Ozone is a gas simply composed of three oxygen atoms. It is not usually emitted directly into the air, but at ground-level is created by a chemical reaction between oxides of nitrogen (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. Motor vehicle exhaust and industrial emissions, gasoline vapours, and chemical solvents as well as natural sources emit NOx and VOCs that help form ozone, which is the primary constituent of photochemical smog.

From a health perspective, ozone is linked to a number of respiratory illnesses including airway irritation, aggravation of asthma, increased susceptibility to respiratory illnesses like pneumonia and bronchitis; and permanent lung damage with repeated exposures.

Ozone also damages vegetation and ecosystems. In the United States alone, it is responsible for an estimated US$500 million in reduced crop production each year.

3.1.6 Carbon Monoxide (CO)

Carbon Monoxide (CO) is a colourless, odourless, poisonous gas composed of one atom each of carbon and oxygen. It is formed when carbon-based fuel is not burned completely.

When inhaled, CO enters the bloodstream, where it binds chemically to haemoglobin, which normally carries oxygen to the cells, and reduces oxygen delivery to all tissues. Even at relatively low concentrations, CO can adversely affect mental function, visual acuity, and alertness. At higher concentrations exposure can be fatal.

3.1.7 Sulphur Dioxide (SO_2)

Sulphur dioxide causes a wide variety of health and environmental impacts because of the way it reacts with other substances in the air. Particularly sensitive groups include people with asthma who are active outdoors and children, the elderly, and people with heart or lung disease. Peak levels of sulphur dioxide air can cause temporary breathing difficulty for people with asthma who are active outdoors. Longer-term exposures to high levels of sulphur dioxide gas and particles cause respiratory illness and aggravate existing heart disease.

Sulphur dioxide also reacts with other chemicals in the air to form tiny sulphate particles. When these are inhaled, they gather in the lungs and are associated with increased respiratory symptoms and disease, difficulty in breathing, and even premature death.

When sulphur dioxide and nitrogen oxides react with other substances in the air they can form acids, which fall to earth as rain, fog, snow, or dry particles – this phenomenon is commonly described as “acid rain”, which may be carried by the wind for hundreds of kilometres.

Acid rain damages forests and crops, changes the makeup of soil, and makes lakes and streams acidic and unsuitable for fish. Continued exposure over a long time changes the natural variety of plants and animals in an ecosystem.

LP Gas emits little or no sulphur dioxide. It is the ideal energy source to replace many of the sulphur-bearing fuels still in use, particularly wood-burning heaters and many industrial process heat sources.

Other issues relating to the sulphur content of fuels are addressed in Technical Appendix A1.

3.1.8 Which Fuels?

The mix of pollutants and their relative emission rates can vary considerably between individual fuels. This document focuses on the most widely available energy sources in general use for cooking, heating, power generation and transport. These are:

- gasoline
- diesel
- liquefied petroleum gas [LP Gas]
- natural gas (methane) [NG]
- coal
- charcoal
- wood and related biomass

While many of these fuels have quite different physical characteristics, they are all related insofar as their basic chemical structure consists almost entirely of carbon and hydrogen.

The first four fuels in the above list are of fossil origin, created over millions of years from the remains of organisms that settled to the sea bottom and were buried under heavy layers of sediment. The resultant heat and pressure has caused the organic matter to be transformed into liquid and gaseous hydrocarbons, which can be recovered by drilling through the sedimentary layers. LP Gas and Methane are often recovered from the same well, and both gases share many health-related benefits.

Coal, on the other hand, is formed from land-based vegetation and tends to be found close to the earth’s surface. Methane, commercially marketed as "natural gas", is often present in coal seams, in addition to being found in the fossil fuel strata.

The last three items on the list either consist of, or are directly derived from, surface vegetation (biomass).

Methane is also generated through short-term decomposition of vegetation and waste. As such, it can be captured at land-fill and similar sites, then stored and distributed. Methane produced in this way represents only a very small fraction of total consumption.

3.1.9 Air Toxic Compounds

In addition to the criteria pollutants, there is a long list of "air toxic" compounds, some of which are designated as carcinogens; others can have serious effects on human neurological and reproductive systems. The US EPA classifies 187 compounds as “hazardous air pollutants”.

Although these compounds are mostly emitted in very small quantities and hence their health impacts are sometimes difficult to establish at the dosage rates typically encountered, they are nevertheless considered sufficiently dangerous to be monitored and, where possible, human exposure minimised. The EPA estimates that mobile (car, truck, and bus, etc) sources of air toxics account for as much as half of all cancers attributed to outdoor sources of air toxics (US EPA 1994).

Virtually all fuels produce some of these dangerous compounds when burned, but there are large differences in emission levels between individual fuels. Gasoline tends to have high air toxic emissions while LP Gas has the lowest, primarily due to its extremely simple chemical structure which promotes very clean and complete burning. To illustrate this, Figure 3.2 compares relative levels of typical motor vehicle engine-out emissions (with petrol = 100 as a reference) of some key air toxics for the most widely available commercial fuels (Anyon, 2002), based on data from an Argonne National Laboratory report (Winebrake J., 2000).

Note: CURE = Cancer Unit Risk Estimate, defined as “the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent (e.g. chemical) at a concentration of 1 microgram per cubic metre in air or 1 microgram per litre in water”. Hence the higher the CURE number, the higher the human cancer risk.

Table 3.3 (below) is based on Australian Government data (NPI 2000) and also highlights the extremely low air toxic emission levels from LP Gas fuelled vehicles, compared with gasoline and diesel equivalents.

Air Toxic Emissions, Passenger Car Exhaust (g/km)
By Road Type

Road Type:	Arterial	Freeway	Residential
Benzene			
Gasoline	0.08291	0.08817	0.09541
Diesel	0.00334	0.00313	0.00518
LP Gas	0.00001	0.00001	0.00002
1,3-butadiene			
Gasoline	0.01064	0.00993	0.01642
Diesel	0.00064	0.00059	0.00099
LP Gas	0.00010	0.00009	0.00015
PAHs			
Gasoline	0.00668	0.00625	0.01035
Diesel	0.00674	0.00628	0.01041
LP Gas	0.00000	0.00000	0.00000
Toluene			
Gasoline	0.05618	0.02531	0.05618
Diesel	0.01573	0.00710	0.01573
LP Gas	0.00000	0.00000	0.00000

Xylenes			
Gasoline	0.08880	0.04175	0.08880
Diesel	0.03405	0.02516	0.03405
LP Gas	0.00000	0.00000	0.00000

Table 3.3: Passenger Car Air Toxic Emissions by Fuel and Road Type (NPI 2000)

For a more comprehensive discussion of regulated pollutants and air toxic substances please refer to Annexes A1 in this document.

4 Quantifying Health Impacts

4.1 Background

Attributing monetary values to human sickness and death is a sensitive and sometimes contentious issue. From a purely academic standpoint it is certainly possible to draw together the monetary costs associated with a range of factors associated with, or directly resulting from a person's illness or death. But it can also be argued that from another perspective the social costs are at least equally as important as simply adding up the dollars.

Logically, economic analysis of pollution health is influenced by the financial circumstances of the persons involved and of the society they live in. Hence these analyses tend to focus on:

- average income levels for the region under consideration and the loss of household income attributable to illness or death;
- the cost of providing hospitalisation and medical services;
- the cost of providing social services and support consequential to the illness or death of an individual;
- the value of lost productivity due to a person's inability to contribute to the economy; and
- estimates of the community's "willingness to pay" to avoid a premature death.

Apart from the last item, most of these factors can be analysed using well researched data and a rational monetary figure, relevant to the general economy of the region being considered, can be applied.

However, once we move away from the relatively orderly socio-economics of the developed world, many of the above factors become irrelevant. In remote areas of developing countries, for most of the population simply surviving from one day to the next becomes the whole focus of life.

In a subsistence society, income levels are often close to zero. Medical attention and access to hospital services are most likely difficult to obtain, or even close to non-existent. Loss of productivity is not measured in Dollars or Euros, but rather the ability of a person to contribute to the community by gathering and preparing food, growing crops or husbanding animals.

So, using the measures applied to inhabitants of a developed economy, the value of a life in a poor society would be extremely low. But of course this is not the case. The life and well-being of a family or friend is just as valuable to members of a money-poor society as it is to the most wealthy city dwellers.

But there is common ground when we focus only on health impacts, where the health consequences of exposure to pollutants are principally determined by:

- exposure levels to the pollutants of concern (usually specified as a concentration in parts per million or micrograms of pollutant per cubic metre of air); and
- the typical dose response (severity of health impact) for the exposure levels encountered.

This report therefore presents health impacts in monetary terms where the issue under consideration is of a macro nature, such as quantifying the consequences of exposure to motor vehicle pollution in urban areas. Where the issues are much more localised, the impacts will be presented in terms of the health risks to individuals, without reference to monetary values.

Although no pollutants are considered unimportant, some are more important than others. In most regions the greatest concern focuses on particulate matter (PM), oxides of nitrogen (NOx) and volatile organic carbons (VOCs). Of these, PM generally rates are highest, as will be seen when health cost impacts are reviewed in the next section.

A massive amount of research has been performed to link exposure levels to health impacts. The huge variability in response of individuals to any given pollutant concentration, coupled with the continuously varying levels of pollution concentration and the difficulties in achieving consistency in diagnosis or severity of illness, there is always a degree of uncertainty in any numerical analysis.

Nevertheless, the techniques developed for Time-series studies involving very large numbers of patients allow valid statistical relationships to be developed between dose level and dose response. Table 4.1 (Künzli et al, 2000) estimates of relative risk of some specific health factors being increased by a 10 µg per cubic metre increase in exposure to particles with a size of 10 microns or less (PM_{10}). This study on which this table is based covered residents of Austria, France and Switzerland. (Note: The figure in the middle column is a multiplier, meaning that each 10µg/m^3 increase in PM10 will increase the current risk by that factor. For example in the first line the current risk level will be multiplied by 1.043 for each 10µg/m^3 increase in PM10 exposure).

Health Outcome	Relative Risk Estimate Associated with a 10 µg/m^3 Increase in PM10	95% Confidence Interval
Mortality (adults >30 years, excluding violent deaths)	**1.043**	**1.026-1.061**
Respiratory hospital admissions (all ages)	**1.013**	**1.001-1.025**
Cardiovascular hospital admissions (all ages)	**1.013**	**1.007-1.019**
Chronic bronchitis incidence (adults >25 years)	**1.098**	**1.009-1.194**
Bronchitis episodes (children <15 years)	**1.306**	**1.135-1.502**
Restricted activity days (adults >20 years)	**1.094**	**1.079-1.502**
Asthma attacks (children <15 years)	**1.044**	**1.027-1.062**
Asthma attacks (adults >15	**1.039**	**1.019-1.059**

years)

Table 4.1: Risk estimates for 10 µg/m3 increase in PM10 used in (Künzli et al, 2000).

Even short-term exposure to PM can have serious health consequences. In 2005 the World Health Organisation issued a publication summarising several years research into daily changes in PM concentrations and their associated health outcomes. The report on which the WHO publication was based (Anderson H et al, 2004) concluded that short-term changes in PM at all levels can lead to inflammatory reactions in the lung, respiratory symptoms, adverse effects on the cardiovascular system and increases in medication use, hospital admissions and mortality. These findings are summarised in table 4.2 below. (Note: The figure in the middle column of table 4.2 is, in this case, a percentage increase in the incidence of these outcomes for each incremental 10µg/m^3 increase in PM10 exposure.)

Health Outcome	Estimated Percentage Increase in Risk per 10 µg/m^3 of PM10	95% Confidence Interval
All-cause mortality	**0.6**	**0.4-0.8**
Mortality from respiratory diseases	**1.3**	**0.5-2.0**
Mortality from cardiovascular diseases	**0.9**	**0.5-1.3**
Hospital admissions for respiratory disease, people age 65 years and over.	**0.7**	**0.2-1.3**

Table 4.2: Risk estimates for 10 µg/m3 increase in PM10 used in (Künzli et al, 2000).

4.2 Health Cost Impacts

As noted earlier, quantifying the cost of illness and premature death from exposure to pollution involves estimating exposure levels and dose response, then linking the calculated health-related consequences to the monetary value of medical care, social services, foregone income and the cost of lost productivity. Most estimates of health cost impacts also include an amount representing societies "willingness to pay" to avoid premature death.

It falls outside the scope of this report to enter into detailed discussion on methodologies and rationale used in the many studies which have been performed to link pollution with financial cost. Instead, we will review the range of estimates which have been put forward in relation to the key air pollutants generated by commonly used fuels. These estimates vary considerably, with some clearly underestimating and some probably over-estimating the net costs to society.

Nevertheless, it should be noted that aggregate health cost impacts are not based solely on ambient exposure levels. Two key factors which come into play are:

- population density (for a given pollutant concentration, doubling the number of people in a given area doubles the overall health cost impact)
- Gross Domestic Product (GDP) on a per capita basis, as this is a general measure of prosperity, income levels and the cost of medical and social services in a region.

For convenience the monetary value attributed to individual pollutants is usually expressed as Euros (or dollars etc) per tonne. This approach is very useful because it allows analysis of scenarios based on the number of sources contributing to overall pollutant concentration levels and, importantly, how pollutant levels can be changed through measures to reduce emissions from individual sources or to reduce the actual number of sources in a given area.

For instance, authorities may wish to explore the value of switching to cleaner fuels standards, or using intrinsically cleaner fuels, or requiring equipment to meet more stringent emission performance standards.

Table 4.3, extracted from a report prepared for the European Commission (Holland et al, 2005), summarises average damage costs (€ per tonne) for the most significant regulated pollutants in all the mainland European Union economies. Please note that the costs include estimated damage to crops, in addition to human health impacts. However, the monetary value of crop damage is only a very small proportion of the total (typically less than 5%) and so the values in the table may be assumed to be closely indicative of estimated health costs.

Pollutant Health Cost (€ per tonne) – European Nations

Pollutants:	$PM_{2.5}$	NOx	VOCs
Austria	€110,000	€24,000	€5,200
Belgium	€180,000	€14,000	€7,100
Czech Republic	€91,000	€20,000	€3,000
Denmark	€48,000	€12,100	€2,000
Estonia	€12,000	€2,200	€420
Finland	€16,000	€2,000	€490
France	€130,000	€21,000	€4,200
Germany	€140,000	€26,000	€5,100
Greece	€25,000	€1,900	€880
Hungary	€72,000	€15,000	€2,700
Ireland	€42,000	€11,000	€2,000
Italy	€97,000	€16,000	€3,500
Latvia	€25,000	€3,700	€650
Lithuania	€24,000	€5,000	€710
Luxembourg	€120,000	€24,000	€8,000
Malta	€27,000	€1,700	€1,300
Netherlands	€180,000	€18,000	€5,400
Poland	€83,000	€10,000	€1,900
Portugal	€64,000	€3,200	€1,600
Slovakia	€58,000	€14,000	€2,000
Slovenia	€64,000	€18,000	€4,400
Spain	€54,000	€7,200	€1,100
Sweden	€34,000	€5,900	€980

United Kingdom	€110,000	€10,000	€3,200

Table 4.3: Pollutant Health Costs (per tonne) for European Countries (Holland M et al 2005).

It should be noted that the above health cost estimates are, for each country, averaged across the urban, provincial and rural regions of each country. Hence the distribution of population densities across each country, together with the pollutant exposure levels in the different regions, result in each country having differences in the relative costs attributed to each pollutant.

An example of the regional variations in health costs for a given country are illustrated in a report (Rabl and Spadaro, 2000), which estimates pollution cost impacts representative of a car journey from Paris to Lyon in France, a distance of 465km. This report takes account of the factors outlined in the preceding paragraph and the aggregated health costs per tonne are summarised in Table 4.4 below.

Pollutant	Health Cost (€ / tonne)
$PM_{2.5}$	160,000
SO_2	10,000
NO_2	15,700
VOC	700
CO	20

Table 4.4: Health damage costs per tonne of pollutant for trip from Paris to Lyon

The average country-wide health cost values are reasonably consistent with other published reports, but it is interesting to note that the Rabl report also quantifies the differences between urban and rural health impacts, which are estimated to be 14 times higher than the average for travel in Paris, and about seven times lower for rural travel in the south-west of France.

The results of the Rabl report underline the substantial added value of adopting low-polluting energy sources in areas with high population densities.

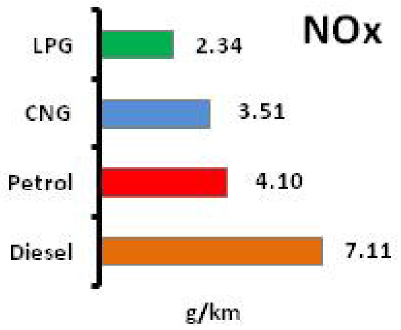
5 LP Gas in Key Applications

The value of switching to LP Gas as an energy source can be demonstrated by examining some practical applications. Using independent research and practical test data to evaluate and compare a range of commercially available liquid and gaseous fuels, together with some "harvested" solid fuels, the health and economic benefits of using LP Gas become self-evident. The applications discussed include:

- Road transport
- Cooking (focusing principally on developing regions)
- Residential space and water heating
- Electrical power generation
- Other Applications

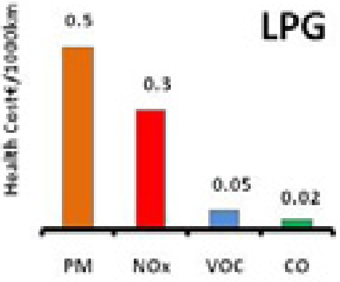
Annexes to this report provide more in-depth coverage of several topics for readers who may wish to explore specific technical issues in more detail.

Based on their relative emission rates in each application, each fuel is assessed in relation to its impact on human health and, where feasible, estimates are made of the consequential economic impacts of human exposure to each fuel, in each of the applications discussed.



Where it is practical to do so, data is presented graphically, using consistent charting formats. For instance, pollutant emissions relevant to each fuel are displayed on a horizontally oriented bar chart similar to that shown opposite, together with numerical values. Units of measurement are those most appropriate to the application (for instance grams per kilometre for road transport or grams per megajoule for heating).

Pollutant emission rates are based on independent test reports from recognised testing or research organisations. Given the inherent variability of emission test results, even from appliances or vehicles of nominally the same type and technology level, data from multiple tests have been aggregated to generate a representative average value, wherever possible.



Where adequate data is available, typical health costs for each pollutant, in the context of each specific application, will also be displayed in a vertically oriented chart style, for each fuel type (see opposite). Again, health costs are reported in units appropriate to the application. Where it is not feasible to quantify health impacts in monetary terms, the differences are expressed as ratios or as qualitative discussion.

Calculated health costs can vary greatly according to a number of local and regional factors. These include: population density, income levels, health care costs and the extent to which social services are available. (For a more detailed discussion of the health and economic impacts of different pollutants, please refer to Section 4.1.

Moreover, pollutant emission rates vary considerably (both in absolute terms and relative to one another) in response to a number of factors, including: the type of appliance, its operating principles, technology levels, the presence or otherwise of post-combustion pollution reduction systems and typical duty cycles. For these reasons, although they have been accounted for wherever it has been feasible to do so, estimates of overall pollutant emissions may not be as precise as those for, say, CO_2. For any given fuel CO_2 is accurately calculated by simply multiplying the mass of fuel consumed by a single constant number, regardless of the application for which the fuel is used or the technologies employed.

5.1 Road Transport

Gasoline and diesel have been the principal fuels used in mainstream road transport for over a century. But concerns over unhealthy air, climate change and dwindling reserves, coupled with the potential for disruptions to supply, have led to greatly increased availability of alternative, lower polluting energy sources for motor vehicles.

Since the middle of the 20th century, motor vehicle use has been closely associated with public health. This issue was brought to the forefront in California, where a rapidly growing and highly motorised population was subjected to severe photochemical smog episodes caused mainly by emissions of hydrocarbon products and oxides of nitrogen which reacted in the presence of California's strong sunlight. The severe incidence of respiratory and heart related illnesses attributable to the smog, coupled with the loss of visual amenity, led to the introduction of regulated limits for pollutant emissions from new cars and periodic checks on in used cars to ensure that they were being properly maintained.

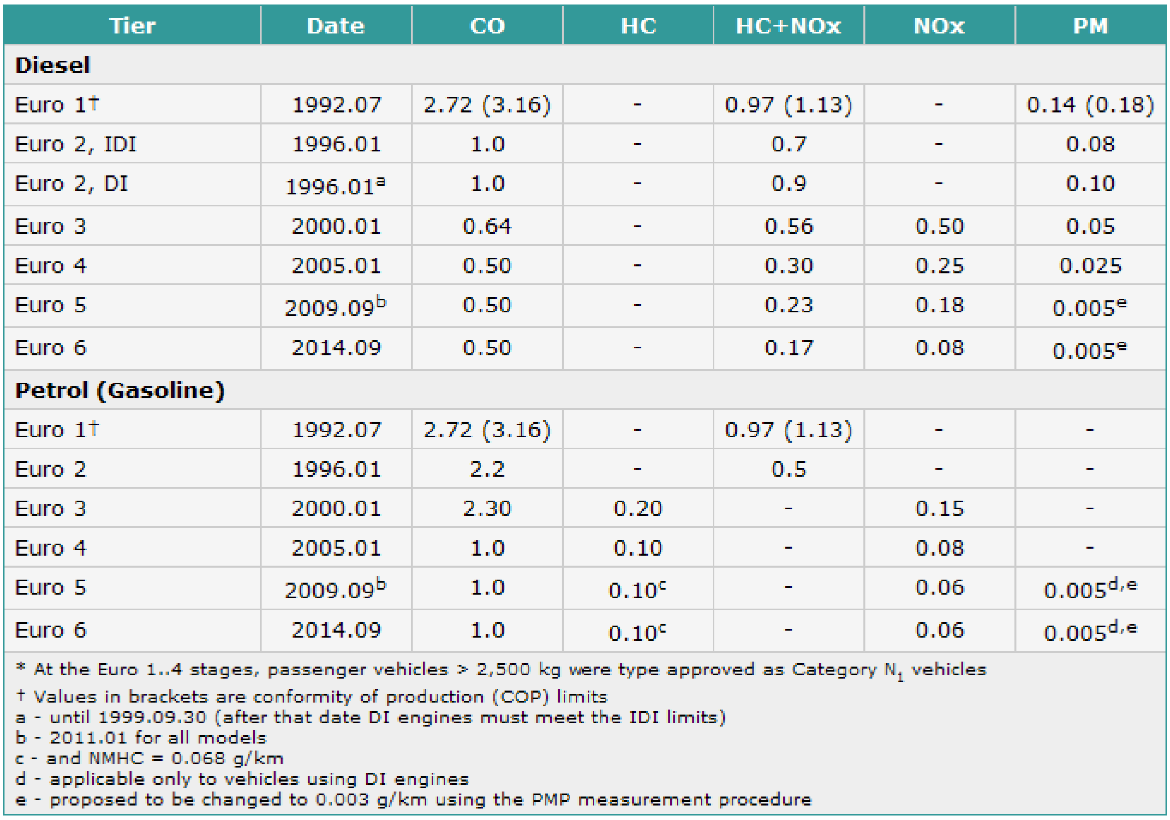
The rapid increase in popularity of diesel powered vehicles, particularly in Europe and Asia, has focused a great deal of attention on the adverse health impacts of fine particulate matter (PM), which is emitted from diesel engines at much higher rates than from gasoline or gaseous fuelled engines.

The particles generated by internal combustion engines are especially dangerous because of their extremely small size, with most particles less than one micron (1/1000 mm) diameter. These tiny particles can penetrate into the deepest and most sensitive parts of the lung, even passing through the lung tissue directly into the bloodstream. Fine particles have been designated by the US EPA as a cancer causing pollutant, and are also directly the cause of serious respiratory and cardiac diseases and possibly brain damage.

For these reasons, the monetary health impact attached to PM is typically around 20 to 30 times higher per kilogram than for VOCs or NOx, and over 100 times higher than for CO.

Over recent years, controlling PM emissions has been the highest priority for regulators, and the maximum permitted emission levels have been reduced by a factor of 28 over the past decade or so. Many new technologies to reduce particle production inside the engine, and to filter particles out of the exhaust, have been developed to meet these more stringent regulations. NOx emissions, because of their influence on ozone as well as particles, are also a high priority.

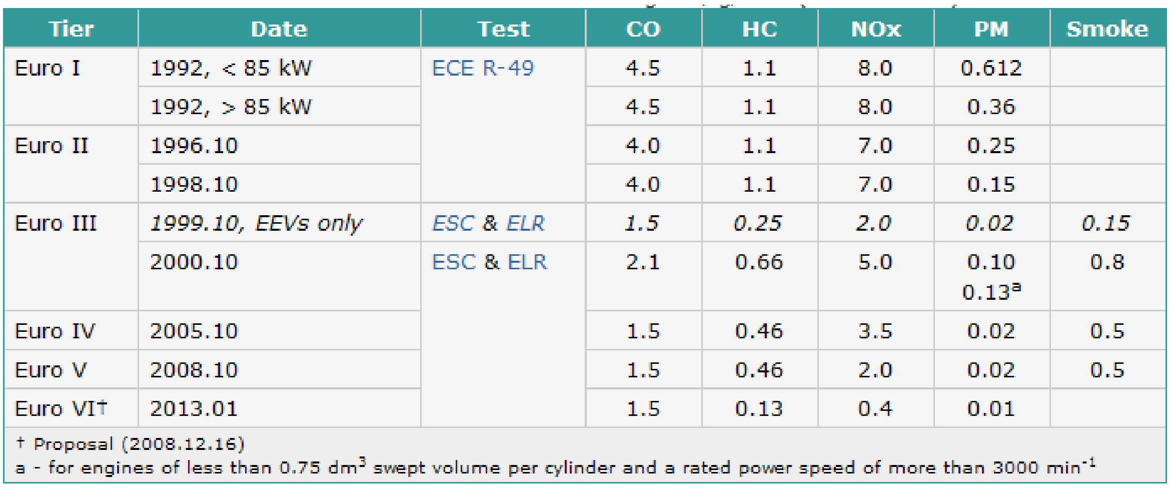
Tables 5.1(a) and (b), below, summarise the progression of European regulation for passenger cars and heavy-duty trucks and buses since their inception in 1992 (*Source: http://www.dieselnet.com*).



Tier	Date	CO	HC	HC+NOx	NOx	PM
Diesel						
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)
Euro 2, IDI	1996.01	1.0	-	0.7	-	0.08
Euro 2, DI	1996.01[a]	1.0	-	0.9	-	0.10
Euro 3	2000.01	0.64	-	0.56	0.50	0.05
Euro 4	2005.01	0.50	-	0.30	0.25	0.025
Euro 5	2009.09[b]	0.50	-	0.23	0.18	0.005[e]
Euro 6	2014.09	0.50	-	0.17	0.08	0.005[e]
Petrol (Gasoline)						
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-
Euro 2	1996.01	2.2	-	0.5	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-
Euro 4	2005.01	1.0	0.10	-	0.08	-
Euro 5	2009.09[b]	1.0	0.10[c]	-	0.06	0.005[d,e]
Euro 6	2014.09	1.0	0.10[c]	-	0.06	0.005[d,e]

* At the Euro 1..4 stages, passenger vehicles > 2,500 kg were type approved as Category N_1 vehicles
† Values in brackets are conformity of production (COP) limits
a - until 1999.09.30 (after that date DI engines must meet the IDI limits)
b - 2011.01 for all models
c - and NMHC = 0.068 g/km
d - applicable only to vehicles using DI engines
e - proposed to be changed to 0.003 g/km using the PMP measurement procedure

Figure 5.1(a): European Emission Regulation Trends for Passenger Cars (g/km)



Tier	Date	Test	CO	HC	NOx	PM	Smoke
Euro I	1992, < 85 kW	ECE R-49	4.5	1.1	8.0	0.612	
	1992, > 85 kW		4.5	1.1	8.0	0.36	
Euro II	1996.10		4.0	1.1	7.0	0.25	
	1998.10		4.0	1.1	7.0	0.15	
Euro III	*1999.10, EEVs only*	*ESC & ELR*	*1.5*	*0.25*	*2.0*	*0.02*	*0.15*
	2000.10	ESC & ELR	2.1	0.66	5.0	0.10 0.13[a]	0.8
Euro IV	2005.10		1.5	0.46	3.5	0.02	0.5
Euro V	2008.10		1.5	0.46	2.0	0.02	0.5
Euro VI†	2013.01		1.5	0.13	0.4	0.01	

† Proposal (2008.12.16)
a - for engines of less than 0.75 dm^3 swept volume per cylinder and a rated power speed of more than 3000 min^{-1}

Figure 5.1(b): European Emission Regulation Trends Heavy Duty Truck and Bus Engines (g/kWh)

Over the past half century, every developed country and most developing countries have progressively introduced similar controls on emission levels from new vehicles. The international nature of motor vehicle manufacturing and trade has also prompted an increasing level of harmonisation in emission standards and regulations. The most broadly implemented standards (generally referred to as the Euro regulations) are those developed through the United Nations Economic Commission for Europe (UNECE), which are uniformly applied across the whole of the

European Union and have also been adopted in many other regions. The European Commission proposes and adopts first the Euro regulations in the European Union, and then those regulations are translated into UNECE regulations. The USA still retains its own set of emission regulations, but work is proceeding to unify the two systems.

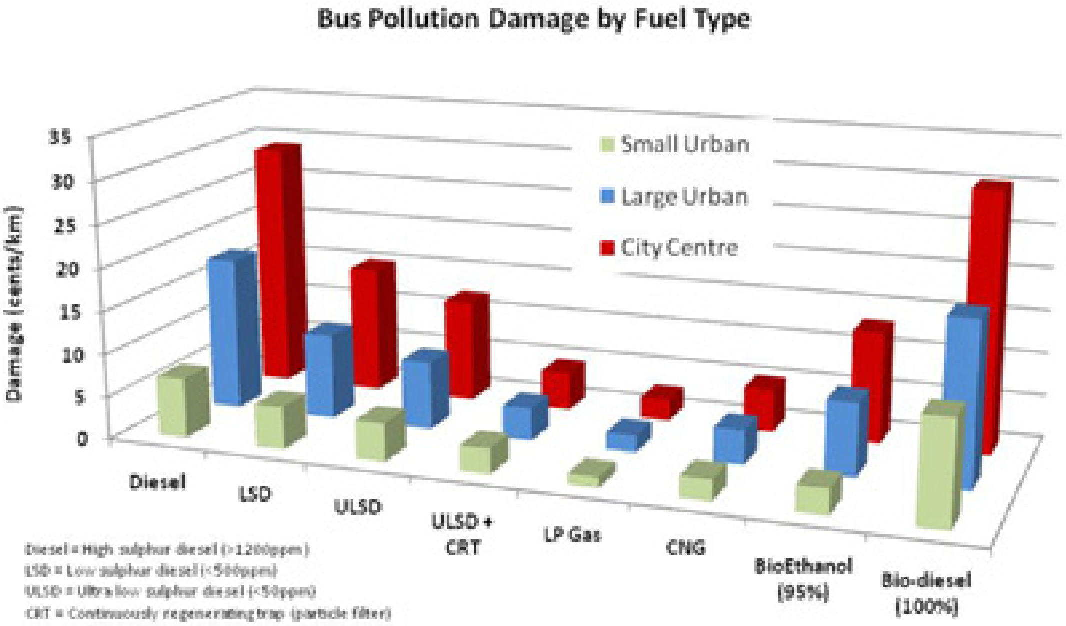
LP Gas (often called Autogas when used as an automotive fuel) is the most widely available and accepted alternative fuel for road transport. Over 13 million LP Gas fuelled vehicles are now in use around the world, consuming over 20 million tonnes of fuel annually. As well as being practical and clean, the attractiveness of LP Gas in many countries is enhanced through fuel taxation policies which make it a much lower cost alternative to gasoline or diesel for both light and heavy duty vehicles.

In many instances, LP Gas fuel systems are fitted to vehicles as an aftermarket conversion, though in some markets, particularly in the Asian region, factory-built LP Gas vehicles represent a large and growing proportion of new vehicles.

Heavy-duty LP Gas engines have been in existence for almost 100 years in the USA, but for many decades their use outside the USA was extremely limited. A number of heavy duty LP Gas engines (mostly adaptations of their diesel counterparts) are now available from several of the larger engine manufacturers. These engines are being used in buses and mid-size trucks, mainly in the USA and South Korea, but increasingly in other regions around the world.

The very low gaseous and particulate emissions from LP Gas engines make them ideally suited for buses and delivery vehicles operating in urban areas. To address this specific issue in monetary terms, in 2001 Australia's Bus Industry Council engaged Mr Paul Watkiss, one of Europe’s foremost experts in transport externality pricing, to translate the outcomes of European externality studies into an Australian context (BIC, 2001).

Focusing on the pollution damage created by buses, on a cents per kilometre basis, his work takes account of Australia’s human and vehicle population densities, city size and morbidity/mortality values, as well as local vehicle emissions performance. The results of his analysis are summarised in the chart below.



(Note: 1.0 Australian cent = approx 0.5 Eurocent)

Figure 5.2: Pollution Damage by Fuel Type in Urban Buses (A$ cents/km)

Figure 5.2 is particularly valuable because, even though the work was completed in 2001, it includes engine and exhaust after treatment technologies which match those required to meet current regulations (i.e. diesels operating on ultra-low sulphur diesel (ULSD) and fitted with exhaust particle filters, now more generally referred to as continuously regenerating traps – CRT).

The chart clearly shows how policies which encourage the uptake of LP Gas fuelled buses and trucks in urban areas have potential to deliver even better outcomes than current diesel technology, in the areas where it is vitally important to have the cleanest possible vehicles.

The lower emissions from purpose built LP Gas buses have enabled operators to deliver Euro III and Euro IV emissions performance well ahead of regulatory schedules.

For more detailed information on particle emissions from gasoline, diesel and LP Gas motor vehicles, please refer to Annex A3 – Particle Emissions from Current Technology Vehicles.

Each of the following four sets of charts and accompanying notes summarises (for different vehicle categories) emissions of the transport vehicle pollutants which are of most concern from a health perspective (PM, NOx, HC, CO).

Health cost impacts for individual pollutants use French values calculated by Rabl and Sparado (Rabl and Spadaro, 2000). The numerical values are in Table 4.4 of this document.

(a) Passenger Cars

The two passenger car sets each present data for vehicles operating on gasoline, diesel and LP Gas. One set relates to pre-2005 cars (Euro 3 compliant) where no particle filter is fitted to the diesel powered vehicles. The second covers current technology (Euro 5) cars, the diesel versions of which are almost universally equipped with a diesel particle filter which reduces tailpipe PM emissions sufficiently to meet the stringent Euro 5 limits.

Data for these charts was drawn principally from a comparative emissions project performed jointly by three independent European emission testing laboratories (EETP, 2004). The data from this project is particularly relevant because it tested the diesel, gasoline and LP Gas variants of seven different Euro 3 certified cars, enabling direct comparisons to be made of their emissions performance on each fuel. Looking ahead to future regulations, the program also included testing of a diesel fuelled variant equipped with a diesel particle filter (DPF).

For the Euro 5 charts, the DPF equipped vehicle results are used for the diesel PM emissions, and NOx emissions are factored to reflect the lower emissions of this pollutant for current technology vehicles. Average emissions of the other pollutants were already sufficiently low in the Euro 3 vehicles to meet current Euro 5 limits, so were not factored.

(b) Heavy Duty Trucks and Buses

Although a considerable body of test data exists for heavy-duty vehicle engines, most results are expressed in grams per kilowatt.-hour (g/kWh), which is not directly convertible to the required grams per kilometre (g/km) units. Of the available g/km data, many different test cycles have been used, with different speed profiles and energy content, which make comparisons extremely difficult.

Fortunately, the Australian Government commissioned a comprehensive series of test programs over the period 2000-2005, involving transient drive cycle chassis dynamometer testing of almost 900 vehicles, including a number of alternative (CNG and LP Gas) fuelled heavy duty vehicles. Data from this testing, together with data from other sources, has been distilled into a comprehensive set of speed-related on-road emission factors (in g/km) by the Queensland State Government for all regulated pollutants, greenhouse gases and a wide range of “air toxic” pollutants.

Based on the anticipated increased stringency of progressively introduced Euro regulations, the data has also been factored to provide emission factors for future years through to Euro 5. Given the high degree of consistency and coherency in the underlying database, these emission factors have been used as the basis for heavy duty and bus emission rates.

Only two fuels are included for heavy duty vehicles: Diesel and LP Gas. Gasoline fuelled heavy vehicles are available, but represent only a tiny proportion of the total population, so have been omitted. CNG, although not explicitly included, is taken to have similar emission characteristics to LP Gas for the pollutants under consideration.

Application:

PASSENGER CARS AND DERIVATIVES

Euro 3 (no particle filter on diesels)

Diesel vehicles manufactured prior to 2005 in Europe, and even today in many countries, diesel vehicles represent by far the greatest health hazard of all fuel types.

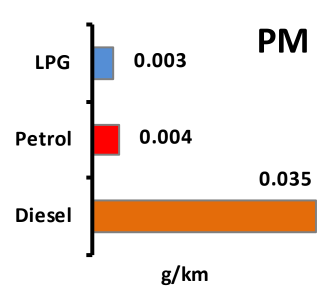
This set of charts highlights the difference in health impacts of vehicles powered by diesel, and those powered by other liquid and gaseous fuels (principally gasoline (petrol) and LP Gas).

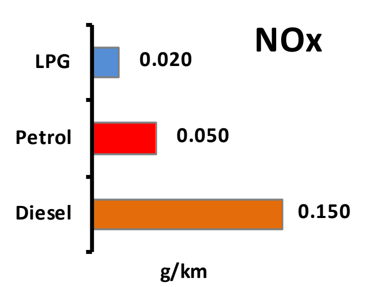
Diesel, because of its intrinsically high emission levels of damaging particulate matter (PM) and oxides of nitrogen (NOx) has much more severe health impacts than the other commercially available fuels.

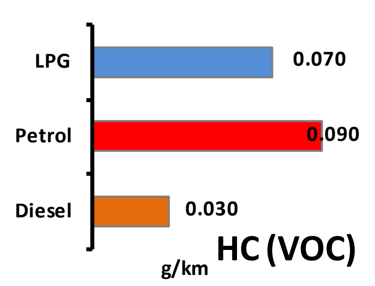
Other regulated pollutants: volatile organic compounds (VOCs) and carbon monoxide (CO) have lower health cost values. They are inherently emitted at low levels from diesels and, since the mid-1980's have been tightly controlled in many spark-ignition vehicles through the installation of catalytic converters.

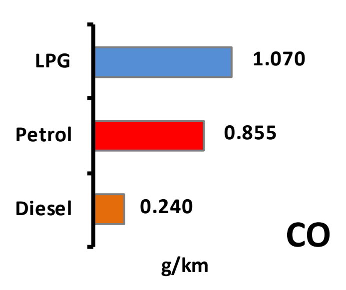
LP Gas has the lowest health cost impacts of all commercially available fuels.

Pollutant Emissions (g/km)

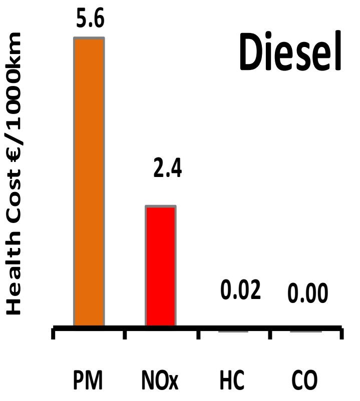


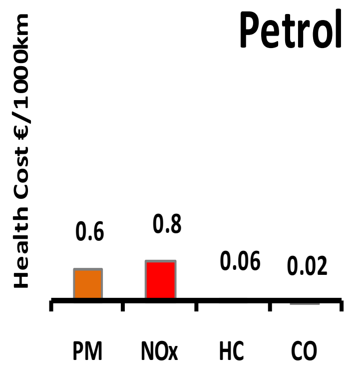


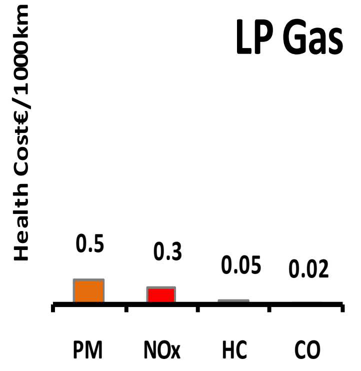




Health Cost (€ per 1000km)

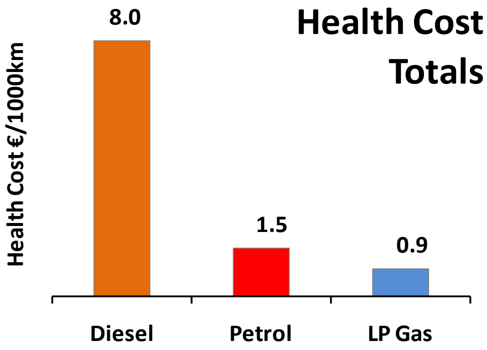






NOTES:

For these older technology engines (which continue to be installed in new vehicles sold in many countries), the health cost impacts are much higher for diesels because of their high emission rates of particles (PM) and NOx.



Application:

PASSENGER CARS AND DERIVATIVES

Euro 5 (with particle filter on diesels)

Until recently, there was a very distinct difference in the health impacts of vehicles powered by diesel, and those powered by other liquid and gaseous fuels (principally gasoline (petrol) and LP Gas).

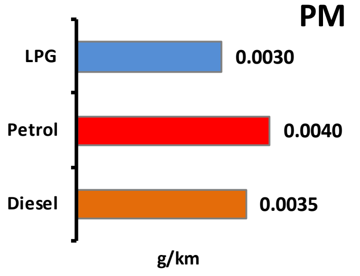
Diesel, because of its intrinsically high emission levels of damaging particulate matter (PM) and oxides of nitrogen (NOx) had much more severe health impacts than the other commercially available fuels.

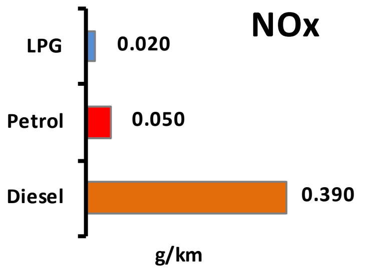
Other regulated pollutants: volatile organic compounds (VOCs) and carbon monoxide (CO) have lower health cost values. They are inherently emitted at low levels from diesels and, since the mid-1980's have been tightly controlled in many spark-ignition vehicles through the installation of catalytic converters.

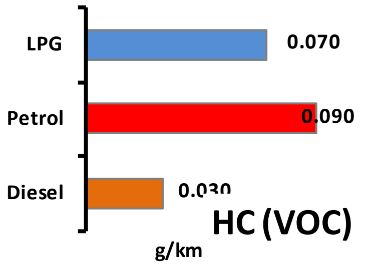
However, since 2004 in Europe, and at later varying times in some other countries, a high proportion of new diesel vehicles have been fitted with particle filters, which typically reduce PM emissions by over 90%.

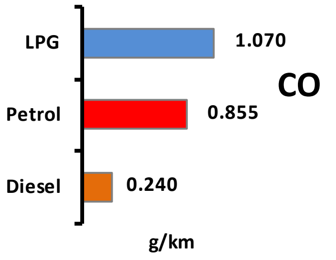
Despite the very significant health risk reductions for diesels, LP Gas remains the cleanest fuel by a wide margin.

Pollutant Emissions (g/km)

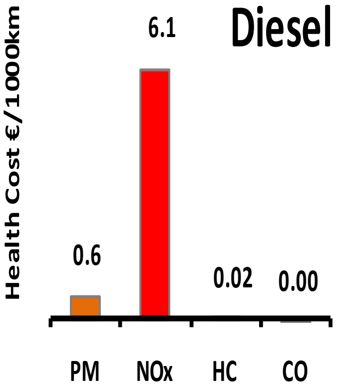


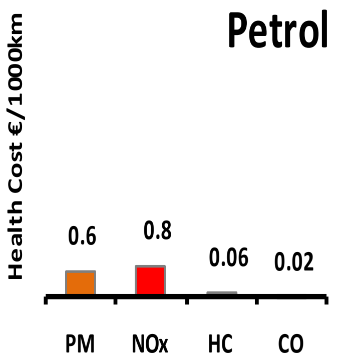


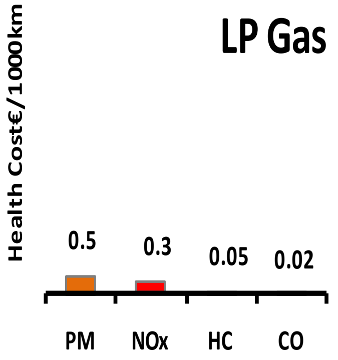


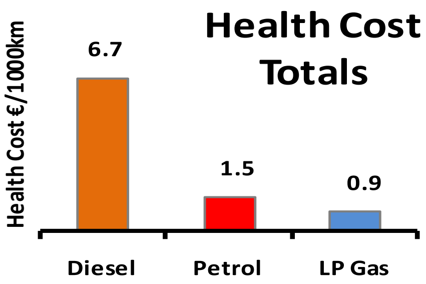


Health Cost
(€ per 1000km)







NOTES: For this class of vehicles, overall health impacts are relatively low for all fuels. The principal differential is high NOx emissions from diesels.	

Application:

HEAVY DUTY TRUCKS & BUSES

Euro 3 (no particle filter on diesels)

This set of charts highlights the difference in health impacts of vehicles powered by diesel, and those powered by gaseous fuels.

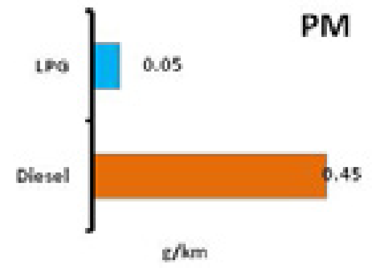
Spark-ignition gas-fuelled vehicles are starting to be used more widely in heavy-duty applications, mainly for urban buses and delivery trucks, but are still very much in the minority.

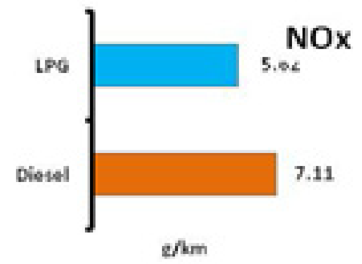
Gasoline (petrol) fuelled HD vehicles are rare, though some continue to be used in the USA and some developing countries.

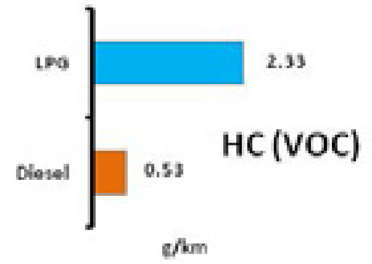
Diesel, because of its intrinsically high emission levels of damaging particulate matter (PM) and oxides of nitrogen (NOx) has much more severe health impacts than the other commercially available fuels.

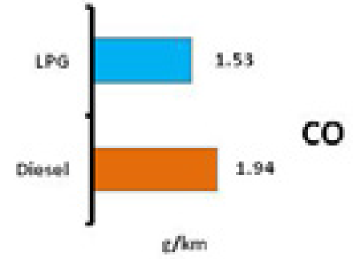
For these vehicles categories, LP Gas and NG have the lowest health cost impacts.

Pollutant Emissions (g/km)

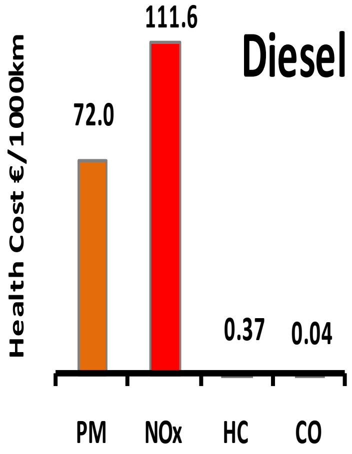


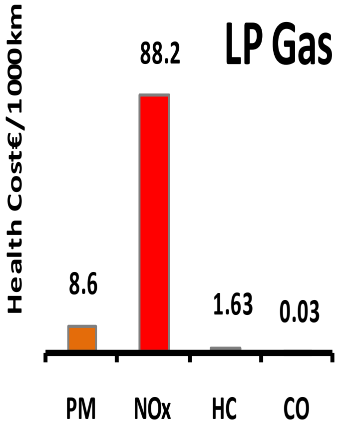






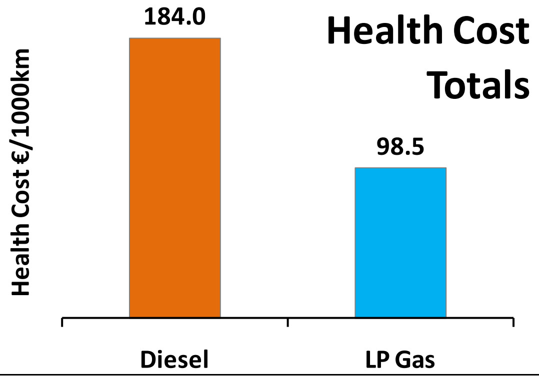
Health Cost (€ per 1000km)





NOTES:

For this class of vehicles, overall health impacts are significantly higher for diesels due to high PM and NOx levels.



Application:

HEAVY DUTY TRUCKS & BUSES

Euro 4/5 (with particle filter on diesels)

Diesel, because of its intrinsically high emission levels of damaging particulate matter (PM) and oxides of nitrogen (NOx) had much more severe health impacts than the other commercially available fuels.

However, since 2004 in Europe, and at later varying times in some other countries, new diesel vehicles have been fitted with particle filters, which reduce PM emissions by over 90%, in some cases by up to 99%.

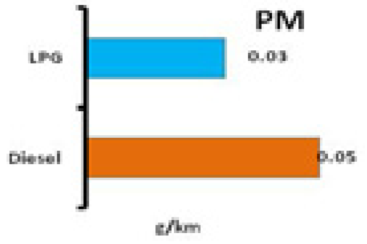
Other regulated pollutants: volatile organic compounds (VOCs) and carbon monoxide (CO) have lower health cost values.

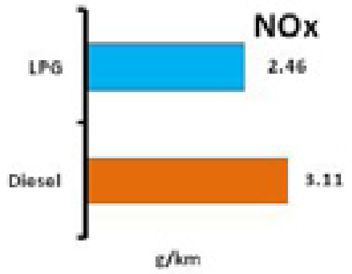
Spark-ignition gas-fuelled vehicles are starting to be used more widely in heavy-duty applications, mainly for urban buses and delivery trucks, but are still very much in the minority.

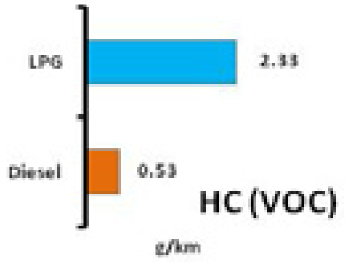
Gasoline (petrol) fuelled HD vehicles are rare, though some continue to be used in the USA and some developing countries.

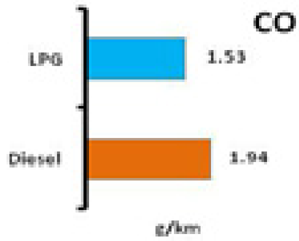
For this group of vehicles, the new diesel technologies greatly reduce fuel-specific differences in health cost impacts.

Pollutant Emissions (g/km)

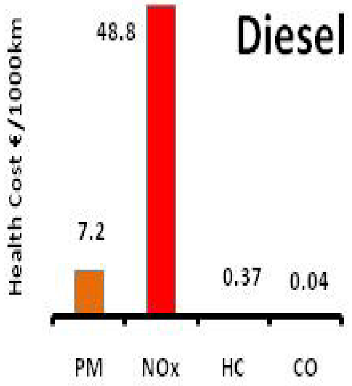


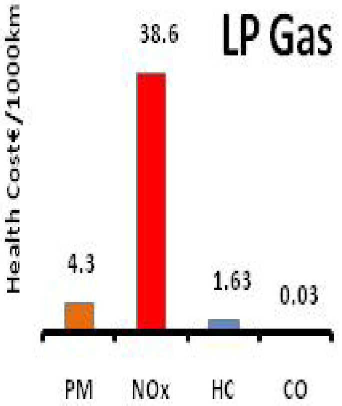






Health Cost
(€ per 1000km)

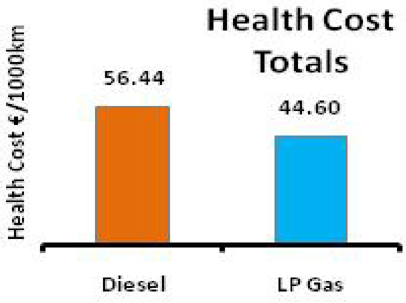




NOTES:

The chart opposite highlights the very significant health benefits flowing from new PM reduction technologies on modern diesel engines. The health cost impacts of all fuels are now at similar levels,

It is important to note the health impact of noise are not monetarized



5.2 Cooking

The cooking appliances used by most people in the developed world operate at the flick of a switch or the twist of a knob. Electricity or a reticulated gas supply provides instant, clean energy for preparing their food. For hundreds of millions of the world's population, the luxury of choice does not exist - everything is dictated simply by the need to survive from one day to the next.

The World Health Organisation estimates that more than half of the world's population rely on dung, wood, crop waste or coal to meet their most basic energy needs. Energy from these fuels is thought to account for nearly one-tenth of all human energy demand today - more than hydro and nuclear power together. Cooking and heating with these fuels in confined spaces, often without any flue, results in exposure to extremely high levels of toxic pollutants. At times, pollutant concentrations can rise to levels 100 times higher than the maximum recommended exposure limits (WHO, 2005-3).

A consequence of this continued exposure, indoor air pollution is estimated to be responsible for the deaths of more than 1.6 million people every year.

As we have seen in other situations, the most dangerous pollutant is very fine particulate matter (PM). A large proportion of these particles are less than 1 micron (1/1000 mm) diameter, with some being even 100 times smaller again. Because of their extremely small size the particles can be inhaled into the deepest and most sensitive parts of the lung. The smallest can pass through the lung tissue and directly into the bloodstream, where they can also lead to heart disease and possibly brain damage.

Respiratory diseases and cancers resulting from exposure to PM are extremely common, and it is the very young and the elderly who suffer the greatest.

The following chart (Figure 5.3) is indicative of the extremely high incidence of respiratory problems for women, very young children and the elderly, who often spend most of their time in the home, in some remote areas in developing nations. The source of pollution causing most of this illness is smoke from fires used for cooking or other domestic activities.

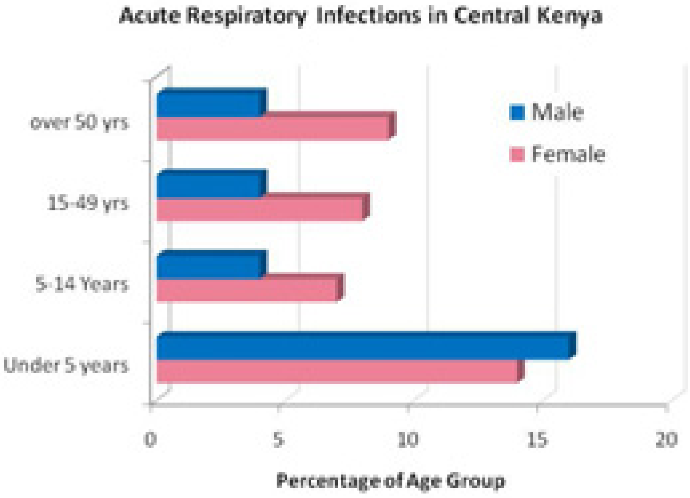


Figure 5.3: Respiratory Infections by Gender and Age Group – Central Kenya (Ezzati, 2000)

A number of studies have been performed to measure concentrations of particulate matter adjacent to areas where indoor cooking is performed using a range of fuel sources. Universally, when the fuel being used is wood, dung, harvest waste or other biomass material, the PM concentration is many times the WHO recommended exposure limits for humans.

For example, an extensive year 2000 research program (Ezzati M et al 2000) in Kenya measured indoor PM levels for 14 hours a day over 137 days, in 38 households. The average PM exposure level was measured to be around 3500 µg per cubic metre during the active learning periods, rising to 4500 µg per cubic metre when the fires were smouldering. These alarming figures are in stark contrast to the World Health Organisation's recommended average exposure limit of 20 µg per cubic metre. The household members were therefore continuously exposed to particle concentrations 200 times higher than the recommended exposure limit.

A 2005 study (Smith KR 2005) compared the relative amounts of pollution generated cooking a single meal using a range of six fuels typically available to households in developing countries, plus biogas. This study also included LP Gas, which was used as the reference against which emissions from all the other fuels were compared on a ratiometric basis. (See figure 5.4)

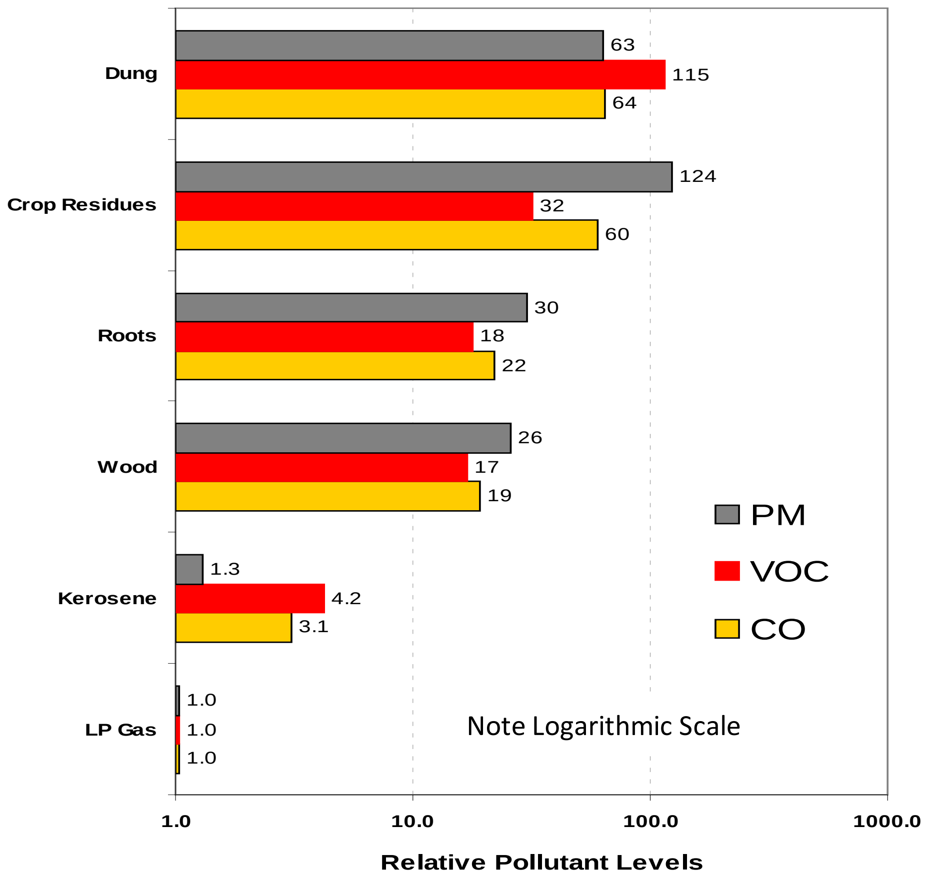


Figure 5.4: Pollutants Emitted Per Meal Relative to LP Gas

The WHO has produced an assessment of a range of risk factors and their contribution to disease. Indoor air pollution was identified as the eighth most important risk factor and is estimated to be responsible for 2.7% of the total global burden of disease. This finding ranks indoor air pollution as exceeding outdoor air pollution by a factor of five, measured by combining the estimated years of life lost due to disability and premature death.

In developing countries with high mortality rates, the ranking increases to an estimated 3.7% of the total impact of disease, making it the highest cause of premature death after malnutrition, unsafe sex and lack of safe water and sanitation.

For many people, especially in rural areas, the choices of fuel for cooking are either solid fuel or LP Gas. As we have seen under the previous two headings, solid fuel is neither an environmentally sound nor a healthy option and its use should be discouraged. In some countries and Germany is an example, emissions from domestic solid fuel appliances are monitored and sanctions can be applied if they are found to have excessive levels of emissions.

But for around half of the world's population the penalties are much greater than a simple fine. In many poorer countries, cooking over an open fire using wood, charcoal, crop waste or even animal dung is the only option available. Exposure to the extremely high levels of pollutants emitted by these fires, particularly in a confined space, is reliably reported by the World Health Organisation and other independent researchers to result in premature deaths of more than 1.5 million people every year. Women and young children are those most greatly affected.

Providing these families with access to simple LP Gas burners to replace the wood burning fireplace can dramatically reduce exposure to these harmful pollutants and the tragic consequences. There are other social benefits. It is often the role of one of the female members of these families to gather the wood required for the days cooking. This duty, which can involve several hours of hard work a day, can be replaced by more meaningful tasks.

5.3 Residential Space and Water Heating

5.3.1 Indoor Air Quality

Air pollution is generally associated with the air outside, but under many circumstances higher levels of pollution can exist indoors. Moreover, since most people spend most (typically around 90 per cent) of their time indoors at home, school or work rather than outdoors, the exposure time is generally much longer, increasing the risk of adverse health outcomes.

If ventilation of rooms is poor, or if heating appliances and associated flues or chimneys are faulty, the concentration of some pollutants can build up to levels which may be harmful to human health. But it should be noted that heaters are not the only cause of high indoor pollutant concentrations – other sources can include chemicals in paints, adhesives and furnishing materials.

Symptoms can range from being quite mild, such as headaches, tiredness or lethargy; or more severe such as aggravation of asthma or allergic responses. All indoor combustion appliances, regardless of the fuel used, need to have an adequate supply of air to ensure proper combustion and to avoid any build-up of fumes in the room. Although unflued gas heaters emit extremely low levels of undesirable substances, compared with wood and other solid fuels, they too must have adequate fresh air ventilation to ensure proper operation.

The most significant emissions associated with unflued gas heaters are nitrogen dioxide (NO_2) and carbon monoxide (CO). Both pollutants are odourless and hence difficult to detect, but CO is of particular concern, since exposure to high levels can have serious consequences. To avoid risks associated with exposure to excessive CO levels, most LP Gas heaters are equipped with an oxygen depletion sensor which automatically turns off the heater if there is insufficient ventilation to sustain complete combustion.

In good condition and properly used, unflued gas heaters only release small amounts of these pollutants, which have not been found to affect human health. But levels can build up with insufficient ventilation or if the heater is faulty, or inappropriately installed.

In contrast, solid fuel heaters produce very high levels of respirable particles which, as we have seen in previous sections of this document can cause ill health or, in extreme cases, death. Although solid fuel heaters in developed countries invariably have a chimney or flue to carry the combustion products outside, leakage through cracked or faulty flues, or the occurrence of chimney “back-draughts” can lead to persistent high levels of particles inside the building.

Open fires, in particular, also require good ventilation to maintain efficient combustion and to generate sufficiently high chimney flows for effectively entraining the smoke and other combustion products. As well as producing high levels of carbon monoxide (CO) and fine particulate matter (PM), solid fuel coal fires also generate a range of acidic sulphur oxides (SOx).

Kerosene heaters emit much lower levels of particle emissions than solid fuel, but the same precautions regarding adequate ventilation must be observed to avoid excessive CO levels. Unvented kerosene heaters may also generate acid aerosols (US EPA 1993).

The large number of variables influencing indoor air pollution levels for any given fuel (ventilation rate, burner design, heat output, flue efficiency, etc) and the disparity between test methods make it difficult to assemble reliable data to compare pollutant exposure levels associated with a range of available fuels.

But it is possible to infer potential impacts by comparing the total pollutant emissions from the combustion of different fuels. Data from the European Environmental Agency (EEA, 2007) allows such a comparison to be made. Because this data impacts primarily on outdoor air quality, the tabulated emissions data is located in Section 5.3.2 – Impacts on Outdoor Air.

A number of studies have been performed to explore possible health effects associated with unflued gas heaters. Most are based on natural gas appliances but, given that the difference in emissions between these fuels is generally quite small, the results of these studies can also be applied in relation to LP Gas with a high degree of reliability. Although the results of some studies show a small effect, others do not, and meta-analyses show no overall effect (Basu and Samet 1999).

In Japan, Shima and Adachi (2000) studied 842 children aged 9–10 years, from 9 elementary schools and found no statistically significant association between the prevalence of respiratory symptoms (measured over three consecutive years) and the presence of unflued gas appliances in the home.

It is therefore reasonable to conclude that, given the general availability of heaters incorporating automatic safety controls, there is little risk of negative health impacts from the use of LP Gas heaters, and the use of these appliances certainly minimizes exposure to other hazardous particle pollutants including sulphur dioxide (SO_2) and fine particulate matter (PM).

Even though these findings confirm the low-polluting characteristics of LP Gas heaters for domestic heating it is worth re-stating that, like all indoor combustion heaters regardless of fuel type, they must receive adequate ventilation for proper operation.

5.3.2 Outdoor Air Quality.

In many locations solid fuel heaters produce enough pollution to directly affect the health of people in the community. The impacts are intensified when temperature inversions, commonly occurring on colder windless evenings, trap the flue gases in layers close to the ground, producing high concentrations of particles and other unhealthy products of combustion. Visual amenity can also be degraded significantly by the smoky haze created by these heaters.

Research in Australia (Ayers et al 1999) clearly shows that cities where wood burning heaters are prevalent have much higher ambient particle levels than other cities. For instance, the four major cities, Sydney, Brisbane, Melbourne and Adelaide yielded average PM_{10} concentrations in the range 20-25 µg/m^3, whereas Canberra and Launceston (where wood heaters are popular) yielded averages 2-3 times higher at 43and 65µg/m^3 (see Figure 5.5).

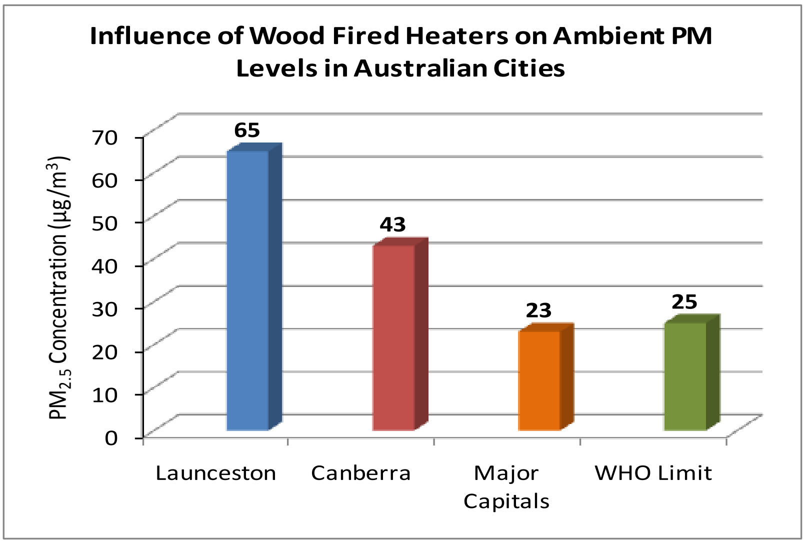


Figure 5.5: Influence of Wood Fired Heaters on Ambient PM Levels in Australian Cities

Both of the wood-burning cities have low housing density, with relatively fewer industrial and transport sources, so without the influence of wood heaters it could be expected that particle levels would actually be lower than the larger cities. The fact that PM levels are significantly higher underlines the impact on local air quality from wood burning, even in modern developed cities.

Table 5.6, below, uses data from the European Environmental Agency, published in a 2009 Swiss report by Atlantic Consulting (Atlantic, 2009) to summarise emission rates in grams per gigajoule (g/GJ) of energy for both combustion heaters and water boilers operating on gaseous and liquid fuels, wood and coal/briquettes. This table highlights the very significant benefits of using gaseous fuels for domestic space and water heating.

			Emissions, g/GJ		
Fuel	**NO_2**	**VOC**	**PM_{10}**	**$PM_{2.5}$**	**CO**
			Residential Combustion Heater		
Gaseous	57.0	10.5	0.5	0.5	31.0
Liquid	68.0	15.5	3.7	3.7	46.0
Wood	74.5	925	695	694	5,300
Coal	109	484	404	397	4,602
			<50 kW Household Boiler		
Gaseous	70.0	10.0	0.5	0.5	30.0
Liquid	70.0	15.0	3.0	3.0	40.0

Wood	120.0	400	475	475	4,000
Coal	130.0	300	38	360	4,000
Briquettes	200.0	200	100	100	3,000

Table 5.6: Emissions from Residential Combustion Appliances for Five Fuels (Atlantic, 2009)

Also, from a practical perspective, switching to an LP Gas heater is not only beneficial to the environment and to community health, but is also much more convenient, more controllable, and avoids dust and grime build-up in the house interior and areas around chimneys or flues.

5.4 Electrical Power Generation

As well as providing motive power for on road vehicles, internal combustion engines are used in numerous other applications. The diversity of these applications makes it impractical to cover them all separately in this report. Additionally, many of the non-road applications utilise only a very limited range of fuel types. For instance virtually all construction, excavation, mining and equivalent heavy duty plant and equipment use diesel fuel. Consequently there is an almost complete lack of data comparing emissions and exposure levels for different fuel types for these applications.

Nevertheless, some important categories of equipment are available to operate on a range of different fuels. The most significant of these is local electricity generation, with numerous examples of generators operating on diesel, gasoline, LP Gas and natural gas. Some other types of equipment, such as pumps, pressure washers and compressors are also available, to a limited extent, for operation using several fuel types. All these applications have one important feature in common, in that they generally operate mostly in constant load, constant speed mode.

Portable and transportable electricity generating plant can therefore be used to characterise emissions and health impacts associated with this class of equipment. Two types of generator will be considered in this section; medium power (typically around 100 kW) and low power domestic or trade type generators, which usually have a rated power less than 15 kW.

5.4.1 Medium Capacity Generator Sets

Many rural and isolated communities in both developed and less wealthy developing regions do not have access to centralised electricity grids as a source of power for lighting, communications and entertainment.

By necessity electrical power must be produced locally, usually by way of a diesel powered generator. Unless the generator's engine is very modern and equipped with the latest emission reduction technologies, people living in the vicinity of the generator plant can be exposed to noise and high levels of ultrafine particles in the diesel exhaust.

These soot particles, and highly toxic chemicals adhering to the soot, are linked to the incidence of cancers, are damaging to the lungs and can also affect the heart and human neurological systems. Compared with a traditional diesel appliance (not fitted with a particle filter), an LP Gas powered generator will typically have 90 to 98% lower particle emission levels, as well as greatly reducing the potential for exposure to other toxic substances.

In more developed areas, this class of generator is generally used either as a standby power source in case of failure of the mains supply, or as a continuous power source on sites where mains power is not readily available, such as on construction sites or where there is a need to drive relatively high powered mobile equipment.

The example used to illustrate the relative emissions and health cost impacts for this category of plant is a generator set operating for a continuous 12 hours every day with a load of 80 kW, powered by a 6.8 litre engine. The fuel types compared are diesel, natural gas and LP Gas.

Table 5.7 summarises the emission rates of each regulated pollutant in grams per kilowatt-hour, together with a health cost value (expressed as Euros per tonne of pollutant emitted) for each pollutant. The health cost values used in the table are representative of mid-level values for road vehicles operating in a typical developed region. Note: *In this example the diesel PM emissions are quite low relative to the gaseous fuels, probably reflecting the constant load-speed nature of generator operation, which avoids the very high PM peaks typically observed during acceleration phases of diesel road vehicles. Conversely, NOx levels are quite high, which is consistent with continuous high load, high temperature combustion.*

Fuel Type	**Pollutant Emissions Rates (g/kWh)**			
	HC	**NOx**	**CO**	**PM**
LP Gas	0.14	0.11	4.61	0.03
Natural Gas	0.09	0.62	3.49	0.03
Diesel	0.40	6.43	1.21	0.28
Health Impact Cost (€/kg)	0.7	15.7	0.02	120

Table 5.7: Pollutant Emission Rates for Typical 80kW Generators on Diesel, NG and LP Gas

The chart below (Figure 5.8) presents the data in Table 5.7 as a graphic representation of the relative emission levels (in grams per kilowatt-hour) for each pollutant and fuel type, while operating at a constant 80 kW load. Emissions data is drawn from the US EPA non-road engine certification database www.epa.gov/OMS/certdata.htm#largeng

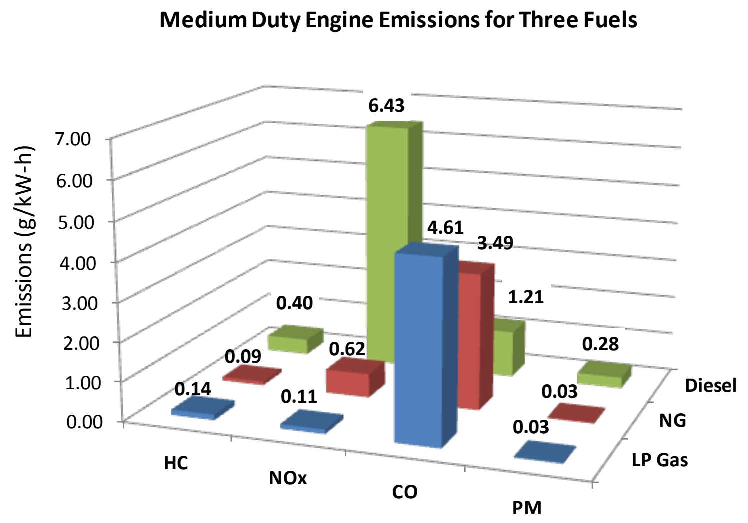


Figure 5.8: Pollutant Emission Rates for Typical 80kW Generators on Diesel, NG and LP Gas

Applying the health cost values in Table 5.7, factored by the annual duty cycle, Figure 5.9 below illustrates the relative health costs for each pollutant/fuel type combination, together with the net total health cost for each fuel.

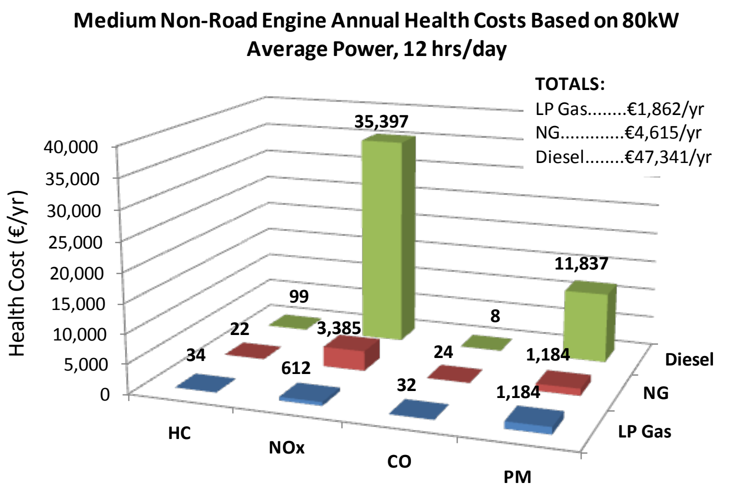


Figure 5.9: Annual Health Impact Costs for Typical 80kW Generators on Diesel, NG and LP Gas

The health impact cost figures clearly indicate the value of using a gaseous fuel, in particular LP Gas, wherever the choice is available.

5.4.2 Small Generator Sets

Generators in this category tend to be constructed for intermittent rather than continuous power generation and are primarily used for recreation or trade-related activities. In areas where the mains power may be unreliable, they are also frequently used for domestic power backup, enabling lighting, refrigeration and other low-power services to be maintained. Their power output ranges typically from around 15 kW for the larger models, down to less than 1.0 kW for the smallest examples.

Fuel choices for these appliances are generally gasoline, LP Gas or diesel. Both two-stroke and four-engines are available, particularly for the gasoline fuelled versions. In many countries the emissions from small engine-powered equipment is not regulated. This can result in very high levels of CO, HC and PM being emitted from some engines, especially if manufactured in one of the countries which currently do not have domestic emission standards for this type of equipment.

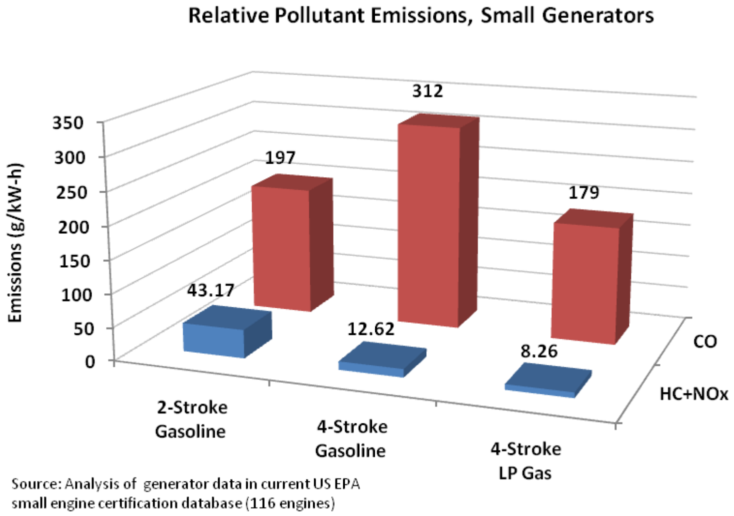
Taking data from a US EPA report summarising non-road engine emissions (US EPA 1991) the following table (Table 5.10) compares emissions of CO, HC, NOx and PM from older generators using 1990's technology levels, when this type of equipment was not required to comply with any emission regulations. In the absence of reliable test data from that era comparing like-for-like gasoline and LP Gas engines, the LP Gas emission figures have been calculated by multiplying the gasoline emission factor by the ratio of LP Gas/gasoline emissions in Figure 5.7, for each pollutant.

		Emissions (g/kW-h)			
		HC	**CO**	**NOx**	**PM**
2-Stroke	Gasoline	279	651	0.39	10.32
4-Stroke	Gasoline	12.73	473	2.72	0.07
4-Stroke	Diesel	1.74	6.70	8.04	1.34
4-Stroke	LP Gas	10.59	473	1.03	0.05

Table 5.10: Pollutant Emission Rates for Unregulated Small Generators on Diesel, Gasoline and LP Gas

Many developed countries have now introduced progressively more stringent regulations for non-road engines, but the limits tend to be quite lax compared with those for on-road vehicles. This is illustrated by the following chart (Figure 5.11), which is directly based on analysis of all relevant certification test data contained in the US EPA's 2008 small engine certification database

(*http://www.epa.gov/OMS/certdata.htm#smallsi*)



Source: Analysis of generator data in current US EPA small engine certification database (116 engines)

Figure 5.11: Pollutant Emissions of Small Generators Operating on Gasoline and LP Gas

Using the same pollutant health cost impact values that have been used in earlier sections of this report, the following chart (Figure 5.12) translates the emission rates into monetary health-related costs, further emphasising the adverse implications of choosing the wrong fuel for this type of equipment.

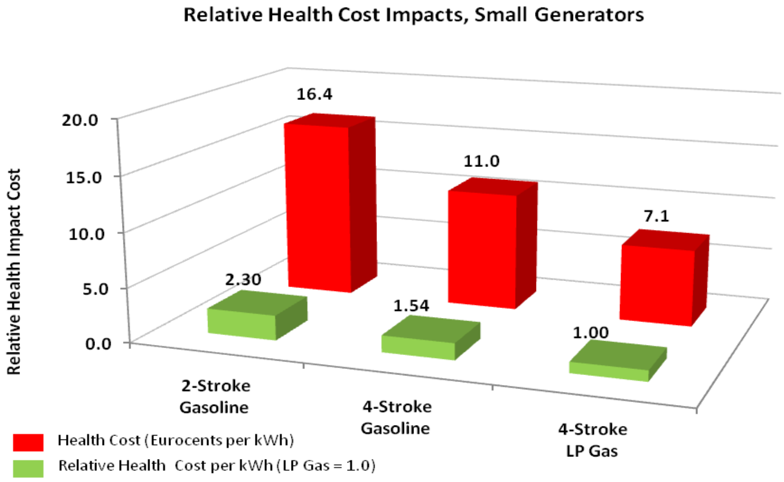


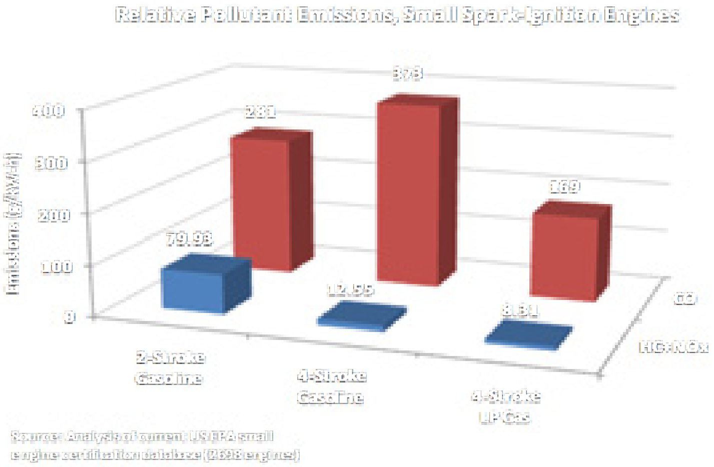
Figure 5.12: Health Cost Impacts of Emissions from Small Generators Operating on Gasoline and LP Gas

5.5 Other LP Gas Applications

In every neighbourhood hundreds, if not thousands of engine powered appliances are owned and used by residents, including lawnmowers, brush cutters, pressure washers, chain saws - the list is very long. Together, the use of this equipment on a typical workday or week end amounts to a considerable energy load, with the pollutants spread across the community.

Using the same methodology as that used in the previous section for small generators, once again the US EPA database has been analysed on a broader front to include all currently certified small spark ignition engines operating on gasoline or LP Gas (dual fuel and mixed fuel engines were excluded from this analysis).

The following two charts (Figures 5.13 and 5.14) tell the same story as their counterparts in the previous Section, but in this case are based on analysis of test data for a total of almost 2700 engines in the database.



Source: Analysis of current US EPA small engine certification database (2698 engines)

Figure 5.13: Pollutant Emissions of Small Generators Operating on Gasoline and LP Gas

In this analysis we see similar trends to those for small generators, though, surprisingly, carbon monoxide emissions from the smallest two-stroke engines (on a grams per kilowatt-hour basis) are actually lower than for the four stroke group, despite the four strokes being generally recognised as having much more efficient combustion than the two strokes.

Figure 5.14 provides a perspective on the relative emissions from current model two and four-stroke small gasoline engines compared with equivalent LP Gas fuelled units.

The health cost analysis follows the same format, though from the cost data we can infer that, overall, the broader spectrum of equipment in the full database tends to have higher emission levels than the generator category discussed in the previous Section. Health impact values (in €/tonne) are the same as those used for motor vehicles and the medium/heavy non-road engine applications analysed in earlier sections.

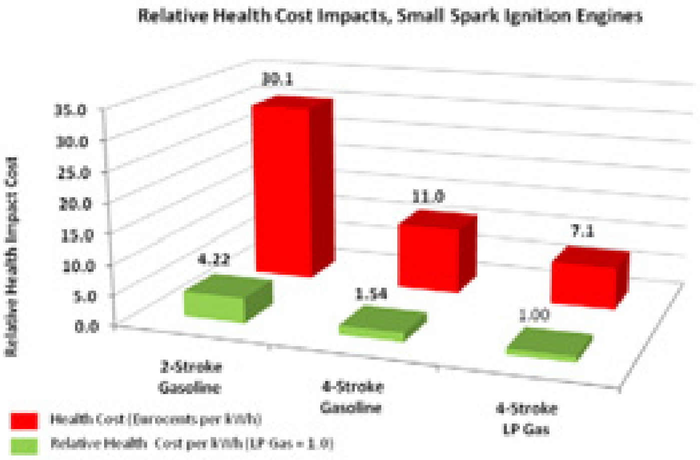
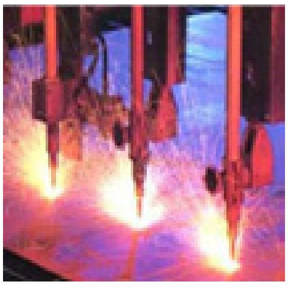


Figure 5.14: Health Cost Impacts of Emissions from Small Engines Operating on Gasoline and LP Gas

Thermal desiccation (also commonly referred to as "flame weeding"), heats plant tissues rapidly to rupture cells but not so extensively as to burn them. It is used widely in Western Europe and the USA to halt the growth of weeds above slow-emerging root crops, such as carrots and potatoes, as well as for killing weed growth around the stems of some above-ground crops such as maize.

LP Gas has proved to be an ideal fuel for this application and is now almost universally used, having supplanted earlier technologies based on kerosene and oil burning. Because it does not introduce any chemicals into the soil, LP Gas fuelled thermal desiccation completely avoids any danger of soil contamination, and is widely used for the farming of organic crops.

So we can see there are many wide-ranging applications for LP Gas as a source of heat energy for industry, the home and for recreation: from metal cutting to grilling a steak to gliding around in a hot air balloon. In all cases, LP Gas provides a convenient, safe, controllable and low polluting energy source, with minimal adverse impacts on public health.



6 Conclusions

Life on this planet depends on energy for its very existence. We need controllable energy to feed and nurture our families, provide heat and light, and transport goods and people to their destinations. Industry and businesses need energy to produce the goods and services we demand.

But there can be a downside. Every year countless numbers of the earth's population have their lives cut short, or suffer serious illness through exposure to combustion pollutants. The social and economic consequences are enormous, but can be minimized by using cleaner fuels.

Making “clean fuel” choices can directly help to improve the wellbeing of whole communities. Improvements in public health flowing from the use of cleaner fuels not only reduces the cost of providing health care and social services, but also contributes to the broader economy by helping to avoid the impacts of diminished productivity.

Solid fuels, ranging from coal, through to wood, crop waste and even animal dung can, when used for cooking and heating, expose families to dangerous levels of pollution – often 20 or even 100 times higher than recommended maximum limits.

The use of wood as a combustion fuel represents not only a highly visible consumption of our limited forest resources, but also has a very high impact on the environment and consequently on our health.

Unfortunately the communities most affected by the use of these fuels are often also the poorest, so reliance must be placed on governments and aid agencies to direct more emphasis and resources towards programs to alleviate the intense suffering that results from the use of these dangerous energy sources.

Even the commonplace and convenient liquid fuels, such as diesel and gasoline, continue to create serious levels of pollution in most developed countries, despite ever-tighter regulation of the appliances and vehicles using these fuels.

To illustrate this, the table below summarises and compares the pollutant and greenhouse emission characteristics of the principal transport fuels, relative to gasoline as a baseline (Anyon, 2002).

	Gasoline	Diesel	CNG	LP GAS
Gaseous Pollutants	O	O	√	√
Particulates	O	X	√	√
GHG Emissions	O	√	√	√
Air Toxics	O	X	√	√

(Legend: √=better, O=neutral, X=worse, ?=Uncertain

Overall, LP Gas rates very highly and gives little or no ground to any others in the table, across all of the features considered to be of greatest importance in a general-purpose fuel. With its intrinsically clean burning characteristics, LP Gas offers a practical avenue towards cleaning up the air we breathe.

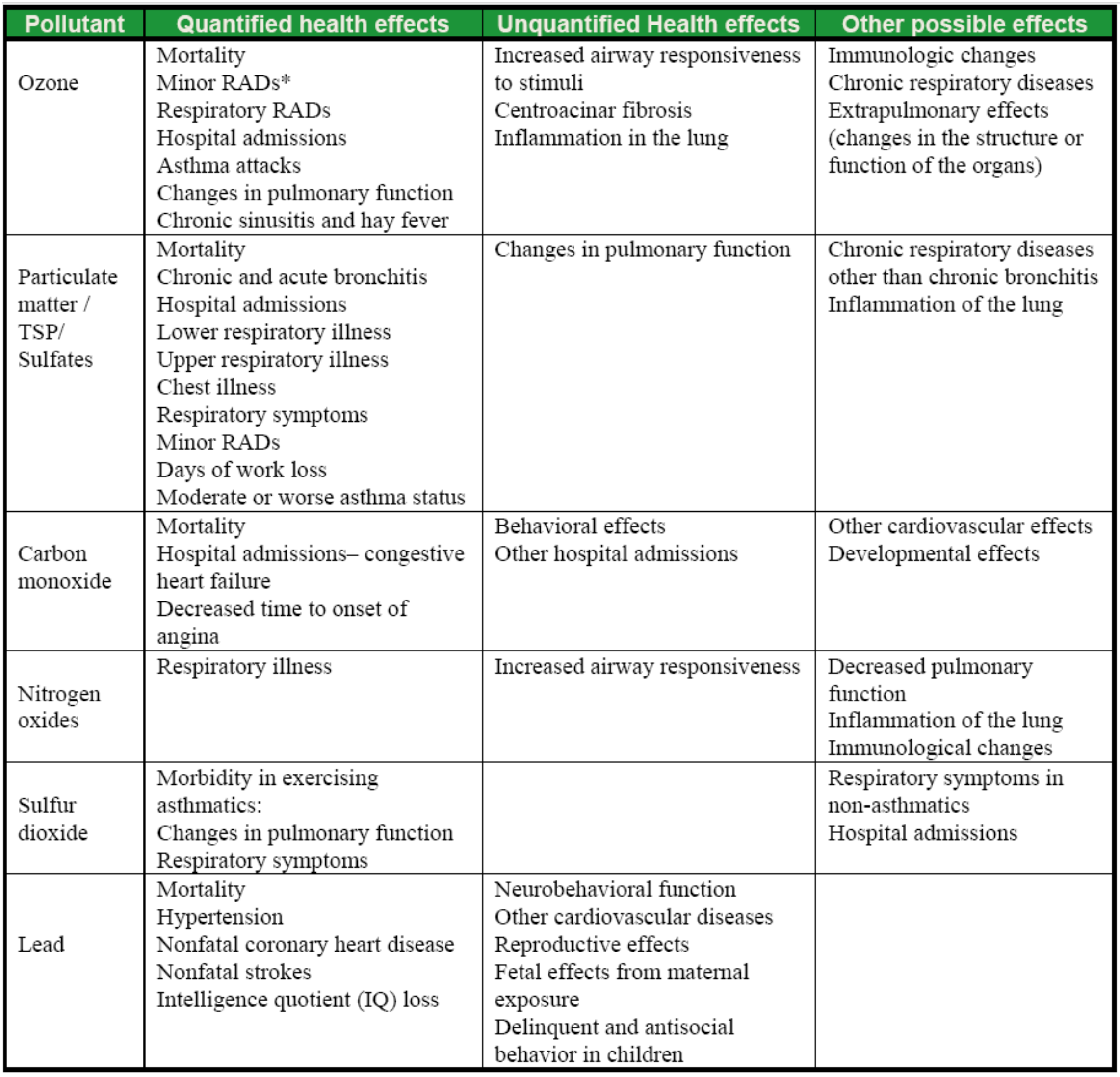
As well as outperforming most traditional fuels, from a health perspective, LP Gas is readily available, convenient and is frequently a lower cost alternative to other energy sources.

TECHNICAL ANNEXES

7 Annex A1 - Pollutants and their Health Effects

This section reviews linkages between pollutants and human health in a little more detail. It will be useful to have an understanding of these linkages when, later in the document, we examine pollutant emission levels from a range of fuels in the most significant energy-intensive applications.

Table 7.1, from a 2009 report published by the Victoria Transport Policy Institute, Canada (VPI 2009) summarises the key health effects of some common pollutants.



Pollutant	Quantified health effects	Unquantified Health effects	Other possible effects
Ozone	Mortality Minor RADs* Respiratory RADs Hospital admissions Asthma attacks Changes in pulmonary function Chronic sinusitis and hay fever	Increased airway responsiveness to stimuli Centroacinar fibrosis Inflammation in the lung	Immunologic changes Chronic respiratory diseases Extrapulmonary effects (changes in the structure or function of the organs)
Particulate matter / TSP/ Sulfates	Mortality Chronic and acute bronchitis Hospital admissions Lower respiratory illness Upper respiratory illness Chest illness Respiratory symptoms Minor RADs Days of work loss Moderate or worse asthma status	Changes in pulmonary function	Chronic respiratory diseases other than chronic bronchitis Inflammation of the lung
Carbon monoxide	Mortality Hospital admissions– congestive heart failure Decreased time to onset of angina	Behavioral effects Other hospital admissions	Other cardiovascular effects Developmental effects
Nitrogen oxides	Respiratory illness	Increased airway responsiveness	Decreased pulmonary function Inflammation of the lung Immunological changes
Sulfur dioxide	Morbidity in exercising asthmatics: Changes in pulmonary function Respiratory symptoms		Respiratory symptoms in non-asthmatics Hospital admissions
Lead	Mortality Hypertension Nonfatal coronary heart disease Nonfatal strokes Intelligence quotient (IQ) loss	Neurobehavioral function Other cardiovascular diseases Reproductive effects Fetal effects from maternal exposure Delinquent and antisocial behavior in children	

Table 7.1: Health Effects of Common Pollutants

7.1 Regulated (Criteria) Pollutants

7.1.1 Particulates (PM)

"Particulate matter," also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulphates), organic chemicals, metals, and soil or dust particles.

The size of particles is directly linked to their potential for causing health problems. The main health concerns relate to particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects. EPA groups particle pollution into two categories:

"Inhalable coarse particles," such as those found near roadways and dusty industries, are larger than 2.5 micrometers and smaller than 10 micrometers in diameter.

"Fine particles," such as those found in smoke and haze, are 2.5 micrometers in diameter and smaller. These particles can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries and automobiles react in the air.

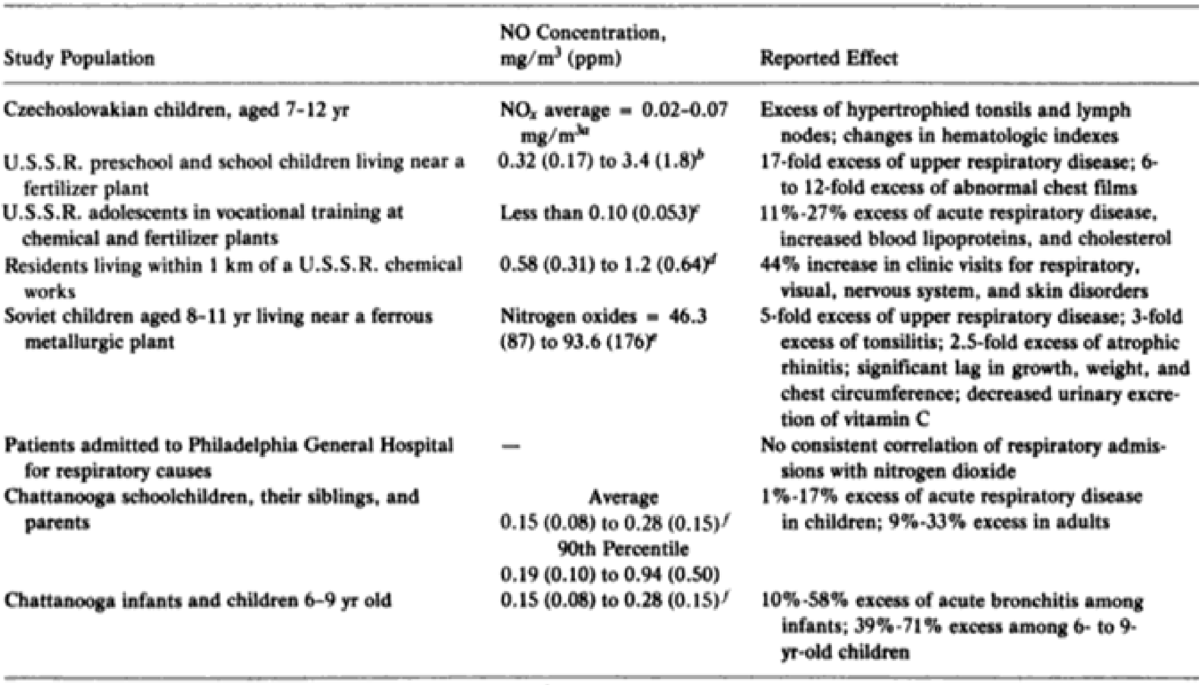
7.1.2 Oxides of Nitrogen (NOx)

The term "Oxides of Nitrogen" covers several gaseous compounds, the most significant of which are nitric oxide (NO), nitrogen dioxide (NO_2) and nitrous oxide (N_2O).

These compounds are formed by a reaction between oxygen and nitrogen during high-temperature combustion, such as in an internal combustion engine or a high-temperature flame. Although these compounds are chemically different, they are often referred to collectively as NOx.

NOx affects human health in two ways. Firstly, in their own right they irritate the eyes and the lungs and are believed to lower the body's resistance to infection. These symptoms are most severely experienced by those people who already have asthma. Nitrogen dioxide has also been proved to also adversely affect plant life.

Clinical studies have shown a relationship between hospital admissions and ambient NOx levels for respiratory problems experienced by otherwise healthy people. But the strongest reactions are encountered by patients who have pre-existing respiratory illnesses. Table 7.2 below provides some examples.



Study Population	NO Concentration, mg/m^3 (ppm)	Reported Effect
Czechoslovakian children, aged 7-12 yr	NO_x average = 0.02-0.07 mg/m^3[a]	Excess of hypertrophied tonsils and lymph nodes; changes in hematologic indexes
U.S.S.R. preschool and school children living near a fertilizer plant	0.32 (0.17) to 3.4 (1.8)[b]	17-fold excess of upper respiratory disease; 6- to 12-fold excess of abnormal chest films
U.S.S.R. adolescents in vocational training at chemical and fertilizer plants	Less than 0.10 (0.053)[c]	11%-27% excess of acute respiratory disease, increased blood lipoproteins, and cholesterol
Residents living within 1 km of a U.S.S.R. chemical works	0.58 (0.31) to 1.2 (0.64)[d]	44% increase in clinic visits for respiratory, visual, nervous system, and skin disorders
Soviet children aged 8-11 yr living near a ferrous metallurgic plant	Nitrogen oxides = 46.3 (87) to 93.6 (176)[e]	5-fold excess of upper respiratory disease; 3-fold excess of tonsilitis; 2.5-fold excess of atrophic rhinitis; significant lag in growth, weight, and chest circumference; decreased urinary excretion of vitamin C
Patients admitted to Philadelphia General Hospital for respiratory causes	—	No consistent correlation of respiratory admissions with nitrogen dioxide
Chattanooga schoolchildren, their siblings, and parents	Average 0.15 (0.08) to 0.28 (0.15)[f] 90th Percentile 0.19 (0.10) to 0.94 (0.50)	1%-17% excess of acute respiratory disease in children; 9%-33% excess in adults
Chattanooga infants and children 6-9 yr old	0.15 (0.08) to 0.28 (0.15)[f]	10%-58% excess of acute bronchitis among infants; 39%-71% excess among 6- to 9-yr-old children

Table 7.2: Examples of Dose Response to Excess Levels of Nitrous Oxide (NAS 1997)

In a second health-related environmental impact, NOx reacts with volatile organic compounds (VOCs) in the presence of sunlight to form ozone (O_3). Ozone is a precursor of photochemical smog, and is discussed separately in this section.

The temperatures and pressures found in the combustion of internal combustion engines are ideal for the formation of NOx, and in some American cities over 60% of all ambient NOx is attributed to motor vehicle sources.

But motor vehicles are not the only source. Industrial engines, furnaces and many industrial processes also generate these compounds. Even nature is a source, with lightning strikes and even the decomposition of micro-bacteria in the soil making a contribution.

From a climate change perspective nitrous oxide is of some significance. Although it is generally emitted in relatively low amounts, it is an extremely powerful greenhouse gas with a CO_2 equivalence of around 410. This number means that one tonne of nitrous oxide has the same impact on climate change as 410 tonnes of CO_2.

7.1.3 Volatile Organic Compounds (VOCs), including Hydrocarbons (HC)

Volatile Organic Compounds (VOCs) are compounds containing at least one carbon atom, excluding carbon monoxide and carbon dioxide, which evaporate readily to the atmosphere. VOCs include a wide range of individual substances from many substance classes such as hydrocarbons, halocarbons and oxygenates.

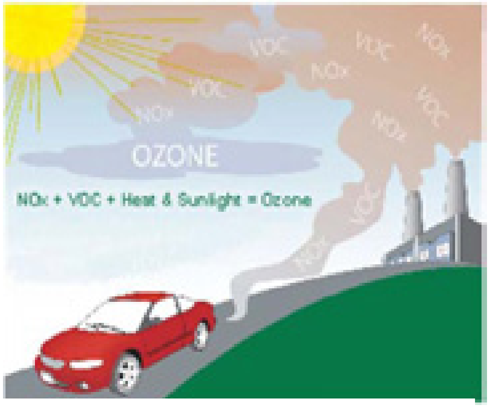
Major VOC emission sources are the organic solvents used in many consumer and commercial products such as cleaning products, paints, commercial printing inks; transportation sector activities such as the exhaust emissions from cars and trucks; various industrial processes such as chemical manufacturing; and combustion of fossil and biomass fuels. Not all VOCs originate from man-made sources, however, in more populated and industrial areas man made emissions predominate.

When VOCs are released to the atmosphere, they can react with other chemicals, notably oxides of nitrogen, in photochemical reactions to form ground-level ozone and particulate matter. These two air pollutants are the main ingredients of smog and cause serious health effects for humans, including many thousands of premature deaths, hospital admissions and emergency room visits every year.

Almost all ground-level ozone and in the order of two-thirds of particulate matter are formed in the atmosphere through the reactions of precursor substances, with VOCs being one of the most significant. Consequently, reduction of atmospheric levels of particulate matter and ozone must be accomplished through reductions of precursors, such as VOCs.

A number of hydrocarbon compounds, classified as **"air toxics"** are extremely hazardous to humans, but many are only generated in very small quantities.

Some air toxics are known to be carcinogenic and this group of chemicals is also suspected to play a role in the rapid growth of a number of "20th century" illnesses, including asthma. However, because their ambient concentrations are extremely low, it has not yet been possible to reliably establish dose response characteristics, nor to place a direct monetary cost on their exposure effects. Air toxics are discussed in some detail in Section 7.2.



(Picture courtesy of US EPA)

7.1.4 Ozone (O_3)

Ozone is a gas simply composed of three oxygen atoms. It is not usually emitted directly into the air, but at ground-level is created by a chemical reaction between oxides of nitrogen (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. Ozone has the same chemical structure whether it occurs high above the earth or at ground-level, and can be "good" or "bad," depending on its location in the atmosphere. In the earth's lower atmosphere, ground-level ozone is considered "bad."

Motor vehicle exhaust and industrial emissions, gasoline vapours, and chemical solvents as well as natural sources emit NOx and VOCs that help form ozone, which is the primary constituent of photochemical smog.

Many urban areas tend to have high levels of ground level ozone and its attendant smog haze, but even rural areas are also subject to increased levels when wind carries ozone and pollutants that form it long distances from their original sources.

Health Effects

People with lung disease, children, older adults, and people who are active can be affected when ozone levels are unhealthy. Numerous scientific studies have linked ground-level ozone exposure to a variety of problems, including:

- airway irritation, coughing, and pain when taking a deep breath;
- wheezing and breathing difficulties during exercise or outdoor activities;
- inflammation, which is much like a sunburn on the skin;
- aggravation of asthma and increased susceptibility to respiratory illnesses like pneumonia and bronchitis; and,
- permanent lung damage with repeated exposures.

Environmental Effects

Ground-level ozone can have detrimental effects on plants and ecosystems. These effects include:

- interfering with the ability of sensitive plants to produce and store food, making them more susceptible to certain diseases, insects, other pollutants, competition and harsh weather;
- damaging the leaves of trees and other plants, negatively impacting the appearance of urban vegetation, as well as vegetation in national parks and recreation areas; and
- reducing forest growth and crop yields, potentially impacting species diversity in ecosystems.

Ozone also damages vegetation and ecosystems. In the United States alone, it is responsible for an estimated US$500 million in reduced crop production each year.

7.1.5 Carbon Monoxide (CO)

Carbon Monoxide (CO) is a colourless, odourless, poisonous gas composed of one atom each of carbon and oxygen. It is formed when carbon-based fuel is not burned completely.

Motor vehicle exhaust is the most significant source of carbon monoxide in most developed countries, and in highly urbanised areas, motor vehicles can account for up to 95% of the total. Other non-road engines and vehicles (such as construction equipment) can account for the remaining engine-generated carbon monoxide emissions. Other sources include industrial processes (such as metals processing and chemical manufacturing), residential wood burning, and natural sources such as forest fires.

Exposure to indoor carbon monoxide can often be more dangerous than breathing outdoor concentrations. Woodstoves, solid fuel heaters and hearths, cigarette smoke, gas and kerosene space heaters are sources of carbon monoxide indoors and concentrations can rise to dangerous levels if there is insufficient ventilation. Most LP Gas heaters are equipped with an oxygen depletion sensor which automatically turns off the heater if there is insufficient ventilation to sustain complete combustion.

Carbon monoxide can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues. Oxygen is transported around the body via the red blood cells by binding to a substance within the red blood cells called haemoglobin, which is also responsible for their red colour.

Haemoglobin takes up oxygen as blood passes through the lungs, and at the same time carbon dioxide, produced by the body's metabolism, is released from the blood into the exhaled breath. The combination of oxygen with haemoglobin is called oxyhaemoglobin and this 'oxygenated' blood is carried away from the lungs through the bloodstream to all the tissues of the body.

Carbon monoxide can also bind to haemoglobin but does so about 240 times more tightly than oxygen, forming a compound called carboxyhaemoglobin. This means that if both carbon monoxide and oxygen are inhaled, carbon monoxide will preferentially bind to haemoglobin. This reduces the amount of haemoglobin available to bind to oxygen, so the body and tissues become starved of oxygen.

Carboxyhaemoglobin also has direct effects on the blood vessels of the body - causing them to become 'leaky'. This is seen especially in the brain, causing the brain to swell, leading to unconsciousness and neurological damage.

The health threat from lower levels of carbon monoxide is most serious for those who suffer from heart disease, like angina, clogged arteries, or congestive heart failure. For a person with heart disease, a single exposure to carbon monoxide at low levels may cause chest pain and reduce that person's ability to exercise; repeated exposures may contribute to other cardiovascular effects.

But even healthy people can be affected by high levels of CO. People who breathe high levels of carbon monoxide can develop vision problems, reduced ability to work or learn, reduced manual dexterity, and difficulty performing complex tasks. At extremely high levels, carbon monoxide is poisonous and can cause death.

Carbon monoxide also contributes to the formation of ground level ozone, which can trigger serious respiratory problems (see Section 7.1.4).

7.1.6 Fuel Sulphur Content and Sulphur Dioxide (SO_2)

Sulphur dioxide causes a wide variety of health and environmental impacts because of the way it reacts with other substances in the air. Particularly sensitive groups include people with asthma who are active outdoors and children, the elderly, and people with heart or lung disease. Peak levels of sulphur dioxide can cause temporary breathing difficulty for people with asthma who are active outdoors. Longer-term exposures to high levels of sulphur dioxide gas and particles cause respiratory illness and aggravate existing heart disease.

Sulphur dioxide also reacts with other chemicals in the air to form tiny sulphate particles. When these are inhaled, they gather in the lungs and are associated with increased respiratory symptoms and disease, difficulty in breathing, and even premature death.

When sulphur dioxide and nitrogen oxides react with other substances in the air they can form acids, which fall to earth as rain, fog, snow, or dry particles – this phenomenon is commonly described as “acid rain”, which may be carried by the wind for hundreds of kilometres.

Acid rain damages forests and crops, changes the makeup of soil, and makes lakes and streams acidic and unsuitable for fish. Continued exposure over a long time changes the natural variety of plants and animals in an ecosystem.

Sulphur dioxide is generated in huge quantities, as Figure 7.3 below illustrates. (US EPA 2002)

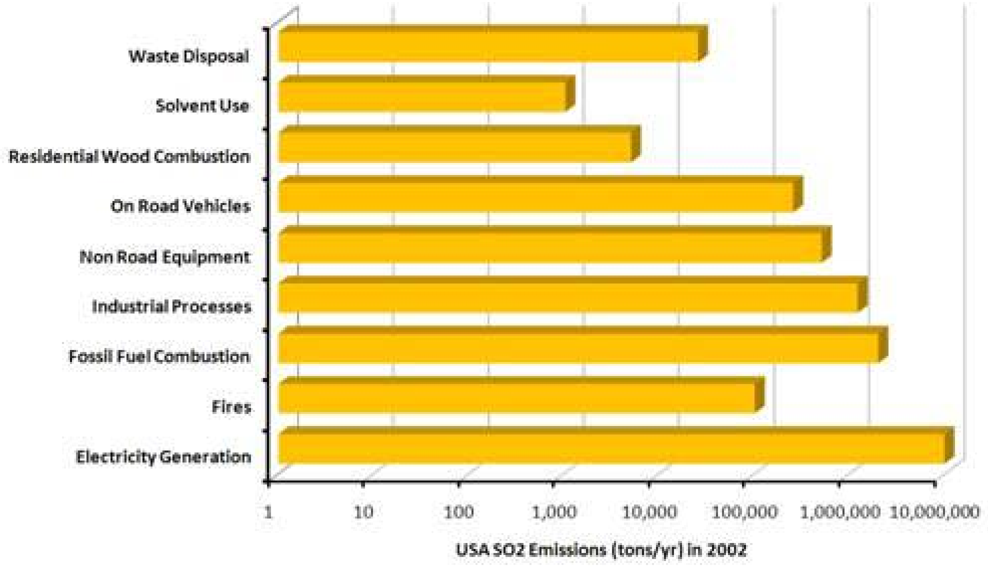


Figure 7.3: Annual Sulphur Dioxide Emissions in the USA (2002), note logarithmic scale

Given the extensive human health impacts and acid rain damage to crops, ecology, buildings and infrastructure, there is clearly a strong imperative to minimise emissions of this pollutant.

Although considerable progress has already been made through the mandating of low sulphur gasoline and diesel fuels, and the introduction of emission reduction measures for power stations, the chart shows that there is considerable scope for further reductions in other areas.

Particle emission rates from diesel engines have a linear relationship with sulphur content in the fuel. The following chart illustrates this relationship.

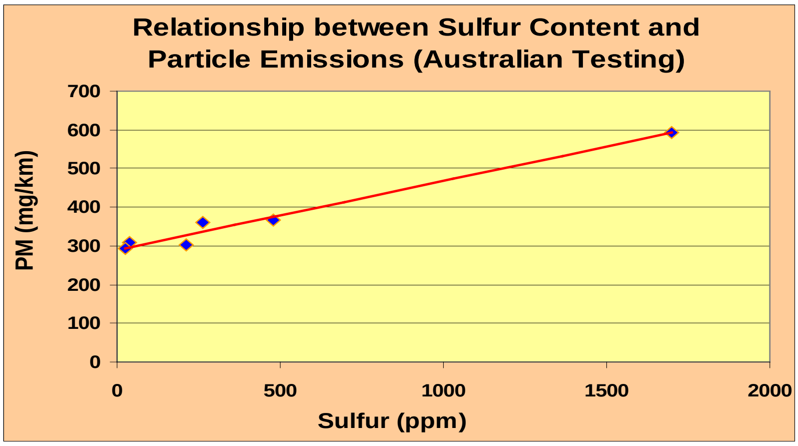


Figure 7.4: Diesel Fuel Sulphur Content Versus Particle Emissions

Testing commissioned by the Australian Government (EA, 2003), summarised in Figure 7.4, utilised six fuels, with sulphur content ranging from 24ppm to 1700ppm. Testing was performed in an independent heavy-duty emission testing facility (Parsons Australia), using the transient "real world" composite urban emissions drive cycle (CUEDC). Two medium-duty diesel vehicles were tested, and the chart represents the averaged emission rates on each fuel. The high sulphur fuel effectively increased PM emissions by 300mg/km, to double the "base" emissions for these vehicles (no particle filter installed).

High sulphur fuels also inhibit the use of modern pollution control technologies, including exhaust catalyst systems and diesel particle filters. Sulphur “poisons” the active surfaces of these devices and can seriously degrade their effectiveness.

LP Gas contains only very small concentrations of sulphur, and consequently emits little or no sulphur dioxide. It is the ideal energy source to replace many of the sulphur-bearing fuels still in use, particularly coal heaters and many industrial process heat sources.

7.1.7 Lead (Pb)

Lead is a widely used metal that, once released to the environment, can contaminate air, food, water, or soil. Exposures to even small amounts of lead over a long time can accumulate to reach harmful levels. Short-term exposure to high levels of lead may also cause harm. Lead can adversely affect the nervous, reproductive, digestive, cardiovascular blood-forming systems, and the kidney. In men, adverse reproductive effects include reduced sperm count and abnormal sperm. In women, adverse reproductive effects include reduced fertility, still-birth, or miscarriage. Children are a sensitive population as they absorb lead more readily and their developing nervous system puts them at increased risk for lead-related harm, including learning disabilities.

Lead additives were frequently used to raise the octane rating of gasoline and were a major source of airborne lead pollution. Most developed countries now ban the use of these additives. LP Gas contains no lead.

7.2 Air Toxic Compounds

Toxic air pollutants, also known as hazardous air pollutants (HAP), are those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects.

The US EPA is lists 187 pollutants as “Air Toxics”. Although these chemicals are known to be extremely hazardous to humans, many of them exist in only extremely low concentrations in ambient air, making it extremely difficult to characterise their toxicity with any degree of certainty. Figure 7.5 compares typical motor vehicle engine-out emissions of some key air toxics for the most widely available commercial fuels (Anyon, 2002), based on data from an Argonne National Laboratory report (Winebrake J., 2000).

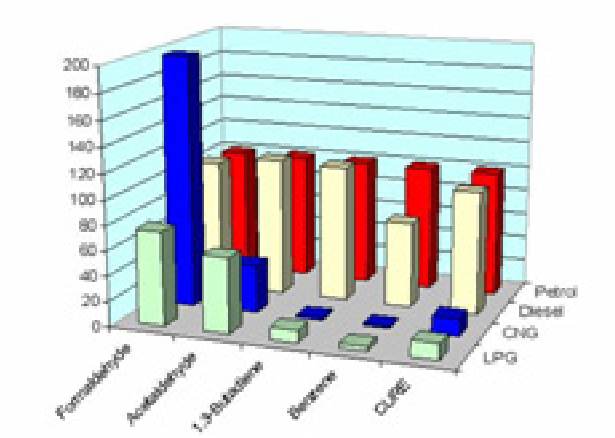


Figure 7.5: Comparison of Transport Sector Air Toxic Emissions by Fuel Type

Note: CURE = Cancer Unit Risk Estimate, defined as “the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to and agent (e.g. chemical) at a concentration of 1 microgram per cubic metre in air or 1 microgram per litre in water”. Hence the higher the CURE number, the higher the human cancer risk.

This document reviews the health effects of five air toxics - benzene, 1,3-butadiene, toluene, xylenes and Polycyclic Aromatic Hydrocarbons (PAH). These five air toxics are ranked by the WHO as having the greatest health damaging potential, based on a combination of their inherent toxicity and typical human exposure levels.

Table 7.6, based on Australian Government data (NPI 2000) also highlights the extremely low air toxic emission levels from LP Gas fuelled vehicles, compared with gasoline and diesel equivalents.

Air Toxic Emissions, Passenger Car Exhaust (g/km) By Road Type			
Road Type:	Arterial	Freeway	Residential
Benzene			
Gasoline	0.08291	0.08817	0.09541
Diesel	0.00334	0.00313	0.00518
LP Gas	0.00001	0.00001	0.00002
1,3-butadiene			
Gasoline	0.01064	0.00993	0.01642
Diesel	0.00064	0.00059	0.00099
LP Gas	0.00010	0.00009	0.00015
PAHs			
Gasoline	0.00668	0.00625	0.01035
Diesel	0.00674	0.00628	0.01041
LP Gas	0.00000	0.00000	0.00000
Toluene			
Gasoline	0.05618	0.02531	0.05618
Diesel	0.01573	0.00710	0.01573
LP Gas	0.00000	0.00000	0.00000
Xylenes			
Gasoline	0.08880	0.04175	0.08880
Diesel	0.03405	0.02516	0.03405
LP Gas	0.00000	0.00000	0.00000

Table 7.6: Passenger Car Air Toxic Emissions by Fuel and Road Type (NPI 2000)

People exposed to toxic air pollutants at sufficient concentrations and durations may have an increased chance of getting cancer or experiencing other serious health effects. These health effects can include damage to the immune system, as well as neurological, reproductive (e.g., reduced fertility), developmental, respiratory and other health problems.

In addition to exposure from breathing air toxics, some toxic air pollutants such as mercury can deposit onto soils or surface waters, where they are taken up by plants and ingested by animals and are eventually magnified up through the food chain. Like humans, animals may experience health problems if exposed to sufficient quantities of air toxics over time.

Once toxic air pollutants enter the body, some persistent toxic air pollutants accumulate in body tissues. Predators typically accumulate even greater pollutant concentrations than their contaminated prey. As a result, people and other animals at the top of the food chain that eat contaminated fish or meat are exposed to concentrations that are much higher than the concentrations in the water, air, or soil.

Humans are exposed to toxic air pollutants in many ways that can pose health risks, such as by:

- Breathing contaminated air.
- Eating contaminated food products, such as fish from contaminated waters; meat, milk, or eggs from animals that fed on contaminated plants; and fruits and vegetables grown in contaminated soil on which air toxics have been deposited.
- Drinking water contaminated by toxic air pollutants.
- Ingesting contaminated soil. Young children are especially vulnerable because they often ingest soil from their hands or from objects they place in their mouths.

- Touching (making skin contact with) contaminated soil, dust, or water (for example, during recreational use of contaminated water bodies).

PAHs are compounds that contain only hydrocarbon and carbon and are a group of over several hundred organic chemicals with two or more fused aromatic rings. Two ring PAHs are found in the vapour phase, two to five ring PAHs can be found in both the vapour and particulate phases and PAHs consisting of five or more rings tend to be solids adsorbed onto other particles in the atmosphere. Benzo-a-pyrene (B[*a*]P) is a five-ring compound and probably the most well known PAH. B[*a*]P is often used a marker for PAHs.

PAHs are formed mainly as a result of incomplete combustion of organic materials during industrial and other human activities, such as processing of coal and crude oil, combustion of natural gas, combustion of refuse, wood burning stoves, motor vehicle exhaust, cooking, tobacco smoke, and natural processes such as carbonisation.

7.2.1 Benzene

Benzene is a natural component of crude oil. Almost all benzene found at ground level comes from human activities. It is emitted from industrial sources and a range of combustion sources including motor vehicle exhaust and solid fuel combustion. Benzene is also emitted from tobacco smoke. The major outdoor source is evaporative emissions and evaporation losses from motor vehicles, and evaporation losses during the handling, distribution and storage of gasoline. Workers in industries exposed to motor vehicle exhaust are at risk of exposure.

Benzene is naturally broken down by chemical reactions within the atmosphere. The length of time that benzene vapour remains in the air varies between a few hours and a few days depending on environmental factors, climate and the concentration of other chemicals in the air, such as nitrogen and sulphur dioxide. It does not bio-accumulate in aquatic or terrestrial systems.

Inhalation is the dominant pathway for benzene exposure in humans. Smoking is an important source of personal exposure. Extended travel in motorcars also produces exposures that are second only to smoking as contributors to the intensity of overall exposure.

Current understanding of health effects of benzene are mainly derived from animal studies and human health studies in the occupational setting.

Acute effects of benzene include skin and eye irritations, drowsiness, dizziness, headaches, and vomiting. The most significant adverse effects of chronic benzene exposure are haematotoxicity, genotoxicity, carcinogenicity and can also lead to birth defects in humans and animals. There appears to be a dose-response relationship without any threshold effect. The mechanisms of benzene toxicity are not well understood.

Benzene is carcinogenic and long term exposure can affect normal blood production and can be harmful to the immune system. It can cause cancers and leukaemia (cancer of the tissues that form white blood cells) in laboratory animals and human populations exposed for long periods, and has been linked with birth defects in animals and humans.

Both the International Agency for Research and Cancer (IARC) and the US EPA have classified benzene as known human carcinogens.

Although all in the population are susceptible to the adverse health effects of benzene, it is thought that at levels occurring in the ambient atmosphere, benzene does not have short-term or acute effects.

Even though adverse health effects have been documented with both acute and chronic exposures to benzene, for the purposes of the derivation of exposure-response functions, the main health endpoint that has been utilized is leukaemia.

7.2.2 1,3-Butadiene

1,3-butadiene is emitted from oil refineries and chemical manufacturing plants. The major source of 1,3-butadiene is incomplete combustion of gasoline and diesel fuel. 1,3-Butadiene is highly reactive and can oxidise to form formaldehyde and acrolin, two toxic substances in their own right. 1,3-Butadiene is emitted from industrial facilities, tobacco smoke and motor vehicle emissions. Workers in industries that use or produce 1,3-butadiene or are exposed to motor vehicle exhaust are at risk of exposure. The probable route of human exposure to 1,3-butadiene is through inhalation.

Exposure to 1,3-butadiene can irritate the eyes, nose and throat. Acute exposure to 1,3-butadiene can cause central nervous system damage, blurred vision, nausea, fatigue, headache, decreased pulse rate and pressure, and unconsciousness. Long term exposure to lower levels has shown increases in heart and lung damage. There are inadequate human data (based on only a few occupational studies) but sufficient animal data to suggest that 1,3-butadiene is a human carcinogen. Chemical compounds closely related to 1,3-butadiene are known human carcinogens.

The US EPA classified 1,3-butadiene in Group B2: probable human carcinogen. IARC classifies 1,3 Butadiene as a probable human carcinogen. The recent WHO revision of air quality guidelines concluded that 1,3-butadiene is probably carcinogenic to humans (Group 2A).

7.2.3 Polycyclic Aromatic Hydrocarbons

PAHs contain only hydrocarbon and carbon and are a group of over several hundred organic chemicals with two or more fused aromatic rings. Benzo-a-Pyrene (B[*a*]P) is probably the most well known PAH carcinogen and is found in the exhaust of engines (especially diesels) as well as being one of many carcinogens found in cigarette smoke.

PAHs are formed mainly as a result of pyrolitic processes, especially the incomplete combustion of organic materials during industrial and other human activities, such as processing of coal and crude oil, combustion of natural gas, combustion of refuse, vehicle traffic, cooking, tobacco smoke, and natural processes such as carbonisation.

Occupational PAH exposure can occur in petroleum manufacture and use, or where coal, wood or other plant materials are burned. Most PAHs in air they are generally found attached to particulate matter. Occupational exposure to PAH may occur in coal production plants, coking plants and coal-gasification sites.

Data from animal studies indicate that several PAH may induce a number of adverse effects including carcinogenicity and reproductive toxicity. B[*a*]P is by far the most intensively studied PAH in animals. The lung carcinogenicity of B[*a*]P is enhanced by co-exposure to other substances such as cigarette smoke and probably airborne particulates. Results from epidemiological studies indicate an increase in lung cancer occurs in humans exposed to coke oven emissions, roofing tar emissions, and cigarette smoke. Each of these contains a number of PAH.

7.2.4 Toluene

Toluene is widespread in the environment due to its use in a variety of commercial and household products and it is found in tobacco smoke. Indoor toluene levels can be higher than outdoor levels during non-occupational exposure to paints and thinners, and also where tobacco smoke is present. Sniffing glue or paint can lead to high exposures. Air pollution from vehicles is a major source of exposure. Toluene is emitted during crude petroleum and natural gas extraction, and petroleum refining. Workers in industries exposed to motor vehicle exhaust are at risk of exposure.

The central nervous system (CNS) is the primary target organ for toluene toxicity in both animals and humans for acute and chronic exposure. CNS dysfunction (often reversible) and narcosis are observed in humans exposed to low or moderate levels. Short term exposure to high levels of toluene can result in light-headedness and euphoria. CNS depression occurs in chronic abusers exposed to high levels.

Symptoms include cerebral atrophy, and impaired speech hearing and vision. Irritation of the upper respiratory tract is associated with chronic inhalation. Toluene does not appear to be carcinogenic. The US EPA has classified toluene in Group D, not classifiable as carcinogenic to human.

7.2.5 Xylenes

Xylenes are emitted during petroleum refining, solid fuel combustion, and are a component of vehicle exhaust. They are also embodied in numerous domestic products.

Acute exposure to xylenes results in irritation of the respiratory tract, transient eye irritation and neurological effects. Chronic inhalation exposure results in Central Nervous System (CNS) effects such as headaches, dizziness, fatigue, tremors and un-coordination. Other effects of chronic exposure include impaired pulmonary function, and possible affects on the blood and kidneys.

The evidence of developmental or reproductive effects on humans in inconclusive. Xylenes do not appear to be carcinogenic.

8 Annex A2 - Ambient Air Quality Standards

8.1 Background

The huge social and economic costs associated with human exposure to air pollution are now widely recognised. As a consequence, most developed (and many developing) economies now have introduced maximum exposure levels, either a goals or, in some cases, mandatory limits.

A 2005 World Health Organisation (WHO) study confirmed that the developed world is not immune from the consequences of air pollution. The research concluded that exposure to current PM levels reduces the life expectancy of every person in the EU by an average of nine months, and has a direct economic impact of up to €161 billion (US$220 billion) every year. (WHO, 2005-1)

Although not mandated in law, the World Health Organisation (WHO) has published guidelines for a range of pollutants (WHO, 2005-2), including recommended maximum exposure levels. In common with the other regulated and recommended limits discussed in this Section, the WHO recommendations are framed as average pollutant concentration over a specified time period (for example micrograms per cubic metre <µg/m3> over a 24-hour period).

In the USA, for instance, standards for ambient air pollution levels are set through the Clean Air Act. The Act is a federal law covering the entire country, but regional governments at both the state and local level required to implement many of the act's requirements. Under the Clean Air Act the US Environmental Protection Agency (EPA) sets limits on a range of air pollutants to help ensure a degree of health and environmental protection to the population.

The Act also gives the EPA powers to intervene at a local level in cases where individual pollution sources such as chemical plants or other industrial activities create an excessively high source of pollution. Although state and local authorities are responsible for implementing much of the activities required under the Act, the EPA may nevertheless intervene and issue sanctions against the state or local agencies, and if necessary can take over enforcement actions in that area.

A set of European Union exposure limits are being phased in over the period 2010 to 2015. They are generally consistent with the approaches taken in other jurisdictions, and also with the WHO recommendations discussed below.

Actual recommended and mandated exposure limits for each of the above examples are tabulated in Section 8.2 below.

Pollutants tabulated in Section 8.2 are of particular significance because whole populations are exposed to them in the air we breathe, but it should be noted that many other pollutants are extremely hazardous and, in circumstances where higher local concentrations occur, can also represent a severe health risk.

8.2 Air Quality Standards and Regulations

Four pollutants have been identified by the WHO as having the greatest net impact on human health. These are tabulated below (Table 8.1), together with the recommended guideline limits.

Pollutant	Exposure limit	Averaging period
Particulate matter (PM10) *	50 µg/m^3	24-hour mean
Particulate matter (PM10)	20 µg/m^3	annual mean
Particulate matter (PM2.5) **	25 µg/m^3	24-hour mean
Particulate matter (PM2.5)	10 µg/m^3	annual mean
Ozone (O3)	100 µg/m^3	8-hour mean
Nitrogen Dioxide (NO2)	40 µg/m^3	annual mean
Nitrogen Dioxide (NO2)	500 µg/m^3	1-hour mean
Sulphur Dioxide (SO2)	20 µg/m^3	24-hour mean
Sulphur Dioxide (SO2)	500 µg/m^3	10-minute mean

** PM10 means particles with an aerodynamic diameter smaller than 10 microns (µm)*

*** PM2.5 means particles with an aerodynamic diameter smaller than 2.5 µm*

Table 8.1: WHO Exposure Guidelines for Key Pollutants

These guidelines represent recommended exposure limits, but many cities have ambient air $PM_{2.5}$ levels that exceed the maximum recommended levels by a factor of five or more. Even worse, measurements taken where wood fires are used for indoor cooking (Park, 2003) found $PM_{2.5}$ concentrations that sometimes exceeded 8,000µg/m^3 – over 300 times higher than the WHO 24-hour limit. This situation is probably repeated in many regions around the world.

Recognising the damage created by air pollution, in addition to its 2005 legislation the European Union is now phasing in a new set of legislated exposure limits. Table 8.2 summarises the coverage of some of these Directives, most of which become mandatory over the period 2010 to 2015. (In some instances member states can apply for extensions of up to five years).

More information on the implementation of these regulations can be found at http://ec.europa.eu/environment/air/quality/standards.htm

Pollutant	Exposure Limit	Averaging period
Fine particles (PM2.5)	25 µg/m^3	1 year
Sulphur dioxide (SO2)	350 µg/m^3	1 hour
Sulphur dioxide (SO2)	125 µg/m^3	24 hours
Nitrogen dioxide (NO2)	200 µg/m^3	1 hour
Nitrogen dioxide (NO2)	40 µg/m^3	1 year
PM10	50 µg/m^3	24 hours
PM10	40 µg/m^3	1 year
Lead (Pb)	0.5 µg/m^3	1 year
Carbon monoxide (CO)	10 mg/m^3	Max daily 8 hr mean
Benzene	5 µg/m^3	1 year
Ozone	120 µg/m^3	Max daily 8 hr mean

Polycyclic Aromatic Hydrocarbons	1 ng/m^3	1 year

Table 8.2: European Union Air Quality Standards

The ambitious targets now being set generate many challenges, as they not only take effect over relatively short lead times, but they also include a broader range of pollutants. Fortunately, many industries now accept that accelerated development of more efficient and lower polluting vehicles, machinery and industrial processes, using cleaner fuels, is now a business imperative.

The following table summarises the US EPA's ambient pollution limits established under the Clean Air Act (*http://www.epa.gov/air/criteria.html*). The limits are generally in line with those promulgated by the European Union (Table 8.2), and those recommended by the WHO (Table 8.1).

Pollutant	Level	Averaging Time
Carbon Monoxide	9 ppm (10 mg/m^3)	8-hour
Carbon Monoxide	35 ppm (40 mg/m^3)	1-hour
Lead	0.15 µg/m^3	Rolling 3-Month Average
Nitrogen Dioxide	0.053 ppm (100 µg/m^3)	Annual (Arithmetic Mean)
Particulate Matter (PM_{10})	150 µg/m^3	24-hour
Particulate Matter $PM_{2.5}$)	15.0 µg/m^3	Annual (Arithmetic Mean)
Particulate Matter ($PM_{2.5}$)[24 hr]	35 µg/m^3	24-hour
Ozone [8hr]	0.075 ppm (2008 std)	8-hour
Ozone [1hr]	0.12 ppm	1-hour
Sulphur Dioxide	0.03 ppm	Annual (Arithmetic Mean)
Sulphur Dioxide	0.14 ppm	24-hour

Table 8.3: USA Clean Air Act - Ambient Pollutant Limits

Many other countries have similar limits or targets, some of which are based on either the WHO or the US limits.

China, for instance, has air quality standards which generally fall between the WHO and the US levels. However, the Chinese standards do not include $PM_{2.5}$, which is one of the most critical pollutants from a health perspective.

Australia's ambient air quality standards, which were promulgated in June 1998 are legally binding on each level of government, and were required to be met by the year 2008. The latest State compliance reports, tabled in 2006, show generally good progress has been achieved, but many States still reported at least several non-compliance areas. Ozone and PM10 appear to be the pollutants where the greatest level of non-compliance exists.

9 Annex A3 –Particle Emissions from Current Technology Engines

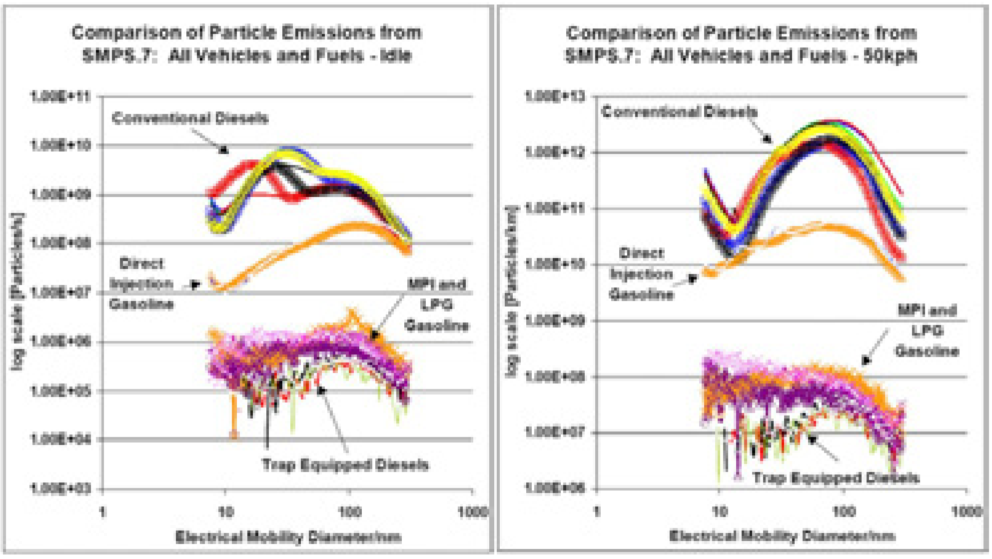


Figure 9.1 – Particle Emissions by Fuel Type and Technology (Ricardo et al 2001)

Figure 9.1 above very conveniently compresses a very large body of PM test data into two highly informative charts. It can be readily seen that the relative emission rates of particles for each fuel type are similar in both the idle testing and the 50 km/h tests, even though the absolute values differed quite substantially.

Conventional diesels (those without any exhaust after-treatment to reduce particle levels) clearly have the highest emission levels while conventional multipoint injected gasoline and LP Gas fuelled vehicles are substantially lower. Readers should note that the vertical scale is logarithmic so each vertical division represents a ten-fold increase in particle concentration.

In both the idle and the 50 km/h tests, the conventional diesel engines have particle concentrations between 100 and 1000 times higher than most of the gasoline and LP Gas vehicles.

But it is interesting to note that direct injection gasoline (DIG) engines also have extremely high PM emissions – typically between 10 and 100 times higher than the current mainstream LP Gas and gasoline engines. The use of gasoline DI technology is likely to increase, as vehicle manufacturers strive to further improve fuel economy. But the charts tell us that this strategy has potentially serious environmental downside, given that gasoline PM emissions have not previously been considered sufficiently high to warrant regulation. The Ricardo results are consistent with the results of other studies into particle emissions from DIG engines.

Responding to the results of this research, the 2009 Euro 5 emission regulations introduce, for the first time, gasoline PM emission limits. This extension to the scope of Euro regulations specifically addressed gasoline DIG engines only – PM from gasoline engines with non-DI fuel delivery systems will not be regulated.

On a more general front, in the US there is a growing concern that particle emissions from gasoline vehicles may represent a larger health threat than previously understood. In 2006 the US Environmental Protection Agency (US EPA) released the results of a large scale testing program in Kansas City to measure particle emissions from gasoline fuelled cars and light trucks in various age groups. The results of these tests are summarised in Figure 9.2 below.

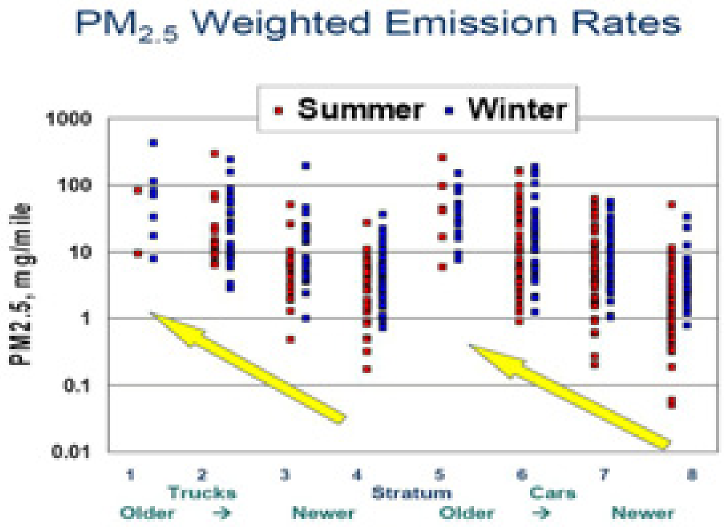


Figure 9.2: $PM_{2.5}$ Emissions from Gasoline Fuelled Vehicles (US EPA 2006)

By way of comparison, the PM emission limit for diesel cars and light commercial vehicles in the Euro 4 standard (in force since 2005 in Europe and progressively adopted in many other economies) is 25 mg per kilometre (equivalent to 40 mg per mile). The 2009 (Euro 5) regulation reduces the limit to 5mg/km (8mg/mile).

From the above chart it can be inferred that many in-use gasoline vehicles are emitting significantly higher PM emissions than current technology diesels.

The high volatility of LP Gas results in almost instant transformation into the gaseous phase when injected directly into the cylinder. This greatly reduces the likelihood of direct injection LP Gas engines producing the high PM levels generated by their gasoline counterparts.

10 References

Anderson H 2004 et al. Meta analysis of time series studies and panel studies of particulate matter (PM) and O zone (03). Report of a WHO task group. WHO regional office for Europe, 2004.

Anyon, 2002. "Liquefied Petroleum Gas as an Automotive Fuel – a 2002 Perspective." Anyon, P., published by the Australian Liquefied Petroleum Gas Association, 2002.

Ayers et al 1999. Chemical and Physical Properties of Australian Fine Particles: A Pilot Study', by GP Ayers, MD Kenwood and JL Gras, of CSIRO, and D Cohen, D Garton and GM Bailey, ANSTO, 1999

Basu and Samet 1999. A Review of the Epidemiological Evidence on Health Effects of Nitrogen Dioxide Exposure from Gas Stoves. Basu R and Samet J, Journal of Environmental Medicine 1(4): 173-187.

BIC, 2001. "Getting the Prices Right: Policy for More Sustainable Fuel Taxation for Road Transport in Australia", submission by the Bus Industry Confederation to the Commonwealth Fuel Tax Inquiry, October 2001

CONCAWE, 1992, Liquefied petroleum gas, product dossier no. 92/102, p. 4 and p. 12, 1992 *DoE, 1994.* Alternatives to Traditional Transport Fuels, Volume 2, Greenhouse Gas Emissions. US Department of Energy,1994

EA, 2003. "Toxic Emissions from Diesel Vehicles in Australia", Anyon et al, Parsons Australia Pty Ltd, for the Federal Department of Environment and Heritage, May 2003.

EETP, 2004. EETP: "European Emission Test Programme", Final report. N. Jeuland, X. Montagne Institut Francais du Petrole, February 2004

Ezzati M et al 2000. Comparison of Emissions and Residential Exposure from Traditional and Improved Cookstoves in Kenya. Ezzati, M., Mbinda, B., Kammen, D. January, 2000

Holland M et al 2005. Damages per tonne emission of PM2.5, NH3, SO2, NOx and VOCs from each EU25 Member State. Mike Holland, Steve Pye, Paul Watkiss, Bert Droste-Franke, Peter Bickel, AEA Technology Environment, March 2005

Kunzli et al 2000. Public-health impact of outdoor and traffic-related air pollution: a European assessment. Künzli, N., Kaiser, R., Medina, S., Studnicka, M., Chanel, O., Filliger, P., Henry, M., Horak,F., Puybonnieux-Texier, V., Quenel, P., Schneider, J., Seethaler, R., Vergnaud, J-C., and Sommer, H. *The Lancet*, Vol 356, September 2000, pp 795-801

NAS 1997. Medical and Biological Effects of Environmental Pollutants-Nitrogen Oxides. National Academy of Sciences, 1997. . ISBN 0-309-02615-6

NPI 2000. Emissions estimation technique manual, National Pollution Inventory. Department of Conservation and Heritage, Canberra, Australia. 2000

Park 2003. Particulate exposure and size distribution from wood burning stoves in Costa Rica. E. Park, K. Lee**.** : Indoor Air, 2003, Vol. 13.

Pope, 2009. "Fine-Particulate Air Pollution and Life Expectancy in the United States." C. A. Pope, M. Ezzati, and D. W. Dockery, New England Journal of Medicine, Volume 360:376-386, January 22, 2009

Rabl A. and Spadaro V. 2000. Health Costs of Automobile Pollution. Revue Française d'Allergologie et d'Immunologie Clinique, vol.40(1), 55-59 (2000)

Ricardo et al 2001. Particulate Research Programme 1998-2001. Ricardo Engineering Ltd, DETR, SMMT, CONCAWE. May 2001

Shima and Adachi 2000. Effect of outdoor and indoor nitrogen dioxide on respiratory symptoms in schoolchildren. Shima M and Adachi M, International Journal of Epidemiology 29:862–870.

Smith K 2004. Indoor air pollution from household use of solid fuels: comparative quantification of health risks. K Smith, S Mehta, M Maeusezahl-Feuz. 2004.

Smith KR 2005. Health impacts of household fuelwood use in developing countries. Smith, K.R. University of California, Berkeley, 2005

US EPA 1991. Non-road Engine and Vehicle Emission Study – Report. United States Environmental Protection Agency, Office of Air and Radiation. November 1991,

US EPA 1993. U.S. EPA/Office of Air and Radiation. "The Inside Story: A Guide to Indoor Air Quality". Web document EPA 402-K-93-007.

US EPA 1994**.** Fact Sheet OMS-2, EPA 400-F-92-004. [Online]

US EPA undated. Air Emission Sources: Sulphur Dioxide. *www.epa.gov/air/emissions/so2.htm*.

VPI 2009. Transportation Cost and Benefit Analysis. Victoria Transport Policy Institute Victoria, BC: Web, 2009.

WHO 2005-1. "European Union can save up to €161 billion a year by reducing air-pollution deaths" Media Release, WHO Media Centre, 14 April 2005.

WHO 2005-2. "Air quality guidelines-global update 2005". *www.euro.who.int/document/e87950.pdf*

WHO, 2005-3. "Indoor Air Pollution and Health", World Health Organisation, Fact sheet N°29, June 2005

WHO, 2006. "Fuel for life: household energy and health". ISBN 92 4 156316 8, World Health Organization, 2006

Winebrake, 2000. "Fuel-Cycle Emissions for Conventional and Alternative Fuel Vehicles: An Assessment of Air Toxics"; Winebrake, J.J.; Wang, M.; He, D. Center for Transportation Research, Argonne National Laboratory: Argonne, IL, August 2000

World Bank 2002. Extract from World Bank report "Cities on the Move: Transport and the Urban Environment". 2002

11 Glossary of Terms

Aerosols: Solid or liquid particles suspended within the atmosphere (see also Particulate Matter, PM_{10}, $PM_{2.5}$, $PM_{1.0}$). Particles generated by combustion of fossil fuels and biomass are most dangerous to human health. They can be inhaled into the most sensitive lung tissues and are strongly linked to respiratory and heart diseases, cancers and, possibly, neurological disorders.

Air Toxics: Also called **hazardous air pollutants**, are those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. . The US EPA is lists 187 pollutants as “Air Toxics”. Although these chemicals are known to be extremely hazardous to humans, many of them exist in only extremely low concentrations in ambient air, making it extremely difficult to characterise their toxicity with any degree of certainty. The US EPA ranks Benzene, 1,3-butadiene, Polycyclic Aromatic Compounds (PAHs), Toluene and Xylenes as the air toxics with greatest potential to damage human health.

Biomass: Organic material, esp. plant matter, which can be converted to fuel and is therefore regarded as a potential energy source.

Carbon Dioxide (CO_2): CO_2 is a colourless, odourless, non-poisonous gas that is a normal part of the atmosphere. All plant life “breathes” CO_2 and, after extracting the carbon to add growth, exhales pure oxygen, which in turn is essential for human life. (see also Greenhouse Gases).

Carbon Monoxide: Is a colourless, odourless, tasteless yet highly toxic gas. Its molecules consist of one **carbon** atom covalently bonded to one oxygen atom. Carbon monoxide can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues.

Concentration: In the context of this document, a number specifying the quantity of a gaseous pollutant contained in a defined volume of air, eg: milligrams per cubic metre(mg/m3) or parts per million by volume (ppmv).

Diesel: A combustible petroleum distillate used as fuel for compression ignition engines, characterized by igniting under the influence of high, rapid pressure rise rather than by spark ignition.

Fossil Fuel: Any combustible organic material, as oil, coal, or natural gas, derived from the remains of former life.

Gasoline: A volatile, flammable liquid mixture of hydrocarbons, refined from petroleum, and used as fuel for internal-combustion spark ignition engines.

Greenhouse Gases (GHG): Include water vapour, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride. These gases allow short wavelength solar radiation into the earth’s atmosphere, but block outgoing longer wavelength radiation emitted by the earth. Elevated concentrations of these gases can result in increased average ambient temperatures (global warming).

Hazardous Air Pollutant (HAP): See Air Toxics.

Hydrocarbons (HC): Are compounds containing only hydrogen and carbon atoms. They are present in the air both as naturally occurring gases and as the product of incomplete combustion of carbon-based fuels. Hydrocarbons are also included in the general category of Volatile Organic Compounds (VOCs).

Kerosene: A mixture of liquid hydrocarbons obtained by distilling petroleum, bituminous shale, or the like, and widely used as a fuel, cleaning solvent, etc.

Lead (Pb): Is a poisonous metal that can damage nervous connections (especially in young children) and cause blood and brain disorders. Because of its low reactivity and solubility, lead poisoning usually only occurs in cases when the lead is dispersed, such as via the exhaust of vehicles using fuel containing octane enhancing lead compounds. The effects of lead are the same whether it enters the body through breathing or swallowing. Lead can affect almost every organ and system in the body, but the main target is the nervous system. Exposure to high lead levels can severely damage the brain and kidneys in adults or children and ultimately cause death.

Liquefied Petroleum Gas (LP Gas): is the generic name for mixtures of hydrocarbon gases, mainly propane and butane, (although small amounts of other compounds, such as propylene and butylenes may also be present in the mixture). Depending on the climate and availability LP Gas can be made up of propane, butane or a range of different mixtures of these gases. When lightly compressed (to approx. 800 kPa or 120 psi), the gases change from a gaseous state to a liquid.

Methane: Is a gas **(CH_4)** produced naturally from the decay of fossil matter, vegetation and other biomass. It is the principal component of "natural gas". Methane is a very powerful greenhouse gas when released to the atmosphere – one kilogram of methane has the same global warming potential as 21 kilograms of carbon dioxide. The definition of methane should in line with the one of LPGas → liquefies under high pressure or very low temperature. Some words on the LNG…

Natural Gas: A combustible mixture of gaseous hydrocarbons that accumulates in porous sedimentary rocks, esp. those yielding petroleum, consisting usually of over 80 percent **methane** together with minor amounts of ethane, propane, butane, nitrogen. Natural gas is also known over the world as the "commercial" name of methane. It may be transported and stored either as a compressed gas (CNG) or in a liquefied state (LNG).

Nitrogen Oxides (NOx): Are a combination of highly reactive gases. Nitrogen dioxide (NO_2), and nitric oxide (NO) are produced when fuel is burned at high temperatures. High levels of nitrogen oxides can lead to smog and acid rain. Nitrous Oxide (N_2O) is an extremely powerful greenhouse gas when released to the atmosphere – one kilogram of N_2O has the same global warming potential as around 420 kilograms of carbon dioxide.

Particulate Matter (PM): Is a mixture of solid particles and liquid droplets suspended in the air. A high proportion of these particles are extremely small, mostly less than 10 microns (about 10 times smaller than the thickness of a human hair). The smallest particles can go down to 10 nanometers in diameter (0.00001mm), which is around 10,000 times smaller than the thickness of a human hair.

$PM_{1.0}$: Particles with an aerodynamic diameter less than 1 micron (0.001mm). Most particles in the exhaust of internal combustion engines and domestic heating appliances are categorised as $PM_{1.0}$ or smaller.

PM_{10}: Particles with an aerodynamic diameter less than 10 microns (0.01mm)

$PM_{2.5}$: Particles with an aerodynamic diameter less than 2.5 microns (0.0025mm)

Sulphur Dioxide (SO_2): Consists of one sulphur atom linked to two oxygen atoms and is usually emitted through the combustion of sulphur-bearing fuels such as coal, diesel and gasoline. Volcanic eruptions are a major natural source of this pollutant. It is linked to the incidence of asthma and other respiratory ailments in humans, and can react with other chemicals in the atmosphere to form acid rain.

Volatile Organic Compounds (VOC): several definitions are used worldwide, the one used in this study refers to compounds containing at least one carbon atom, excluding carbon monoxide and carbon dioxide, which evaporate readily to the atmosphere. Major VOC emission sources are exhaust emissions from cars and trucks, solvents used in products such as cleaning products and paints.