GLOBAL WARMING, AND ROLE OF SUPPLEMENTARY CEMENTING MATERIALS AND SUPERPLASTICIZERS IN REDUCING GREENHOUSE GAS EMISSIONS FROM THE MANUFACTURING OF PORTLAND CEMENT

V.M. Malhotra
Scientist Emeritus, CANMET, Ottawa, CANADA

ABSTRACT: This paper discusses some aspects of global-warming, and the role of supplementary cementing materials and superplasticizers in reducing greenhouse gas emissions to the atmosphere. The data are presented as to the CO_2 emissions per capita per year from various countries. Also, the relative information is given on the availability of cement and supplementary cementing materials worldwide. The paper mentions very briefly the development of high-performance, high-volume fly ash (HVFA) concrete that incorporates large dosages of superplasticizers. The use of HVFA concrete can reduce very significantly the use of cement in concrete, thus contributing to the reduction in the greenhouse gas emissions. The paper is concluded by referring to the tradable emission rights, and the utilization of fly ash.

Keywords: CO_2 emissions, concrete, environment, fly ash, global warming, portland cement, supplementary cementing materials, sustainable development.

ACI Honorary Member V. Mohan Malhotra is Scientist Emeritus, International Centre for Sustainable Development of Cement and Concrete (ICON), CANMET, Natural Resources Canada, Ottawa, Canada. He is a former member of the ACI Board of Direction and has served on numerous ACI and ASTM committees. He is a prolific author, editor, and researcher, and has received many awards and honours from the ACI, ASTM, and other institutions throughout the world.

“There was no bigger long-term question facing the global community than the threat of climate change”

Tony Blair, Prime Minister, U.K.
BBC News, June 17, 2004

“This world faces an economic and development catastrophe if the rate of global warming is not reduced”

Jennifer Morgan, Director
WWF=s Global Climate Change Program
BBC News, March 14, 2005

“We need to take urgent and informed active now if we are to avoid the worst impact of climate change”

Sir John Bond, HSBC Chairman
in a letter to British Prime Minister
that was signed by a dozen British and American companies
Globe & Mail, Toronto, CANADA, July 5, 2005

INTRODUCTION

The World Earth Summits in Rio de Janeiro, Brazil in 1992, and Kyoto, Japan in 1997 made it abundantly clear that for long-term sustainable development it is essential that the rate of greenhouse gas emissions must not be allowed to go on increasing. The term "sustainable development" has been defined by many people in many ways. As recorded at the Massachusetts Institute of Technology, Cambridge, U.S.A., the term Asustainable development@ has as many as 57 competing definitions[*].However, most accepted definition is by the Norwegian Prime Minister Gro Harlem Bundtland: AThe ability of humanity to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs@.

The primary greenhouse gas emissions affecting the sustainable development are the carbon dioxide (CO_2) emissions. The other greenhouse gases of concern include nitrous oxide (NOx) and methane (CH_4), but their amount emitted is relatively small compared with that of CO_2.

Apart from the U.S.A. and Australia, almost all other developed countries are placing mandatory quotas on the emission of these gases, and these involve stabilizing these emissions to 6% below the 1990 level by the year 2010-2012. As the manufacturing of portland cement contributes significantly to the CO_2 emissions, this paper emphasizes the increased use of large volumes of fly ash, other supplementary cementing materials and superplasticizers in the construction industry to reduce these emissions.

GLOBAL WARMING

CO_2 Emissions Per Capita Per Year by Different Countries

The U.S.A. and Canada are the largest contributors of CO_2 emissions in the world with CO_2 emissions estimated at approximately 20 tonnes per capita per year, followed by the EU countries at about 9 tonnes (Table 1). The developing countries like China and India have low emissions at present, but their rapid industrialization is going to increase the rate of emissions per capita significantly in the near future.

Table 1. CO_2 Emissions in Tonnes per Capita Per Year*

U.S.A.	20
Canada	20
EU	9
China	3
Latin America	3
India	1

**The numbers are approximations only, and have been collected from published information for the year 2004*

[*]Sanders, Doug, "Why Sustainable Development is Neither", Globe and Mail, Toronto, Oct. 19, 2003.

Concentration of CO_2 in the Atmosphere

The concentration of CO_2 has been increasing steadily in the world since the industrial revolution in the 1800's. At the time of the industrial revolution, the concentration of CO_2 in the atmosphere was 260 ppm, in 1988 the concentration of CO_2 observed in Hawaii was 350 ppm. If no action is taken on global warming, the rate of concentration in the atmosphere is going to increase dramatically (Fig. 1).

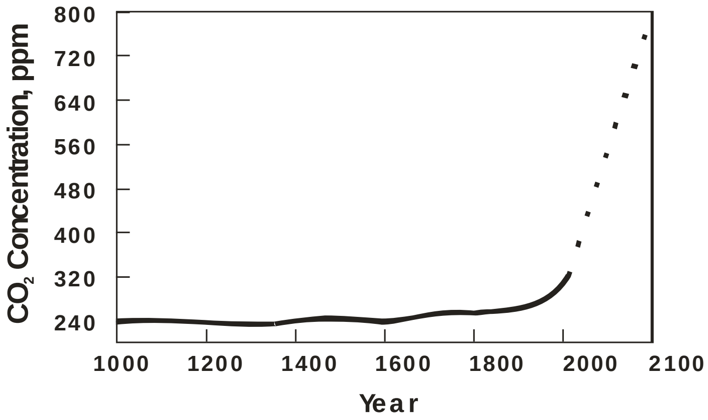

Figure 1. Concentration of $C0_2$ in the atmosphere since 1800's

Sequestration of Carbon Dioxide

Carbon dioxide sequestration involves techniques that capture GHG emissions so that they can be stored underground rather than be allowed to enter into the atmosphere. Unfortunately, sequestration is a very difficult technique, and has not been, to-date, demonstrated successfully - though research is being performed by some industrial companies. For the immediate future, sequestration of CO_2 is not very promising, and is not an option.

Absorption of CO_2 Emissions by the Oceans

The world=s oceans have absorbed nearly half of the CO_2 emissions during the past 200 years. This amounts to nearly 118 billion tonnes of the CO_2 emissions since 1800's. This is the positive aspect. However, there are negative aspects of the phenomenon. Because as CO_2 dissolves in seawater, it triggers the formation of acids that can dissolve the shells and skeletons of marine animals and reduces their ability to produce calcium carbonate shells. This, in turn, can affect productivity of the oceans in terms of marine life and reefs.

GLOBAL TEMPERATURE RISE AND CLIMATE CHANGE

An increase in CO_2 emissions affects adversely the global climate. The Inter-governmental Panel on Climate Change (IPCC), meeting in Geneva, recently warned that the average global temperature is expected to rise between 1.4 and 5.8 ºC over the next 100 years. Only seven years ago, the Panel had predicted a maximum temperature rise of 3.5 ºC over the same period. It is of interest to note that the average global temperature has risen only 0.6 ºC over the past 100 years.

Attempts have been made to determine a specific rise in Earth's average temperature that can cause unacceptable damage. The European Union's[1] scientific groups have set this threshold at 2.5 ºC of additional rise in temperature from the current conditions. An international task force[2] under Senator Olympia Snow of the U.S.A. and Stephen Byers, a member of the U.K. Parliament, and consisting of scientists, business leaders and policy experts have also selected the above threshold of 2.5 ºC beyond which major damages could occur.

Linearity and Ecology

Ecology is non linear[1]. It may follow a straight line for a while, then it hits a point of no return, that is a threshold, and then it crashes. The recent collapse of the massive shelf ice in the Antarctic is the perfect example of this threshold concept. The scientific community knew that there were warming trends but could not foresee that more than five billion tonnes of Antarctic ice would crumble in a matter of months.

Retreating of Arctic Ice

A scientific commission consisting of scientists from eight countries including Canada and the U.S.A., have recently completed a four year study on the retreating of Arctic ice. The Commission has concluded that the retreat of Arctic ice and thawing of tundra are a direct result of the accumulating carbon dioxide and other emissions from human activities worldwide.

The recent collapse of the massive ice shelf of more than five billion tonnes, in the Antarctic is a perfect example of accelerating flows of ice to the sea with serious consequences of rise in sea levels. This can also lead to the potential of intensified droughts and floods.

World Leader in Global Warming

North America is the world leader in global warming as it can be seem from the following statistics:

- In 1998, the North American continent accounted for 25.8 per cent of the global emissions of carbon dioxide, a leading greenhouse gas.
- North American's per capita annual gasoline consumption for motor vehicles is nine times the global average.
- By 1996, the North American continent's impact on the environment also called the 'ecological imprint' has grown 4.4 times the world's average.
- North Americans burn an estimated 25.7 billion litres of fuel annually in traffic jams.[2]
- Canada and the U.S. consume 25 per cent of global energy used each year, despite having only about 5 per cent of the world's population.[3]
- Although today's cars are 90 per cent cleaner than those of the 1970's, U.S. drivers now drive on average twice as many kilometres as they did in the 70's. Also, automobile fuel efficiency gains have been offset by an 18-year old trend towards heavier cars such as SUVs.
- Total energy use in North America grew 31 per cent between 1972 and 1997.[1]

[1, 2] International Herald Tribune, February 1, 2005

[1] Professor Eric Post, Penn. State University, Global & Mail, May 6, 2002
[2 -3] U.N. Report, Globe and Mail, August 15, 2002
[1-2] U.N. Report, Globe & Mail, August 15, 2002

- Although the average U.S. family size has fallen 16 per cent, the size of new homes has risen 48 per cent, with resulting increase in energy use.[2]

Figure 2 shows the percentage of different greenhouse gas emission in the U.S.A. for the year 2002.

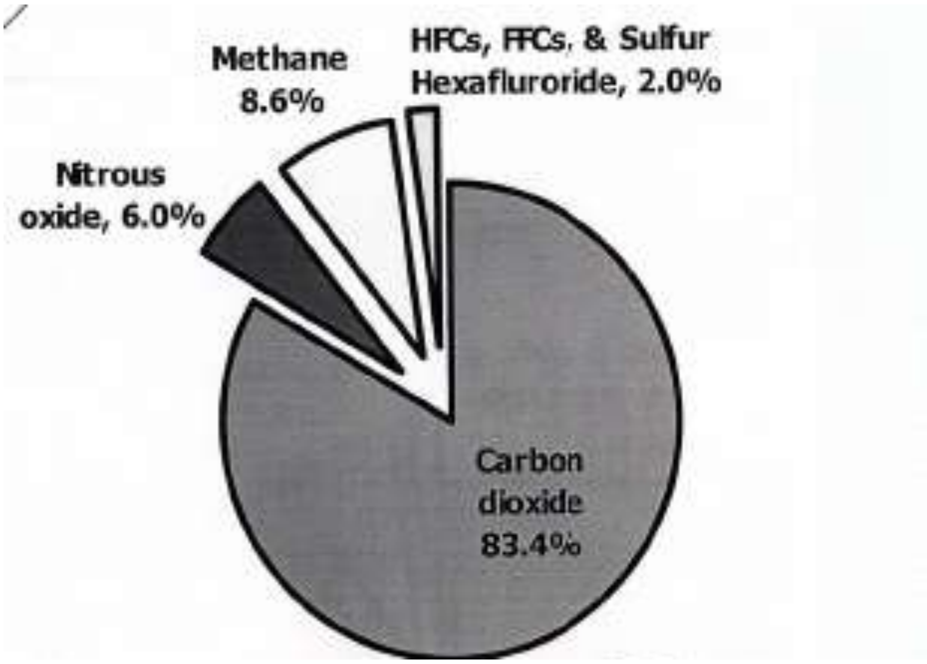

Figure 2. U.S. Greenhouse Emission, 2002
(U.S. Environmental Protection Agency)

CO_2 Emissions by Automobiles in the U.S.A.

Cars are the largest single source of CO_2 emissions into the atmosphere, and every litre of gasoline burned produces about 2.5 kg of CO_2. The average car getting 10.6 km/L (25 miles per gallon) and travelling 20,000 km (12,500 miles) per year emits about 4.7 tonnes of CO_2. Therefore, 20 million passenger cars (10 per cent of the total number of cars in the U.S.A.) will emit about 94 million tonnes of CO_2 into the atmosphere. This amount of CO_2 is about the same as emitted by the cement plants in the U.S.A.

Potential Impact of Global Warming

At present, there are no means of quantifying the potential effect of global warming. Different research groups involved in this area have different forecasts, and these range from gloomy to very gloomy. In general, they all agree that the following events are the most likely outcome of climate change:

1. Disappearance of glaciers that feed major river systems in south and south east Asia
2. Melting of the Antarctic glaciers
3. Melting of the permafrost in the north
4. Flooding that endangers coastal low-lying areas
5. Damaged ecosystem that endanger fisheries
6. Danger of very serious air pollution

7. Increased danger of insect-born diseases
8. Increased threat of forest fires and very serious floods
9. Forests turning to grasslands
10. Extremely serious shortages of water in parts of Africa and Asia

WATER – THE WORLD'S NEXT CRISIS!

Water Shortage

The global warming will affect very seriously the availability of water in the future. The Himalayan glaciers are melting fast. This could lead to water shortages for hundreds of millions of people. The glaciers that regulate the water supply to Ganges, Indus, Brahmaputra, Mekong, Thanklwin, Yantse and Yellow rivers are believed to be retreating at a rate of about 10 to 15 metres each year. It is estimated that 500 million people on the planet live in countries critically short of water, and by 2025, the above number will leap to 3 billion. According to the Pacific Institute for Studies in Development and Security, water shortages have risen in recent years across the southwest and northwest of the U.S.A. These have also occurred in India, China and Africa. As a result, some industrial plants had to close or had disruptions. For example, in 2004, in the southwest Indian state of Kerala, PepsiCo Inc. and Coco-Cola Co. plants were ordered closed amid drought-induced water shortages. Once again, the U.S.A. is the world leader in water usage as shown below:

Continent	Water Consumption, litres/day
North America	600
Europe	300
Africa	30

Water Wastage

In spite of the looming water crisis in the not too distant future, there is a huge wastage of water worldwide. For example, 9.5 billion litres of water it would take to support 4.76 billion people of their daily needs as set by the United Nations. On the other hand, currently 9.5 billion litres of water are being used to irrigate the world's golf courses. Furthermore, there seems to be no end in sight for the building of new golf courses, especially in China and southeast Asia and, to a lesser extent, in India.

PORTLAND CEMENT AND GREENHOUSE GAS EMISSIONS DURING ITS MANUFACTURING

Portland Cement Production

Ordinary Portland cement is a major construction material worldwide, and will remain so for the foreseeable future (Table 2). The net cement production is expected to rise from about 1.7 billion tonnes in 2000 to about 2 billion tonnes in 2010. (These figures can change depending upon the economy of the world). The major increases will take place in China and India, and to a lesser extent in the former Soviet Union. In the U.S.A., it is expected that the cement production will increase from about 100 million tonnes in year 2000 to about 130 million tonnes in 2010. In view of the huge tonnage involved, it is imperative that the manufacturing of cement be made as environmentally friendly as possible Table 3 provides data on cement production, population and GDP of some selected countries.

Table 2. Regional and World Cement Production to Year 2010*
(million tonnes)

	1995	2000	2005	2010	% of	% of
European Union	168.1	187.9	194.1	189.3	12.1	9.4
Other parts of Europe	65.8	80.0	90.2	94.7	4.7	4.9
Former Soviet Union	58.1	80.3	110.1	128.2	4.2	6.6
North America	92.9	94.9	94.8	94.7	6.6	4.9
Central and South	89.4	106.6	127.4	145.0	6.4	7.5
Africa	64.8	74.3	80.7	85.5	4.6	4.4
Middle East	63.5	75.6	76.9	73.4	4.6	3.8
East Asia	623.4	732.7	798.8	844.3	44.6	43.4
S/SE Asia	161.2	219.1	255.0	279.2	11.6	14.4
Oceania	8.0	10.6	11.1	11.8	0.6	0.6
World Totals	1396.1	1662.1	1839.1	1946.1	100.0	100.0

**From: World Cement Annual Review, World Cement, Vol. 28, No. 7, July 1997, pp. 3-60.*
Note: Recent published data indicate that the North American production had already exceeded 120 million tonnes in year 2002, and will reach 130 million tonnes in year 2010.

Table 3. Production of Cement/Population/GDP of Selected Countries - 2004*

Country	Production million/tonnes	Population millions	Amount - Cement per person, kg
CHINA	850	1299	654
INDIA	110	1065	103
U.S.A.	97	293	331
JAPAN	69	127	543
SOUTH KOREA	60	49	1224
RUSSIA	46	144	319
SPAIN	40	40	1000
BRAZIL	38	184	206

* *From: Professor Tang Mingshu, Nanjing University of Technology June 2005*

The Cement Industry=s Sustainable Program[*] developed by the world Business Council for Sustainable Development (WBCSD) resulted in the 2002 "Agenda for Action". This industrial protocol was undersigned by the C.E.O.=s of the world=s ten leading cement manufacturers. The "Agenda for Action" covers a five year period, and is directed at improving among other things, the following:

- Climate protection
- Fuels and raw materials
- Emission reductions
- Environmental impact

The Swiss global cement producer HOLCIM Ltd., a member of WBCSD, has taken a leading role in the cement industry in its response to sustainable development, and has pledged to reduce by 2010 specific net CO_2 emissions by 20% globally against the reference year 1990[**].

Greenhouse Gas Emissions from the Manufacturing of Portland Cement

Not only is the manufacturing of portland cement highly energy intensive, it also is a significant contributor of the greenhouse gases. The production of one tonne of cement contributes about 1 tonne of CO_2 to the atmosphere, together with minor amount of NOx and CH_4. Even though the amount of GHG other than CO_2, is small, these are much more damaging than the former. The relative damage index of different GHG is given below, with CO_2 taken as one:

CO_2	1x
Methane	20x
Nitrons oxides	200 x
Flourine	15000 x

The total CO_2 emissions per tonne of cement can range from about 1.1 tonne of CO_2 from the wet processing plants to about 0.8 tonnes from a plant with precalcinators.

About half of the CO_2 emissions are due to the calcination of limestone and the other half are due to the combustion of fossil fuels. According to Cahn et al[*], the emissions from the calcination of limestone are fairly constant at about 0.54 tonnes of CO_2 per tonne of cement; the emissions from the combustion depend on the carbon content of the fuels being used and the fuel efficiency.

Global Perspective

Globally, in 1995, the production of cement was about 1.4 billion tonnes, thus emitting about 1.4 billion tonnes of CO_2 to the atmosphere. According to world energy outlook 1995, issued by the International Energy Authority (IEA), the worldwide CO_2 emissions from all sources were 21.6 billion tonnes. Thus, the worldwide cement production accounts for almost 7 percent of the total

---

[*]World Cement, Vol. 34, No. 4, April 2003, p. 42.

[**]ACI Concrete International, Vol. 25, No. 3, March 2003, p. 16.

[*]Cahn, D. et al., "Atmospheric CO_2 and the U.S. Cement Industry", World Cement, Vol. 28, No. 8, August 1997, pp. 64-68.

world CO_2 emissions. From the projections made by the cement companies, this proportion is expected to remain steady in the next decade (Table 4). Notwithstanding the "Agenda for Action" of WBCSD, this implies that the cement companies are not expecting the emergence of major environmentally friendly cement manufacturing technologies in the immediate future.

Table 4. World-wide Cement Production and $C0_2$ Emissions

Year	Cement Production, billion tonnes	Total $C0_2$ Emissions, billion tonnes	$C0_2$ Contribution by cement industry, %
1995	1.4	21.6	7
2010	1.9	28-30	7

Note: Recently published data indicate that total CO_2 emissions have already reached 28 billion tonnes.

Developing Countries

The infrastructure needs of developing countries have led to huge increases in demand for portland cement (Table 5). This has led to the installation of a large number of new cement plants in China and India. For example, a new plant with a capacity of 2 million tonnes of clinker has just been commissioned in India,[**] and the plans are to double the capacity of this plant to 4 million tonnes per year in the near future, thus making it the world=s largest single clinker plant. Paradoxically, the above countries are also installing huge coal-fired power plants to supply electricity to meet the growing needs of the population and manufacturing industries. For example, it is anticipated that by year 2010, India will double the capacity of the electric power generation from what is being generated today, resulting in an increase in fly ash availability to about 160 million tonnes annually. In that year, the portland cement production is expected to reach 130 million tonnes. Table 6 presents current production and anticipated production for the world for portland cement, fly ash and other cementitious and pozzolanic materials. **It is evident from Table 6 that fly ash is and will remain the major supplementary cementing material for years to come. It is therefore important that we concentrate our major efforts for the increased use of fly ash in concrete.**

Table 5. Coal Ash Production and Utilization, 2004*

Country	Production	Utilization in Concrete
China	>600	>15

*The above data include fly ash, bottom ash, and slag. For every 100 tonnes of fly ash, there are approximately 25 tonnes of bottom ash and boiler slag. The above production and utilization rates have been taken from published data and personal communications. They are, at best, estimates only, and therefore the margin of error could be as high as 10 percent.

[**]Anantharaman, V.J., "India=s Largest", World Cement, Vol. 33, No. 23, December 2002, pp. 53-56.

Table 6. World-wide Production (millions of tonnes)

	Cement	Fly Ash	Others*
Current Production	1600	900	20
Anticipated Year	3000	2000	>100

** slag, silica fume, natural pozzolans, rice-husk ash, metakaolin*

Unfortunately, the much needed industrial developments in China and India are affecting adversely the environment in two ways. The installation of new cement plants is increasing substantially the CO_2 emissions, and the construction of very large capacity thermal power stations is resulting in huge amounts of fly ash and bottom ash becoming available that are not being recycled in any meaningful manner. Most of the fly ash is being dumped in lagoons, landfill sites and abandoned quarries. Thus, potentially valuable cementing resources are being wasted in precisely the countries that need it most to reduce the greenhouse gas emissions, and to make economical and durable concrete structures.

ROLE OF FLY ASH AND OTHER SUPPLEMENTARY CEMENTING MATERIALS IN REDUCING CO_2 EMISSIONS

As mentioned earlier, there are hardly any new technologies on the horizon that can reduce CO_2 emissions during the manufacturing of portland cement. This leads us to the conclusion that the answer lies in reducing the output of cement clinker, and the loss in clinker production to be overcome by the use of fly ash and other supplementary cementing materials such as blast-furnace slag and rice-husk ash.

Availability of Fly Ash

Based on the fragmented information available, the current annual production of fly ash is of the order of 900 million tonnes worldwide. The big producing countries are China, India, and the U.S.A.. In addition to this, there are millions of tonnes of fly ash that have been stockpiled over the years. It has been reported that in the U.K. alone, 120 million tonnes could be recovered from the stockpiles[*]. The Wisconsin Power, in Milwaukee, U.S.A. is already doing so[**]. The utilization rate of fly ash in concrete varies from country to country (Table 5). In the U.S.A., fly ash is used as a separately-batched material at concrete batch plants, where as in Europe and India, fly ash blended cements are being produced for use in concrete. Currently, most fly ash blended cements in India incorporate abut 20 percent fly ash; however one company produces blended cement with about 30 percent fly ash.

Notwithstanding that coal-burning power plants produce huge amounts of CO_2 emissions, and are environmentally unfriendly, it should be kept in mind that for the foreseeable future, power needs of the world especially China, India and the U.S.A., will be met by the coal-burning power plants

[*]Sear Lindon, “The Future of Pulverized Fuel Ash Concrete”, Concrete, Vol. 37, No. 2, 2003, pp. 50-51.

[**]Personal communication from Bruce Ramme, Wisconsin Power, Milwaukee, U.S.A.

because there are huge reserves of good quality coal available worldwide, and the power produced from these sources is still cheaper than from other sources. Figure 3 shows the projection of world coal use indicating that the coals use will increase from 5.5 billion tonnes in 2005 to about 7.0 billion tonnes in 2020. In 2002, the percentage of electricity generated by coal in the U.S.A.was 51 per cent and is believed that this will stay about the same by 2025 (Figure 4). To meet the additional electrical capacity planned (327,000 megawatts) in China, India and the U.S.A., these countries will need 562, 213 and 72 new coal-fixed plants by year 2012. Furthermore, in northern Europe, nuclear power plants are being phased out, and the reserves of natural gas worldwide are limited compared to that of coal. **Thus it can be safely stated that fly ash will be available in huge quantities for at least up to year 2050.**

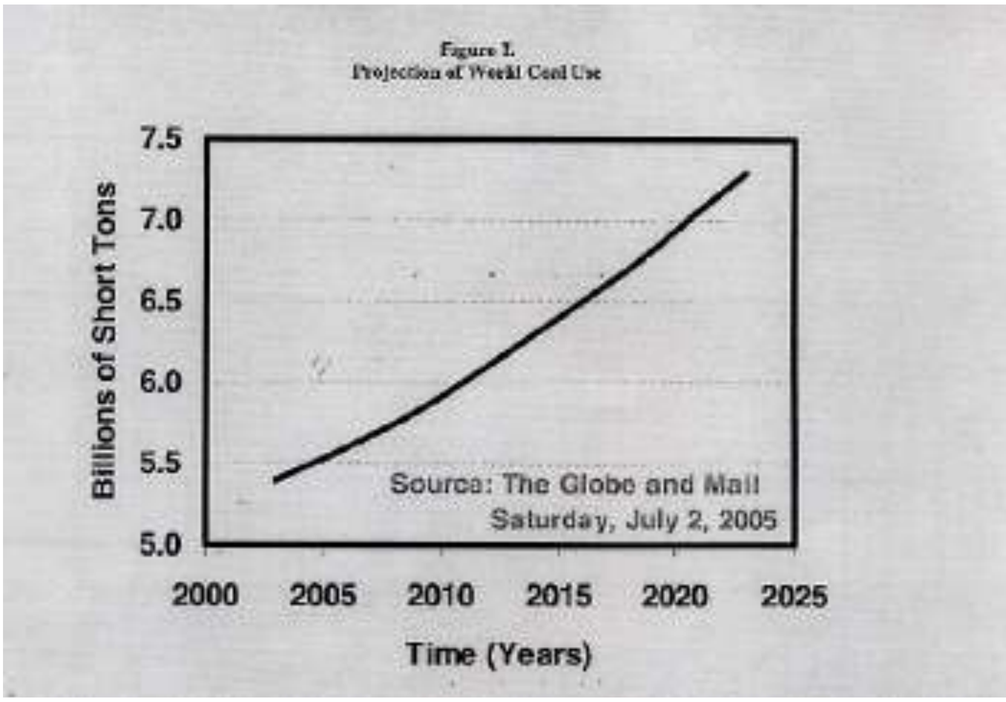

Figure 3. Projection of World Coal Use

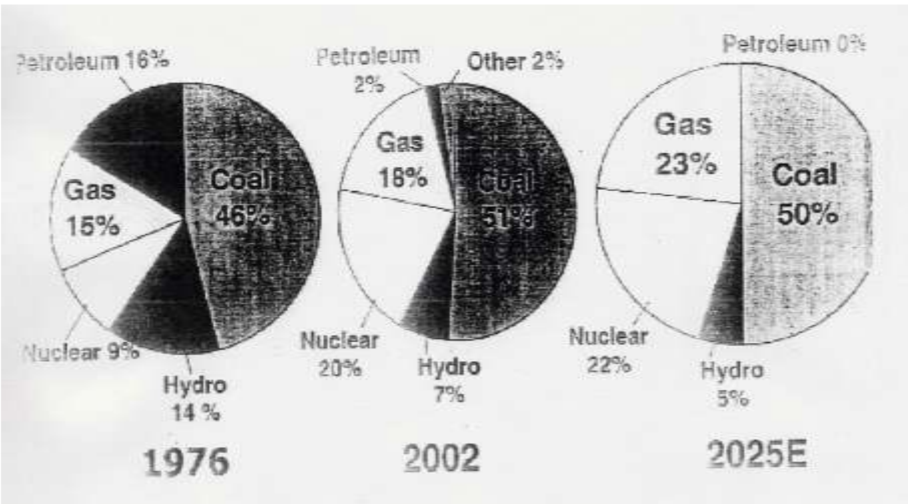

Figure 4. Percentage of Electricity for Fuel Type in the U.S.A.

The vast majority of the available fly ashes for use in concrete are low-calcium fly ashes (ASTM C 618, Class F), and are basically the by-product of burning anthracite or bituminous coal. These fly ashes, in themselves, possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. In recent years, high-calcium (ASTM C 618, Class C) fly ash is being marketed in the U.S., Canada, Poland, Greece, and some other countries. These fly ashes are by-products of burning lignite or sub-bituminous coal, and have cementitious properties in addition to being pozzolanic.

It should be mentioned that not all the available fly ash is suitable for use in concrete. However, technologies are available that can beneficiate those fly ashes that fail to meet the fineness and carbon content requirements, the two most important parameters of a fly ash for use with cement in concrete. These include removal of carbon by electrostatic and floatation methods. Grinding and air classification methods have been used to produce fly ash with high fineness.

High-Volume Fly Ash Concrete Technology

One of the major developments in the area of fly ash utilization in concrete has been the technology of high-volume fly ash (HVFA) concrete by Malhotra* and his associates at CANMET, Ottawa, Canada. It is believed that in years to come, this development will affect profoundly the use of cement in concrete. Several papers in this publication describe some case histories in the U.S.A., using HVFA concrete.

Other Supplementary Cementing Materials

In addition to fly ash, the other supplementary cementing materials that are available in large quantities and can be used to replace portland cement in concrete include granulated, blast-furnace slag, natural pozzolans, rice-husk ash, silica fume and metakaolin.

The worldwide production of granulated, blast-furnace slag is only about 25 million tonnes per year. The rice-husk is not yet available commercially, although the worldwide potential is about 20 million tonnes. The use of granulated blast-furnace slag in concrete has increased considerably in recent years, and this trend is expected to continue. Rice-husk ash, when it becomes available commercially, will along with fly ash and granulated blast-furnace slag, be the most significant supplementary cementing material for use as a partial replacement for portland cement in concrete to reduce CO_2 emissions. The use of natural pozzolans is rather limited because of their high-water demand when incorporated in concrete, and the need for calcination. Both Mexico and Turkey produce portland/pozzolanic cements with cement replacement levels of about 30 percent.

Silica fume, a highly pozzolanic material, is a by-product of when silicon metal or ferro silicon alloys are produced in smelters using electric arc furnaces. The world-wide production is estimated to be about 2 million tonnes. Its primary use is to enhance the durability of concrete by making it less permeable. It is normally not used as a cement replacement material but is added to the

---

*Malhotra, V.M., and Mehta, P.K., "High-Volume Fly Ash Concrete: Materials, Mixture Proportions, Construction Practice, and Case Histories", 2002, 101 pp., (Available from: Supplementary Cementing Materials for Sustainable Development Inc., Ottawa, Canada, K1Y 2B3).

concrete mixture in addition to portland cement. Thus its contribution to CO_2 emission reduction is indirect because durable structures require less repair and maintenance. The performance of metakaolin in concrete is like that of silica fume, but as metakaolin is a manufactured product, unlike silica fume which is a by-product, its use in concrete contributes very little to reduction of greenhouse gas emissions. No data have been published on the amount of metakaolin available, but it is believed to be of the same order as silica fume.

Limestone fillers are being used increasingly in Europe in the clinkering and grinding phase of portland cement production; however, these have not made any significant inroads in North America because those are not by-product materials and there are concerns as to the long-term durability of concrete incorporating these fillers.

ROLE OF SUPERPLASTICIZERS IN REDUCING CO_2 EMISSIONS

There are two possible ways in which superplasticizers can be used to reduce cement content in mixture proportioning, and thus contribute to CO_2 emissions reduction. These are:

(a) To produce concrete with very low water-to-cement ratio. To achieve high-strength concrete, the water content of the mixture is reduced while maintaining the same cement content. The reduced workability is compensated for by incorporating superplasticizers. By this method, water reductions of up to 30% have been achieved, and concrete with water-to-cement ratio as low as 0.28 has been successfully placed. Thus, high performance, high-strength concrete can be made without increasing the cement content.

(b) To produce concrete with reduced cement content. Superplasticizers can be used to produce concrete with reduced cement content while the water-to-cement ratio is maintained constant. As in method (a), the decrease in workability of concrete is compensated for by incorporating superplasticizers.

As mentioned earlier, superplasticizers are a vital component of HVFA concrete in which more than 50 percent of portland cement can be replaced by fly ash while still maintaining or increasing the strength and durability characteristics of concrete.

GLOBAL TRADE IN FLY ASH

Until recently, portland cement was indigenously produced in every country and there was very little international trade in this product. However, with the advent of large multinational cement companies, the portland has become an internationally traded product. For example, the U.S.A. imports cement from a large number of countries including Mexico, Canada, and Spain. During the years 2002 and 2004, the U.S.A. was importing between 15 and 20 million tonnes of cement per year. Similarly fly ash is becoming an internationally traded product. South Africa and India are exporting some fly ash to the middle east and there is considerable trade in fly ash among European countries. It is not unrealistic to assume that in the foreseeable future, like portland cement, large volumes of fly ash would be traded internationally for use in concrete.

TRADEABLE EMISSION RIGHTS AND THE UTILIZATION OF FLY ASH

"Tradeable emissions" refers to the economic mechanisms that are expected to help countries worldwide meet the stringent emission reduction targets established by the 1997 Kyoto Protocol.

It is being speculated that in the not too distant future one tonne of emissions will have a trading value of about $40 (U.S.), the current value being $25.00 (U.S.). Thus, for example, if a country can replace 50 percent of cement utilization by fly ash or slag, the country would have saved about 50 percent of the CO_2 emissions from reduced need for cement. For a country that produces 100 million tonnes of cement annually, this 50 percent replacement by fly ash would amount to savings in CO_2 emissions of 50 million tonnes. This, in turn, translates into a trading value of 1,250 million dollars (U.S.) annually. One must keep in mind that the value of the trading of emission rights can fluctuate widely. However, given the political and environmental pressures, the utilization of fly ash will pay rich dividends. The developed countries have a major stake in this issue. If these countries can transfer fly ash utilization technology to developing countries, and demonstrate the actual reduction in the installation of new cement plants in these countries, the former countries can rightly claim CO_2 emission credits.

Canada has approved the Kyoto Protocol to cut the greenhouse gas emissions to 6 percent below 1990 levels by year 2010-2012. In order to give an idea of huge financial stakes involved, it is estimated that it will cost about $100 billion over 15 years for Canada to cut greenhouse gas emissions by as much as it promised at the Kyoto climate change conference.

HOW THE CEMENT AND CONCRETE INDUSTRY CAN CONTRIBUTE TO REDUCTION OF CO_2 EMISSIONS

There are a number of ways by which the cement and concrete industry can contribute towards reducing CO_2 emissions. Some of these are:

- Use less portland cement
- Use more supplementary cementing materials
- Use less unit water content by using more water reducers and superplasticizers
- Incorporate recycled aggregates in concrete
- Use stainless steel reinforcement in critical parts of structures to make them more durable
- Where possible, specify strength acceptance criteria on 56 or 91 days instead of 28 days
- Use lightweight concrete where possible

CONCLUSIONS

Environmental issues associated with the CO_2 emissions from the production of portland cement demand that supplementary cementing materials in general, and fly ash, ground granulated blast-furnace slag and rice-husk ash in particular, be used in increasing quantities to replace portland cement in concrete. Given the almost unlimited supply of good quality fly ash worldwide, and the development of technologies such as high-volume fly ash concrete, it is proposed that the installation of new cement plants should be avoided as much as possible. In addition, the ageing portland cement plants should be phased-out, and the resulting loss in capacity should be compensated for by the use of supplementary cementing materials.

The combined use of superplasticizers and supplementary cementing materials can lead to economical high-performance concrete with enhanced durability. It is hoped that the concrete industry would show leadership and resolve, and make contributions to the sustainable development of the industry in the 21st century by adopting new technologies to reduce the emission of the greenhouse gases, and thus contribute towards meeting the goals and objectives of the 1997 Kyoto Protocol.

The following quotation[1] from Dr. David King, Chief Science Advisor, Government of the U.K. is an appropriate concluding statement:

“Climate Change was a far grater threat to the world than international terrorism”

[1] BBC News, U.K. Edition, January 2004