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The global and urban environment: the need for clean power systems

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The objective of this paper is to provide a contextual background in support of clean power systems such as fuel cells for the expansion of our global energy resources. While there are many arguments available to justify such an expansion, the American Lung Association believes the benefit to human health and the environment from the reduction in air pollution from energy generation is a primary argument in favor of the greater utilization of fuel cells.

The American Lung Association is very proud of its achievements in promoting clean air and a healthier environment. For over 45 years we have worked to eliminate air pollution. Our interest in pollution dates to its founding in 1904, when our main focus was tuberculosis. Then, as today, air pollution was seen as a burden on lungs already scarred by disease. As the scope of the American Lung Association's mission has grown to embrace all lung diseases, the commitment to fighting pollution has become even more critical.

This year the American Lung Association will celebrate the 25th anniversary of its Clean Air Week, an annual event dedicated to improving air quality. Clean Air Week was originally developed to commemorate the air pollution disaster in Donora, Pennsylvania. This special week continues to serve as a reminder that air pollution control is a partnership – citizens, government, and industry working together to achieve clean air. This partnership remains essential to our ongoing efforts to ensure clean air for the world's inhabitants. The American Lung Association appreciates the partnership with clean energy interests including companies involved with fuel cell technology in its efforts to control air pollution. The energy-related air pollutants and their health effects are discussed, and the context for this partnership and value of its extension and amplification can be seen.

The production and consumption of energy are integral parts of our urban lifestyles – from cooking, heating and lighting, to transportation and industrial processes. Fossil fuels meet most of these energy demands in cities throughout the world either directly or by conversion to electrical energy. Growing urban populations and levels of industrialization lead to greater demand for energy, which in turn increases the levels of air pollution.

The United States regulatory system was used for a review of the energy-related air pollutants and their health effects. A summary of information related to these pollutants in the world's major cities is followed by a review of projected energy consumption trends. This approach allows a rare and brief opportunity to enjoy a major public health and environmental protection victory. As a result of litigation brought by the American Lung Association under the Clean Air Act, the United States Environmental Protection Agency (EPA) has adopted new Ambient Air Quality Standards for ozone and for particulate matter that significantly lower permitted levels of air pollution. These new requirements make the US air quality standards among the most stringent worldwide. The support from many people during this litigation was well appreciated.

Fig. 1 shows the commonly controlled energy-related air pollutants – ozone, sulfur dioxide, particulate matter and nitrogen dioxide – and their respective sensitive populations or populations at risk. The severity and magnitude of health effects from exposure to these pollutants is demonstrated in Fig. 2.

The health effect ranked highest in severity, of course, is premature death. To put this in perspective, consider just one pollutant – particulate matter. If the levels of particulate matter in developing countries were reduced to meet the World Health Organization (WHO) guidelines, now less protective than the new US standard, between 300 000 and

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Pollutant	Sensitive Population
Ozone	‣ Those with lung disease ‣ Elderly ‣ Pre-adolescents ‣ Healthy Exercising Adults ‣ "Responders" (5 to 20 percent of the "normal" population)
Sulfur Dioxide	‣ Those with lung disease ‣ Elderly ‣ Pre-adolescents
Particulate	‣ Those with lung disease ‣ Elderly ‣ Pre-adolescents
Nitrogen dioxide	‣ Those with lung disease ‣ Pre-adolescents

Fig. 1. Sensitive populations.

700 000 premature deaths per year could be avoided. While this is significant, further down the diagram, the severity decreases as the magnitude or size of the population at risk increases.

The most dangerous of the air pollutants commonly regulated is a grab-bag of pollutants known as particulate matter or soot. Particulate matter is measured by the WHO as black smoke. Particulate matter has a notorious history: to control it in the 12th Century, the King of England banned the burning of coal. Violators were hanged. The most harmful airborne particulate matter is the by-product of combustion in motor vehicles, powerplants, and industry. However, some large cities such a Beijing, have significant problems with particulate matter due to natural events such as dust storms.

Particulate matter varies in size and composition depending on the origin. The small particle, known as a fine or inhalable particle, is of primary concern. These particles are formed by burning coal, gasoline, oil and diesel fuel. They can penetrate into the deepest recesses of the lung and may remain for months or even years. Specific health effects of particulate matter are shown in Fig. 3. Effects range from premature death to declines in lung function.

The sensitive populations at risk include children, the elderly, asthmatics and people with cardiovascular and chronic pulmonary disease which includes emphysema and chronic bronchitis (Fig. 4).

The new US ambient air quality standard for particulate matter regulates fine particles as 2.5 μm or less. It sets an annual limit of 15 $\mu g/m^3$ with a 24-h standard of 65 $\mu g/m^3$. By setting an annual limit of 15 $\mu g/m^3$, the standard focuses on the most important public health issue, i.e. controlling the amount of pollution and the exposure to which individuals are subjected. In any regulatory process, you do not always get all that you ask for, and this is true for the new 24-h standard. It provides less protection in urban areas than the American Lung Association had desired and will put less focus on controlling energy-related pollutants such as those from the use of diesel fuels.

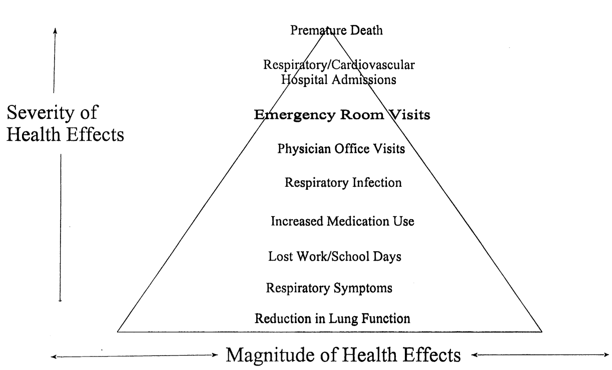

Fig. 2. Severity of health effects.

- Premature death
- Hospital admissions and emergency room visits for respiratory and cardiovascular disease
- Respiratory disease symptoms
- Respiratory infection
- Medication use
- Restricted activity days
- Upper and lower respiratory symptoms
- School absences/work loss days
- Decreased lung function

Fig. 3. Summary of particulate matter health effects.

Ozone is a highly toxic, invisible gas. While ozone at stratospheric levels provides critical protection from the sun's harmful UV-B radiation, ozone at the ground level is toxic. As a photochemical oxidant, ozone can be reduced by curbing the emissions of it precursors such as oxides of nitrogen from powerplants, cars and trucks; and hydrocarbons primarily from gasoline and industrial solvents.

The specific health effects of ozone are shown in Figs. 5 and 6. Effects range from premature death, through accelerated declines in lung function leading to development of lung disease to declines in athletic performance. The populations at risk make ozone unique.

Recent research has demonstrated that the sensitive populations now include healthy, exercising adults and people with allergies. Other sensitive populations include children, people with chronic lung disease including asthma, and the elderly (Fig. 7).

At levels typically found in many US cities and the world's major cities, ozone literally oxidizes pulmonary

- Elderly
- People with cardiovascular and chronic pulmonary disease
- People with asthma
- Children

Fig. 4. Populations at risk: particulate matter.

- Premature death, including people with asthma and chronic lung disease
- Increased hospital visits and admissions for people with asthma and other respiratory problems
- Possible acceleration of decline in lung function, leading to development of chronic obstructive lung disease
- Increased production of fibrous tissue associated with lung scarring
- Production of lesions in lung tissue
- Possible impairment of immune system in resisting lung infections
- Biochemical evidence of inflammation
- Biological changes in lung cells

Fig. 5. Summary of ozone health effects.

tissue, causing holes in cell walls. Over time, ciliated cells – the hair-like cells – are destroyed, causing lungs to stiffen and decreasing the ability to breathe normally. The destruction of these cells also interferes with the lung's defense mechanisms, causing increased susceptibility to infections.

The new US ambient standard has been tightened from 0.12 ppm measured over 1 h to 0.08 ppm measured over 8 h. It is a concentration-based approach, with the average fourth highest concentration over a 3-year period determining attainment. The EPA's decision is the first time in 20 years that the ozone standard has been updated. Putting this into perspective, at the White House signing ceremony, vice-president Gore commented that 20 years ago he had tried to learn disco dancing by watching John Travolta in *Saturday Night Fever*. The new standard recognizes research that has demonstrated exposure to ozone below the old 0.12 ppm standard can cause significant health effects. As pointed out earlier, this standard identifies a new population at risk, i.e. healthy exercising adults. The longer time frame for the standard also recognizes the real-world exposure to ozone. The new standard's focus on concentration will not only identify areas of the country that are out of attainment but will also allow an assessment of how much an area is out of attainment. Again, the American Lung Association did not get all that it would have wanted

- Increased airway reactivity to bronchoconstricting stimulus
- Short-term reduction in lung function
- Decline in athletic performance
- Symptoms
  - Headache
  - Cough
  - Pain on taking breath
  - Wheezing
  - Irritation of upper respiratory tract
  - Shortness of breath

Fig. 6. Summary of ozone health effects (continued).

- Exercising healthy adults
- Children
- People with chronic lung disease (i.e. chronic bronchitis, emphysema)
- Elderly
- People with asthma
- People with allergies (atopics)

Fig. 7. Populations at risk: ozone.

in this new standard, such as the third highest concentration. However, this standard will increase pressure for greater control of precursors to ozone such as oxides of nitrogen from all sources but specifically cars and heavy-duty trucks.

The last energy-related pollutant to be discussed is sulfur dioxide. This pollutant is an invisible gas created when sulfur contained in coal, oil, or diesel fuel is burned. In the United States, approximately 70% of sulfur dioxide emissions are from coal-fired powerplants, while industry accounts for another 13%. In addition, sulfur dioxide undergoes a chemical reaction in the atmosphere to form other pollutants, including sulfates, a component of particulate matter.

The health effects of sulfur dioxide are devastating. In Japan, for example, the damage to human health from SO_2 pollution was so severe that by 1988, the government designated 90 000 residents as official sulfur dioxide 'victims'.

Asthmatics, particularly children, are the most sensitive to sulfur dioxide. Physiologically, sulfur dioxide triggers a sudden inflammation in the tissue of the lung's airways, limiting the ability to breathe. An asthmatic exposed to sulfur dioxide can, within minutes of exposure to SO_2, become incapacitated with an asthma attack. Unfortunately, the American Lung Association's litigation to require the EPA to set a short-term SO_2 standard to reflect the health impact of exposure was unsuccessful on procedural counts.

Developing an effective control strategy for air pollution, especially in the world's major cities, requires an understanding of many factors. The common thread, however, is the rate of industrialization and socio-economic development. Production and consumption of energy goes hand-in-hand.

Although detailed emission inventories are not widely available for all cities, on the basis of observed trends in national emissions, one can conclude that mobile sources now constitute the main source of air pollution in the majority of cities in industrialized countries. In developing countries, in contrast, cities have a greater variety of primary air pollution sources. The contribution of mobile sources and stationary sources differs markedly between cities depending on the transportation system, and the density and type of industry. Cities in Latin American, for example, have higher vehicle densities than in many other developing regions and are more likely to experience a higher contribution to the

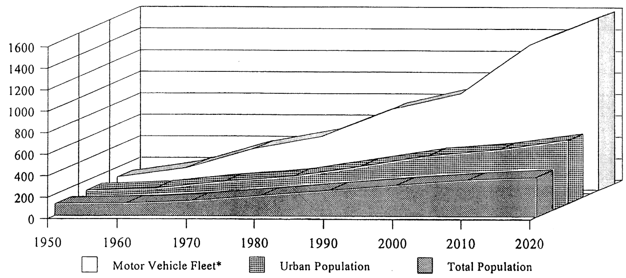

Fig. 8. Projected rate of increase. *Excluding motorized two- and three-wheelers.

total urban inventory from mobile sources. Cities located in temperate regions that are dependent on coal or biomass fuels for heating and other domestic purposes have a very different emissions inventory.

Since 1950 the global fleet has grown ten-fold and is expected to double from the present total of 630 million vehicles within the next 20–30 years. As demonstrated in Fig. 8, the growth rate is projected to outpace both the growth rate for the total population and the urban population.

The information on energy-related air pollution in the world's major cities in Figs. 9–11 is the result of the Global Environment Monitoring System which has been monitoring air pollution in urban areas since 1974. Fig. 9 lists the cities with significant particulate or soot air pollution. The cities in bold exceed the WHO guidelines by more than a factor of two. The underlined cities exceed the guidelines by up to a factor of two. The cities in italics generally meet the guidelines and there are no data available for the remaining cities. Similarly, Fig. 10 indicates the cities having the greatest ozone problems. And finally, Fig. 11 shows the same information for sulfur dioxide.

Bangkok	Los Angeles
Beijing	**Manila**
Bombay	**Mexico City**
Buenos Aires	Moscow
Cairo	*New York*
Calcutta	Rio de Janeiro
Delhi	Sao Paulo
Jakarta	**Seoul**
Karachi	**Shanghai**
London	*Tokyo*

Serious problem, WHO guidelines exceeded by more than a factor of two

Moderate to heavy pollution WHO guidelines exceed by up to a factor of two

Low pollution, WHO guidelines are normally met

No data available or insufficient data for assessment

Fig. 9. Soot levels.

Bangkok	**Los Angeles**
Beijing	Manila
Bombay	**Mexico City**
Buenos Aires	Moscow
Cairo	New York
Calcutta	Rio de Janeiro
Delhi	**Sao Paulo**
Jakarta	*Seoul*
Karachi	Shanghai
London	**Tokyo**

Serious problem, WHO guidelines exceeded by more than a factor of two

Moderate to heavy pollution, WHO guidelines exceed by up to a factor of two

Low pollution, WHO guidelines are normally met

No data available or insufficient data for assessment

Fig. 10. Ozone levels.

Regrettably, the picture presented here is not very reassuring. Some 1.2 billion urban dwellers worldwide are exposed to excessive levels of one or more pollutants, based on WHO guidelines. Unfortunately, only about 20% of the world's population, in its major cities, live in cities with acceptable air quality. Given the fact that US air quality standards in many instances are now more stringent than the WHO guidelines, this number will be revised downward.

How do we change this picture? The majority of air pollution control relies on the political will of governments and the knowledge of local or national authorities. Generally air quality standards or emissions standards are identified. By

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No data available or insufficient data for assessment

Fig. 11. SO_2 levels

Example Source Categories	Technology Name(s)
Electricity Generation	‣ Thin film photovoltaics: amorphous silicon, cadmium telluride, thin-layered crystalline-silicon ‣ Fuel cells: proton exchange membrane, molten carbonate, phosphoric acid, solid oxide
Small engines	‣ Clean air 2-stroke engines, vaporizing carburetors, alternative fuels for commercial engines/vehicles
On-road and non-road vehicles	‣ Exhaust aftertreatment technology: vacuum insulated catalyst, plasma treatment, non-thermal plasma reactor, oxygen enrichment membrane ‣ Alternative fuels: medium duty truck engine conversion kit, propane/butane fuel blends, LNG technology for locomotives ‣ Electric vehicles & batteries: advanced inductive elective vehicle, advanced batteries and charging systems ‣ New vehicle designs: Partnership for New Generation Vehicle

Fig. 12. Emerging technologies for lower emissions of ozone precursors and particulate matter.

requiring compliance with such standards, governments can encourage the development of new technologies. In theory, the world's major cities use this approach. Control technologies generally focus on the modification of the fuel or combustion technique or removal of pollutants from flue gases. The type and location of the source and the overall cost effectiveness of different technologies influence decision making. Little attention, however, has been given to integrating environmental goals – air pollution control – with energy goals.

As most of the pollutants are energy-related, energy consumption in the future becomes a critical component of any solution. In the United States, energy consumption is expected to reach 111 quadrillion Btu by 2015, representing a 22% increase from the 1995 consumption. Petroleum products for transportation will continue to be the largest share of the total energy consumption in the US. By 2015, total energy demand for transportation is expected to reach 32.3 quadrillion Btu compared with 24.4 quadrillion Btu in 1995. Motor gasoline use accounts for more than half of the transportation energy demand.

On the global scale, by 2015, world energy consumption will increase to 542 quadrillion Btu, 1.6 times the current level. Higher standards of living in emerging economies are contributing to the increased use of energy for electric power generation and for personal automobile transportation.

Future strategies must recognize this energy picture if we are to put sustainable air pollution control programs in place. In the United States we are now evaluating control strategies to achieve the emissions reductions necessary to meet the new standards for particulate matter and ozone. The EPA has identified a significant shortfall in reductions needed to attain the new standards – approximately 3.9 million tons of particulate matter, 331 000 tons of volatile organic compounds (VOCs), and 432 000 tons of oxides of nitrogen annually.

Fuel cells have been identified as a primary, cost effective strategy for filling this gap. This is in part because fuel cells can supply conventional power needs cleanly and efficiently. Fuel cells are also adaptable to many uses. For example, more then 70% of the emissions inventory for VOCs and 42% of the inventory for oxides of nitrogen are generated by area sources and non-road mobile sources suggesting that specific applications of fuel cells can provide significant air pollution control benefits.

As the programs in the US Clean Air Act have been implemented to meet the health-based air quality standards, many new technologies have been developed to control air pollution. Because of ongoing needs to offset growth in emission sources, and because in many ways the Act has been a technology-forcing statute, new and creative air pollution control technologies have been continuously under development. This has resulted in a rapid pace of innovation. Ten years ago, technologies such as selective catalytic reduction for oxides of nitrogen emissions from power plants, reformulated gasoline, low emission vehicles, and energy efficiency improvements in industrial processes, commercial, residential and appliance applications were not contemplated. Today they are used successfully across the United States and throughout the world.

The air pollution control industry is large and growing. The demand for cleaner products and cleaner production with lower costs, combined with the need for air quality improvements and energy efficiency, creates strong incentives for innovation.

Fig. 12 shows some of the emerging technologies that could play a significant role in sustainable air pollution control and energy conservation. Among them, fuel cells for electricity generation, on-road and non-road vehicles.

So we come full circle, a strategic alliance to improve the world's air quality that relies on technological innovation with a market that will only continue to grow over time. For the American Lung Association, the reasons for pursuing clean power systems are grounded firmly in the value and quality of human life. While the engineering challenges remain, the primary obstacles are economic and political.