

Note: This is a reference cited in AP 42, *Compilation of Air Pollutant Emission Factors, Volume I Stationary Point and Area Sources*. AP42 is located on the EPA web site at www.epa.gov/ttn/chief/ap42/

The file name refers to the reference number, the AP42 chapter and section. The file name "ref02_c01s02.pdf" would mean the reference is from AP42 chapter 1 section 2. The reference may be from a previous version of the section and no longer cited. The primary source should always be checked.

AP-42 Section 11.6
Reference 4
Report Sect. _____
Reference _____



PORTLAND CEMENT ASSOCIATION

1620 Eye Street, N.W., Suite 520, Washington, DC 20006 • 202/293-4260
Facsimile 202/293-4263

ROBERT W. CROLIUS
Vice President
Washington Affairs

March 11, 1992

Ron Myers
Emission Factor and Methodologies Section
Emission Inventory Branch
MD-14
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Dear Ron:

Per our telephone discussion of last week, enclosed are a number of documents which discuss our issues of concern regarding carbon dioxide emissions from the cement process.

Cement emissions of CO₂ come both from fuel combustion and decarbonization of limestone. As such, the cement industry is considered a major point source of CO₂. However, as cement generally only accounts for 10-15% of the concrete mix, CO₂ emissions in terms of concrete in place are actually low.

We'll be in touch shortly to arrange a meeting.

Sincerely,

A handwritten signature in dark ink, appearing to read 'Robert W. Crolius', written over the word 'Sincerely,'.

Enclosures

11-11-11



The Secretary of Energy

Washington, DC 20585

May 25, 1990

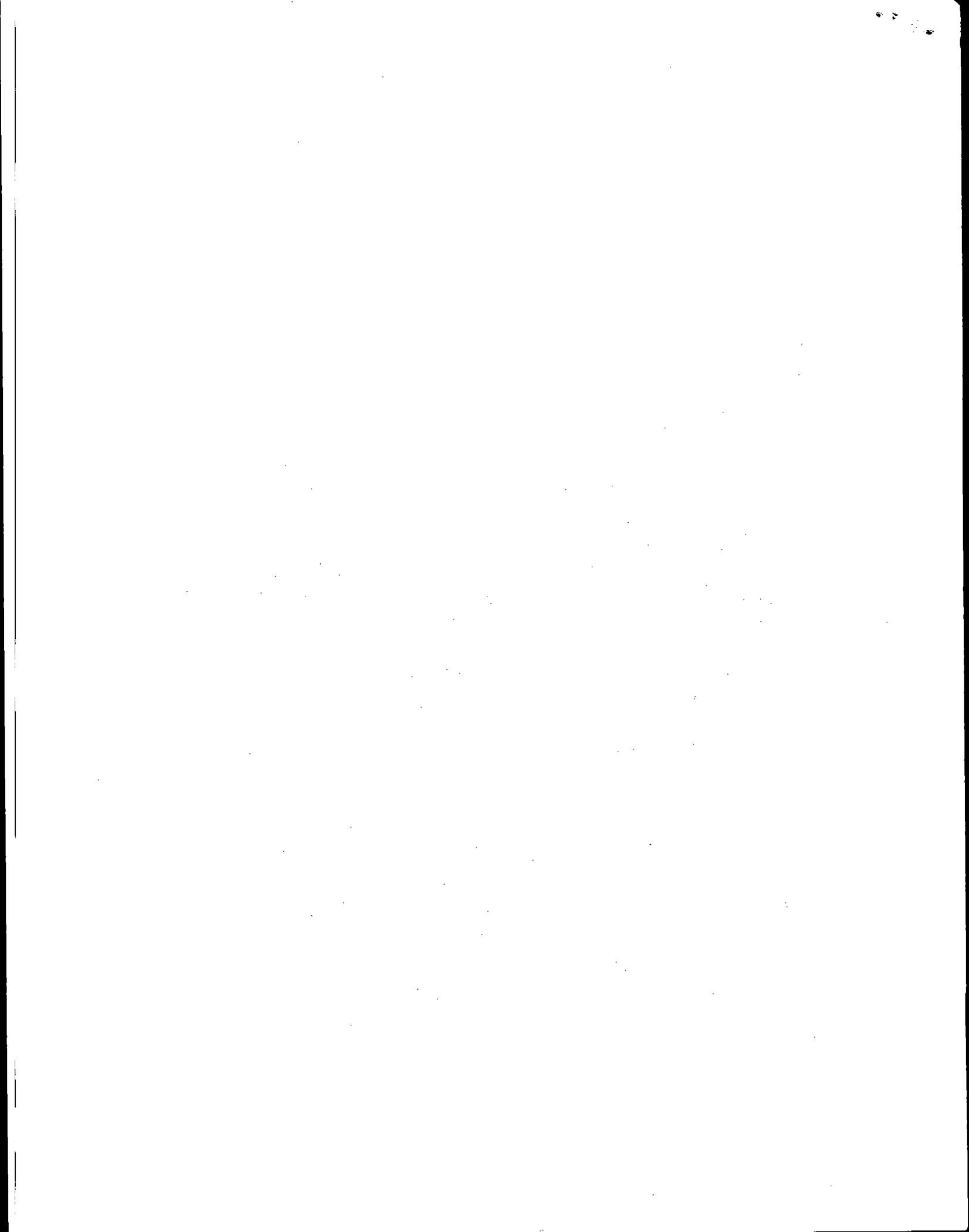
The Honorable John D. Dingell
Chairman
Committee on Energy and Commerce
U.S. House of Representatives
Washington, DC 20515

Dear Mr. ^{John:} Chairman:

This is in response to your letter of March 7, 1990, concerning correspondence from cement firms and groups regarding the impact of proposed carbon dioxide (CO₂) reductions in the the Senate Clean Air Act bill. Specifically, we have reviewed the January 11, 1990, letter from Mr. Robert W. Crolius, Vice President, Washington Affairs, Portland Cement Industry (PCI) to Senator Max Baucus on this issue. Our comments on the technical and economic issues raised in this letter are summarized in the enclosure.

The magnitude of the estimated CO₂ emissions from U.S. cement plants cited in the PCI letter appears to be approximately four times lower than Environmental Protection Agency (EPA) estimates. This apparently is due to the manner in which the EPA data were interpreted. However, the significant point made in the PCI letter that "virtually half the carbon dioxide emissions are not related to energy use and come from a chemical process for which there is...no substitute" is technically accurate.

Our calculations indicate that a mandated 25 percent reduction in overall CO₂ emissions for the cement industry would be very difficult to achieve. Coal and coke fuels are used in over 75 percent of all cement production. Measures to achieve a 25 percent reduction would require a switch to "cleaner plants to the most fuel efficient configuration. However, the latter is also the most capital intensive, and the technical feasibility of such conversion is unknown.



With respect to economics, capital and operating costs for CO₂ removal, recovery, and disposal have been estimated for fossil fuel power plants. However, we are not aware of any estimates of the costs of recapturing CO₂ emissions from cement plants.

Sincerely,



James D. Watkins
Admiral, U.S. Navy (Retired)

Enclosure

cc: The Honorable Norman F. Lent
Ranking Minority Member
Committee on Energy and Commerce

The Honorable Philip R. Sharp
Chairman
Subcommittee on Energy and Power

The Honorable Carlos J. Moorhead
Ranking Minority Member
Subcommittee on Energy and Power

The Honorable Samuel K. Skinner
Secretary of Transportation

The Honorable John H. Gibbons
Director
Office of Technology Assessment

The Honorable William K. Reilly
Administrator
Environmental Protection Agency

Carbon Dioxide Emissions from Portland Cement Manufacturing

Introduction

Atmospheric carbon dioxide (CO₂) is produced both from natural sources and by human activities. Of man's activities, the two most significant are fossil fuel burning and deforestation, with fossil fuel burning being the largest source of human generated CO₂. The only other major industrial sources of CO₂ are cement manufacturing and gas flaring. Exhibit 1 depicts the estimated CO₂ emissions from fossil fuel consumption and cement production in the U.S. from 1950 to 1986. Although CO₂ emissions from cement production have increased by about 85 percent from 1950 to 1986, they still constitute only a small fraction of the total anthropogenic CO₂ emissions.

Cement Manufacturing

Typical portland cements are a mixture of approximately 60-67 percent calcium oxide (CaO), 18-26 percent silicon dioxide (SiO₂), 4-7 percent aluminum trioxide (AlO₃), and 2-7 percent iron trioxide (Fe₂O₃), as well as small amounts of sulfur trioxide (SO₃) and other alkali oxides. When mixed with water, portland cement undergoes a chemical reaction which results in the hydration and hydrolysis of these minerals into crystalline complexes, resulting in a hardened structure.

The manufacture of portland cement involves the blending and processing of mostly naturally-occurring raw materials in order to arrive at the fine grey powder known as portland cement. The primary sources of the calcium in portland cement are mostly naturally occurring materials such as limestone, cement rock, oystershell, and marl. The silicon content of portland cement is provided primarily by such sources as clay and shale, sand, and sandstone (1)¹.

Carbon Dioxide Emissions

In the manufacture of portland cement, CO₂ is released primarily from two processes:

- o the calcining of limestone or other calcereous materials (the main raw material for Portland cement)
- o the combustion of fossil fuels for process energy.

¹ Numbers in parentheses denote references listed at the end of this paper.

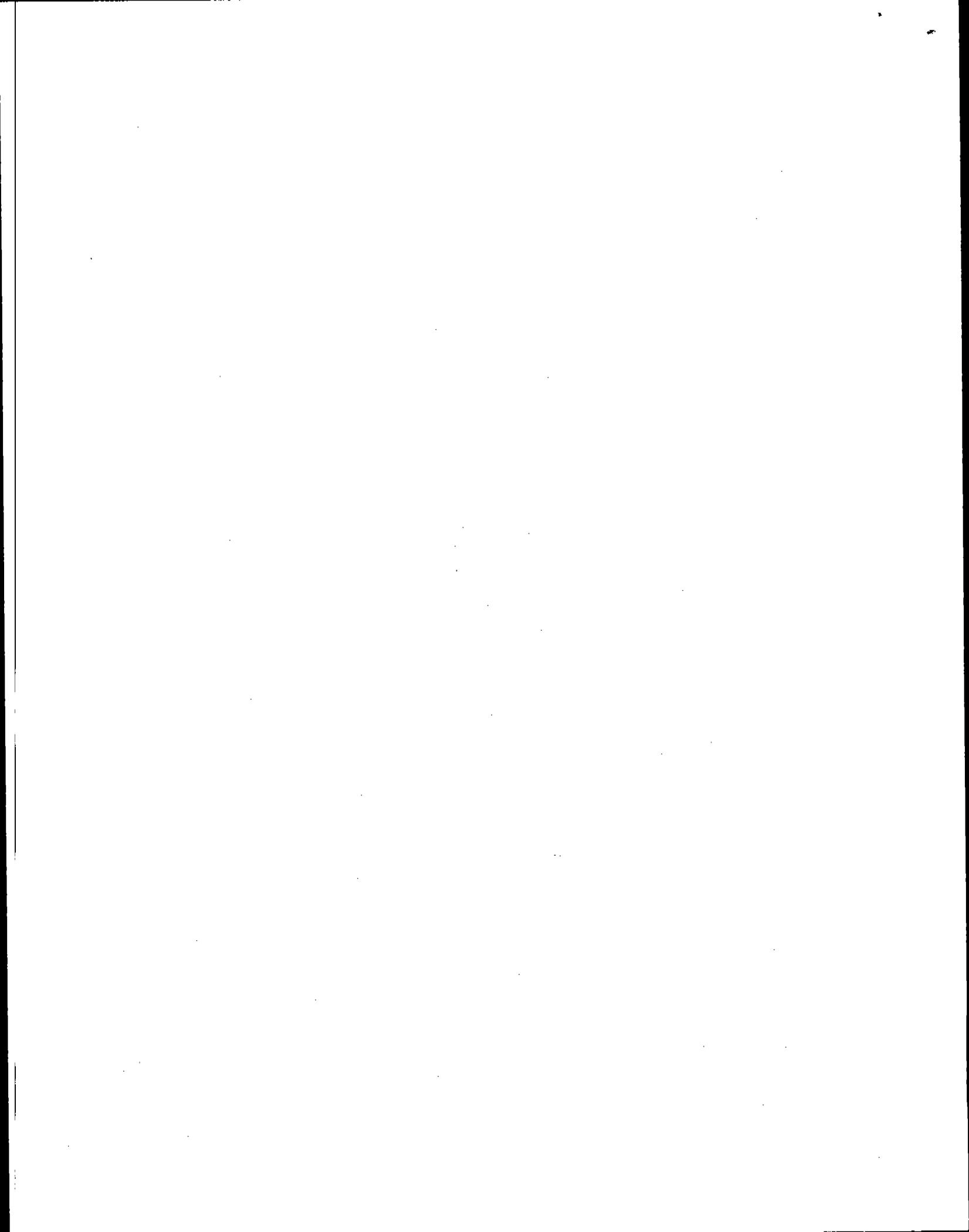
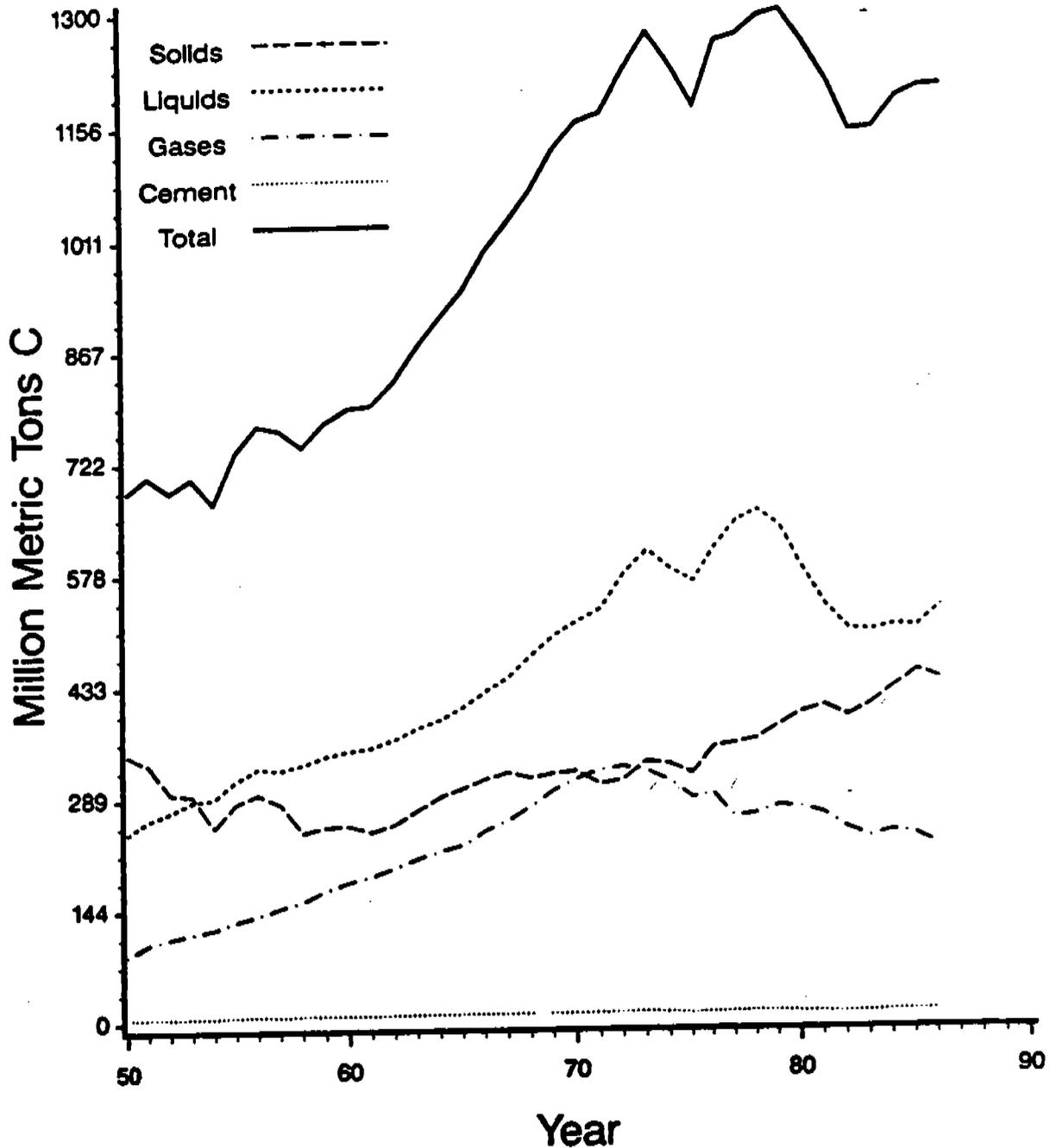
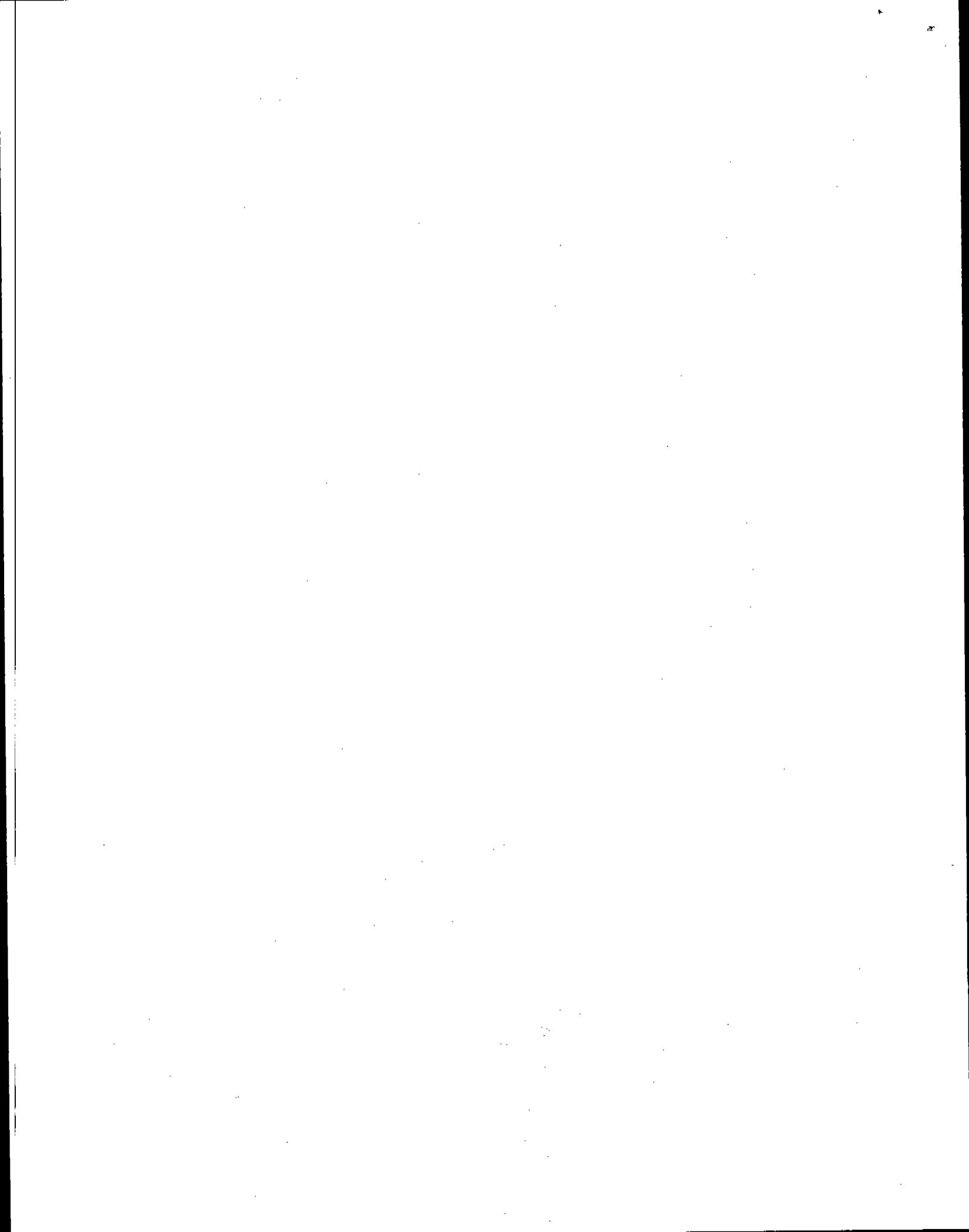


Exhibit 1. U.S. Carbon Dioxide Emissions



Source: Marland, G., et al. (Oak Ridge National Laboratory), Estimates of CO₂ Emissions from Fossil Fuel Burning and Cement Manufacturing. Based on the United Nations Energy Statistics and the U.S. Bureau of Mines Cement Manufacturing Data, ORNL/CDIAC-25, NDP-030, prepared for the U.S. Department of Energy, May 1989.



The calcining of limestone involves the high temperature thermal decomposition of calcium carbonate (CaCO_3), the primary constituent of limestone, into calcium oxide (CaO) and carbon dioxide (CO_2). The thermal energy required to perform calcining is provided in the portland cement industry today most commonly by the combustion of coal. Other process energy requirements arise from ore crushing and sizing and other operations.

In order to produce the average 63.5 percent calcium oxide present in 2000 pounds (lb) of portland cement, approximately 2270 lb of CaCO_3 (the primary constituent of raw materials for cement manufacture) must be calcined (2). During this process, approximately 1000 lb of CO_2 will be released during portland cement production through the combustion of fossil fuels necessary to provide process heat and other required energies. According to Portland Cement Association (PCA) data for 1988, the production of each ton (2000 lb) of finished product requires the expenditure of the following amounts of process energy.

Average for All U.S. Plants:	4.877 million BTU
Average for U.S. Wet Process Plants:	5.718 million BTU
Average for U.S. Dry Process Plants:	4.492 million BTU
Average for U.S. Dry Process Plants:	
Without Preheaters:	5.363 million BTU
With Preheaters:	4.061 million BTU

In 1988, this energy was provided by the following fuels in the following proportions in the average U.S. plant:

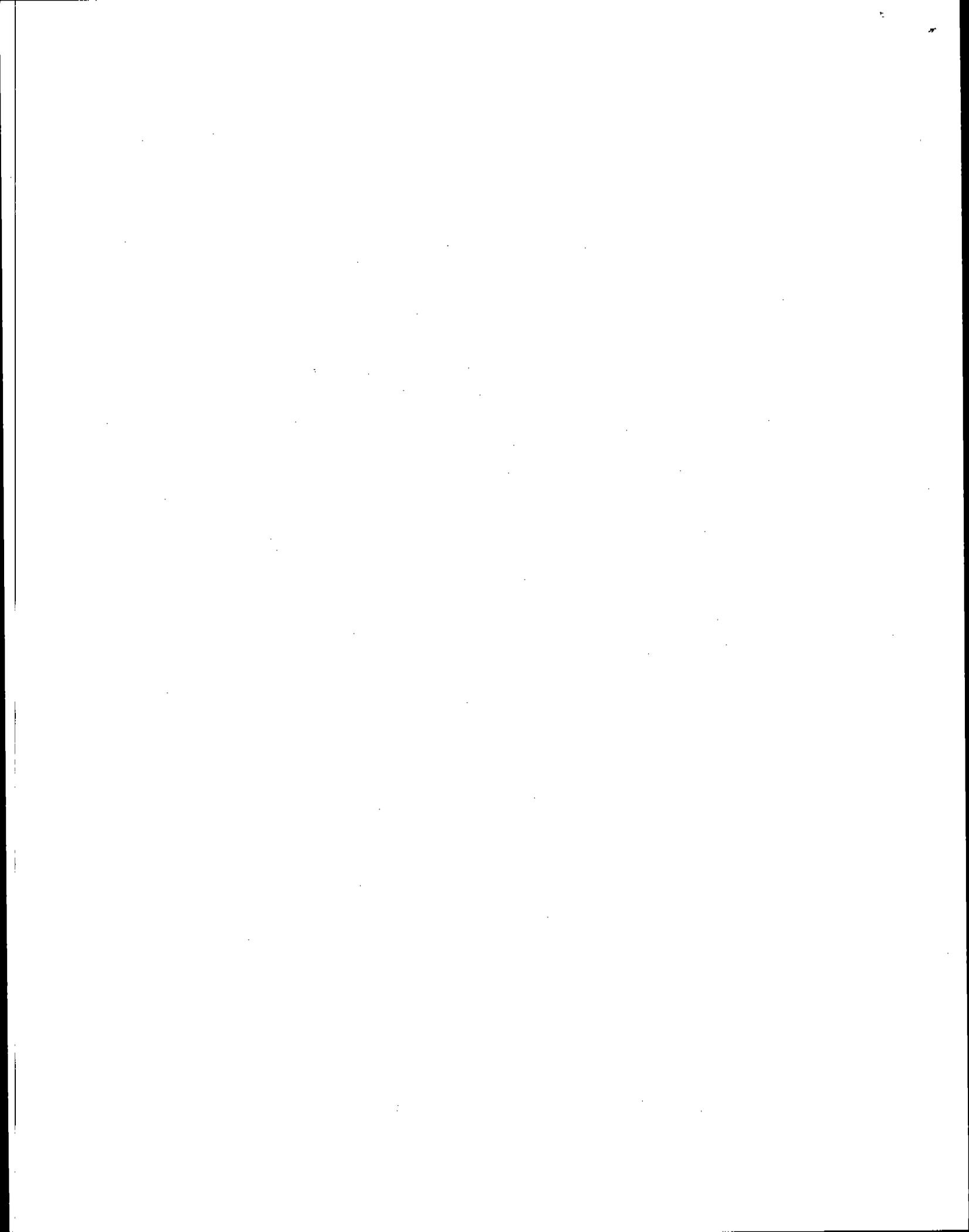
Coal and Coke:	76.1 percent
Natural Gas:	9.0 percent
Petroleum Products:	1.7 percent
Waste Fuels:	3.0 percent
Electricity:	10.2 percent

According to U.S. Environmental Protection Agency (EPA) estimates (3), the combustion of these fuels results in the following CO_2 releases per million BTU burned:

Coal:	233 lb
Natural Gas:	140 lb
Gasoline and Diesel:	170 lb
Liquefied Petroleum Gas:	171 lb
Electricity:	175 lb

Because of varying compositions, no data are readily available for CO_2 production from waste fuels, so the values for gasoline and diesel were assumed for these types of fuels.

Using the figures denoted above, the CO_2 released as a consequence of fossil fuel combustion during the production of 2000 lb of portland cement is estimated to be as follows:



For All Plants:

Coal and Coke Combustion:	864.8 lb
Natural Gas Combustion:	61.4 lb
Petroleum Products Combustion:	14.1 lb
Waste Fuels Combustion:	24.9 lb
Electricity Generation:	87.1 lb
TOTAL:	<u>1052.3 lb</u>

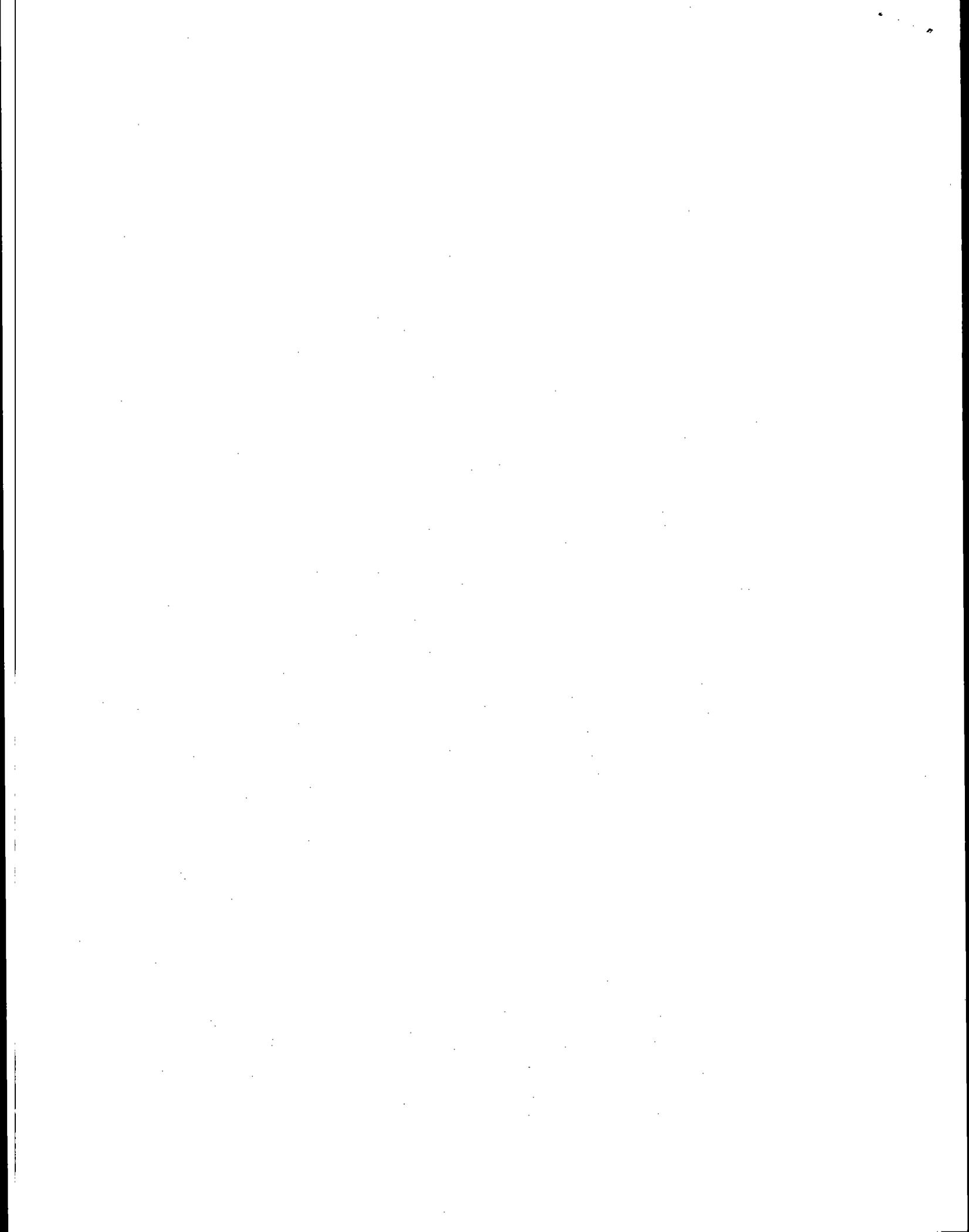
Combining this figure with that obtained from the calcining of calcium carbonate yields a figure of approximately 2050 lb of CO₂ released per ton of portland cement produced.

The letter from the Portland Cement Association appears to contain a factual misstatement in that it quotes an EPA estimate for CO₂ release from cement manufacture to be "approximately 0.137 million metric tons of carbon dioxide...from calcining, and 0.165 million metric tons of carbon dioxide...from fossil fuel used for kiln firing and electricity" per million tons of cement produced. In actuality, the EPA (and other sources) estimate that "0.136 million metric tons of carbon as carbon dioxide" is released per million tons of cement produced and approximately "0.165 million metric tons of carbon as carbon dioxide" is released from energy consumption (4). The effect of this error is to underestimate the total emissions of CO₂ from cement production by a factor of approximately 3.7. When these figures are adjusted to compensate for this error, the estimates cited in the PCA letter become 997 lb of CO₂ from calcining and 1210 lb of CO₂ per 2000 lb of portland cement, a figure which is approximately 8 percent higher than the calculated estimate noted earlier.

Despite this misstatement, the point made in the PCA letter that "virtually half the carbon dioxide emissions are not related to energy use and come from a chemical process for which there is, or can be, no substitute" is well taken. The production of CO₂ is an immutable feature of that manufacturing process.

Potential CO₂ Emissions Reductions

Given that approximately 50 percent of the CO₂ emissions from portland cement manufacturing are irreducible, a mandated 25 percent decrease in the overall CO₂ emissions from portland cement manufacture could be accomplished only by a 50 percent decrease in CO₂ emissions from associated fossil fuel energy usage, as stated in the PCA letter. However, the point is made in the PCA letter that "a 50 percent reduction in CO₂ emissions from fuel along...would have to be met by a 50 percent increase



in fuel efficiency." This is not strictly true, since a greater reliance on cleaner (but more expensive) fuels such as natural gas by the portland cement industry could substantially reduce CO₂ emissions associated with fuel use by approximately 33 percent.

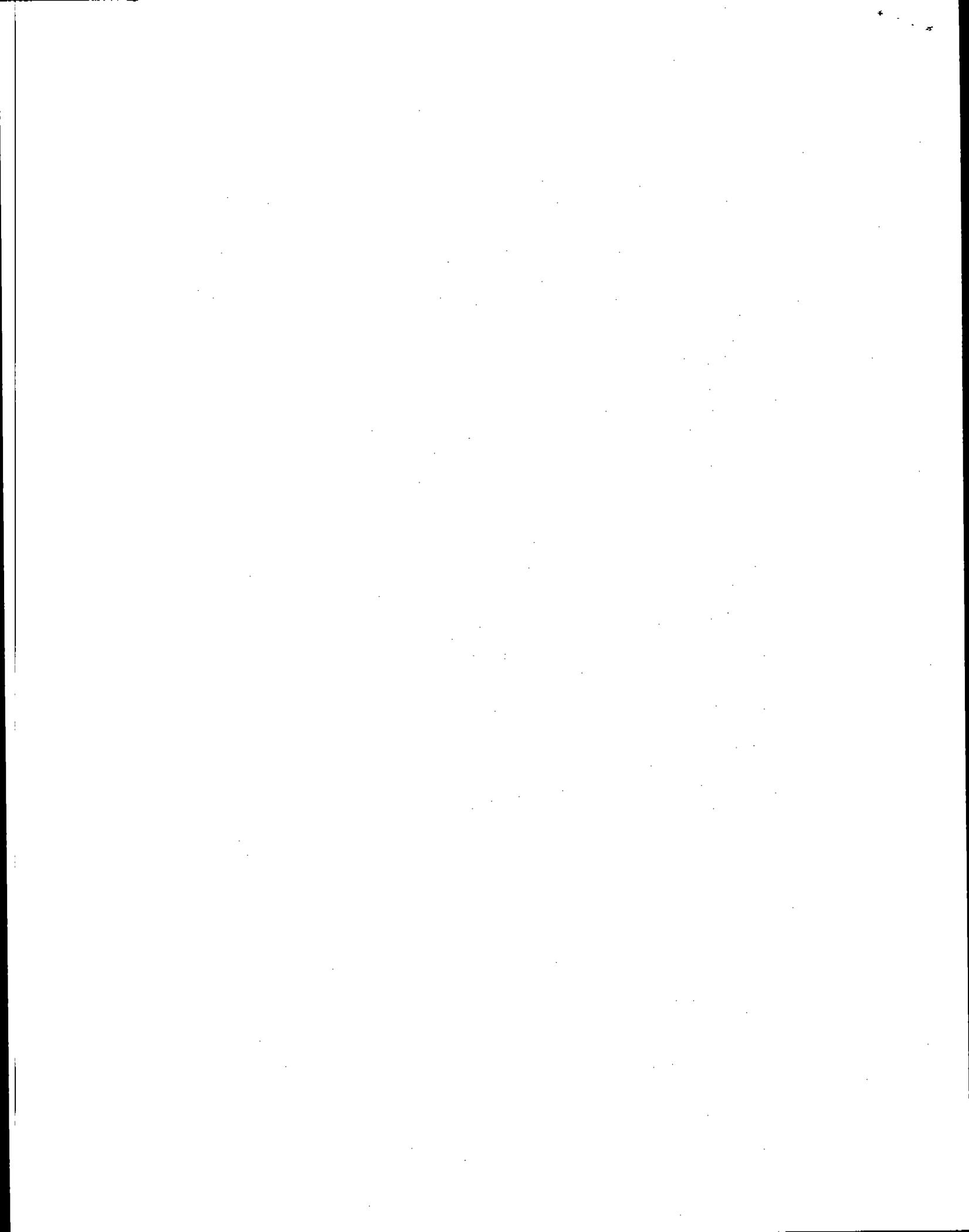
In addition to switching to cleaner fuels, energy efficiency gains across the industry as a whole could also reduce CO₂ emissions. For example, if all portland cement plants were converted to the most fuel efficient (and capital intensive) configuration (dry process with preheater), then CO₂ emissions as a consequence of fuel use could be reduced approximately 17 percent using the present fuel mix. If the preceding fuel switching and energy efficiency improvements were undertaken concurrently, then 44 percent decrease in current CO₂ emissions from fuel use would be accomplished. This would correspond to approximately 22 percent of the proposed mandated 25 percent reduction from the portland cement manufacturing process as a whole.

Another point addressed in the PCA letter is that there is "no feasible way of recapturing CO₂ from exhaust gases." In an economic sense, this is probably correct since CO₂ recovery equipment is extremely expensive to purchase and operate. In addition, the efficacy of such equipment in reducing emissions from portland cement plants is somewhat doubtful due to the problem of final disposal of collected CO₂ and the fuel use requirements of such equipment. Capital and operating costs for CO₂ removal, recovery, and disposal systems have been estimated for fossil fuel power plants (5). However, analogous estimates for cement plants are not readily available.

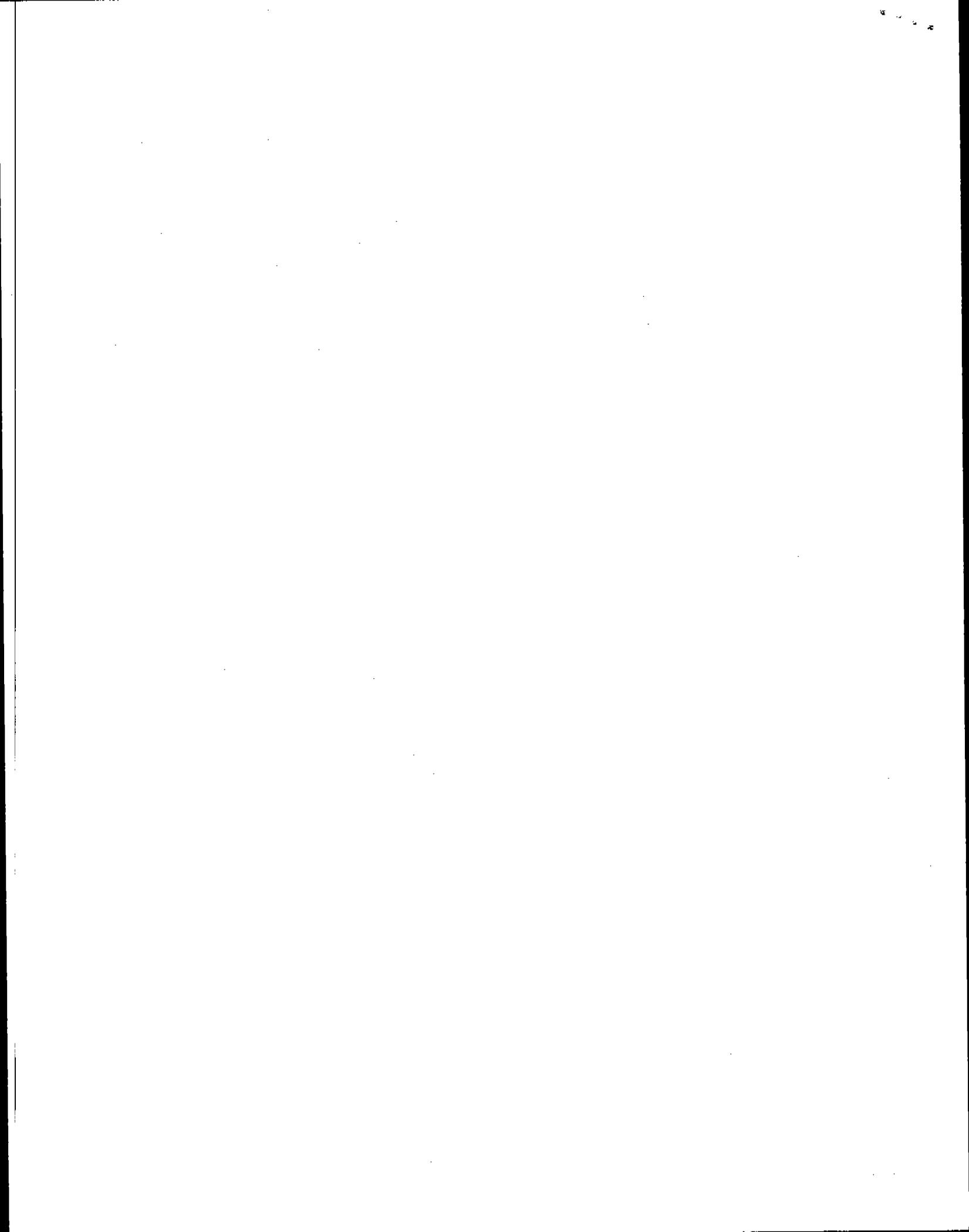
Finally, it should be pointed out that the high-temperature incineration of wastes by cement kilns is accomplished today with a high degree of efficiency. Such operations preclude the need for additional dedicated hazardous waste incinerators. Mandated reductions in CO₂ emissions would probably limit to a degree the more extensive beneficial use and destruction of these waste fuels in cement kilns.

References

1. Marland, G., et al. (Oak Ridge National Laboratory), Estimates of CO₂ Emissions from Fossil Fuel Burning and Cement Manufacturing, Based on the United Nations Energy Statistics and the U.S. Bureau of Mines Cement Manufacturing Data, ORNL/CDIAC-25, NDP-030, prepared for the U.S. Department of Energy, May 1989.
2. Shreve, R.N., Chemical Process Industries, 3rd Edition, McGraw-Hill, Inc., 1967.



3. Bartus, D. (U.S. Environmental Protection Agency), Effects of Fuel Ethanol Production and Use on CO₂ Production and Global Warming, Draft, June 1, 1989.
4. U.S. Environmental Protection Agency, Policy Options for Stabilizing Global Climate, Volume 2, Chapter VII, Draft Report to Congress, February 1989.
5. Steinberg, M., et al. (Brookhaven National Laboratory), A Systems Study for the Removal, Recovery and Disposal of Carbon Dioxide from Fossil Fuel Power Plants in the U.S., DOE/CH/00016-2, prepared for the U.S. Department of Energy, December 1984.



JOHN D. DINGELL, MICHIGAN, CHAIRMAN

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File

U.S. House of Representatives
Committee on Energy and Commerce
 Room 2125, Rayburn House Office Building
 Washington, DC 20515

March 7, 1990

JOHN S. ORLANDO, CHIEF OF STAFF
 JOHN M. CLOUGH, JR., STAFF DIRECTOR

The Honorable James D. Watkins
 Secretary
 Department of Energy
 1000 Independence Avenue, S.W.
 Washington, D.C. 20585

The Honorable William K. Reilly
 Administrator
 Environmental Protection Agency
 401 M Street, S.W.
 Washington, D.C. 20460

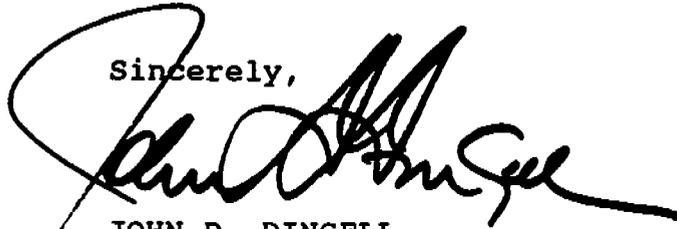
Dear Secretary Watkins and Administrator Reilly:

Enclosed is some correspondence I have received from cement firms and groups regarding the impact of the Senate Clean Air Act bill on that industry regarding proposed carbon dioxide reductions. I am very interested in the comments and request that you review and comment on the technical and other implications. Please identify any matters with which you disagree. What would be the economic impact on users of cement?

I request a reply within 30 days after receipt of this letter.

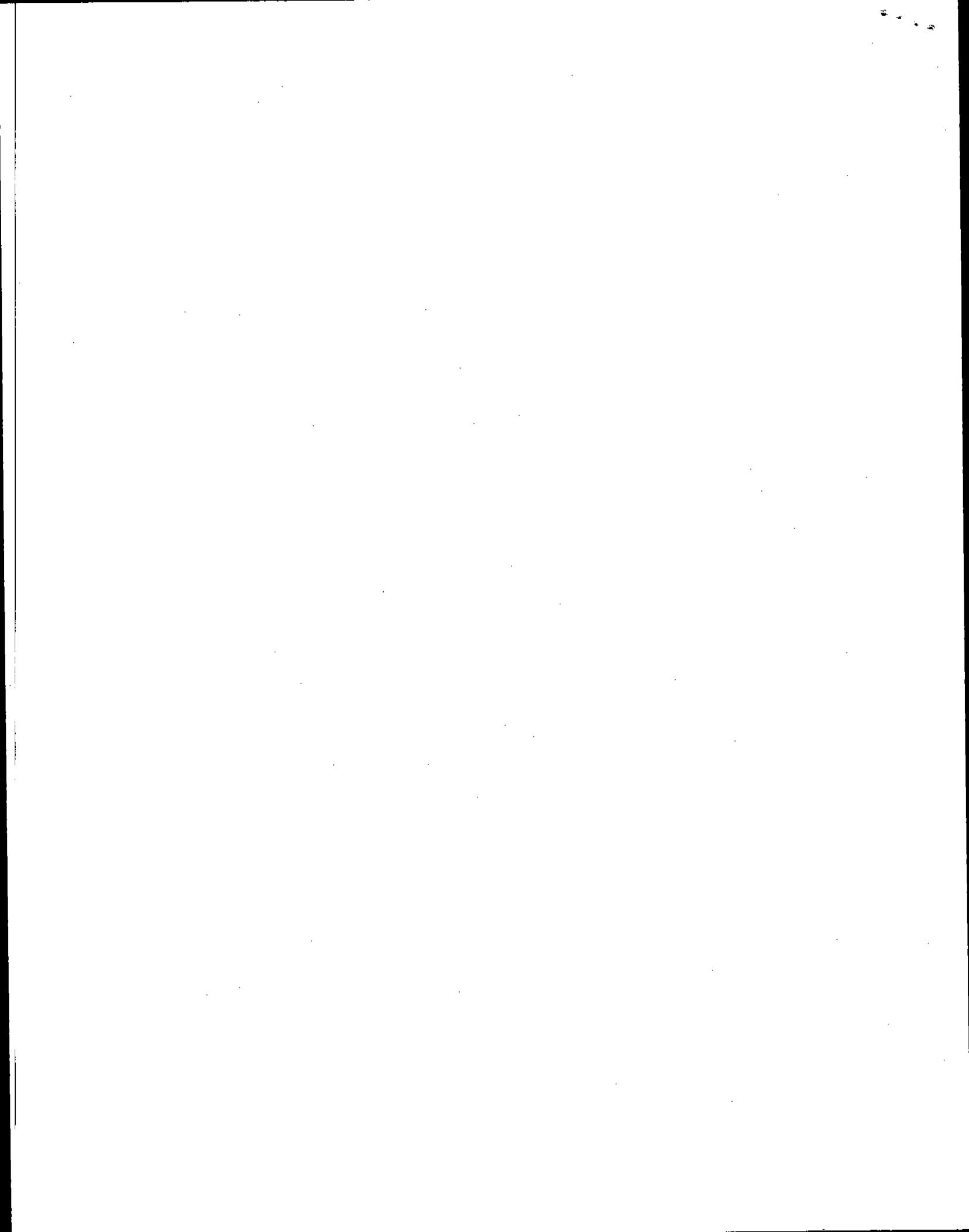
With best wishes.

Sincerely,



JOHN D. DINGELL
 CHAIRMAN

cc: The Honorable Norman F. Lent, Ranking Minority Member
 Committee on Energy and Commerce





PORTLAND CEMENT ASSOCIATION

Suite 520, 1620 Eye St., N.W., Washington, D.C. 20006. Telephone 202/293-4260

January 11, 1990

Honorable Max Baucus
Chairman
Subcommittee on Environmental Protection
Committee on Environment and Public Works
SD-458 Dirksen Senate Office Building
United States Senate
Washington, DC 20510

Dear Senator Baucus:

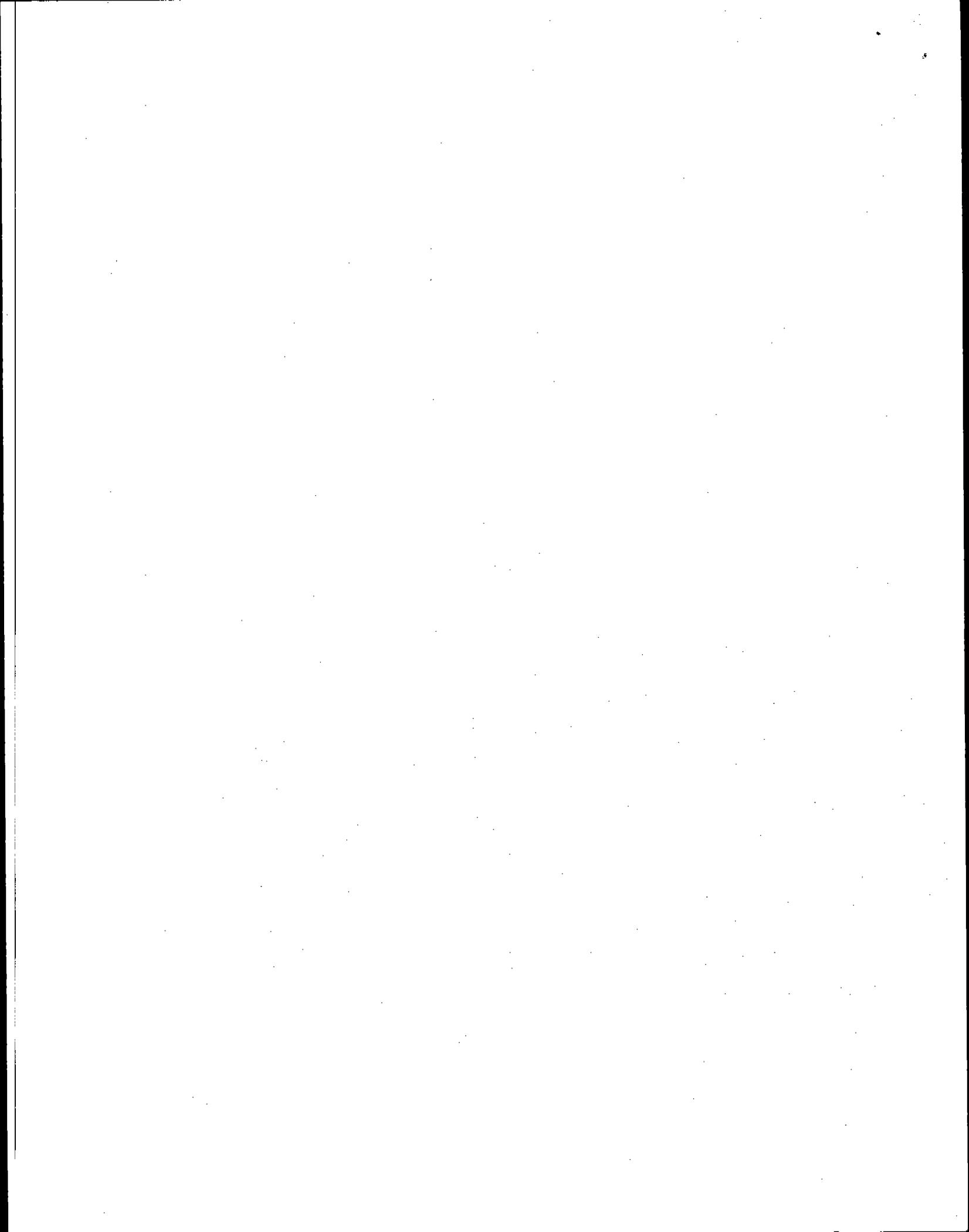
Re: Carbon Dioxide Emissions from Cement Operations

As the Senate resumes consideration of Clean Air Act amendments and also begins the longer-term process of determining appropriate responses to the phenomenon of global climate change, the Portland Cement Association wants to correct what appears to be a misunderstanding, or a lack of understanding, of the cement manufacturing process which could wreak havoc on our industry if allowed to persist. PCA is the research, market development, education and public affairs arm of the North American cement industry, representing about 80% of U.S. production capacity.

As a major user of fossil fuels, particularly coal, the cement industry is often mentioned as a "major" emitter of carbon dioxide. What must be understood, however, is that only about 55% of carbon dioxide emissions from cement manufacture are due to fossil fuel combustion. About 45%, or almost half, of cement CO₂ emissions come from the raw materials used to make portland cement.

Cement is made by heating calcareous materials such as limestone, shells, marl, cement rock, or chalk, with smaller amounts of clay, shale, slate, or sand, to very high temperature in a rotary kiln. During the heating process, two distinct chemical reactions take place, calcination and clinkerization. Clinkerization is the final process where all the materials combine into a homogeneous substance (called clinker) which is then ground with gypsum to make the familiar gray power, cement. However, it is the process of calcination, which occurs in the kiln prior to clinkerization, that is most relevant to this discussion.

Calcination is the action through which carbon dioxide is driven off from limestone (calcium carbonate) and magnesium carbonate, leaving free lime and magnesia. The carbon dioxide is then vented with the exhaust gases. Calcination is a chemical reaction essential to cement manufacture. You cannot make cement without it.



Honorable Max Baucus

Page 2

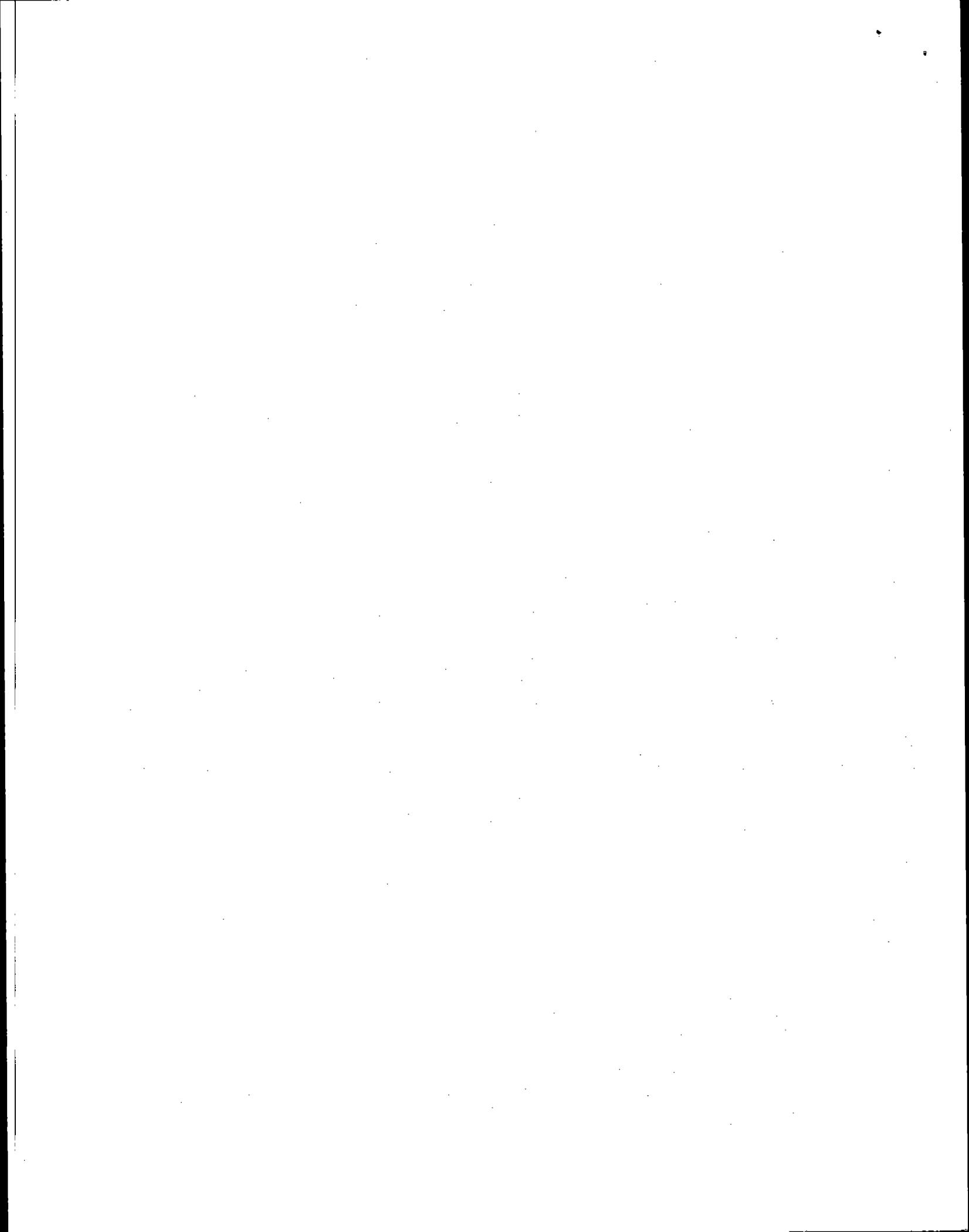
In a draft report on global climate change, the Environmental Protection Agency estimates that for every million tons of cement produced, approximately 0.137 million metric tons of CO₂ is emitted from calcining, and 0.165 million metric tons of CO₂ is produced from fossil fuel used for kiln firing and electricity. Therefore, virtually half the carbon dioxide emissions are not related to energy use and come from a chemical process for which there is, or can be, no substitute.

Your pending legislation, the "Global Environmental Protection Act of 1989", (S.676) would require a 25% reduction over 1988 levels in CO₂ emissions from cement kilns by the year 2000, if technologically feasible. I must tell you that this is impossible to do. Given that almost half the emissions are unrelated to fuel and also uncontrollable, you essentially are attempting to mandate a 50% reduction in CO₂ emissions from fuel alone. As there is no feasible way of recapturing CO₂ from exhaust gases, the 50% reduction would have to be met by a 50% increase in fuel efficiency, which is again an unattainable goal.

You should be aware of two things that have been, or are being, done in the cement industry to improve efficiency and reduce overall energy use and the resulting emissions. First, during the period 1972-1985, total energy consumption by cement producers decreased 40% in terms of British thermal units (Btus) and declined 25% in Btus per ton of output. The enclosed PCA Energy Report dated July, 1986 more fully discusses this reduction. This is a significant achievement. The growing use of preheaters and precalciners and other conservation technologies represents a very costly investment at a time when the U.S. industry faces increased competition. S.676 would give no credit for what has been a remarkable improvement in energy efficiency over the last fifteen years. Future technological improvements, as they come, will be more costly and slower to achieve.

Another factor which should be considered during these debates is the growing use of waste-derived fuels for energy recovery in the cement industry. Cement kilns, because of their high operating temperatures and long residence times of the gases, are an excellent media for waste destruction. In pending regulations, EPA has acknowledged the great service that kilns can provide in removing potentially hazardous materials from the environment. Kilns can easily meet the 99.99% destruction efficiency required, and, in some cases, have met a 99.9999% limit.

By using waste fuels, a number of goals are achieved. First, potentially harmful materials are destroyed. Second, and most important to this discussion, fossil fuels are replaced, thereby reducing overall emissions. If cement kilns weren't burning waste fuels, incinerators would be burning them in addition to the cement industry's continued use of 100% fossil fuel. Waste fuels, particularly liquids, also generally burn more cleanly than coal. Third, the cement industry can realize important cost savings in what is a very competitive world market.



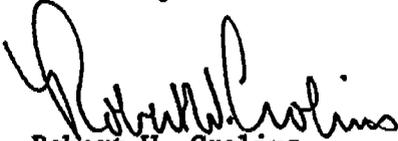
Honorable Max Baucus

Page 3

Clearly the cement industry has made giant strides over the last fifteen years to conserve energy and thereby reduce emissions of carbon dioxide and other pollutants. As energy requirements continue to be a major cost in cement production, you can be assured that additional steps will be taken to increase energy conservation in the coming years. However, to mandate a totally unrealistic reduction, especially without taking into account the significant efficiencies already attained and the ongoing efforts to utilize recycled materials, would be a disservice to an industry which has worked hard to be a positive contributor to efforts to enhance environmental quality.

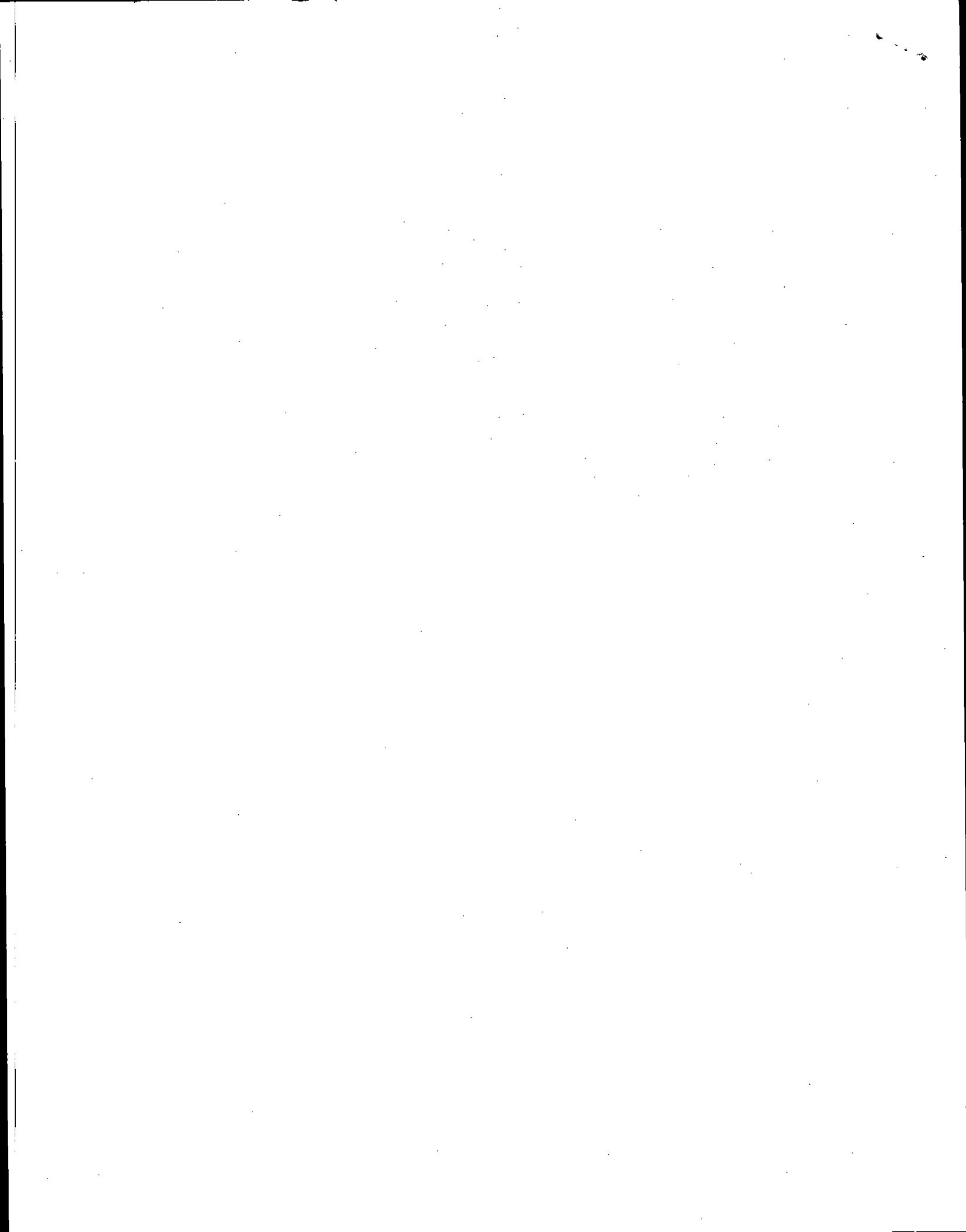
I want to pledge our full cooperation as the Senate moves to address these important issues. If we can provide any additional information or support, please call on us. The cement industry is committed to protection and clean up of the environment, but we urge you to pursue a program that is fair and reasonable, and, most importantly, achievable.

Sincerely,



Robert W. Crolius
Vice President
Washington Affairs

Enclosure





The Secretary of Energy
Washington, DC 20585
May 25, 1990

The Honorable John D. Dingell
Chairman
Committee on Energy and Commerce
U.S. House of Representatives
Washington, DC 20515

Dear Mr. ~~Chairman~~ John:

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James D. Watkins
Admiral, U.S. Navy (Retired)

Enclosure

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Committee on Energy and Commerce

The Honorable Philip R. Sharp
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Introduction

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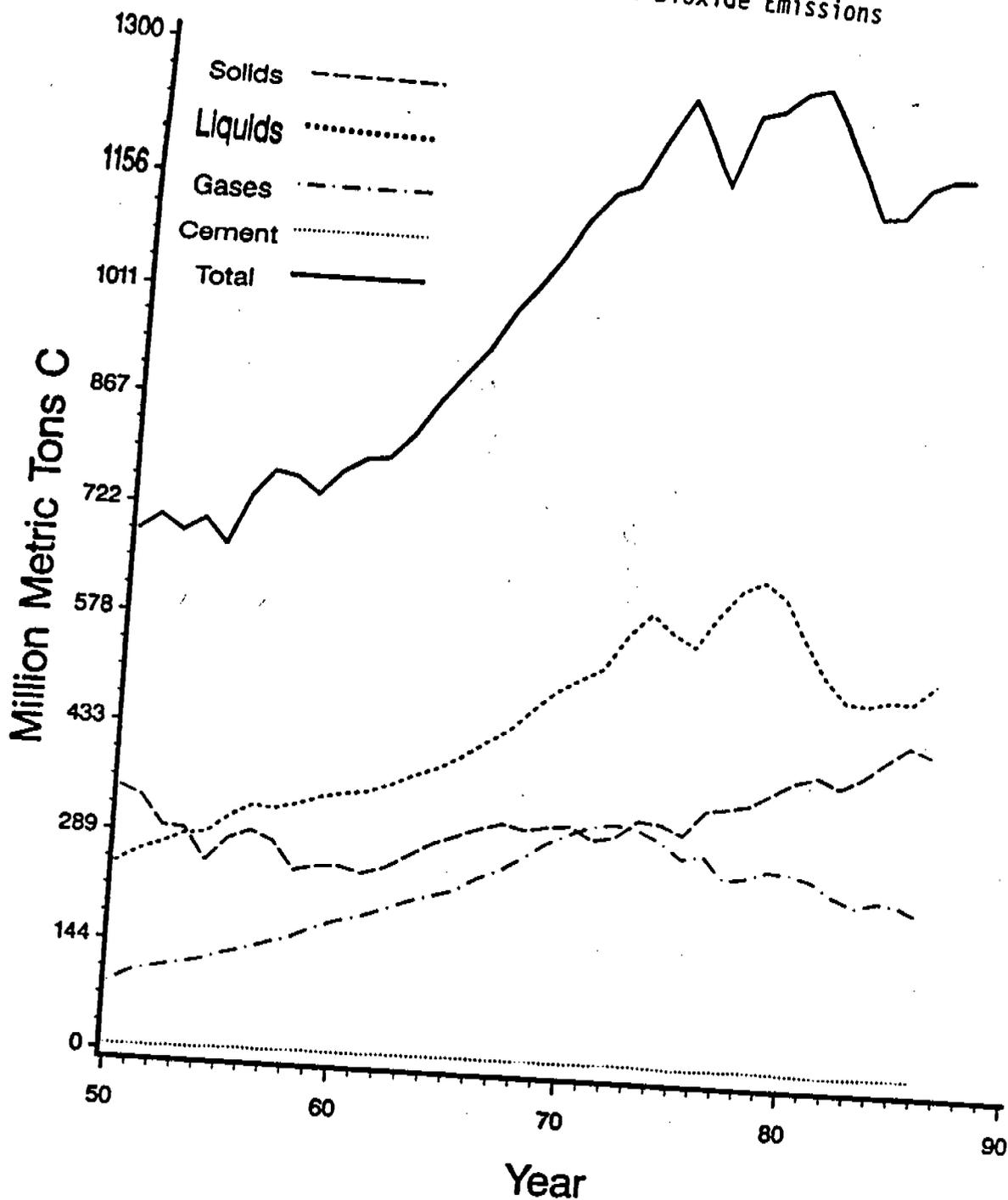
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Average for U.S. Wet Process Plants:	5.718 million BTU
Average for U.S. Dry Process Plants:	4.492 million BTU
Average for U.S. Dry Process Plants:	
Without Preheaters:	5.363 million BTU
With Preheaters:	4.061 million BTU

In 1988, this energy was provided by the following fuels in the following proportions in the average U.S. plant:

Coal and Coke:	76.1 percent
Natural Gas:	9.0 percent
Petroleum Products:	1.7 percent
Waste Fuels:	3.0 percent
Electricity:	10.2 percent

According to U.S. Environmental Protection Agency (EPA) estimates (3), the combustion of these fuels results in the following CO_2 releases per million BTU burned:

Coal:	233 lb
Natural Gas:	140 lb
Gasoline and Diesel:	170 lb
Liquefied Petroleum Gas:	171 lb
Electricity:	175 lb

Because of varying compositions, no data are readily available for CO_2 production from waste fuels, so the values for gasoline and diesel were assumed for these types of fuels.

Using the figures denoted above, the CO_2 released as a consequence of fossil fuel combustion during the production of 2000 lb of portland cement is estimated to be as follows:

3. Bartus, D. (U.S. Environmental Protection Agency), Effects of Fuel Ethanol Production and Use on CO₂ Production and Global Warning, Draft, June 1, 1989.
4. U.S. Environmental Protection Agency, Policy Options for Stabilizing Global Climate, Volume 2, Chapter VII, Draft Report to Congress, February 1989.
5. Steinberg, M., et al. (Brookhaven National Laboratory), A Systems Study for the Removal, Recovery and Disposal of Carbon Dioxide from Fossil Fuel Power Plants in the U.S., DOE/CH/00016-2, prepared for the U.S. Department of Energy, December 1984.

The Cement Industry and Global Climate Change: A Discussion

I. Introduction

As the sixth largest industrial user of energy and as a major consumer of fossil fuels, particularly coal, the portland cement industry has a significant stake in current debates over global climate change. Cement manufacturing is often mentioned as a major source of carbon dioxide which is considered to be a "greenhouse" gas. This paper discusses the cement manufacturing process; some of the unique industry problems that policymakers must understand; current and historical energy use patterns in the industry; pros and cons of suggested modifications to the process; and, regulatory and legislative initiatives to reduce CO₂ emissions.

II. The Cement Manufacturing Process

A. Raw Materials and Chemical Reactions

Cement is made by heating calcareous materials such as limestone, shells, marl, cement rock, or chalk, with smaller amounts of clay, shale, slate, or sand, to very high temperature in a rotary kiln. During the heating process, two distinct chemical reactions take place, calcination and clinkerization.

Calcination is the process through which carbon dioxide is liberated from the calcareous raw materials. The carbon dioxide is then vented to the atmosphere with other exhaust gases. Calcination is a chemical reaction essential to cement manufacture. It is prerequisite to clinkerization. Cement cannot be made without it.

Clinkerization is the final process in which the raw materials combine into a homogeneous substance called clinker. The clinker is then ground with gypsum to make the familiar gray powder known as cement.

B. Process Variations

Currently in the portland cement industry, four different processes are used to make cement. All accomplish the same necessary chemical reactions and all use the rotary kiln mentioned above.

Wet Process: Raw material is mixed in a slurry and pumped to the kiln. Better blending of raw mix and easy handling of materials are advantages, but the process is the most energy intensive as the water must be evaporated prior to calcination and clinkering.

Dry Process

Long Dry: Raw materials are fed to the kiln in a dry state. As in the wet process, long kilns are required for sufficient heating of raw materials. This is more energy efficient than wet process.

Preheater: Combustion exhaust gases from a dry kiln are passed through a series of cyclones, thereby transferring what would be wasted heat to raw materials prior to their entry into the kiln. Preheater technology is more energy efficient than long dry kilns.

Precalciner: Similar to preheater kilns but an additional combustion vessel is added at the bottom of the preheater tower and prior to the kiln. This is the most energy efficient process in the industry and is considered state-of-the-art.

III. Fuel Use in the U.S. Cement Industry

In 1972, 61% of the process fuel requirements of the U.S. cement industry were met with petroleum products and natural gas. With the oil embargo and a changing energy emphasis, this figure dropped to 7% in 1985. In that year, 92% of the process energy came from coal and coke¹. Natural gas and petroleum use had climbed to 11% by 1988². From 1972 to 1985, total energy consumption by cement producers decreased 40% in terms of British thermal units in part due to lower domestic production resulting from competition from imports. Energy consumption per ton of product has declined by 25%. Waste-derived fuels are now being used more extensively in the cement industry as well. This practice will be discussed in more detail later.

IV. Carbon Dioxide Emissions from Cement Manufacture

A critical factor in understanding carbon dioxide emissions from cement manufacture is that approximately 45% to 54% of the CO₂ comes from sources other than fossil fuel combustion.³ As mentioned earlier, an integral step in cement manufacture is calcination. As raw materials are heated (calcium carbonate, magnesium carbonate), the carbon dioxide is driven off, leaving free lime and magnesia. These are heated further with the other ingredients, eventually resulting in cement clinker. Calcination is an absolutely necessary step in the process which must take place regardless of the energy/heat source being utilized. Therefore, in discussing strategies for reducing carbon emissions from cement manufacture, it is important to understand that only that portion of the carbon emissions derived from fossil fuel combustion (45% to 54%) can be addressed under current or any foreseeable technology. All potential reductions must be derived from the roughly 50% of CO₂ emissions from the fuel. As an example, in practical terms a program which calls for a 20% reduction in CO₂ emissions from cement facilities must translate into a 40% reduction in CO₂ from the fuel combustion, as the CO₂ from the calcination of raw materials is unavoidable and irreducible.

V. Strategies for Carbon Dioxide Emissions Reduction

Presently there is no economical way to "scrub" or recapture CO₂ emissions at the stack in cement operations. Any future technology which would address CO₂ capture and control likely will be prohibitively costly. Two potential reduction strategies remain: (1) switching to fuels that produce less carbon dioxide, and (2) continued improvements in energy efficiency.

VI. Conversion to Natural Gas

At the end of 1989, Portland Cement Association data showed 114 cement plants operating in the United States. Ten plants listed natural gas as a primary fuel. An additional 54 plants listed natural gas as an alternative fuel. 50 plants apparently have no natural gas option available⁴.

If the 50 plants currently without natural gas were asked to convert to gas, actual on-site plant modifications would be minimal, largely requiring replacement of the burner and addition of necessary piping in the plant. However, the major capital cost would be the investment required to connect to a natural gas pipeline. As the cement industry is a regional industry with manufacturing facilities dispersed throughout the country -- some quite remote -- access to natural gas supplies would vary. In some cases, gas may be readily available. In other situations, the connection might require many miles of pipeline, resulting in very costly investment. In marginal operations, a mandated conversion to natural gas could conceivably result in a plant closure with the attendant lost capacity and jobs.

A Department of Energy study has suggested that switching to cleaner (but more expensive) fuels such as natural gas would reduce CO₂ emissions from fuel use by 33%⁵. While on the surface this may be appealing, it may not be economically or environmentally justifiable. As a "clean" burning fuel which emits lower rates of both carbon dioxide and sulfur dioxide, natural gas should be reserved for household use and use in industrial processes requiring the cleaner fuel. There simply is not enough natural gas for it to become the primary fuel of America. We must rely as well on our vast coal resources. The cement industry can burn coal easily. While coal combustion does emit carbon dioxide and sulfur dioxide, significant amounts of the sulfur are absorbed during cement manufacture and end up in the final product. If a utility were to burn the same coal, for example, emissions of sulfur dioxide would be higher per ton of coal burned.

A rational energy policy must therefore take into account a whole range of economic and environmental considerations. What fuel is best burned where? What is an appropriate fuel mix within the industrial sector, and what are reasonable trade-offs given limited supplies of certain fuels?

VII. Upgrading to Energy Efficient Technology

Another strategy for reducing carbon dioxide emissions would be to upgrade all less efficient manufacturing facilities to state-of-the-art, energy-efficient precalciner configuration. This approach would replace all existing wet and long-dry kilns. Existing preheater and precalciner operations would not be affected.

A. For the purposes of this discussion, the following facts are pertinent⁶:

- * 1989 cement clinker capacity in the U.S. was 81.5 million tons.
- * 41.5 million tons represents post-1971 preheater and precalciner capacity which would not be upgraded.
- * 26 million tons are wet process capacity.
- * 14.1 million tons are long-dry capacity.
- * 6.1 million tons are pre-1955 capacity (2.97 million wet, 3.14 long-dry.)

B. In a November 6, 1990 discussion with the Fuller Company, a builder of cement plants, the following cost estimates were provided.

- * Greenfield, new capacity using precalciner technology costs in the range of \$150-200 per annual ton of production, depending on the size and design of the proposed facility.
- * Upgrading of existing facilities (raw materials, materials storage, materials handling equipment remain in place) costs approximately 60% of a greenfield plant, or \$90-120 per annual ton of production.
- * A 100 ton per hour, 800,000 ton per year finish mill costs \$25 million.

C. In analyzing the possible impact on the industry of an across-the-board upgrading of facilities, the following assumptions are made:

- * All pre-1955 capacity (6.1 million tons) would be retired and replaced by 750,000 ton per year, greenfield precalciner plants.
- * All remaining wet and long-dry process capacity would be upgraded by the replacement of kilns and raw mills with 500,000 ton precalciners and roller mills.
- * Some smaller capacity plants would close. The increase in capacity of other plants would require the addition of 10 million tons of finish mill capacity by fifteen 100 Ton Per Hour (800,000 TPY) units.

D. The following table outlines the projected costs to upgrade to all precalciner technology given the aforementioned assumptions:

<u>Task</u>	<u>Projected Costs</u>
1. Greenfield replacement of pre-1955 capacity [6.1 million tons X (\$150-200)]	\$0.915-1.220 billion
2. Upgrading of post-1955 wet and long-dry capacity [35 million tons X (\$90-120)]	\$3.150-4.200 billion
3. Upgraded finish mill capacity	\$0.375 billion
4. Total projected upgrade cost	\$4.440 to 5.795 billion

E. An interesting comparison to the \$4.440-5.795 billion projected cost is found in the Bureau of Mines 1989 advance annual summary of cement activity⁷. It estimates that 1989 U.S. production of portland cement was 75.6 million tons, representing a value of \$3.7 billion. For analytical purposes only, assuming a profit of 5% of sales, it would require 24 to 30 years of cement industry profits to pay for the upgrading all plants to state-of-the-art.

IX. The Impact of Selected Energy Tax Proposals on Cement

A number of pending proposals would seek to decrease carbon emissions and increase energy efficiency through imposition of carbon or "Btu" taxes. These would severely impact the U.S. cement industry's ability to compete in world markets with relatively little environmental gain.

Current coal utilization in the industry for process combustion is approximately 11 million tons annually. Under a bill proposed by Rep. Pete Stark (D-CA), coal use could eventually be taxed at \$15/ton. This works out to a \$165 million bill to the cement industry. A \$35/ton tax would be \$385 million, and \$100/ton would cost cement \$1.1 billion dollars!

Assuming total conversion to natural gas [coal figured at 22.5 million Btu/ton and natural gas at 1000 Btu/cu.ft.], current coal use would be replaced by about 247.5 billion cubic feet of natural gas. At Mr. Stark's proposed tax of \$0.40 per thousand cubic feet, the cement industry would still pay a carbon tax of \$99 million while burning fuel with less carbon content.

A Btu-based tax could also be prohibitive. Assuming a conservative Btu utilization rate of 4.4 million Btus/ton, the 75.6 million tons of cement production in 1989 consumed 332.6 trillion Btus of energy.

X. The Trend Is Already Positive

While the debate continues and the issues become clarified, a number of positive trends can already be identified in the cement industry. First, energy efficiency is improving. Depending on economic factors, energy can account for approximately 20-35% of the cost of the product. As such, there is continuing and persistent pressure to reduce fuel consumption and thereby collaterally reducing corresponding emissions.

As stated previously, total relative energy consumption was reduced 40% in the period 1972-85, with a 25% reduction in Btus per ton of output⁹. Network Consulting estimates that carbon dioxide emissions from cement production have already been reduced by 17.2% since 1972¹⁰!

The use of waste-derived fuels in the cement industry as a replacement fuel is a second positive trend. As long as the Btu content is high, many waste streams can be used as fuel in cement kilns. The long residence times of the exhaust gases and the high temperatures (3200-3400°F) ensure proper destruction of the waste materials while recovering their energy value. In many cases, these fuels burn with less carbon dioxide emissions than coal. Since these fuels otherwise might have to be destroyed in other thermal devices such as commercial incinerators, additional carbon dioxide emissions are prevented. By using these waste fuels in cement manufacture, carbon emissions are not increased and can actually be reduced, depending on the material being used.

About one third of the 114 operating U.S. cement plants are at some stage of developing waste fuel capability; more will follow. In addition to hazardous waste-derived fuels such as spent solvents, cement plants are burning tires, agricultural wastes such as rice hulls and wood chips, and are experimenting with municipal waste and biomass.

Waste fuel use is a tremendous environmental benefit in itself while conserving fossil fuel. Any government action to address carbon or other emissions should encourage this emerging technology.

XI. Conclusion

The portland cement industry is admittedly a source of carbon dioxide emissions, as are a number of other critical industries. The issue is complex and not easily addressed. However, the following points should be emphasized:

- * The industry has made great improvements in energy efficiency in the last fifteen years. Modernization continues. As inefficient capacity is replaced, CO₂ emissions per ton of production will continue to decrease.

- * Cement manufacturers can be very flexible in determining fuel selection. While conversion to natural gas reduces CO₂ emissions, it seems imprudent to "waste" gas in a process that can so easily burn many other fuels.
- * Waste-derived fuel use is a growing practice in the industry which should be encouraged.
- * Cement demand will increase in the 1990's and beyond. Imports likely will increase to meet this demand, particularly if overly-restrictive environmental policies inhibit expansion of domestic production capacity. Cement will continue to be made, but outside the United States where the commitment to environmental quality is not as strong. This could result in a net negative impact on the global environment.
- * Portland cement concrete is a product which is absolutely essential to our economy. Our transportation network which moves goods and services depends on it. Concrete, despite the initial energy investment in the cement, is not an energy-intensive construction material, as are such other materials such as steel, glass, or plastic. It is durable and is demonstrated to contribute to increased gasoline mileage.

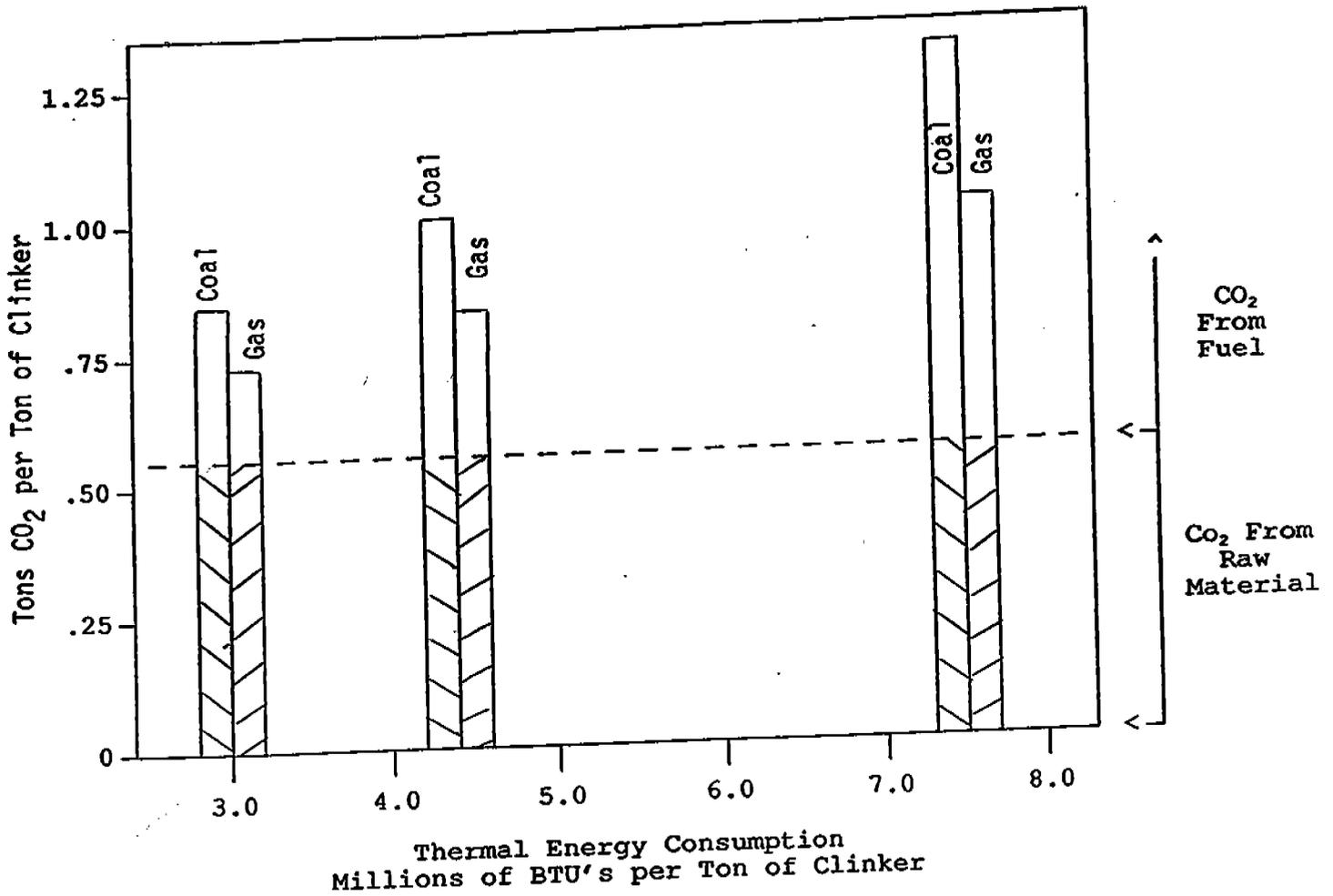
For additional information contact the Portland Cement Association
Washington Office, 1620 Eye St., N.W., Suite 520, Washington, DC 20006
(202) 293-4260.

FOOTNOTES

1. Energy Report U.S. Portland Cement Industry, Portland Cement Association, July 1986.
2. Carbon Dioxide Emissions from Portland Cement Manufacturing, Department of Energy, attachment to May 25, 1990 letter from Secretary of Energy Watkins to House Energy and Commerce Committee Chairman Dingell.
3. Study of Carbon Dioxide Emissions Related to the Metallurgical and Nonmetallic Mineral Processing, report prepared for the Bureau of Mines by Network Consulting, Inc., April 1990; Portland Cement Industry Approximate Carbon Dioxide Emissions Tons CO₂ Per Ton of Clinker, Walter L. Greer, Ash Grove Cement Company, November 1, 1990; Carbon Dioxide Emissions from Portland Cement Manufacturing, (see entry #2).
4. U.S. and Canadian Portland Cement Industry: Plant Information Summary, Portland Cement Association, December 31, 1989.
5. See entry #2.
6. See entry #4.
7. Cement in 1989, Advance Annual Summary, Bureau of Mines, Department of the Interior, July 25, 1990.
8. See entry # 7.
9. See entry # 1.
10. Study of Carbon Dioxide Emissions Related to the Metallurgical and Nonmetallic Mineral Processing (see entry #3).

Appendix I

**PORTLAND CEMENT PRODUCTION
APPROXIMATE CO₂ EMISSIONS
Tons CO₂ per Ton of Clinker**



Most Efficient <-----> Least Efficient
 Precalciners-----Preheaters-----Long Dry Kilns-----Wet Kilns

Source: See Appendix II

ASH GROVE CEMENT COMPANY

8900 INDIAN CREEK PARKWAY, SUITE 600, P. O. BOX 25900
OVERLAND PARK, KANSAS 66225

(913) 451-8900

11/1/90

WALTER L. GREER
VICE PRESIDENT-ENVIRONMENTAL AFFAIRS

PORTLAND CEMENT INDUSTRY *APPROXIMATE CARBON DIOXIDE EMISSIONS TONS CO₂ PER TON OF CLINKER

		<u>Energy Consumption (million BTUs/Ton)</u>		
		<u>Low</u>	<u>Average</u>	<u>High</u>
		3.0	4.4	7.5
Coal Burning				
From Raw Material (Tons)		0.54	0.54	0.54
	(%)	64	54	41
From Fuel (Tons)		0.31	0.46	0.78
	(%)	36	46	59
Total (Tons)		0.85	1.00	1.32
	(%)	100	100	100
Gas Burning				
From Raw Material (Tons)		0.54	0.54	0.54
	(%)	74	66	55
From Fuel (Tons)		0.19	0.28	0.48
	(%)	26	34	45
Total (Tons)		0.73	0.82	1.02
	(%)	100	100	100

*Assumes no dust removal from the kiln system. Emission rates could increase by 5-10%, depending on the amount and chemical state of the dust that is removed.

Approximately 0.955 tons of clinker are required to make one ton of cement. To obtain the approximate, **maximum**, carbon dioxide emissions from the U.S. cement industry, multiply the annual cement production by 0.955 and by the 1.0 Tons of CO₂/Ton of Clinker industry average emissions on coal. Currently about three-fourths of the thermal energy for the industry is supplied by coal. The balance is from natural gas and supplemental fuels.

Example: 1990 estimated cement production = 80 million tons.

$$80,000,000 \times 0.955 \times 1.0 = 76,400,000 \text{ tons of CO}_2$$

FC → MK ✓
FC → JSF ✓

c.c. Directors
General Managers

THE CEMENT INDUSTRY FEDERATION LIMITED
INCORPORATED IN THE ACT

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Management Committee Paper No 2/1991
Amended March 1991

CEMENT AND CONCRETE AND THE GREENHOUSE EFFECT

1 Introduction

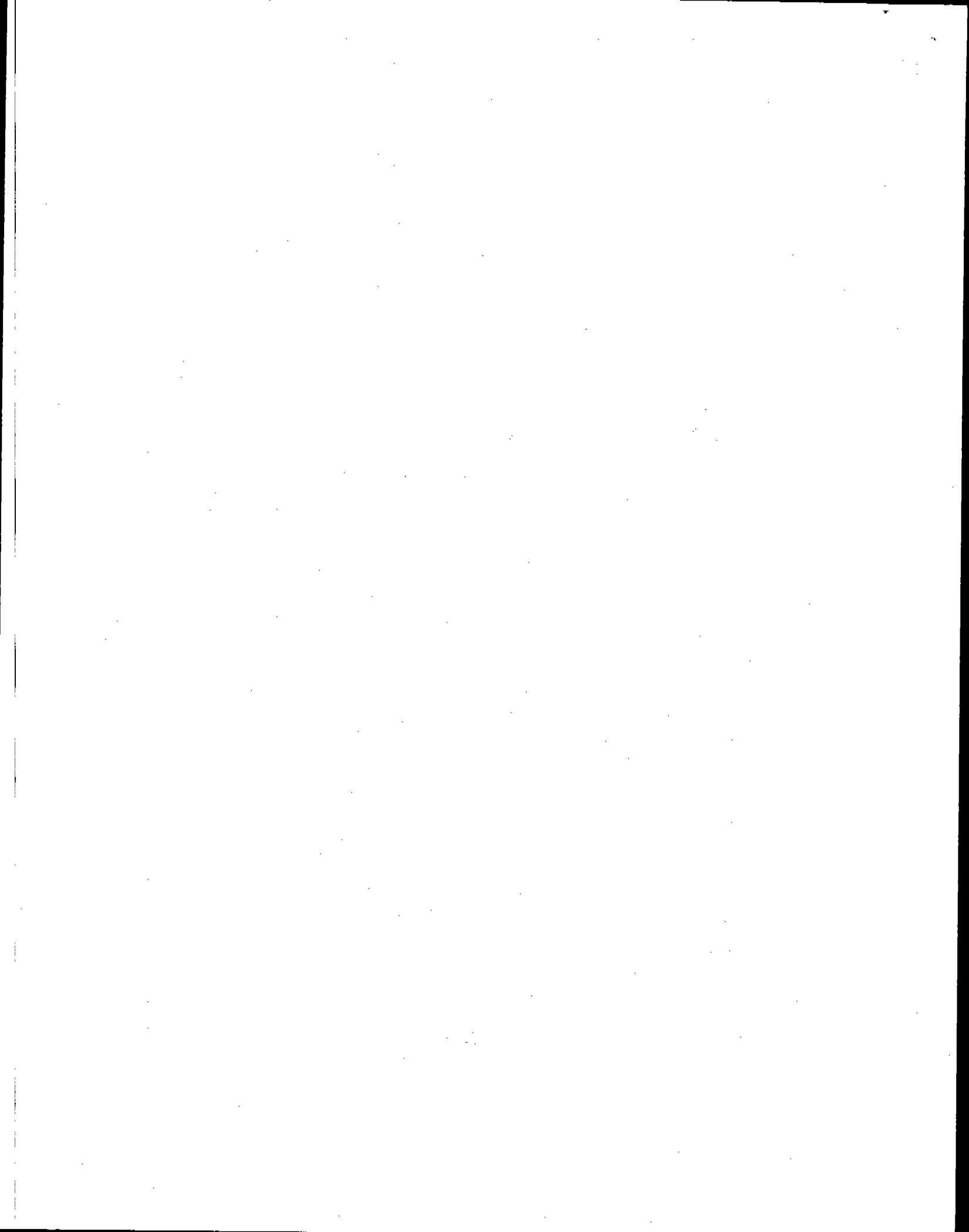
The term 'Greenhouse effect' with its prediction of wide change to the world's climate and present lifeforms and lifestyles has caught the public's imagination. A number of activities and processes contribute to the emission of greenhouse gases. These range from animal emissions to manufacturing processes. Among these activities energy production is a major source of CO₂ emissions. In buildings, the amount of energy we use is affected by the materials we build with, the type of buildings we construct and most importantly, the on-going energy requirements of the buildings as people live and work in them.

At the outset it is desirable to see the contribution of cement and concrete in the context of overall energy demand in the world and in Australia. This aspect is addressed in the following section. The paper goes on to address those areas where cement and concrete have an effect: manufacture of cement; building with concrete; and the ongoing energy requirements of buildings.

The concern about the Greenhouse effect has lead to planning and commitment by Governments throughout the world to reduce CO₂ emissions. For example, the Australian Federal Government has adopted an interim planning target to reduce emissions of greenhouse gases, eg CO₂, methane, nitrous oxide, excluding ozone depleting gases, by 20% from 1988 levels by the year 2005 (1). That is the amount of greenhouse gas emissions in 2005 are to be 80% of that in 1988. This will be made more difficult by the fact that energy demand is expected to rise over this period (2).

However, in developing a response strategy it must be remembered that "we will need to ensure that the implementation of options does not result in a decrease in Australian industrial activity which is taken up overseas, with no overall reduction in global greenhouse gas emissions" (3).

The Australian Minerals and Energy Council (4) notes that to reduce the forecast growth of CO₂ emission will require government interaction and changes in lifestyle. They also comment that "Australia's ability to implement costly measures to reduce emissions and adapt to any climate change will clearly be linked to the strength of our economy".



2 CO₂ Emission - A Global and Australian Overview

A number of gases, eg carbon dioxide (CO₂), methane (CH₄), chlorofluorocarbons (CFC's) and nitrous oxide (N₂O), contribute to the greenhouse effect. The most abundant of these is CO₂.

Generally the effect of these other gases is converted into the effect of an equivalent mass of CO₂, so that there is a common base for any comparison. For example, the relative greenhouse contribution of one molecule of CFC is equivalent to that of 25,000 molecules of CO₂. Thus the reason for urgency in phasing out CFC's.

The Australian Government policy is to phase out CFCs and halons by 1997 and this is the reason for excluding them from the equation for greenhouse gas emission.

Figure 1 gives a comparison of the estimates of CO₂ emission from fossil fuel combustion in 1987 for various countries.

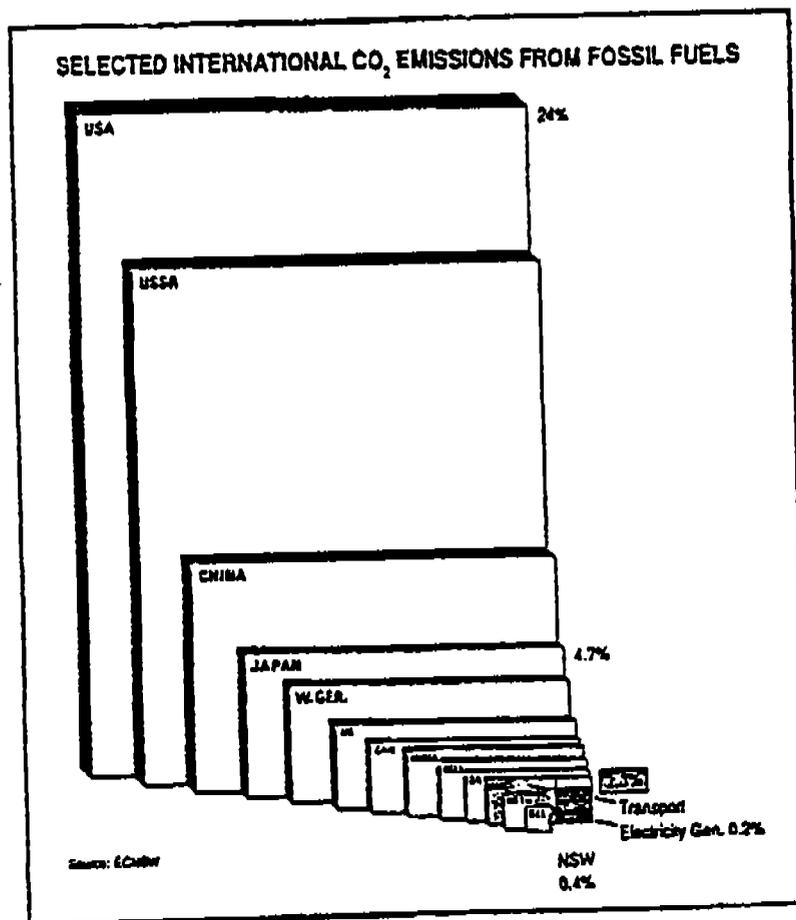
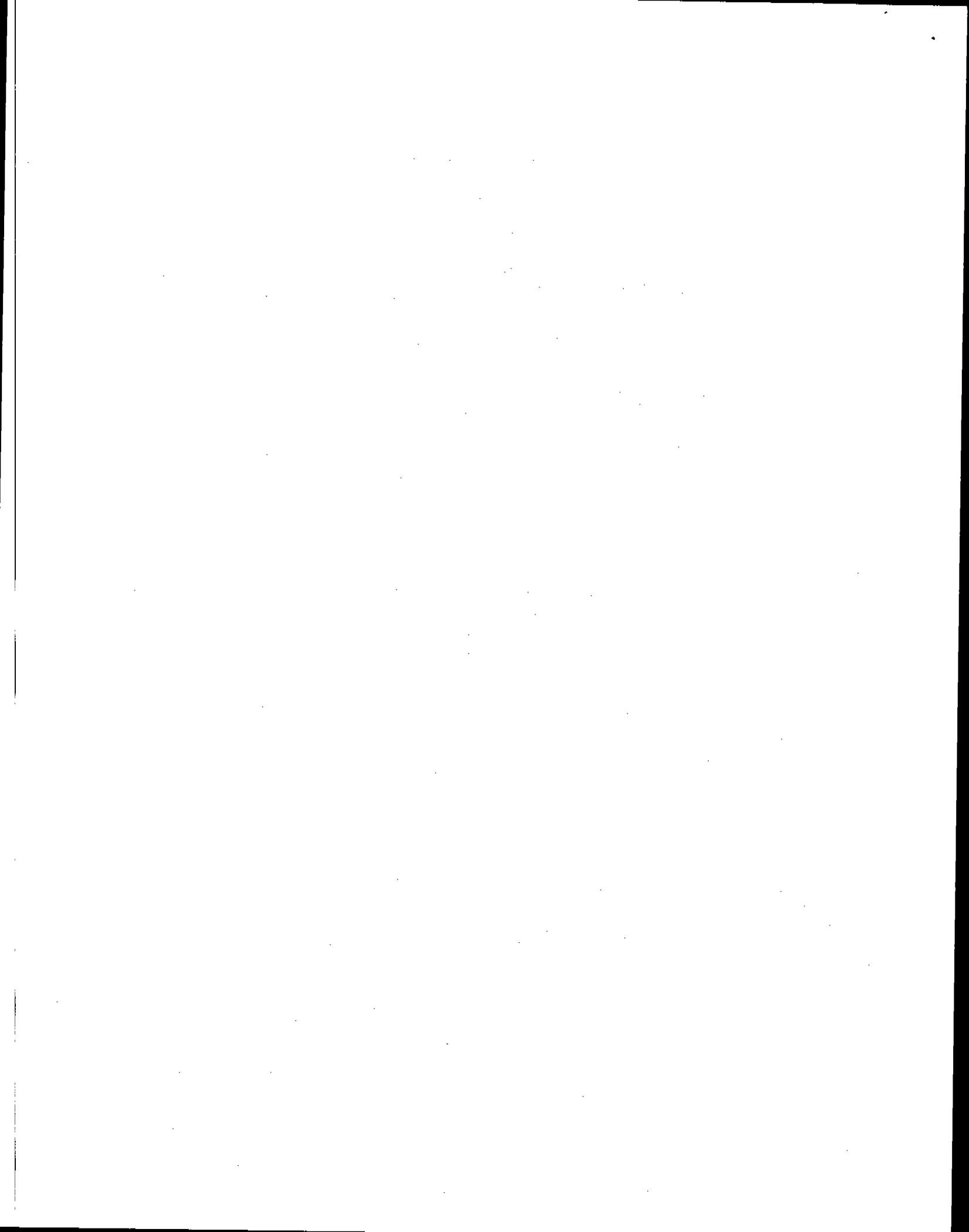


Figure 1 Selected international CO₂ Emission from Fossil Fuels (5)



Australia's contribution to global carbon dioxide emission from fossil fuels is about 1.3%. This figure is small when compared with countries such as USA, USSR and China. It also shows that action to reduce carbon dioxide will be effective only if taken by all countries particularly by the large CO₂ producers (US, USSR and China). Any independent action taken by a smaller country such as Australia, would be very limited in effect. Nevertheless, it would indicate that particular government's and communities' commitment to reducing CO₂ emission.

However Australia has the fifth highest per capita emission rate in the world. This should not be equated solely with high individual use of electricity in the home. Transport, energy-intensive industries and heavy reliance on coal to generate electricity are contributing factors.

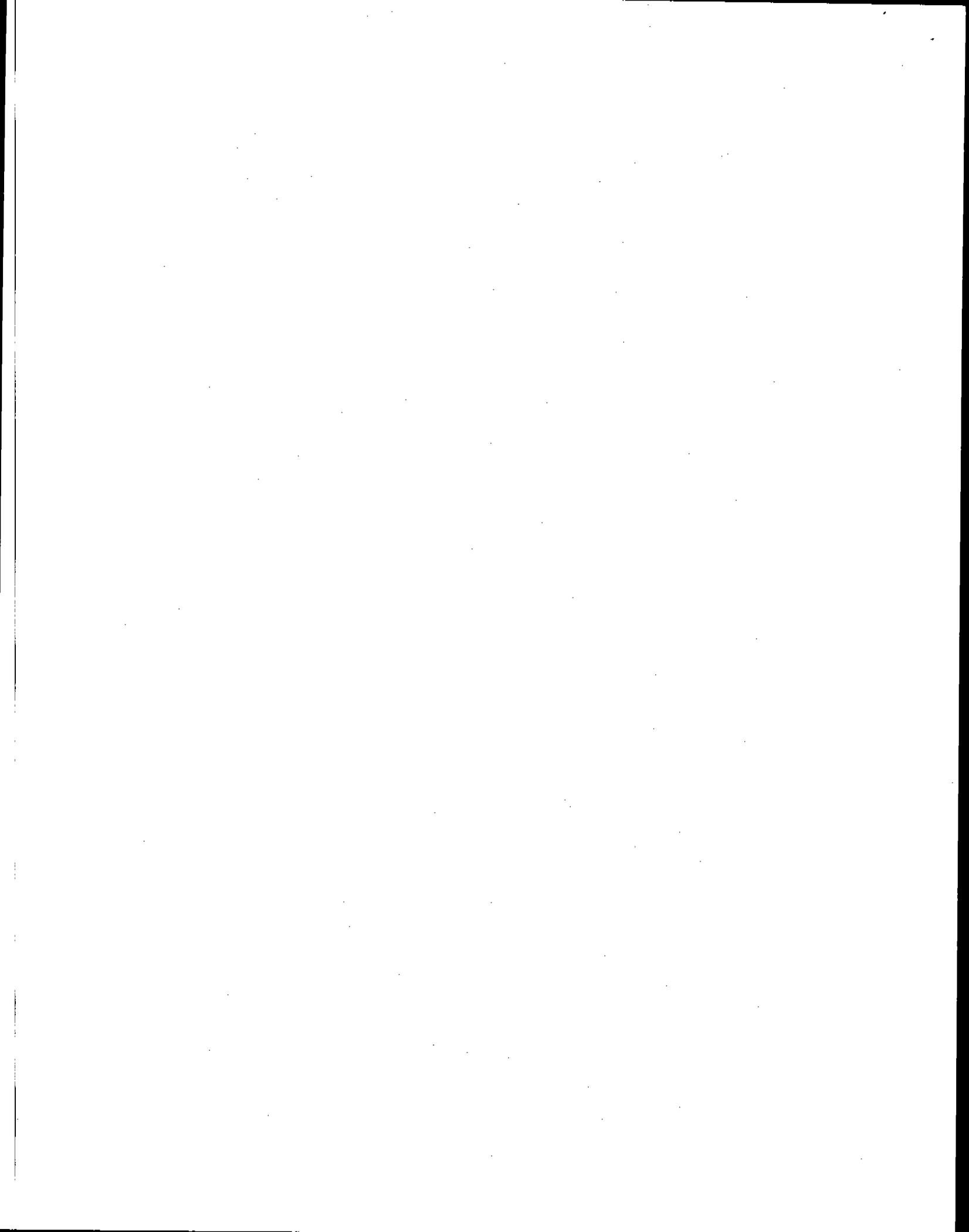
Looking now, just at Australia, the relative contribution of the cement industry can be gauged from Table 1.

Table 1 CO₂ emission in Australia from all sources (adapted from Ref 3)

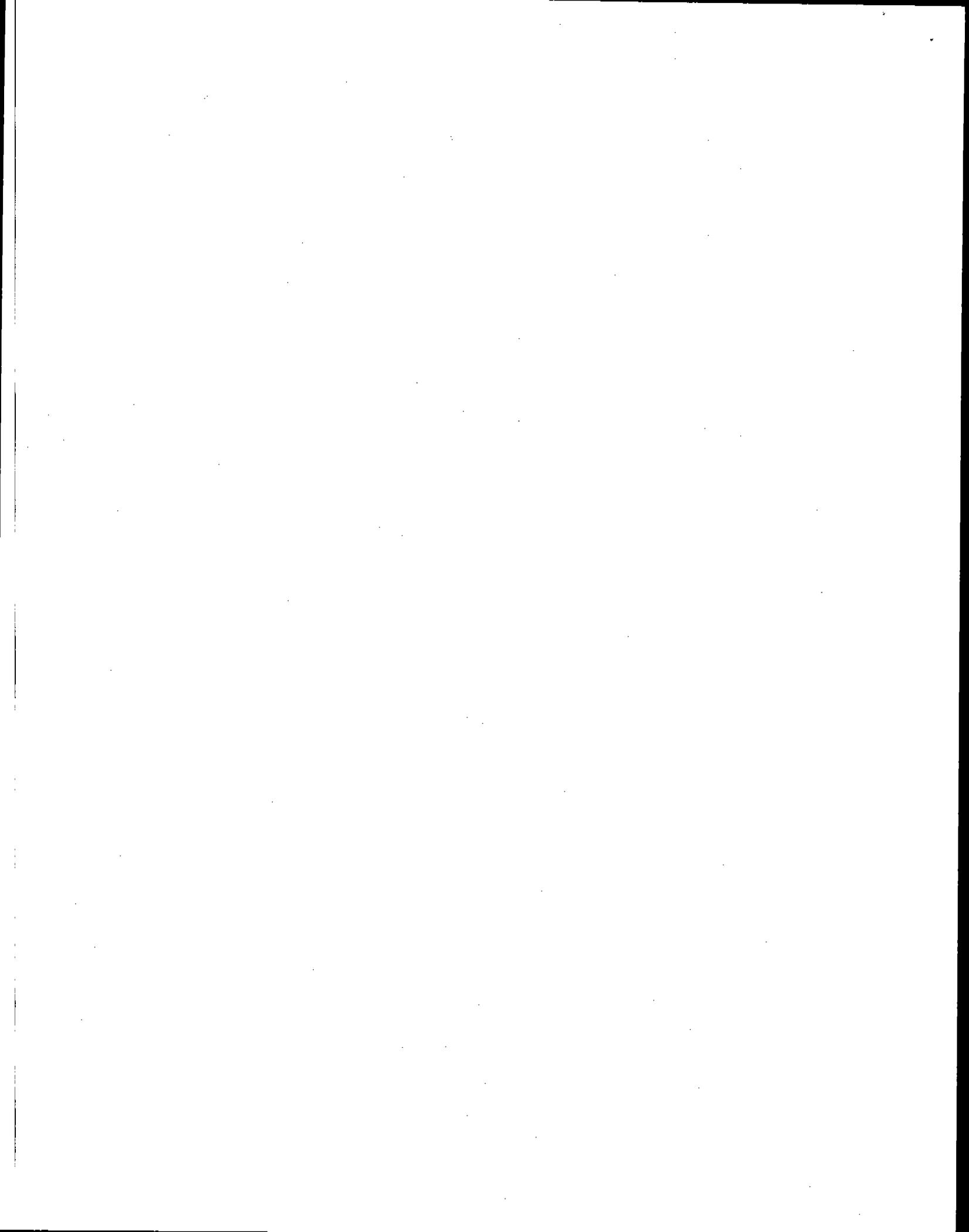
Source	CO ₂ Million Tonnes	Approximate Percentage
Road Transport	55.6	19
Residential	40.7	14
Iron and Steel	35.1	12
Non-ferrous metals	31.7	11
Chemicals	24.8	9
Mining	13.6	5
Non-metallic minerals	8.3	3
Wholesale/retail	8.3	3
Air transport	7.2	3
Cement production*	7.0	2
Food, Beverages, Tobacco	6.6	2
Paper and paper products	6.0	2
Agriculture, fishing and forestry	5.5	2
Other industry	5.0	2
Community Services	4.9	2
Water transport	4.3	2
Cement-based and Concrete Products	4.0	1
Others	21.4	7

* Based on an average figure of 1 tonne CO₂ per tonne of cement (see Section 3)

Producing energy is a major source of CO₂ emission for example electricity from a coal-burning power station. A single conversion factor for a unit of energy (GJ) to tonnes of CO₂ is difficult to arrive at, as this will vary with the source of energy. For example hydro-electric power releases only small amounts of CO₂ due to ancillary processes. Table 2 lists the conversion factors for various sources of energy from overseas and Australian data.



MCP 2/10



For the purpose of this paper an average value of 0.11 tonnes CO₂ per GJ of energy has been adopted.

Table 2 Emissions of CO₂ for Unit of Energy

Source	Emission Coefficient (tCO ₂ /GJ)	
	Overseas	Australia (for all States)
Black Coal	0.086	0.093
Brown Coal	0.086	0.093
Coke	-	0.188
Electricity	-	0.300*
Natural Gas	0.052	0.064
Petroleum products	0.068	0.071
LPG	-	0.061
Wood	0.113	0.096
Bagasse	0.191	0.099

* excludes Tasmania

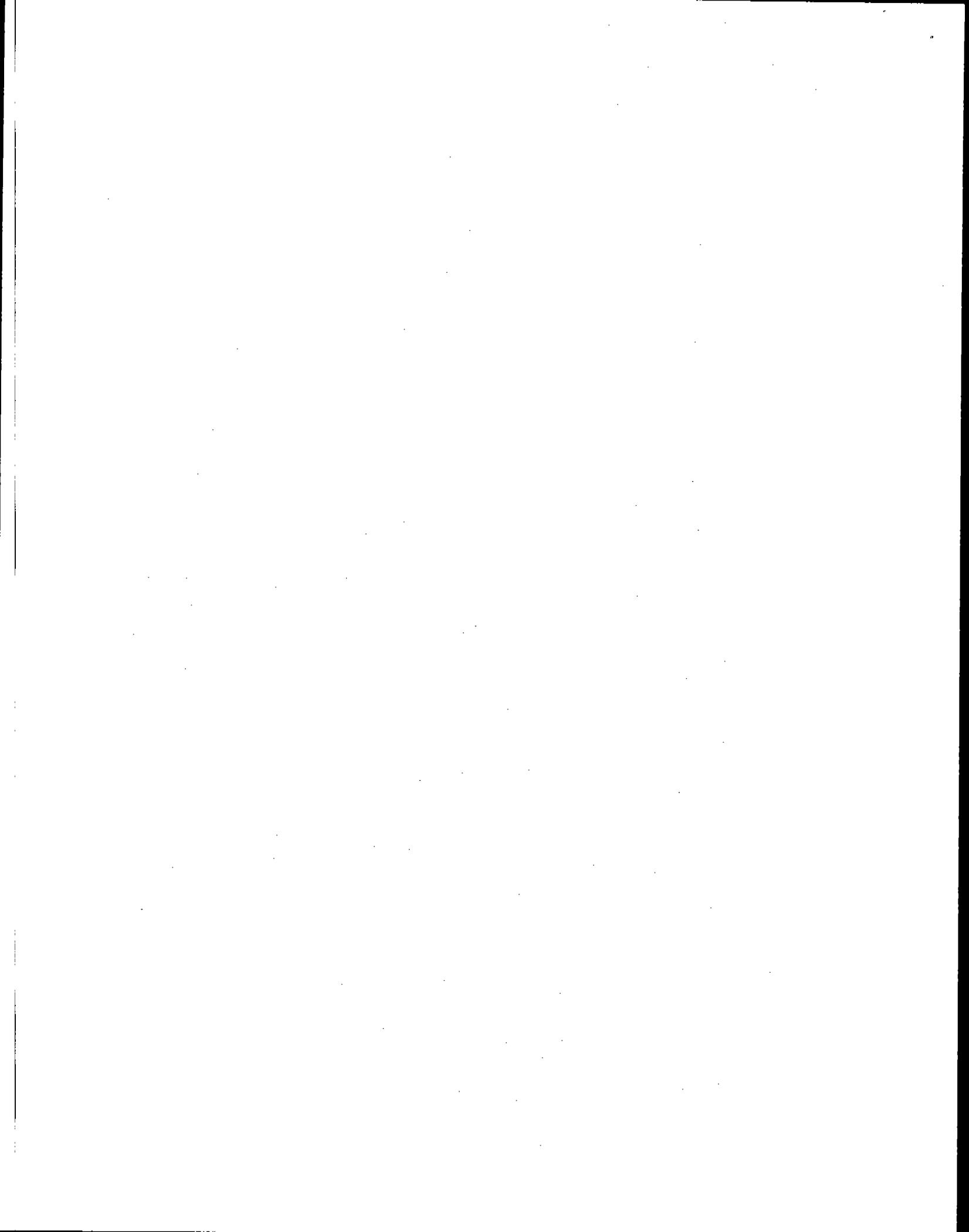
3 The Contribution of the Cement Industry

Figures supplied by Member Companies indicated that the total CO₂ emissions generated, including those from external power generation, range from 800 to 1400kg CO₂/tonne of cement. An average figure of 1 tonne of CO₂ per tonne of cement seems reasonable, which gives about 7 million tonnes of CO₂ for the cement industry. (This is the figure which was used to modify the figures in Reference 3 to give Table 1). The value of 1 tonne of CO₂ per tonne of cement is also that adopted by CEMBUREAU.

The relative contribution of the cement industry for the total CO₂ emissions in Australia is approximately 2%. This is about one fifth of that produced by the iron and steel industry, one eighth of that by road transport and one seventh of that by residential requirements.

Nevertheless, despite its small contribution to the overall generation of CO₂, the cement industry is actively pursuing strategies and adopting measures to reduce its energy demand and become more energy efficient. These measures include: the transition from wet to dry process, improving production techniques, eg the use of suspension preheater kilns, and the use of natural gas rather than coal.

Apart from minimising the CO₂ emissions from the production of portland cement, the cement industry actively promotes the use of by-products from other industries such as fly ash, granulated iron blast-furnace slag and silica fume. If the contribution of these materials is discounted, then the energy requirements of blended cement typically, fall within the range of 60 to 80 % of the figure 1 tonne of CO₂ per tonne of cement.



Thus the cement industry is playing its part in the general government strategy of reducing CO₂ emissions by:

- recycling and reducing demand for energy;
- improved industrial processing technology;
- use of renewable energy technologies or sources of energy with less CO₂ emission;
- use of waste products from other industries.

4 The Role of Cement and Concrete Products in Building Construction

Having reviewed the contribution of the cement manufacturing industry to the production of greenhouse gases the relative contribution of concrete-based members in building construction is now examined. This is usually done in energy terms and allows the relative efficiency of various forms of construction to be evaluated. (It must be stated that considerable variation occurs in the base figures. This is due to the differing bases used to evaluate the energy required for production and the range of product covered by a simple generic term, eg concrete may range from 1.3 to 2.2 GJ/m³ (6)).

Apart from the variation in the base figures for materials the choice of member type and form of construction is governed by a number of other factors, eg durability, fire resistance, maintenance and aesthetics. These make any simple calculation somewhat meaningless and possibly misleading.

With these reservations Munn (6) has shown that the energy requirement for concrete is largely determined by the energy requirement of the cement, which contributes between 45 to 80 % of the energy demand for a cubic metre of concrete delivered to the job site. He also noted that "the mix designer, in achieving maximum economy in concrete, is simultaneously optimising energy demand". The energy demand of typical mixes to produce N25 concrete using different binders is given in Tables 3 to 6.

Note that in these Tables the energy component for fly ash and slag is based on the energy requirements to process these materials after production/collection as a by-product.

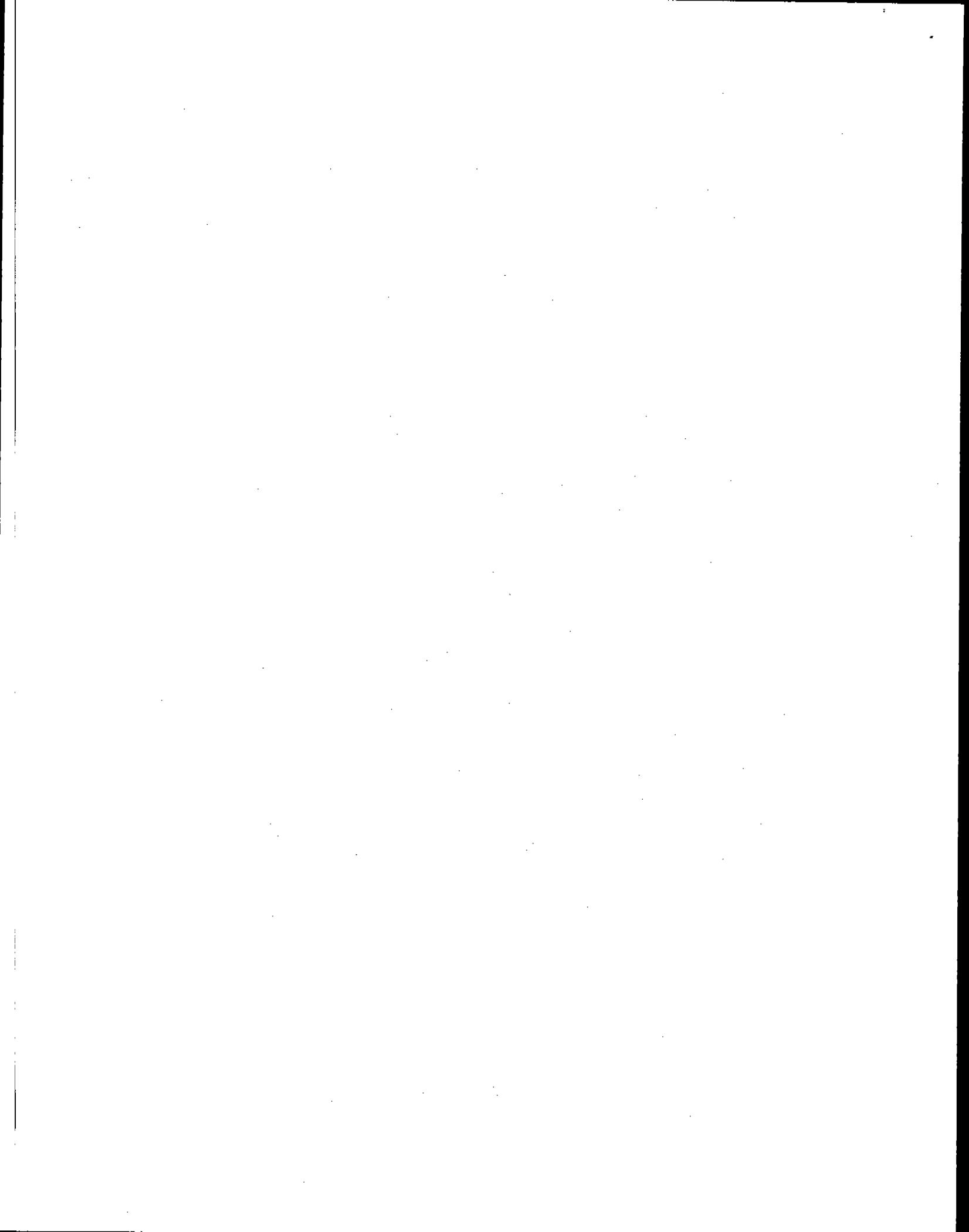


Table 3 Energy component for portland cement concrete

Material	Energy (GJ/tonne)	Mix Weight (kg/m ³)	Energy (GJ/m ³)
Cement	(4.5 - 7.1) ⁽⁷⁾ 5.7	300	1.71
Fly ash	0.26	-	-
Slag	0.8	-	-
Coarse aggregate	0.13	1000	0.13
Fine aggregate	0.07	900	0.06
Water and chemical admixtures	na	180	negligible
	Materials total		1.90
	Manufacture		0.08
	Delivery		0.12
	Total		<u>2.10 (0.23t CO₂)</u>

Table 4 Energy requirement for portland cement fly ash concrete (75:25)

Material	Energy (GJ/tonne)	Mix Weight (kg/m ³)	Energy (GJ/m ³)
Cement	(4.5 - 7.1) ⁽⁷⁾ 5.7	250	1.43
Fly ash	0.26	80	0.02
Slag	0.8	-	-
Coarse aggregate	0.13	1000	0.13
Fine aggregate	0.07	850	0.06
Water and chemical admixtures	na	180	negligible
	Materials total		1.64
	Manufacture		0.08
	Delivery		0.12
	Total		<u>1.84 (0.20t CO₂)</u>

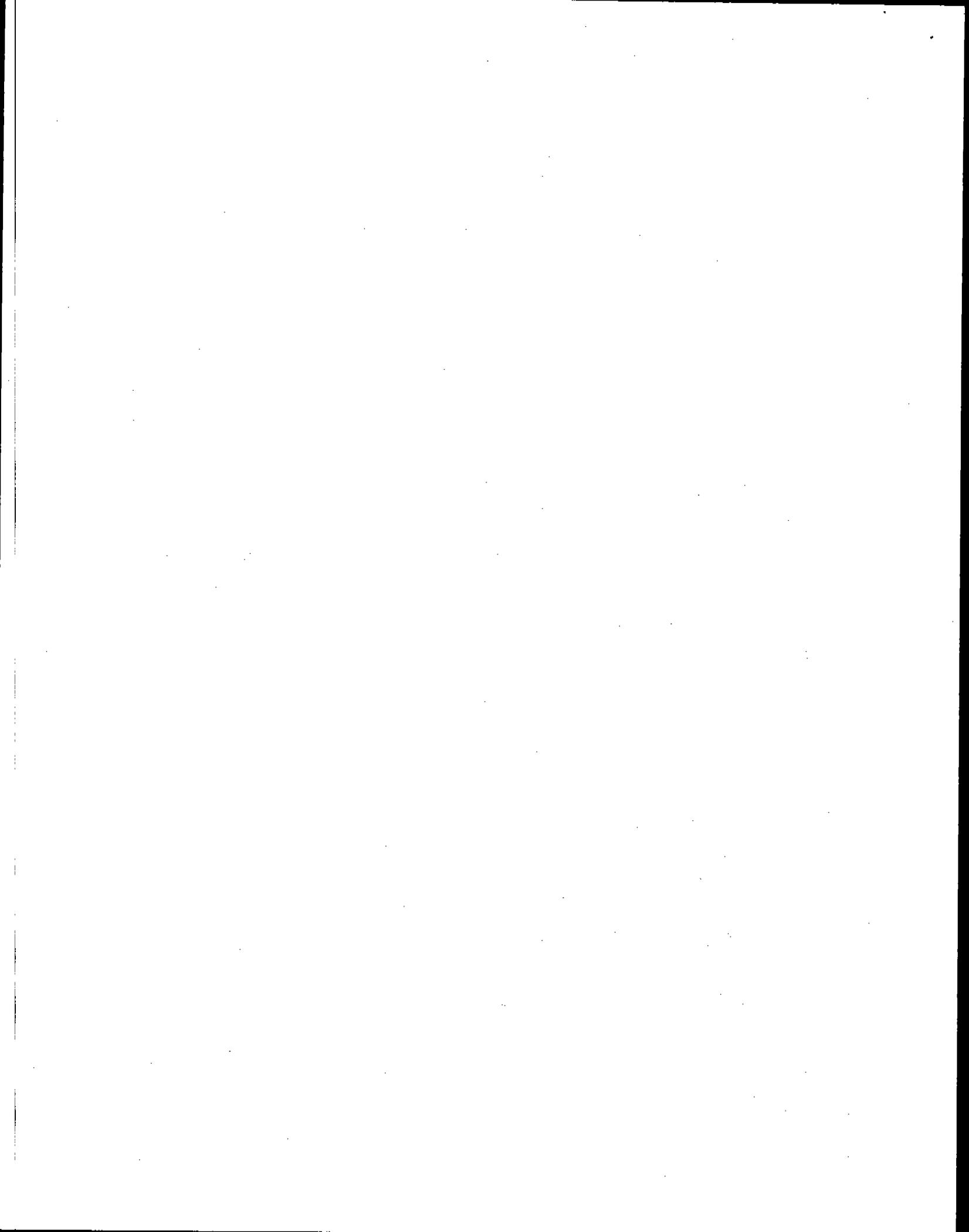
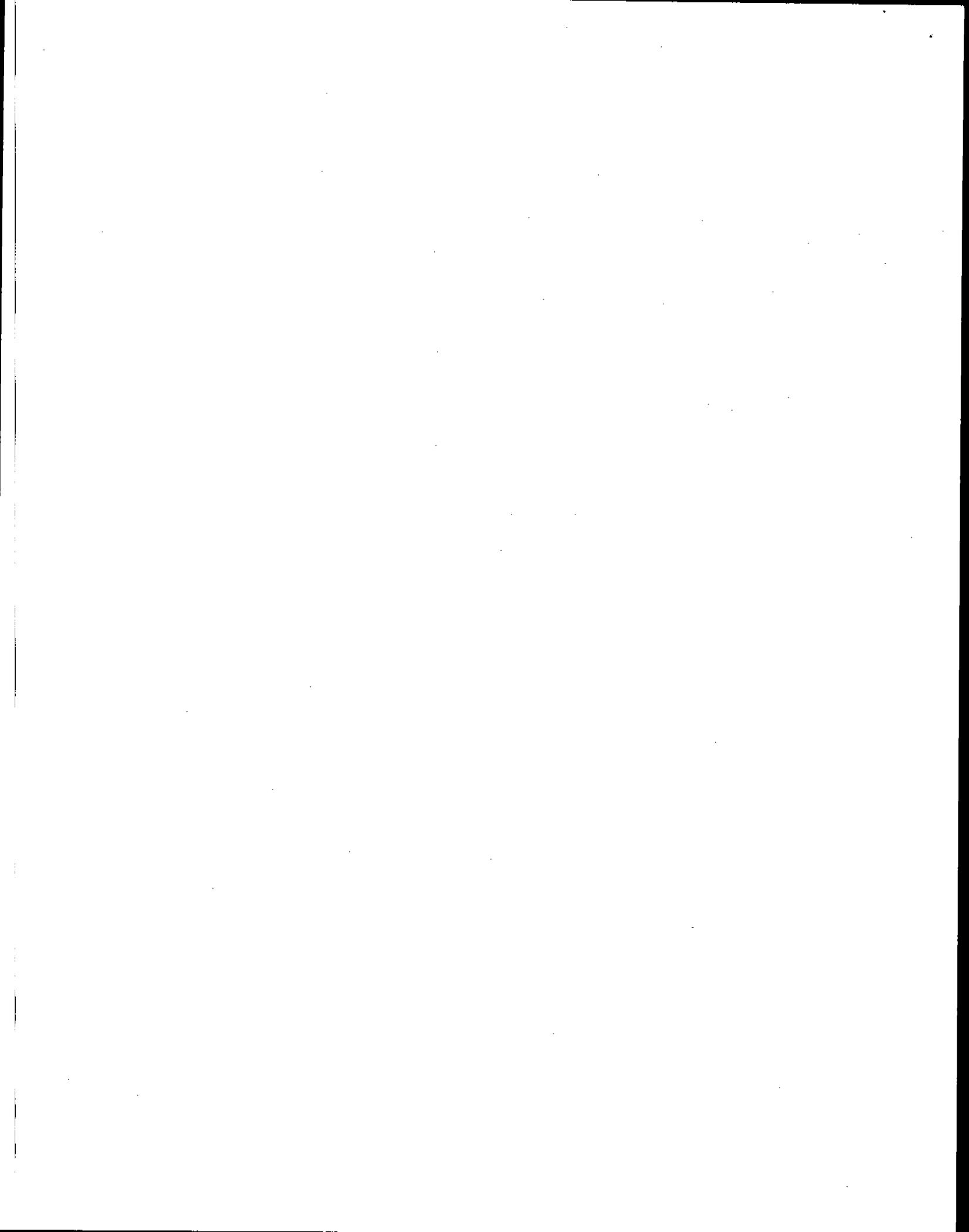


Table 5 Energy requirement for portland cement slag concrete (65:35)

Material	Energy (GJ/tonne)	Mix Weight (kg/m ³)	Energy (GJ/m ³)
Cement	(4.5 - 7.1) ⁽⁷⁾ 5.7	195	1.11
Fly ash	0.26	-	-
Slag	0.8	105	0.08
Coarse aggregate	0.13	1000	0.13
Fine aggregate	0.07	900	0.06
Water and chemical admixtures	na	180	negligible
	Materials total		1.38
	Manufacture		0.08
	Delivery		0.12
	Total		<u>1.58 (0.17t CO₂)</u>

Table 6 Energy requirement for portland cement, fly ash, slag concrete (50:24:26)

Material	Energy (GJ/tonne)	Mix Weight (kg/m ³)	Energy (GJ/m ³)
Cement	(4.5 - 7.1) ⁽⁷⁾ 5.7	163	0.93
Fly ash	0.26	80	0.02
Slag	0.8	87	0.06
Coarse aggregate	0.13	1000	0.13
Fine aggregate	0.07	850	0.06
Water and chemical admixtures	na	180	negligible
	Materials total		1.20
	Manufacture		0.08
	Delivery		0.12
	Total		<u>1.40 (0.15t CO₂)</u>



In terms of simple building elements Beijer (8) has shown that for a column/wall one metre high to carry a 1000 tonne load constructed of various materials the relative energy requirements are steel 100%, clay masonry 66% and concrete 16%. He notes that as concrete is so far superior, consideration of buckling will scarcely change the result. In a comparison of beams it is shown that for simple beams in span range of 5 to 20 m, concrete beams require only about 50% of the energy of the steel alternative.

In terms of building structure a steel frame is clearly uneconomic in energy terms. A study by Haseltine (9) has shown that compared to a concrete-framed structure a steel-framed one required between 130 and 137 % more energy. This variation arises from the type of internal subdivision/walling used and the external claddings. The paper indicates the energy requirement for the total buildings is largely controlled by that of the basic structure. Claddings examined included brick facades (least energy requirement) and precast concrete (highest energy requirement). Aluminium windows are far more energy expensive than timber windows. Surprisingly it was shown that the difference between aluminium, glass curtain walling and precast concrete incorporating aluminium windows was relatively insignificant. An unwindowed precast facade had the highest energy requirement.

There is no similar study on the energy requirements for detached dwellings.

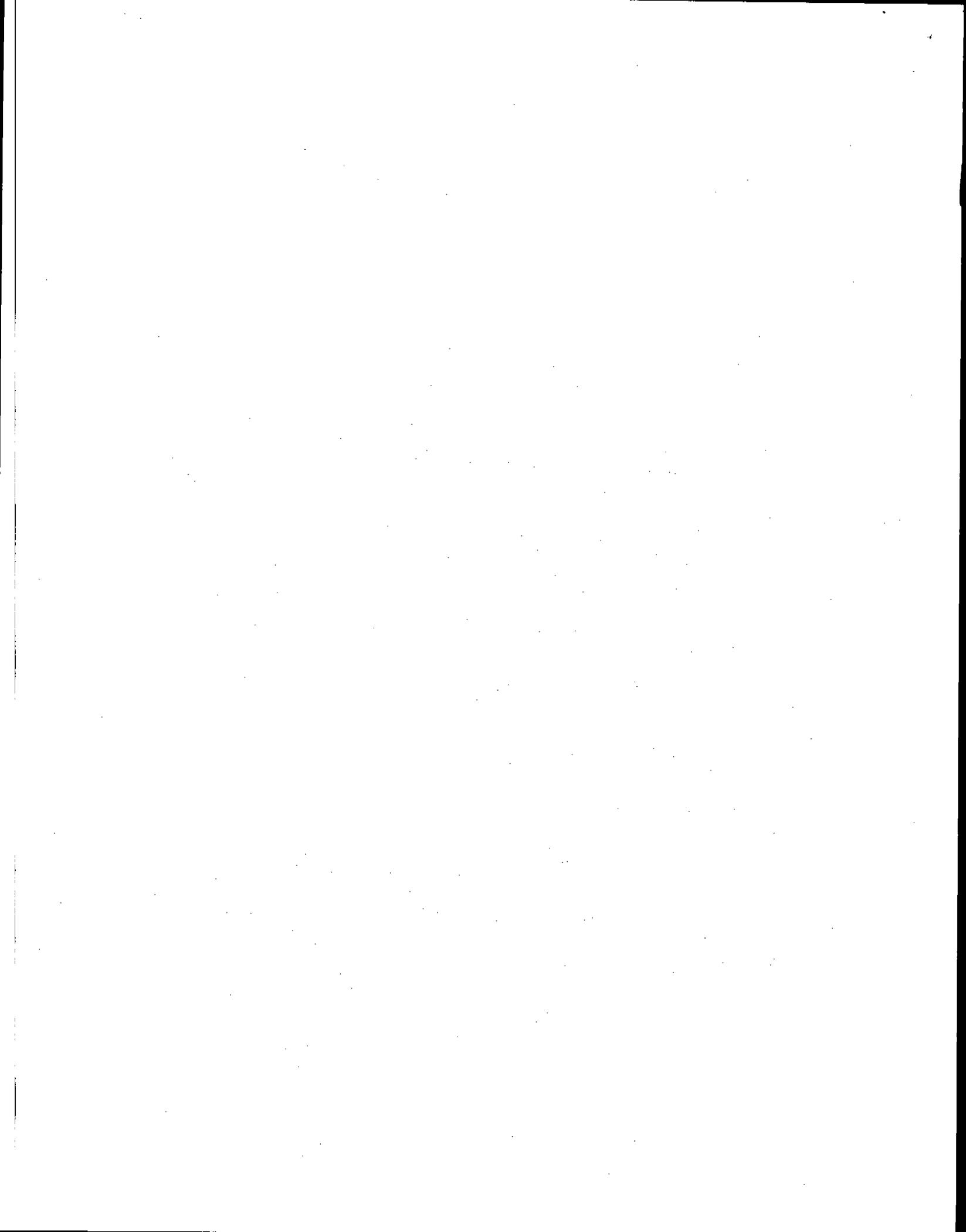
The same trend for building structures is true for bridges. A comparison for a 35-metre span bridge in Japan (10) showed the steel alternative at 200% of the prestressed concrete structure.

5 The On-going Energy Requirements of Buildings

As shown in Table 1, the contribution of the residential sector of CO₂ emission ranks second to that of road transport.

The energy consumption is also high accounting for some 12% of all the energy demand in Australia (3). This is expended in appliances such as electric ranges, refrigerators and lighting.

Depending on location a significant proportion of this energy is also expended on heating or cooling the house in winter and summer. The Victorian government has made substantial headway in promulgating requirements for new houses to incorporate insulation in floors, ceilings and walls. This can be justified in economic terms showing that the increased cost of providing insulation can be paid back within four years (11).



Providing a concrete slab-on-ground floor also improves the thermal performance of the home. For example for an uninsulated house in Victoria a slab-on-ground floor provides a 10% benefit over a timber floor. When the house is insulated this saving falls to 5%, a still not insignificant figure as the initial cost is also lower. This is illustrated in Figure 2.

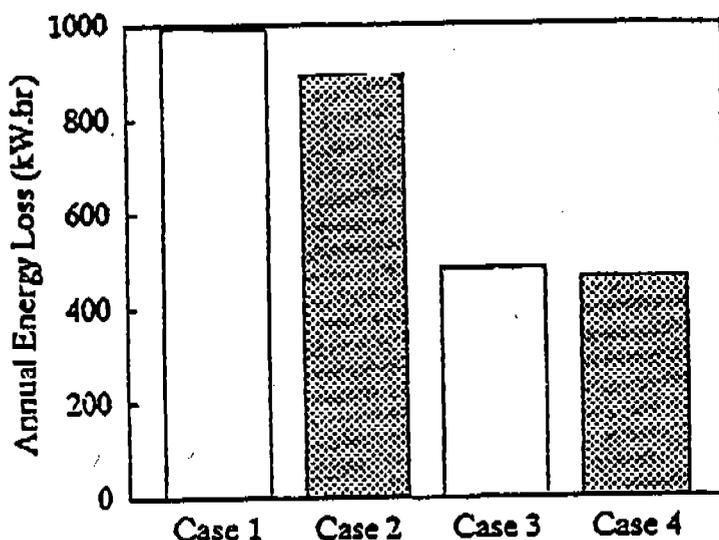
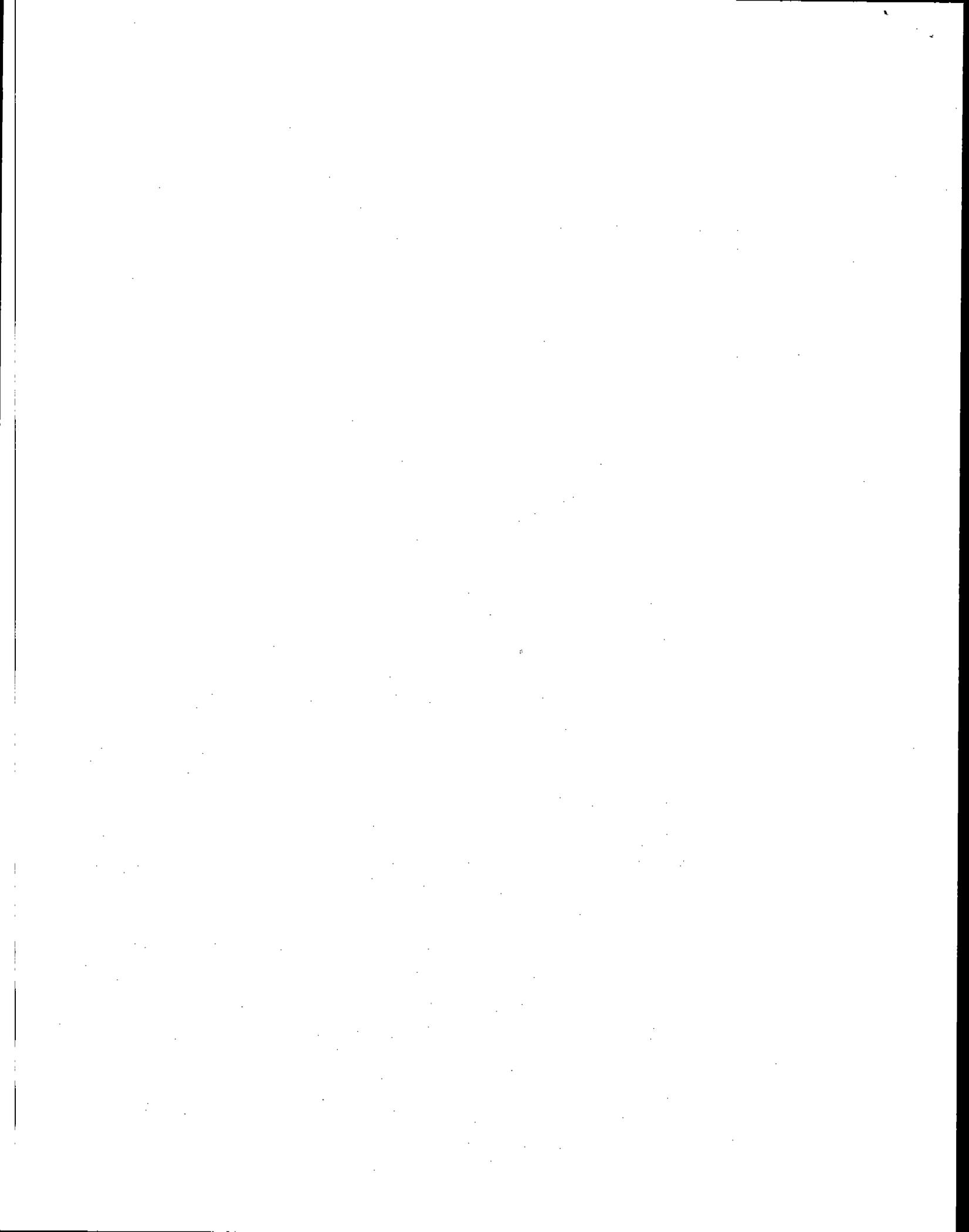


Figure 2 Comparison of Annual Energy Loss for various forms of residential housing construction
 Case 1 Uninsulated, brick veneer, tile roof, timber floor
 Case 2 Uninsulated, brick veneer, tile roof, concrete sog floor
 Case 3 Insulated, brick veneer, tile roof, timber floor
 Case 4 Insulated, brick veneer, tile roof, concrete sog floor

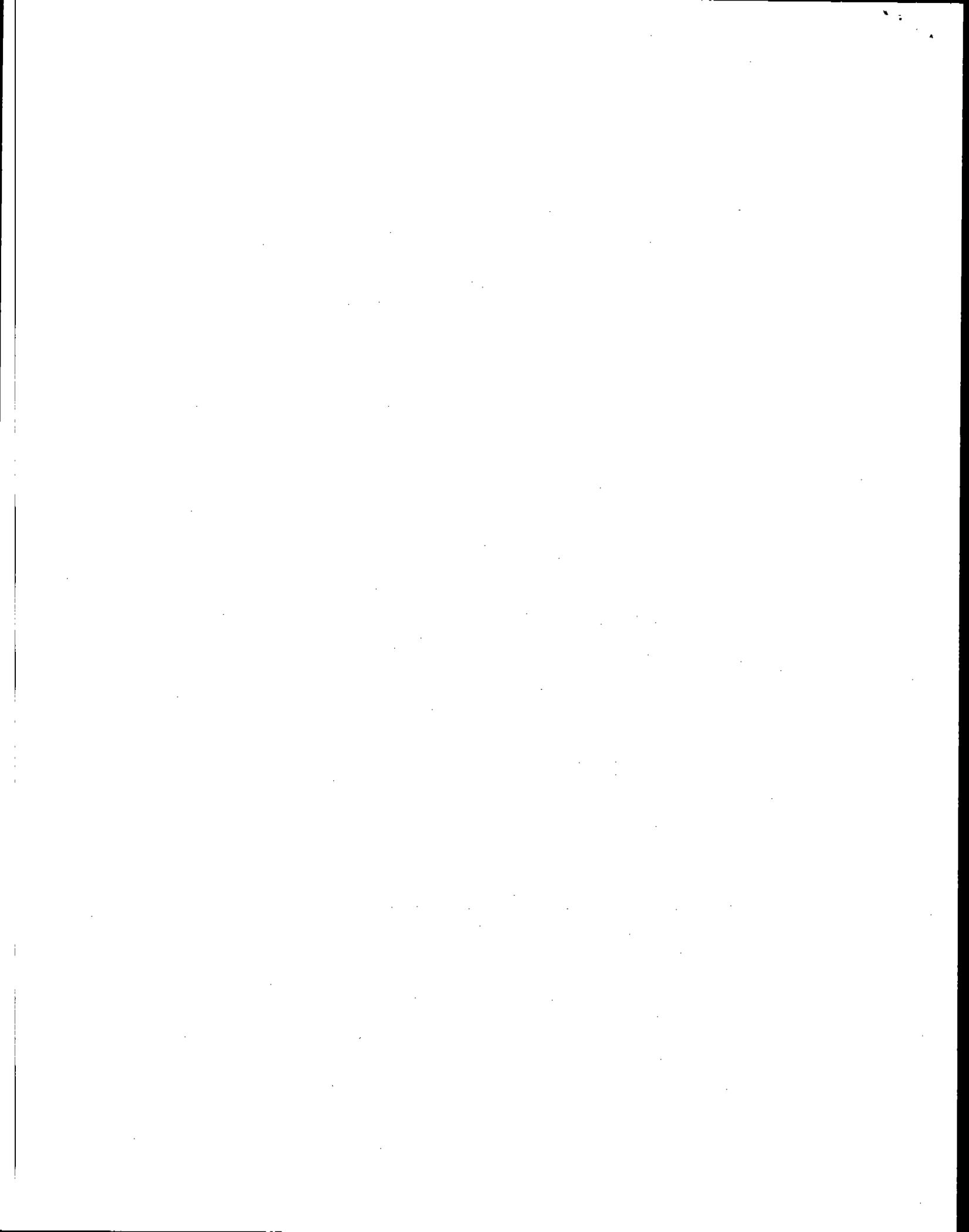
The importance of the type of cladding and their effect on the energy requirements of commercial buildings is also significant. It is estimated that between 30 to 50% of energy consumption in a typical Australian air-conditioned building goes into internal climate control (12). Harkness (13) has shown that using a moulded precast facade reduced the total cooling loads for a Brisbane office building by 50% compared to a flush glazed facade or by 37% compared to a double glazed, green heat-absorbing glass in a flush facade. See Figure 3.

The relationship between the energy required to build a house 'capital energy' and the 'operational energy' expended over its life has been estimated by Hill (14). He suggests that the 'capital energy' to build the house including allowances for appliances, redecoration and repair is about 1000 GJ (110t CO₂) and the 'operational energy' 60 years at 150 GJ/year is 9000 GJ (990t CO₂). About half of this energy is expended in space heating and cooling (15).

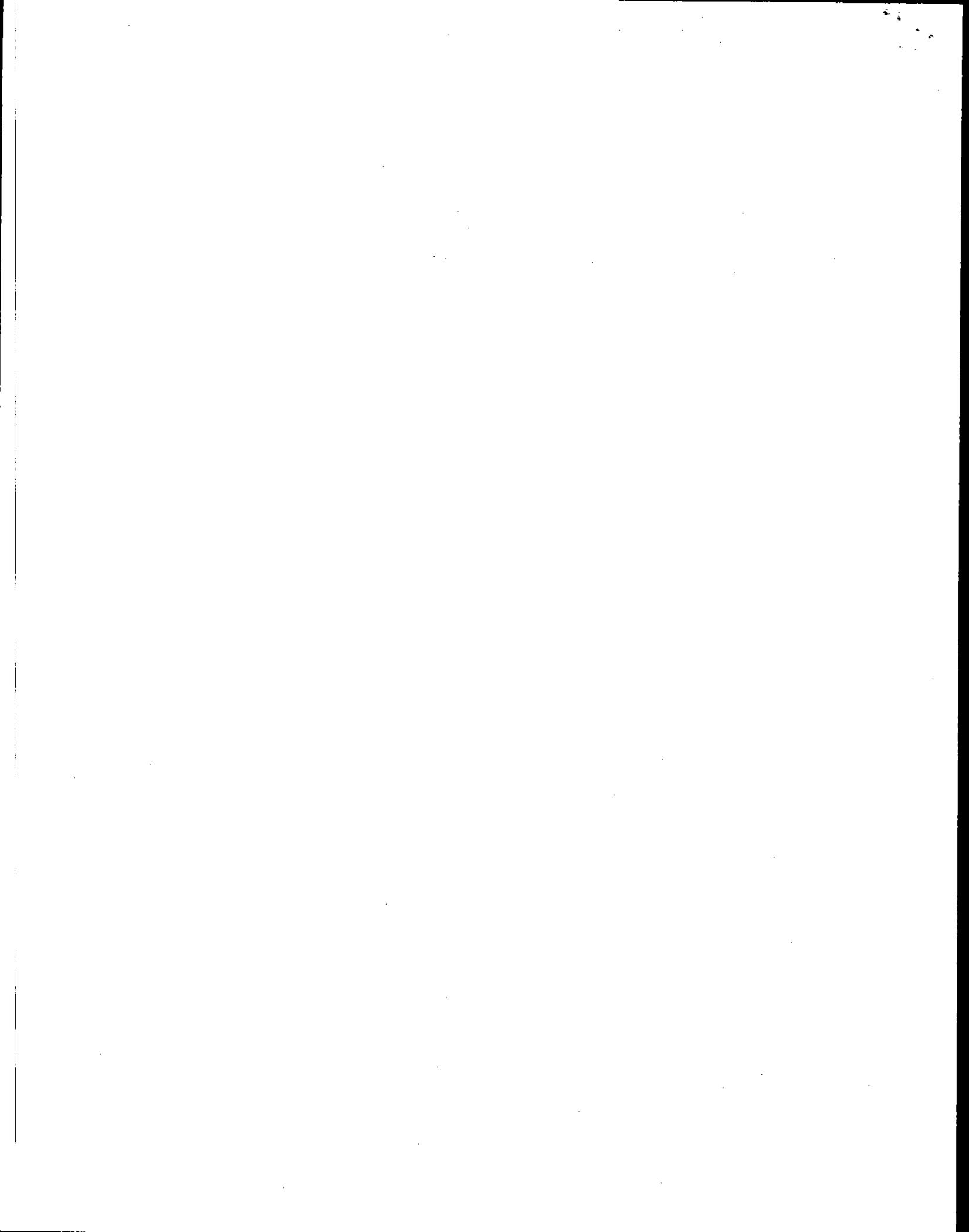
Because of this relationship between capital and operational energy Ballantyne (15) has suggested that efforts to reduce energy usage should be concentrated on improving the efficiency of those energy-using activities in the operational energy area.



- 1 Australian Government Joint Statement 'Government Sets Targets for Reductions in Greenhouse Gases'. October 1990.
- 2 Senate Standing Committee on Industry Science and Technology 'Rescue the Future: Reducing the Impact of the Greenhouse Effect'. January 1991.
- 3 Discussion paper Reducing Greenhouse Gas Emissions. Report of the Prime Minister's Working Group on Greenhouse Gas Emissions. December 1989.
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- 14 Hill, R.K. 'The Capital Energy Requirement of a House'.
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Association
Européenne
du Ciment
The European
Cement
Association

190-2-3
160-5
HES

I 17107JPJ/VG
Brussels, 20 September 1991

Dear Sir,

Re : Proposed EC Tax on CO₂ Emissions

Please find attached, for your information, the comments of the European Cement Industry on the above subject.

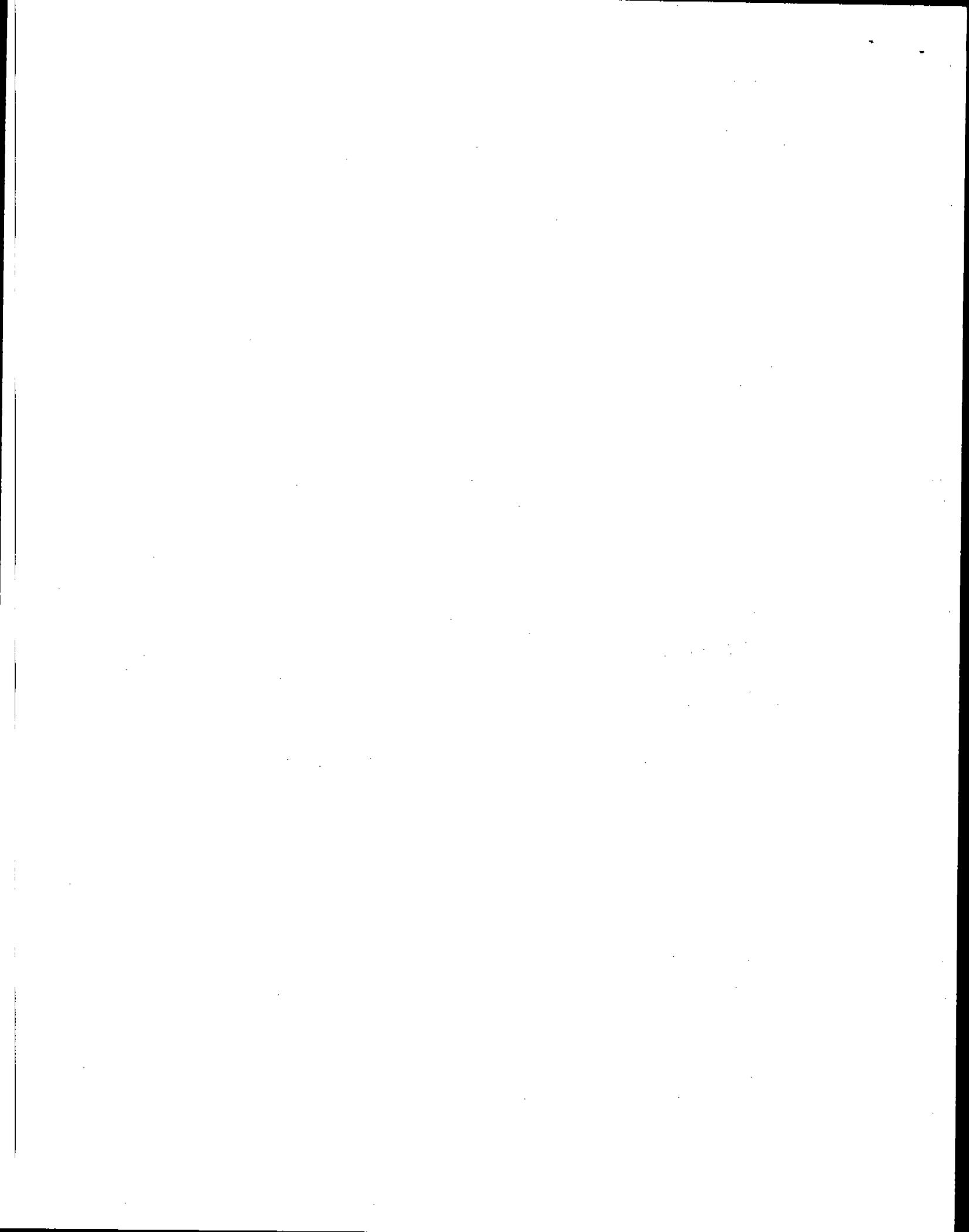
This position paper has been prepared by Cembureau - the European Cement Association - and is designed to bring forward the specific issues and concerns of the cement industry in the global warming discussion.

With a production of 212 million tonnes in 1990, representing a turnover in excess of 14 billion ECU, the cement industry of the 19 Cembureau countries (*) accounts for nearly 20 % of world cement output. As producer of a basic commodity for construction and civil engineering - which are the basis for economic growth - the cement industry claims its place amongst the European industrial sectors. In this context, it wishes to contribute actively to the present environmental debate.

Yours faithfully,

E. Durand-Réville
Managing Director

(*) EEC countries, EFTA countries and Turkey





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Position Paper

September 1991

Economic and Fiscal Instruments for Environmental Policy

Comments of the European Cement Industry on Taxation of CO₂ Emissions

Carbon dioxide (CO₂), a non-toxic gas released by any form of combustion, is considered to be a major contributor to the greenhouse effect and the global warming of the earth. Principal percentage contributions to CO₂ emissions from human activities are as follows: deforestation (23%), energy production (22.5%), transport (22.5%), domestic heating (16%) and industry (16%). Even if the contribution of industry to the global warming issue is relatively small, the cement industry accounts for a significant part of total industrial emissions. This is because, in the cement manufacturing process, CO₂ release occurs through the inherent chemistry of cement production (decarbonation of limestone) and as a result of the combustion of fuel required.*

In view of the risks of CO₂ for the global climate, the cement industries in the EC fully support the Community's initiative adopting a policy target of stabilizing carbon dioxide release at its 1990 level by the year 2000. The purpose of the present document, however, is to highlight a number of issues and concerns specific to the cement industry as a contribution to the general discussion on emissions of carbon dioxide and climate change.

CO₂ release from the process

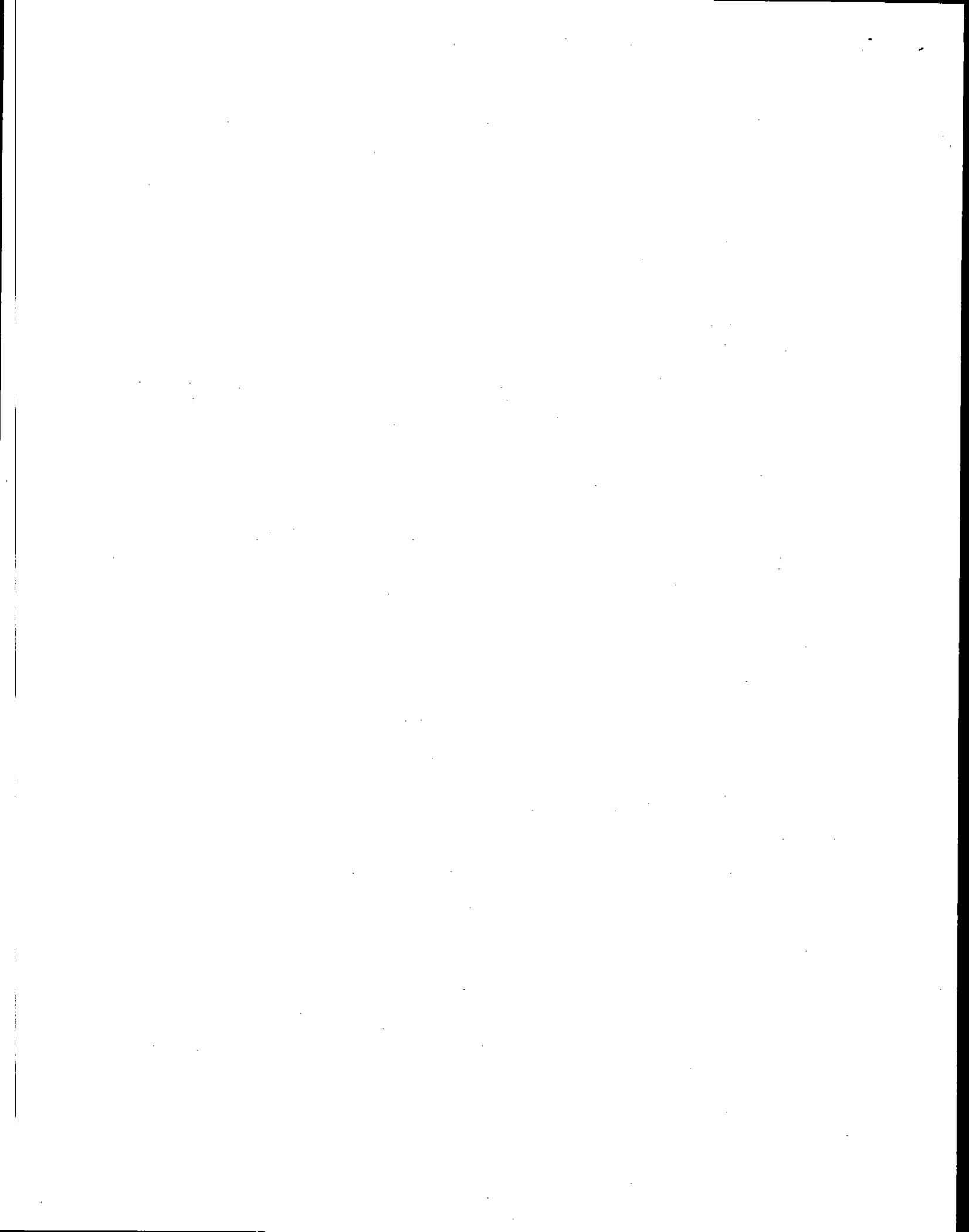
Over half of the CO₂ released during the manufacture of Portland cement clinker (the principal intermediate material used for the manufacture of cement) arises from decarbonation of the raw materials, mainly limestone. The quantity of CO₂ released per tonne of limestone decarbonated cannot be reduced and is an inherent feature of the clinker making process.

However, more than 20 years ago, the European cement industry already took the initiative to reduce the quantity of clinker required per tonne of cement by replacing part of the clinker with secondary raw materials, such as fly ash and blast furnace slag, and with natural pozzolanas and fillers. The industry thus produces blended cements with a lower carbon dioxide release ratio. If the contributions from those materials were to be discontinued for lack of an acceptable legal climate, an increase of some 20 % in the quantity of CO₂ release from the process would be incurred.

CO₂ release from energy

Release of carbon dioxide also occurs as a result of the energy required for the process. Cement manufacture in the European Community is already a highly energy efficient process. Fuel consumption has been reduced by 35 % since 1960 as a result of optimization of the manufacturing process and major capital investment. This mainly concerned the switch from a wet to a dry process using less energy and the systematic use of preheaters.

* Source : Department of the Environment, UK (figures 1980-1985).

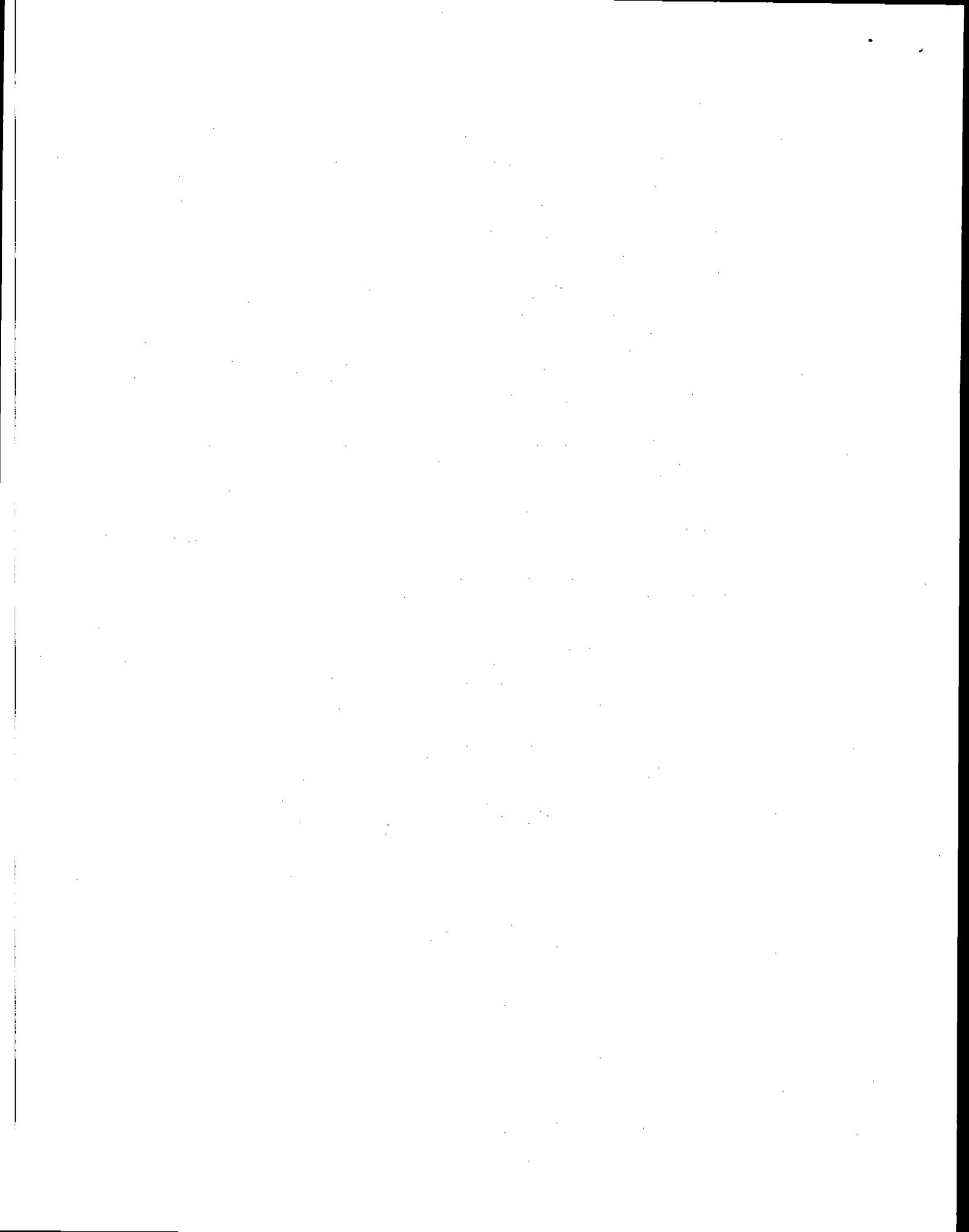


There is, at present, no alternative available to the use of carbon fuels as principal energy source. However, on-going research leads the cement sector to recognize that many materials which may be classified as wastes can be used as secondary fuels in cement kilns without altering the quality of the finished product. By using these materials (such as tyres, used oils, organic solvents) as kiln fuels, the industry is not only reducing the quantities of these materials which would otherwise have to be disposed of, but can contribute to the overall reduction of CO₂ release through the replacement of primary fuels. Again, a legal framework in this particular area is vital if the industry is to be encouraged to use these materials.

Considering the contribution of the industry it represents to the stabilization of carbon dioxide release during the past 20 years, Cembureau - the European Cement Association - wishes to state the following :

- . The Community's policy target of stabilizing CO₂ release at their 1990 level by the year 2000 should be achieved in a manner appropriate to the particular requirements of different sectors and not by the application of "blanket" regulations or taxes.
- . The European Community is only responsible for 13 % of total world CO₂ release. Therefore, in order to be effective, any measures taken must be introduced globally, i.e. with the same provisions in all countries.
- . A European tax in the range of US \$ 10 per bl of oil equivalent would increase the selling price of cement by an estimated 10 to 15%. This would lead, in the long run, to the transfer of production to other - less energy efficient - countries, and induce an overall increase of CO₂ release. Moreover, imports of cement from these countries would adversely affect market conditions and aggravate structural overcapacities in Europe.
- . An acceptable legal climate is essential if the cement industry is to be encouraged to conduct further research into the use of secondary raw materials and secondary fuels as a contribution towards CO₂ abatement. This entails that cement producers should not be regarded as waste disposal companies. Equally, users of secondary fuels should not be regulated in the same way as producers of wastes.

Finally, it should be emphasized that significant progress in the CO₂ issue can reasonably be expected in other parts of Europe since the Cembureau countries, among others, are committed to play an active role in helping their counterparts in Eastern-Europe implement sound environmental management principles, including efforts to reduce the release of CO₂.





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Press Release

23 September 1991

Note to Editors

September 23rd 1991

The following press release is issued on behalf of the Secretary General of the Association des Constructeurs Européens d'Automobiles, the European Cement Association, the European Chemical Industry Council, the European Association of Metals, the European Petroleum Industry Association and the European Federation of Industrial Energy Consumers.

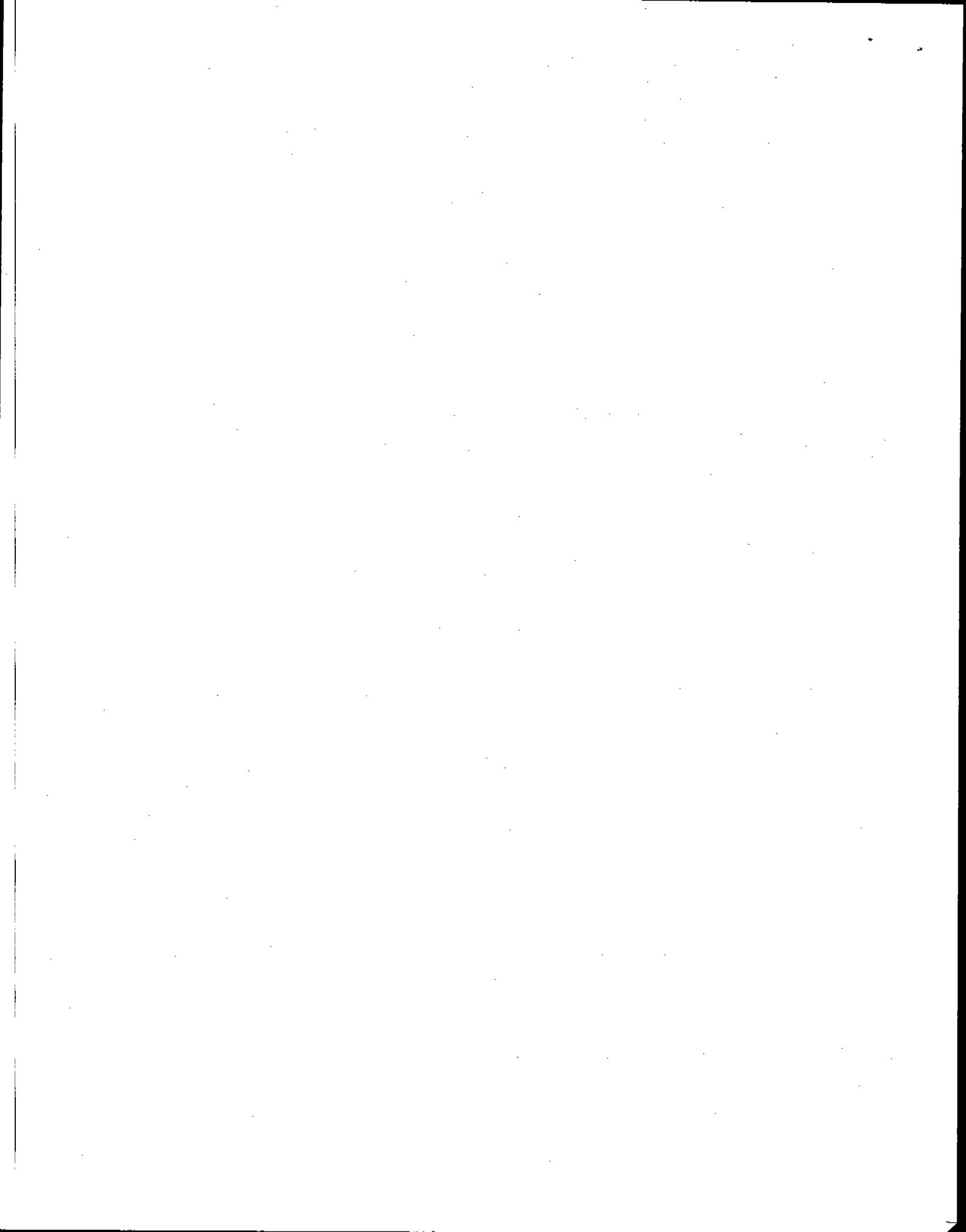
Details of the release are based on separate statements by the six organisations. The Cembureau Position Paper reflecting the views of the European Cement Association on taxation of CO₂ emissions is attached.

For specific queries and the full texts of position papers, where available, please contact :

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Mr. A. MONGON	IFIEC	Ch. de Charleroi, 111/113 B-1060 Brussels	Tel: 32-2/533 40 11 Fax: 32-2/539 29 59

Reference is made to the Union of Industrial and Employer's Confederations of Europe UNICE

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Press Release

23 September 1991

EUROPEAN INDUSTRY URGES THE COMMISSION TO FIND OTHER SOLUTIONS THAN TAXES FOR REDUCING CO₂ EMISSIONS

Brussels, Sept. 23 - European organisations representing various important branches of industry draw the attention of the European Communities to the severe economic and social consequences that would result from any decision to impose unilateral energy/CO₂ taxes to reduce greenhouse gas emissions. Such a move would weaken the competitive position of European Industries and threaten jobs and prosperity.

Europe's automobile, cement, chemicals, non-ferrous metals and petroleum industry associations as well as the federation of industrial energy consumers request the EC Commission to press instead for concerted international action covering all countries, and not only the industrial countries of the EC.

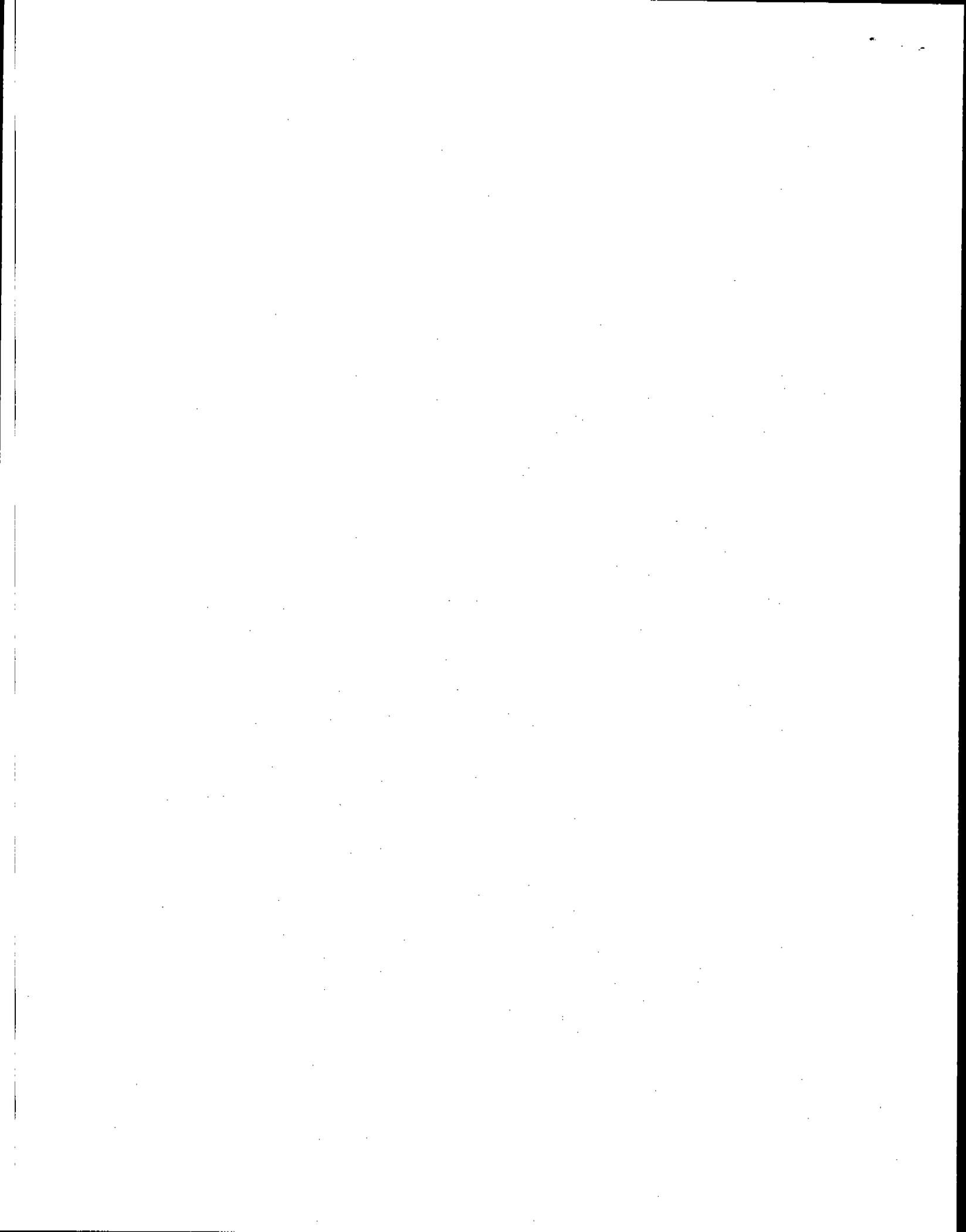
The Association des Constructeurs Européens d'Automobiles (ACEA), the European Cement Association (CEMBUREAU), the European Chemical Industry Council (CEFIC), the European Association of Metals (EUROMETAUX), the European Petroleum Industry Association (EUROPIA) and the European Federation of Industrial Energy Consumers (FIEC-Europe) wish to stress their members' conviction that a unilateral community-wide tax on energy/CO₂ emissions would cause severe economic damage without any certainty of achieving the desired environmental objective. Many of the associations have already issued separate statements making this point, but they decided that the implications of a tax for the future of European industry were so severe that a joint reiteration of their warning would more effectively alert European decision makers and the public to the dangers associated with such a measure.

Community ministers have set as their objective the stabilisation of carbon dioxide emissions within the EC at their 1990 level by the year 2000, but have not yet decided on the means for achieving that goal. The Commission is presently finalising its proposals for reaching this objective.

The European industry associations consider that, far from relieving the CO₂ problem, unilateral action by the Community could have the opposite effect. Higher energy/CO₂ taxes could force efficient, energy-intensive, industries in the EC to close down, leaving a gap in supply and generating unsatisfied global demand which would prompt sometimes less efficient, energy-intensive, industries outside the EC to raise production to meet it.

All studies show that the Community contributes some 13 % to global man-made CO₂ emissions, while much higher contributions come from the United States and central and eastern Europe. In their recent statements, CEFIC and CEMBUREAU have called on the Commission and member governments to focus on the reduction of greenhouse gas emissions in eastern and central Europe where the returns would be far higher than in western Europe. CEFIC has also stressed the need to develop action plans to reduce energy consumption by voluntary measures and technological progress and CEMBUREAU has pointed out that significant contributions to CO₂ abatement have already been achieved in cement plants by using by-products and waste as secondary raw materials and fuels.

more .../



EUROMETAUX has said governments should give priority to the least costly measures per ton of CO₂ avoided. **EUROPIA** has said governments should consider voluntary agreements and provide incentives for energy conservation measures which, in their own right, would be beneficial both to the environment and to the economy. The petroleum industry group has said such alternatives to taxes on oil consumption and other forms of energy use had not been sufficiently explored. Along this line, **ACEA**, while emphasizing that all CO₂ sources should be examined, has stressed the significant improvement of its products in the past and its readiness to take an additional self-commitment to participation in the EC objective.

The Union of Industrial and Employer's Confederations of Europe (**UNICE**), in its Position Paper (12-12-90), has already expressed its views on the use of economic and fiscal instruments in environment policy. Among criteria to be met **UNICE** underlines that of "Economic Acceptability" which is essential to preserve the competitiveness of European industry.

As stated by **CEFIC** in a recent colloquium attended by Commissioner Ripa di Meana, an open dialogue among the Commission, other EC institutions and industry would certainly help in finding ways to achieve common environmental objectives under a global approach.

- end -

**STUDY OF CARBON DIOXIDE
EMISSIONS RELATED TO THE
METALLURGICAL AND
NONMETALLIC MINERAL
PROCESSING**

REPORT

**Branch of Technical Analysis
U. S. Department of Interior
Bureau of Mines**

**Prepared
by**

**Network Consulting, Inc.
316 Pennsylvania Ave.,SE
Washington, DC 20003**

April, 1990

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CHAPTER 1

SUMMARY

The U.S. Bureau of Mines requested that Network Consulting, Inc. undertake a study to estimate the quantity of carbon dioxide emissions related to the metallurgical and nonmetallic mineral primary products and recycling key commodities. Eighty-three primary mineral commodities and nine recyclable commodities were studied. The carbon dioxide emissions were derived from Bureau of Mines contract studies (1, 2, 3, 9) which estimated the energy consumption of these commodities. Industry was then contacted to update their energy efficiencies that were accomplished since the date of the contract studies.

The results of our study, taking into account the efficiency information that was available, are shown in Table 1.1:

Table 1.1

Commodity	U.S. CO ₂ Production (1000 tons)	World CO ₂ Production (1000 tons)
Aluminum	61,317	293,753
Quicklime	22,084	171,985
Portland Cement	82,443	1,180,804
Chlorine	74,593	366,713
Copper	11,784	84,505
Iron and Steel	57,335	517,612
Lead	1,023	8,642
Ammonia	28,392	219,401
Zinc	1,668	41,314
Other high-priority Mineral Commodities	33,844	86,396 *
Other Mineral Commodities(Intermediate & Low Priority)	31,799	219,872
Total	406,282	3,190,997

kill worldwide

* Estimated from USBM private communication

This table shows that Aluminum, Portland Cement, Chlorine and Iron and Steel are the principal contributors to carbon dioxide emissions for the metals and minerals industry in the U.S., representing 68% of the emissions. The top seven commodities with high emissions represent 83% of the carbon dioxide generated. The high priority commodities represent 92.2% of the carbon dioxide emissions of the U.S. metals and minerals industry in 1987. It must be noted that electric arc steelmaking, utilizing 100% scrap, produce approximately twice the carbon dioxide emissions as compared with conventional conversion of ores via the blast furnace-basic oxygen route.

Transportation of high volume commodities to consumers could add substantially to the carbon dioxide emissions, but were not covered under the scope of this study.

Since there is no production data by process for the secondary metals, no total U.S. and World figures were calculated.

Increased energy efficiency would further reduce carbon dioxide emissions. However, in Portland cement and quicklime manufacture, carbonate decomposition were the major source of emissions. Further improvements could be realized in the aluminum industry with the replacement of carbon anodes with a permanent anode, or utilizing a different process that would not process alumina, but aluminum chloride.

For further reductions, emphasis should be stressed on displacing fossil-related energy sources with renewable energy sources or nuclear or geothermal.

Recycling metals lowers some carbon dioxide emissions. In the case of aluminum, especially recycled beverage containers, the mixing of alloys puts a constraint on how much material can be recycled.

CHAPTER 2

INTRODUCTION

A. Background

Carbon dioxide is emitted in large quantities as a combustion product from burning fuels such as coal, oil, and natural gas. The growing and major concern about these emissions is that, with expanded firing of fossil fuels, carbon dioxide may build up in the earth's atmosphere faster than the biomass can absorb it. This, in turn, as argued by some scientists, will cause a "greenhouse effect" so that heat from the sun will be retained within the atmospheric envelope more efficiently than at present.

The resultant global warming possibility is already receiving national attention. For instance, in 1986, as evidence began to mount, the Senate Environmental and Public Works Committee directed the Council on Environmental Quality to assure that global warming was included in the environmental impact statements prepared by Federal agencies.

By 1989, legislation had been introduced to counter the "greenhouse effect". Typical were H.R. 1078, the Global Warming Prevention Act of 1989, and H.J. Res. 207, the National Global Warming Policy Act. Both pieces of legislation would encourage the international cooperation on energy and natural resource conservation. Both also call for substantial reduction of carbon dioxide emissions in the atmosphere by the year 2000 through energy conservation, including new fuel economy standards for cars; greater use of clean-burning fuels; the development of renewable energy resources, such as sunlight, wind, water, and wood; urban forestry programs; and the protection of tropical rainforests. All U.S. Aid developing nations would be required to include energy and natural resource conservation plans.

The Executive Branch has responded with the U.S. Global Change Research Program. The strategy of this program was developed by the Committee on Earth Sciences of the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), which is chaired by the Director of the Office of Science and

Technology Policy in the Executive Office of the President. The program is described in "Our Changing Planet: The FY1990 Research Plan". One part of the program is concerned with industrial production as part of Human Interactions; including carbon dioxide emissions. The publication (p. 74) notes: 'Measurements of fossil fuel carbon dioxide do not yet provide adequate information regarding the uses to which energy is put outside the United States. Uncertainty surrounding current estimates of emissions from non-fossil fuel carbon dioxide is unacceptably great.

One contributor to effluent carbon dioxide is metallurgical and nonmetallic mineral processing. The effluent carbon dioxide from this processing is related to its energy consumption.

Production of primary metals consumed about 5,800 trillion BTU in 1973, or 7.9 percent of the total U. S. energy consumption. Processing of nonmetallic minerals, (such as lime, fluorspar, barite, cement, glass, and brick) consumed as additional 2,600 trillion BTU, or 3.6 percent of the total. In 1974, the U. S. Bureau of Mines contracted with Battelle /Columbus Laboratories to develop an integrated data bank on energy use patterns in the metallurgical and nonmetallic mineral processing industries. Detailed information on the differing kinds and quantities of energy consumed for specific processing steps in the large number of operations used in these industries had not been readily available previously. A major objective of the contract study [1,2,3] was to provide comprehensive information on details of energy consumption by type and quantity for each step of the metals and minerals producing industries from ore extraction to primary product.

This energy information can be used as the basis of making estimates of sources and quantities of carbon dioxide emissions related to the metallurgical and nonmetallic mineral processing. Energy information for metal recycling is available from a subsequent Bureau of Mines contract study by Arthur D. Little [9]. The current study by Network Consulting, Inc. has been undertaken under the Bureau of Mines contract in order to estimate the quantity of carbon dioxide emissions related to metallurgical and nonmetallic mineral processing needed for U.S. and world consumption of primary products and for recycling key metals. The carbon dioxide emitted has been identified as to source, e.g., coal, oil, or natural gas burned to produce electricity, process steam, or process heat; oil or gasoline used for transportation; or carbonate decomposition. This has been done for the primary mineral commodities that use nearly all of the energy for these processing industries as well as for 9 secondary metals.

B. Format and Methodology

The estimates of carbon dioxide emissions in this study are based on the data related to the Bureau of Mines contract reports and publications on energy use patterns in metallurgical and nonmetallic mineral processing and metal recycling [1,2,3,9]. In fact, the reader should have these reports available because this study is essentially a follow-on that uses the same order of presentation and table formats without the accompanying text.

The 83 mineral primary commodities were divided into three groups - high, intermediate, and low priority - for the Battelle studies. The principal basis for priority selection were energy consumption per ton to produce the commodity and total energy needed to produce the tonnage of the commodity consumed in the United States.

The energy used for the groups were:

Category	Energy use	Percentage
High priority	$7,678 \times 10^{12}$ Btu's	91.9%
Intermediate priority	553×10^{12} Btu's	6.6%
Low priority	125×10^{12} Btu's	1.5%
	$8,356 \times 10^{12}$ Btu's	100.0%

The highest priority group consisted of 14 commodities, primarily the major metals and the major nonmetallic mineral products. The intermediate priority groups contained 27 commodities - a large number of nonmetallic minerals, a few ferroalloys, and several nonferrous metals including magnesium, titanium and sodium. The low priority group consisted of 42 commodities, primarily the major metals and the major nonmetallic mineral products.

For the high-priority commodities, the main part of the report includes tables that give carbon dioxide emissions for the major divisions of each process. Appendix A of this report has complete tables for each high-priority commodity. These tables are directly related to those in the Battelle report (1) and show pounds of carbon dioxide emissions that are associated with each process step, unit process, and unit operation rather than million Btu's.

The intermediate- and low-priority commodities are also shown in the main part of this report in a table that gives carbon dioxide emissions for each process. The detailed tables for these commodities are not included in the Appendix, but are available from Network Consulting, Inc.

For the low-priority commodities, detailed carbon dioxide emission estimates were not made. Instead, the "other fuels" factor (164 lbs. carbon dioxide/million Btu's) was used for the low-priority commodities to convert total energy (3) to estimated carbon dioxide emissions. To insure the validity of the assumption, the factor was used to convert all total energy quantities for low-priority commodities to carbon dioxide emissions. These figures were compared with the estimates for this study for the same commodities. On a percentage basis, the mean was 95.5%. (That is $\text{Battelle energy data} \times \text{carbon dioxide factor } 164 \text{ lbs. carbon dioxide/million Btu} \times 100 / \text{Network Consulting carbon dioxide estimate}$.) The standard deviation was 10.5, and the variance was 110.2.

For the nine secondary or recycled materials, the carbon dioxide estimates are shown in the main part of the report in a table that reflect those given in the Arthur D. Little study (9). Columns for energy in Btu's have been replaced with columns showing carbon dioxide emissions. Appendix B shows more details.

Worldwide emissions of carbon dioxide for all 83 mineral commodities are shown as estimates with each commodity in the tables in the main part of this report.

The factors used to convert each energy component to carbon dioxide emissions are shown in Appendix C of this report.

Chapter 3

High-Priority Commodities

This chapter deals with the carbon dioxide emissions of the high-priority commodities which consume approximately 90% of the total energy use in metallurgical and nonmetallic mineral processing. This information is based on the contract reports (1, 2, 3) from which the estimated carbon dioxide emissions were derived. The following is a list of the tables for the specific commodities:

Commodity	Primary Product	Table No.
Aluminum	Aluminum Ingot	3.1
Calcium	Quicklime	3.2
Cement	Portland Cement	3.3
Chlorine	Chlorine	3.4
Copper	Refined Copper	3.5
Glass	Glass Containers	3.6
Iron and Steel	Raw Steel	3.7a,b,c,d
Lead	Refined Lead	3.8
Nitrogen	Ammonia	3.9
Phosphorus	Phosphorus	3.10
Zinc	Elemental Zinc	3.11a,b,c

In the case of aluminum, 21% of the world's carbon dioxide emission for the industry are derived by the U.S. smelters with the Eastern European countries* (including The Soviet Union) slightly ahead. In the case of quicklime, 13% of the world's carbon dioxide emissions coming from the U.S. industry with the Eastern European countries (including The Soviet Union) contributing approximately 44%. In the case Portland cement industry, carbon dioxide emissions from U.S. plants account for 7% of the world industry contribution with the Eastern European countries (including The Soviet Union) contributing 38%. In the chlorine industry, the U.S. portion of the industries contribution is 20% with the Far East contributing 28%. The U.S. copper industry contributes only 14% of the carbon dioxide emissions for this industry, while the Eastern European countries (including The Soviet Union) contributes 24%.

In the iron and steel industry, for the blast furnace production of pig iron, the U.S. emits approximately 9% of the carbon dioxide emitted from the world blast furnaces. The iron and steel industry contribute a total of 475,720,000 tons of carbon dioxide, with the U.S. contributing 52,695,000 tons, or 11%.

For the lead industry, the U.S. contributes 12% of this industry's world contribution. In the case of ammonia, the U.S. carbon dioxide emissions are 11% of the industry's world contribution.

For zinc, the electrothermic and electrolytic processes of the U.S. contribute 1.7 million tons compared to a world total of 41 million tons, or 4%.

Common brick, cement copper, nitrogen, iron and carbon steel casting, phosphoric acid, basic refractories, fire clay brick, and sulfuric acid were not analyzed because of lack of data.

* Albania, Bulgaria, Czechoslovakia, German Democratic Republic, Hungary, Poland, and Romania.

TABLE 3-1
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF ALUMINUM

	POUNDS OF CARBON DIOXIDE NET TON OF ALUMINUM
BAUXITE PRODUCTION	796.9
BAYER PROCESSING	9,546.4
CARBON ANODE MANUFACTURE	4,265.5
CARBON CATHODE MANUFACTURE	239.8
REDUCTION	30,151.8
TOTAL	45,000.4

CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF ALUMINUM
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	3,685.0	82,913.3
SOUTH AMERICA	1,573.0	35,392.8
OTHER NORTH AMERICA	1,734.0	39,015.4
EUROPE	3,787.0	85,208.3
MIDDLE EAST	429.0	9,652.6
EASTERN EUROPE AND THE SOVIET UNION	3,879.0	87,278.3
FAR EAST	1,933.0	43,492.9
AFRICA	634.0	14,265.1
TOTAL	17,654.0	397,218.8

TABLE 3-2
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF QUICKLIME

	POUNDS OF CARBON DIOXIDE NET TON OF QUICKLIME
LIMESTONE QUARRYING OR MINING	22.0
CRUSHING	28.2
TRANSPORTATION	7.8
CALCINING	3,077.2
TOTAL	3,135.2

CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF QUICKLIME
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	15,758.0	24,702.0
SOUTH AMERICA	7,958.0	12,474.8
OTHER NORTH AMERICA	7,283.0	11,416.7
EUROPE	23,133.0	36,262.9
MIDDLE EAST	1,142.0	1,790.2
EASTERN EUROPE AND THE SOVIET UNION	53,434.0	83,762.3
FAR EAST	10,349.0	16,222.9
AFRICA	3,658.0	5,734.2
TOTAL	122,715.0	192,366.2

TABLE 3-3
 CARBON DIOXIDE EMISSIONS FROM THE PRODUCTION OF
 PORTLAND CEMENT

	POUNDS OF CARBON DIOXIDE PER TON OF CEMENT
RAW MATERIAL PREPARATION	137.4
CLINKER PREPARATION	2,253.7
CLINKER MILLING	115.3
TOTAL	2,506.4

per ton of cement

CARBON DIOXIDE EMISSIONS FROM THE PRODUCTION OF
 PORTLAND CEMENT
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	79,501.0	99,630.9
SOUTH AMERICA	54,643.0	68,478.8
OTHER NORTH AMERICA	46,131.0	57,811.5
EUROPE	210,223.0	263,452.1
MIDDLE EAST	50,173.0	62,876.9
EASTERN EUROPE AND THE SOVIET UNION	435,890.0	546,258.6
FAR EAST	215,612.0	270,205.6
AFRICA	46,500.0	58,273.9
TOTAL	1,138,673.0	1,426,988.3

* NOTE THAT PORTLAND CEMENT IS ESTIMATED FROM TOTAL CEMENT PRODUCED IN THE UNITED STATES
 PORTLAND CEMENT IS APPROXIMATELY 95.5% OF TOTAL CEMENT PRODUCTION

TABLE 3-4
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF CHLORINE

	POUNDS OF CARBON DIOXIDE PER TON OF CHLORINE
CHLORINE PROCESSING*	3,662.4
CAUSTIC SODA PROCESSING*	6,895.4
	10,557.7

* BRINE PREPARATION AND ELECTROLYSIS HAS BEEN INCLUDED

CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF CHLORINE
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	14,130.4	74,592.5
SOUTH AMERICA	3,611.1	19,062.7
OTHER NORTH AMERICA	365.3	1,928.4
EUROPE	18,030.3	95,179.7
MIDDLE EAST	434.5	2,293.8
EASTERN EUROPE AND THE SOVIET UNION	11,404.0	60,200.0
FAR EAST	19,750.0	104,257.9
AFRICA	1,742.0	9,195.6
TOTAL	69,467.6	366,710.6

TABLE 3-5
 CARBON DIOXIDE EMISSIONS FROM THE PRODUCTION OF
 REFINED COPPER

	POUNDS OF CARBON DIOXIDE PER TON OF COPPER
ORE PREPARATION	3,628.7
CONCENTRATOR	7,199.9
SMELTER	1,086.3
COPPER PREPARATION	4,520.9
ACID PLANT	576.6
REFINING	1,642.1
TOTAL	18,654.5

CARBON DIOXIDE EMISSION FROM THE
 PRODUCTION OF REFINED COPPER
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	1,263.4	11,784.0
SOUTH AMERICA	1,436.6	13,399.5
OTHER NORTH AMERICA	657.6	6,133.6
EUROPE	986.7	9,203.2
MIDDLE EAST	33.1	308.4
EASTERN EUROPE AND THE SOVIET UNION	2,167.7	20,218.7
FAR EAST	1,569.2	14,636.3
AFRICA	945.8	8,821.5
TOTAL	9,060.0	84,505.3

TABLE 3-6
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF GLASS CONTAINERS

	POUNDS OF CARBON DIOXIDE PER NET TON OF GLASS
RAW MATERIAL PREPARATION	924.7
MELTING	1,396.8
FORMING	553.2
TOTAL	2,874.7

CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF GLASS CONTAINERS
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	13,660.8	21,599.0
SOUTH AMERICA	N/A	N/A
OTHER NORTH AMERICA	N/A	N/A
EUROPE	N/A	N/A
MIDDLE EAST	N/A	N/A
EASTERN EUROPE AND THE SOVIET UNION	N/A	N/A
FAR EAST	N/A	N/A
AFRICA	N/A	N/A
TOTAL	13,660.8	21,599.0

TABLE 3-7a.
 CARBON DIOXIDE PRODUCTION FROM THE
 PRODUCTION OF IRON IN THE BLAST FURNACE

	POUNDS OF CARBON DIOXIDE PER TON OF HOT METAL
ORE	696.0
COKE	233.6
MILL SCALE AND SCRAP	1.1
REFRACTORIES	13.1
FUELS	1,285.7
MISCELLANEOUS ENERGY SOURCES	-1,807.4
TOTAL	422.1

CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF IRON IN THE BLAST FURNACE
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	48,308.0	10,194.2
SOUTH AMERICA	30,856.0	6,511.4
OTHER NORTH AMERICA	16,790.0	3,543.1
EUROPE	108,337.0	22,861.9
MIDDLE EAST	276.0	58.2
EASTERN EUROPE AND THE SOVIET UNION	116,724.0	24,631.8
FAR EAST	233,905.0	49,360.0
AFRICA	9,722.0	2,051.6
TOTAL	564,918.0	119,212.3

TABLE 3-7b.
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION IN
 OPEN-HEARTH STEEL PRODUCTION

	POUNDS OF CARBON DIOXIDE PER TON OF STEEL
HOT METAL AND SCRAP	287.2
ADDITIVES	724.7
OXYGEN	38.6
REFRACTORIES	104.8
FUELS AND ENERGY	552.6
TOTAL	1,207.9

CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF OPEN HEARTH-STEEL
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	2,674.5	1,615.3
SOUTH AMERICA	1,030.9	622.6
OTHER NORTH AMERICA	760.1	459.1
EUROPE	4,857.3	2,933.6
MIDDLE EAST	94.1	56.8
EASTERN EUROPE AND THE SOVIET UNION	9,604.0	5,800.4
FAR EAST	4,767.1	2,879.1
AFRICA	357.2	215.8
TOTAL	24,145.3	14,582.8

TABLE 3-7c
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF
 BASIC-OXYGEN STEEL

	POUNDS OF CARBON DIOXIDE PER TON OF STEEL
HOT METAL AND SCRAP	347.8
ADDITIVES	351.5
OXYGEN	34.1
REFRACTORIES	60.7
FUELS AND ENERGY	81.3
TOTAL	675.4

CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF BASIC OXYGEN STEEL
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	33,966.5	14,866.9
SOUTH AMERICA	13,091.9	5,730.2
OTHER NORTH AMERICA	9,653.4	4,225.2
EUROPE	61,688.1	27,000.4
MIDDLE EAST	1,194.8	523.0
EASTERN EUROPE AND THE SOVIET UNION	121,971.1	53,385.8
FAR EAST	60,542.4	26,499.0
AFRICA	4,536.9	1,985.8
TOTAL	306,645.2	134,216.4

TABLE 3-7d
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF
 ELECTRIC FURNACE STEEL

	POUNDS OF CARBON DIOXIDE PER TON OF STEEL
STEEL AND SCRAP	51.0
ADDITIVES	238.9
ELECTRODES	176.8
OXYGEN	7.9
REFRACTORIES	68.1
FUELS AND ENERGY	1,013.3
TOTAL	1,556.0

CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF ELECTRIC FURNACE STEEL
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	52,509.9	40,853.2
SOUTH AMERICA	20,239.2	15,746.3
OTHER NORTH AMERICA	14,923.5	11,610.6
EUROPE	95,365.6	74,195.4
MIDDLE EAST	1,847.1	1,437.1
EASTERN EUROPE AND THE SOVIET UNION	188,558.9	146,700.7
FAR EAST	93,594.5	72,817.4
AFRICA	7,013.8	5,456.8
TOTAL	474,052.5	368,817.5

TABLE 3-8
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF LEAD

PRODUCTION OF LEAD	POUNDS OF CARBON DIOXIDE PER TON OF LEAD
RAW MATERIAL PREPARATION	1,299.5
BENEFICATION	260.3
CHARGE PREPARATION AND SINTERING	421.9
BLAST FURNACE	1,858.9
DRESSING	244.6
SULFURIC ACID PLANT	124.4
REFINING	759.6
TOTAL	4,969.1

CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF LEAD
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	411.8	1,023.2
SOUTH AMERICA	104.9	260.7
OTHER NORTH AMERICA	347.6	863.5
EUROPE	760.4	1,889.2
MIDDLE EAST	0.0	0.0
EASTERN EUROPE AND THE SOVIET UNION	880.7	2,188.2
FAR EAST	850.9	2,114.0
AFRICA	122.0	303.2
TOTAL	3,478.3	8,642.0

TABLE 3-9
 CARBON DIOXIDE EMISSION FROM THE
 PRODUCTION OF AMMONIA

	UNITS	UNITS PER TON OF AMMONIA	LBS OF CARBON DIOXIDE RELEASED PER UNIT	LBS CARBON DIOXIDE PER NET TON OF AMMONIA
REFORMING				
NATURAL GAS (FEED) (1)	CUFT	22,310.0000	0.1340	2,989.5
STEAM (FEED) (2)	LBS	4,545.0000	0.0000	0.0
NATURAL GAS (FUEL)	CUFT	8,420.0000	0.1340	1,128.3
CATALYST, 5 LBS	MM BTU	0.0020	164.0000	0.3
SUBTOTAL				4,118.1
SHIFT REACTION				
CATALYST, 3 LBS	MM BTU	0.0010	164.0000	0.2
ELECTRICAL ENERGY	KWH	4.0000	1.8180	7.3
SUBTOTAL				7.4
CARBON DIOXIDE REMOVAL				
ELECTRICAL ENERGY	KWH	14.0000	1.8180	25.5
ETHANOLAMINE, 3 LBS	MM BTU	0.0060	164.0000	1.0
SUBTOTAL				26.4
METHANATION				
ELECTRICAL ENERGY	KWH	2.0000	1.8180	3.6
CATALYST, 5 LBS	MM BTU	0.0020	164.0000	0.3
SUBTOTAL				4.0
COMPRESSION SYNTHESIS GASES				
NATURAL GAS (FUEL)	CUFT	7,190.0000	0.1340	963.5
SYNTHESIS				
NATURAL GAS (FUEL)	CUFT	420.0000	0.1340	56.3
ELECTRICAL ENERGY	KWH	8.0000	1.8180	14.5
CATALYST, 5 LBS	MM BTU	0.0020	164.0000	0.3
SUBTOTAL				71.2
TOTAL (3)				5,190.6

- (1) STEAM IS A CHEMICAL REACTANT IN THE REFORMING STAGE. ALTHOUGH IT IS FORMED ELSEWHERE IN THE PROCESS, THE ENERGY REQUIRED TO FORM STEAM AND HEAT IT TO REACTION TEMPERATURE IS INCLUDED IN THE NATURAL GAS (FUEL) UNITS.
- (2) THE CARBON DIOXIDE PRODUCED FROM THE FEED GAS IS REMOVED IN A CONCENTRATED STREAM AND SHOULD BE RECOVERABLE. THIS IS 57.6% OF THE CARBON DIOXIDE RESULTING FROM AMMONIA PRODUCTION.
- (3) THIS TOTAL BREAKS DOWN BY TYPE AS FOLLOWS

	LBS CARBON DIOXIDE PER TON AMMONIA
NATURAL GAS	5,137.6
ELECTRICAL ENERGY	50.9
CHEMICALS	2.1
	5,190.6

TABLE 3-9 (CONTINUED)
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF AMMONIA
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (4) (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	13,284.0	28,391.9
SOUTH AMERICA	1,899.0	4,058.7
OTHER NORTH AMERICA	6,484.0	13,858.3
EUROPE	13,506.0	28,866.4
MIDDLE EAST	3,042.0	6,501.7
EASTERN EUROPE AND THE SOVIET UNION	48,760.0	104,215.0
FAR EAST	13,829.0	29,556.8
AFRICA	1,849.0	3,951.9
TOTAL	102,653.0	219,400.7

(4) SHORT TONS OF CONTAINED NITROGEN. THE CONVERSION IN 14/17 OF TOTAL FACTOR

TABLE 3-10
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF ELEMENTAL PHOSPHORUS

	POUNDS OF CARBON DIOXIDE PER TON OF PHOSPHORUS
MINING AND PREPARATION	2,438.8
FURNACING	34,698.1
TOTAL	37,136.9

CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF ELEMENTAL PHOSPHORUS
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	345.4	6,412.9
SOUTH AMERICA	N/A	N/A
OTHER NORTH AMERICA	N/A	N/A
EUROPE	N/A	N/A
MIDDLE EAST	N/A	N/A
EASTERN EUROPE AND THE SOVIET UNION	N/A	N/A
FAR EAST	N/A	N/A
AFRICA	N/A	N/A
TOTAL	N/A	N/A

TABLE 3-11a
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF ZINC
 BY THE ELECTROTHERMIC PROCESS

	POUNDS OF CARBON DIOXIDE PER TON OF ZINC
FEED PREPARATION	2,000.6
ROASTING AND MIXING	392.2
SULFURIC ACID PRODUCTION	211.1
SINTERING	1,628.0
ELECTROTHERMIC REDUCTION	10,076.0
TOTAL	14,308.0

CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF ZINC
 BY THE ELECTROTHERMIC PROCESS
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	67.0	479.1
SOUTH AMERICA	70.6	504.8
OTHER NORTH AMERICA	151.4	1,063.2
EUROPE	501.3	3,586.6
MIDDLE EAST	0.0	0.0
EASTERN EUROPE AND THE SOVIET UNION	512.0	3,663.1
FAR EAST	302.6	2,164.5
AFRICA	53.4	382.2
TOTAL	1,658.3	11,863.4

TABLE 3-11b.
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF ZINC BY
 THE VERTICAL RETORT PROCESS

	POUNDS OF CARBON DIOXIDE PER TON OF ZINC
FEED PREPARATION	2,666.0
ROASTING	106.5
SULFURIC ACID PRODUCTION	95.9
RETORT FEED PREPARATION	7,894.1
VERTICAL RETORT REDUCTION	1,914.9
TOTAL	12,677.5

CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF ZINC BY
 THE VERTICAL RETORT PROCESS
 WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	N/A	N/A
SOUTH AMERICA	N/A	N/A
OTHER NORTH AMERICA	N/A	N/A
EUROPE	N/A	N/A
MIDDLE EAST	N/A	N/A
EASTERN EUROPE AND THE SOVIET UNION	N/A	N/A
FAR EAST	N/A	N/A
AFRICA	N/A	N/A
TOTAL	N/A	N/A

TABLE 3-11c

CARBON DIOXIDE EMISSIONS FROM THE
PRODUCTION OF ZINC BY THE
ELECTROLYTIC PROCESS

	POUNDS OF CARBON DIOXIDE PER TON OF ZINC
FEED PREP	2,231.3
ROASTING	174.9
SULFURIC ACID PRODUCTION	497.9
LEACHING	298.9
ELECTROLYSIS	6,554.5
MELTING AND CASTING	226.2
ZINC DUST	0.1
NATURAL GAS (STEAM PLANT)	328.2
TOTAL	10,312.0

CARBON DIOXIDE EMISSIONS FROM THE
PRODUCTION OF ZINC BY THE
ELECTROLYTIC PROCESS
WORLD SUMMARY TABLE

COUNTRY	PRODUCTION (THOUSAND TONS)	CARBON DIOXIDE (THOUSAND TONS)
UNITED STATES	230.7	1,189.3
SOUTH AMERICA	243.0	1,253.1
OTHER NORTH AMERICA	521.5	2,689.1
EUROPE	1,726.8	8,903.6
MIDDLE EAST	0.0	0.0
EASTERN EUROPE AND THE SOVIET UNION	1,763.7	9,093.5
FAR EAST	1,042.1	5,373.3
AFRICA	184.0	948.8
TOTAL	5,711.9	29,450.6

CHAPTER 4

OTHER MINERAL COMMODITIES

Table 4.1 presents a summary of carbon dioxide emissions for intermediate and low-priority products. In some instances there was no information available for the analysis. Table 4.2 presents the summary of the U.S. and world production of carbon dioxide.

TABLE 4.1

SUMMARY TABLE OF CARBON DIOXIDE EMISSIONS FOR INTERMEDIATE
AND LOW PRIORITY PRIMARY PRODUCTS

COMMODITY	PRIMARY PRODUCT	ENERGY REQUIRED PER TON OF PRODUCT (1)	LBS OF CARBON DIOXIDE PER TON OF PRODUCT
(2) ANTIMONY	ANTIMONY OXIDE	186.0	30,504.0
	ANTIMONY METAL	5.8	951.2
(4) ARGON (1)	LIQUID ARGON	4.3	801.9
(2) ARSENIC	ARSENIC OXIDE	3.0	492.0
(4) ASBESTOS (1)	ASBESTOS FIBERS	6.9	1,169.0
(4) BARITE (1)	MISSOURI TYPE	1.7	279.9
	NEVADA TYPE	0.4	63.1
(2) BERYLLIUM	BERYLLIUM METAL	5,253.0	861,492.0
(2) BISMUTH	BISMUTH METAL	26.0	4,264.0
(4) BORAX (1)	BORAX	8.6	1,932.0
(4) BRICK (1)	COMMON BRICK	3.5	499.6
	FIRECLAY BRICK	4.2	592.3
(4) BROMINE (1)	ELEMENTAL BROMINE	14.8	2,954.7
(2) CADMIUM	CADMIUM METAL	160.0	26,240.0
(2) CESIUM	CESIUM METAL	528.0	86,592.0
(4) CLAY (1)	BENTONITE	2.0	281.4
	FIRECLAY	0.1	24.2
	KAOLIN	4.0	1,029.9
(2) COBALT	COBALT METAL	124.0	20,336.0
(2) COLUMBIUM	FERROCOLUMBIUM	189.0	30,996.0
(2) CORUNDUM AND EMERY	GRADED EMERY ABRASIVE GRAIN	2.1	344.4
(4) DIATOMITE (1)	CALCINED DIATOMITE	8.2	1,201.3
(4) FELDSPAR (1)	GROUND FELDSPAR	2.4	405.4
(4) FERROCHROMIUM (1)	HIGH-CARBON FERROCHROMIUM	61.3	11,487.2
	LOW-CARBON FERROCHROMIUM	128.6	26,025.4
(4) CHROME SILICIDE (1)	REVERT CHROME SILICIDE	125.8	23,718.2
(4) FERROMANGANESE (1)	FROM ELECTRIC ARC FURNACE	52.4	10,601.0
	FROM BLAST FURNACE	47.2	-94.8
(4) FERROSILICON (1)	FERROSILICON	27.1	14,522.1
(4) FLUORSPAR (1)	FLUORSPAR CONCENTRATES	5.1	829.7
(2) DIAMOND	INDUSTRIAL DIAMONDS (NATURAL)	720,000.0	118,080,000.0
(2) GALLIUM	GALLIUM METAL	11,677.0	1,915,028.0
(2) GARNET	SIZED GARNET	11.0	1,804.0
(2) GEM STONES	NATURAL GEM STONES	720,000.0	118,080,000.0
(2) GERMANIUM	GERMANIUM INGOT	2,145.0	351,780.0
(2) GOLD	GOLD BARS	58,855.0	9,652,220.0
(2) GRAPHITE	NATURAL GRAPHITE FLAKES AND FINES	35.0	5,740.0
(4) GYPSUM (1)	CALCINED GYPSUM	1.5	225.7
(2) HAFNIUM	HAFNIUM SPONGE	661.0	108,404.0
(2) INDIUM	INDIUM METAL	509.0	83,476.0
(2) IODINE	ELEMENTAL METAL	538.0	88,232.0
(2) KYANITE	RAW KYANITE	4.0	656.0
(2) LITHIUM	LITHIUM HYDROXIDE	396.0	64,944.0
(4) MAGNESIUM (1)	MAGNESIUM METAL FROM SEA WATER	358.2	64,349.8
(2) MERCURY	MERCURY METAL	395.0	64,780.0
(4) MICA (1)	GROUND MICA	16.4	3,389.8
(4) MOLYBDIC OXIDE (1)	MOLYBDIC OXIDE	144.7	23,864.3
(4) NICKEL (1)	NICKEL BY ELECTROREFINING	143.7	23,658.1
(4) OXYGEN (1)	GASBOUS OXYGEN FROM AIR	9.0	2,390.6
(2) PERLITE (1)	EXPANDED PERLITE	5.4	825.1
(2) PLATINUM	PLATINUM SPONGE	(3) N.A.	N.A.

TABLE 4.1 (CONTINUED)

SUMMARY TABLE OF CARBON DIOXIDE EMISSIONS FOR INTERMEDIATE
AND LOW PRIORITY PRIMARY PRODUCTS

COMMODITY	PRIMARY PRODUCT	ENERGY REQUIRED PER TON OF PRODUCT (1)	LBS OF CARBON DIOXIDE PER TON OF PRODUCT
(4) POTASSIUM CHLORIDE (D)	BY FLOTATION	2.6	444.8
	BY CRYSTALLIZATION	8.0	1,551.7
(4) PUMICE (D)	CRUSHED AND SIZED PUMICE	0.3	45.2
(2) QUARTZ CRYSTALS	MANUFACTURED QUARTZ CRYSTALS	1,120.0	183,680.0
	NATURAL QUARTZ CRYSTALS	N.A.	N.A.
(2) RADIUM	RADIUM SALT CRYSTALS	N.A.	N.A.
(2) RARE EARTH METALS	RARE EARTH OXIDES	41.3	6,773.2
(2) RHENIUM	RHENIUM POWDER	3,108.0	509,712.0
(2) RUBIDIUM	RUBIDIUM SPONGE	2,419.0	396,716.0
(4) SAND AND GRAVEL (D)	WASHED AND SIZED SAND AND GRAVEL	0.1	18.4
(2) SCANDIUM	SCANDIUM OXIDE	787.0	129,068.0
(2) SELENIUM	SELENIUM POWDER	297.0	48,708.0
(2) SILVER (D)	SILVER BARS	1,474.0	241,736.0
(4) SODIUM (D)	SODIUM METAL	119.0	21,432.3
(4) SALT (D)	SALT (NaCl)	4.8	1,087.9
(2) STONE	CRUSHED AND SIZED STONES	0.1	9.2
(2) STRONTIUM	CELESTITE (STRONTIUM SULFATE)	1.6	254.2
(4) TALC (D)	SIZED TALC	N.A.	153.1
(2) TANTALUM	TANTALUM POWDER	249.0	40,836.0
(2) TELLURIUM	TELLURIUM METAL	83.0	13,612.0
(2) THALLIUM	THALLIUM SPONGE	31.5	5,166.0
(2) THORIUM	THORIUM OXIDE	134.0	21,976.0
(2) TIN	TIN INCOIT	190.0	31,160.0
(4) TITANIUM (D)	KROLL PROCESS	423.0	73,383.9
	TWO-STAGE SODIUM REDUCTION PROCESS	370.3	65,873.4
	FROM RUTILE ORE (CHLORIDE PROCESS)	93.5	18,408.9
	FROM LEUCOXENE ORE (CHLORIDE PROCESS)	102.2	20,114.7
	FROM ILMENITE ORE (SULFATE PROCESS)	68.3	9,249.1
	FROM SOREL SLAG (SULFATE PROCESS)	94.0	14,545.9
(2) TUNGSTEN	TUNGSTEN POWDER	346.0	56,744.0
(4) URANIUM (D)	URANIUM OXIDE (ACID LEACH)	776.4	121,982.3
	URANIUM OXIDE (ALKALINE LEACH)	1,122.6	173,500.7
	URANIUM OXIDE ("RESIN-IN-PULP")	795.4	129,686.0
(2) VANADIUM	FERROVANADIUM	491.0	80,524.0
(4) VERMICULITE (D)	EXFOLIATED VERMICULITE	7.8	1,301.0
(2) YTTRIUM	YTTRIUM OXIDE	1,265.0	207,460.0
(2) ZIRCONIUM	ZIRCONIUM SPONGE	N.A.	N.A.
	BATCH CHLORINATION	1,491.0	244,524.0
	CONTINUOUS CHLORINATION	1,193.0	195,652.0

1) FROM REFERENCE 3.

2) ESTIMATED: MM BTU X 164 = LBS CARBON DIOXIDE

3) NOT AVAILABLE

4) CALCULATED DIRECTLY FROM CONVERSION FACTORS

D INTERMEDIATE PRIORITY

TABLE 4-2
CARBON DIOXIDE EMISSIONS FROM THE
U.S. AND WORLD PRODUCTION OF VARIOUS COMMODITIES

COMMODITY	U.S. PROD. (1) OF PRODUCT THOU. TON	U.S. PROD OF CARBON DIOXIDE THOU. TONS	WORLD PROD. (1) OF PRODUCT THOU. TON	WORLD PROD OF CARBON DIOXIDE THOU. TONS
ANTIMONY	20.7	315.8	27.2	415.2
ARGON	N.A.	N.A.	N.A.	N.A.
ARSENIC	0.0	0.0	60.5	14.9
ASBESTOS	55.8	32.6	4,413.8	2,579.9
BARITE	443.0	62.0	4,689.0	656.2
BERYLLIUM	0.2	104.2	0.1	59.0
BISMUTH	0.0	0.0	4.5	9.5
BORAX	689.0	665.6	2,209.0	2,133.9
BROMINE	167.5	247.5	255.8	377.9
CADMIUM	1.7	21.9	18.8	246.6
CAESIUM	0.0	0.0	N.A.	N.A.
CLAY	14,081.0	1,981.5	24,631.0	3,466.1
COBALT	1.8	18.1	29.7	301.9
COLUMBIUM	0.0	0.0	N.A.	N.A.
CORUNDUM AND EMERY	0.0	0.0	19.3	3.3
DIATOMITE	658.0	395.2	1,350.0	810.9
FELDSPAR	720.0	145.9	3,811.0	772.5
FERROCHROMIUM	118.0	677.7	2,995.0	17,202.1
CHROME SILICIDE	N.A.	N.A.	N.A.	N.A.
FERROMANGANESE	112.9	598.7	217.6	1,153.5
FERROSILICON	357.3	2,594.0	720.0	5,228.0
FLUORSPAR	70.0	29.0	5,174.0	2,146.4
DIAMOND	N.A.	N.A.	N.A.	N.A.
GALLIUM	NEG.	NEG.	0.0	21.1
GARNET	42.3	38.1	24.8	22.4
GEM STONES	NEG.	NEG.	0.0	59,040.0
GERMANIUM	0.0	2.4	0.0	1.1
GOLD	0.2	821.7	1.8	8,683.5
GRAPHITE	224.9	645.5	694.2	1,992.3
GYPSUM	15,612.0	1,761.9	98,897.0	11,161.0
HAFNIUM	N.A.	N.A.	N.A.	N.A.
INDIUM	0.0	0.0	0.0	0.9
IODINE	2.0	88.2	14.0	615.7
KYANITE	25.0	8.2	326.8	107.2
LITHIUM	N.A.	N.A.	300.5	9,757.8
MAGNESIUM	137.1	4,411.9	217.6	7,001.8
MERCURY	N.A.	N.A.	6.8	219.1
MICA	160.6	272.1	166.7	282.6
MOLYBDIC OXIDE	37.6	448.2	55.6	663.9
NICKEL	0.0	0.0	867.1	10,256.9
OXYGEN	N.A.	N.A.	N.A.	N.A.
PERLITE	533.0	219.9	1,296.0	534.7
PLATINUM	0.0	0.0	8,671.0	NEG.

(1) 1987 DATA FROM REFERENCE 18

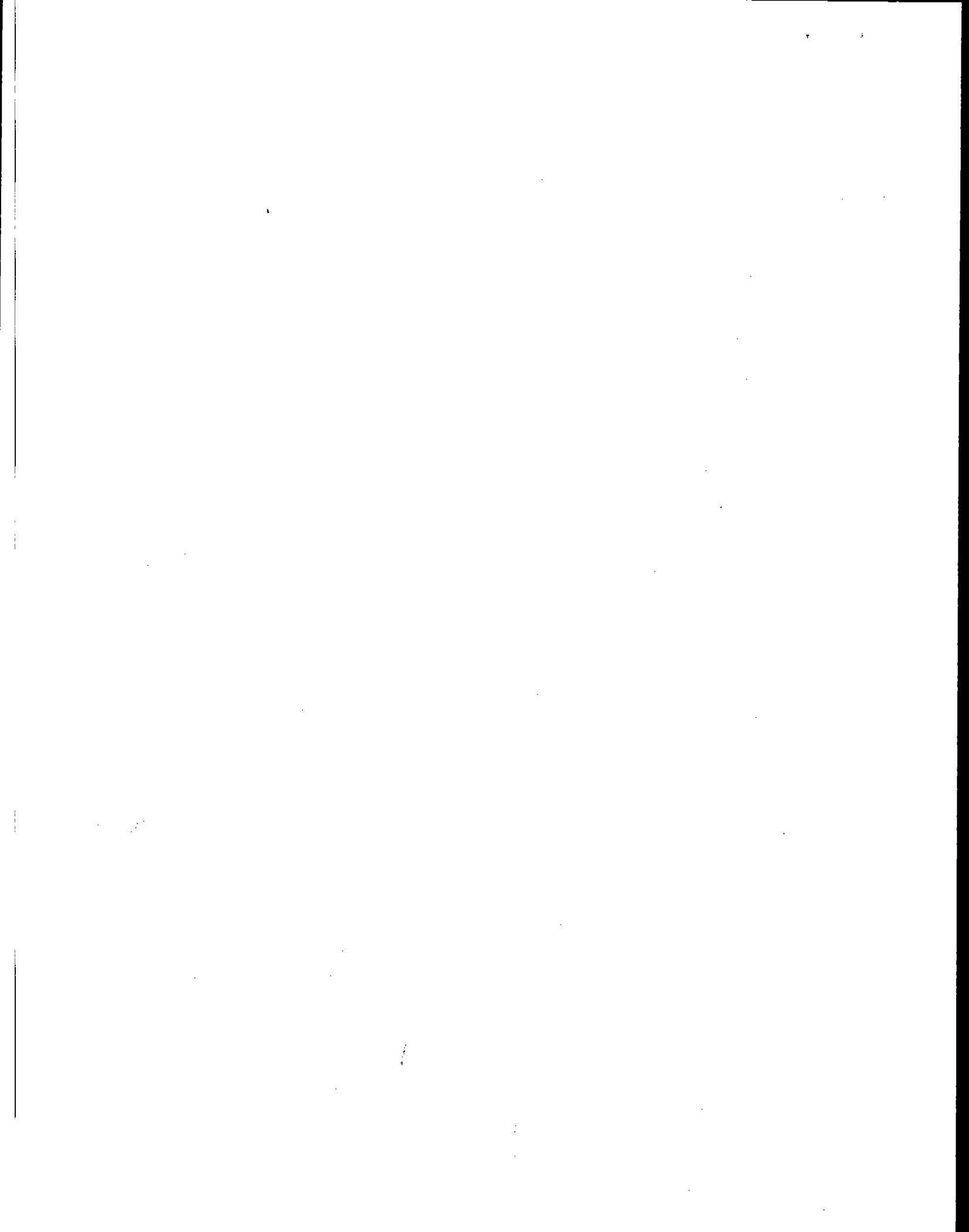


TABLE 4-2 (CONTINUED)
 CARBON DIOXIDE EMISSIONS FROM THE
 U.S. AND WORLD PRODUCTION OF VARIOUS COMMODITIES

COMMODITY	U.S. PROD. (1) OF PRODUCT THOU. TON	U.S. PROD OF CARBON DIOXIDE THOU. TONS	WORLD PROD. (1) OF PRODUCT THOU. TON	WORLD PROD OF CARBON DIOXIDE THOU. TONS
POTASSIUM CHLORIDE	1,391.4	309.4	28,550.0	6,349.5
PUMICE	392.0	8.9	11,361.0	256.8
QUARTZ CRYSTALS	N.A.	N.A.	N.A.	N.A.
RADIUM	N.A.	N.A.	N.A.	N.A.
RARE EARTH METALS	18.4	62.4	32.2	109.2
RHENIUM	0.0	2.8	0.0	5.1
RUBIDIUM	N.A.	N.A.	N.A.	N.A.
SAND AND GRAVEL	896,200.0	8,245.0	3,600,000.0	33,120.0
SCANDIUM	0.0	0.0	0.0	0.0
SELENIUM	0.0	0.0	0.7	16.7
SILVER	1.4	164.9	13.3	1,613.2
SODIUM	N.A.	N.A.	N.A.	N.A.
SALT	N.A.	N.A.	N.A.	N.A.
STONE	1,200,000.0	5,510.4	4,800,000.0	22,041.6
STRONTIUM	0.0	0.0	202.3	25.7
TALC	1,258.0	96.3	8,310.0	636.1
TANTALUM	N.A.	N.A.	N.A.	N.A.
TELLURIUM	0.0	0.0	0.0	0.3
THALLIUM	N.A.	N.A.	N.A.	N.A.
THORIUM	0.0	0.5	28.4	312.4
TIN	4.3	67.1	204.7	3,188.9
TITANIUM	19.7	721.9	32.0	1,174.1
TUNGSTEN	0.0	1.1	40.2	1,141.5
URANIUM	0.0	0.4	0.0	2.9
VERMICULITE	0.0	0.0	34.3	1,381.0
VANADIUM	N.A.	N.A.	N.A.	N.A.
YTRIUM	N.A.	N.A.	N.A.	N.A.
ZIRCONIUM	N.A.	N.A.	747.0	556.9
TOTAL		31,799.0		219,571.8

* WORLD ESTIMATES ACCORDING TO USBM PRIVATE COMMUNICATION

(1) 1987 DATA FROM REFERENCE 18

CHAPTER 5

RECYCLED PRODUCTS

Table 5.1 presents the summary of carbon dioxide emissions by commodity and process in secondary metal recycling. Table 5-2 gives the summary of production of recycled materials. Very little data exists on world recycling activities.

The use of secondary metals is clearly attractive from the point of both material conservation and energy conservation (with the consequent reduction of carbon dioxide emissions). IC 8791 (9) details the much lower energy requirements for utilizing recycled metals compared to producing primary metals. On the other hand, the IC also states that the results should be used with care, especially in view of the variety of energy intensive techniques that can be used for collecting scrap.

An example of energy intensive recycling can be seen in the use of heavy trucks in a stop-and-go mode to pick up 5 to 10 pound bundles of old newspapers throughout some suburban communities.

There is increased use of scrap steel at mini-mills in the United States, but the information in this report (see Table 6-1) shows that steel made in an electric arc furnaces produces 1.78 times as much carbon dioxide as does steel made from ore that is treated by conventional blast furnace and basic oxygen furnaces.

There is also a great deal of aluminum recycling in this country, mostly used beverage cans. It should be recognized, however, that the extent of this recycling can be constrained by the mixing of the two different alloys that are used for the tops and bodies of each can. The story of differing alloys of aluminum is one with a historical perspective. At the start of World War II, old pots and pans were collected in massive drives to supply metal for air frames. Most of it went to waste because the alloys collected were not suitable for any other uses.

Much of the problem of recycling revolves around the identification and separation of alloys that can be processed readily for reuse. While it may not have significant impact on overall carbon dioxide emissions, the problem of recycling increasingly more sophisticated materials should be addressed by R & D.

TABLE 5-1

SUMMARY OF CARBON DIOXIDE EMISSIONS BY COMMODITY
AND PROCESS IN SECONDARY METAL RECYCLING

COMMODITY/PROCESS	PRODUCT	LBS CARBON DIOXIDE PER TON OF PRODUCT
ALUMINUM:		
REVERB MELTING ALUMINUM SCRAP	INGOTS (CASTINGS ALLOY)	924.0
DO	HOT METAL (CASTINGS ALLOY)	2,737.2
REVERB MELTING ALUMINUM CANS.	HOT METAL (CAN STOCK)	1,259.5
COPPER:		
REVERB MELTING No.1 SCRAP	WIREBAR	511.4
ANODE FURNACE/ELECTROLYTIC REFINING	DO	11,439.5
No.2 COPPER SCRAP		
CUPOLA/CONVERTER/ELECTROLYTIC REFINING	DO	16,867.0
LOW-GRADE COPPER SCRAP		
REVERB MELTING BRASS/BRONZE SCRAP.	BRASS OR BRONZE INGOTS	1,062.7
IRON AND STEEL:		
ELECTRIC ARC FURNACE	CONTINUOUSLY CAST BLOOMS/BILLETS	1,511.4
	CASTINGS	5,182.0
CUPOLA.		
LEAD:		
POT MELTING	INGOTS	86.8
BLAST FURNACE ALONE (HARD LEAD)	DO	1,416.8
BLAST FURNACE/REVERB FURNACE COMBINATION:		
HARD LEAD FROM BLAST FURNACE	DO	2,699.9
NICKEL ALLOYS:		
INDUCTION MELTING (DOUBLE VACUUM)	DO	3,358.7
AIR INDUCTION MELTING.	DO	1,888.2
STAINLESS STEEL: ARGON-OXYGEN-	STRAND CAST BILLETS	1,802.4
DECARBURIZATION (AOD).		
TIN: TIN-RECOVERY FROM DETINNING LEACH	ELECTROLYTIC TIN	25,805.1
SOLUTION BY ELECTROWINNING.		
TITANIUM: VACUUM ARC FURNACES.		6,103.0
(DOUBLE MELTING)		
ZINC:		
DISTILLATION RETORTS	ZINC DUST	3,247.8
MUFFLE FURNACES	ZINC DUST	2,688.0
POT MELTING CLEAN DIECASTINGS	CAST ALLOYS	363.7
POT MELTING OFF-SPECIFICATION DIE CASTINGS.	DO	458.9

TABLE 5-2
SUMMARY TABLE OF RECYCLED PRODUCTS

PRODUCT	U.S. PROD. OF PRODUCT THOU. TON	WORLD PROD. OF PRODUCT THOU. TON
ALUMINUM	2,189.2	N.A.
COPPER	304.9	613.7
LEAD	782.9	1,921.3
TIN	1.3	N.A.
NICKEL	46.7	N.A.
STAINLESS STEEL	1,155.0	N.A.
TITANIUM	N.A.	N.A.
ZINC	72.7	270.7
MUNICIPAL SOLID WASTE	1,825.0	N.A.

CHAPTER 6

DISCUSSION OF FINDINGS

Seven commodities amount for most (83%) of the carbon dioxide emissions related to metallurgical and nonmetallic mineral processing. The distribution of the major sources of carbon dioxide is shown for these commodities in Table 6-1. This information is based on the contract reports (1, 2, 3, 9) from which the estimated carbon dioxide emissions were derived. As energy efficiencies in all industrial sectors have improved, the quantities of carbon dioxide emissions have decreased. The consequent quantities could be documented for only three commodities:

Reduction in Carbon Dioxide	Emissions Per Ton Produced
Portland Cement	17.2%
Aluminum	26.0%
Quicklime	10.6%

Details of the reductions based on recent information from the industries is shown in Table 6-2, which follows the same format as Table 6-1.

No new information was obtained on chlorine, ammonia, or copper.

The steel industry has reduced its energy consumption by 34% between 1972 and 1988. This single piece of information cannot be used to estimate the change in carbon dioxide emissions from the major sources for producing both BOF and electric arc furnace steel. There are two reasons. First, there is noteworthy differences in the carbon dioxide emissions from each method of steel making. That is, 876 pounds of carbon dioxide per ton of BOF steel and 1,556 pounds of carbon dioxide per ton of EAF steel, both taken to the initial raw steel from the furnace. Between 1972 and 1988, U.S. production of BOF steel has been cut by 30%, while electric arc furnace increased by 34%. Second, the reduction reported by the

Table 6-1

**Commodities With Highest CO₂ Emissions
(lbs. and % CO₂ per ton commodity)**

CO ₂ Source	Cement	Aluminum	Chlorine (liquid)	Steel BOF	Steel EAF	NH ₃	Lime	Copper
Calcination	1,145 45.7%						1,570 50.1%	
Elec. Energy	216 8.6%	29,646 65.9%	6,475 61.3%	54 6.2%	1,000 64.3%	51 1.0%	105 3.3%	8,903 47.7%
Fuel	1,099 43.9%	1,791 4.0%		27 3.1%	13 0.8%	5,138 99.0%	1,418 45.2%	6,942 37.2%
Steam		6,906 15.3%	3,879 36.7%					118 0.6%
Process Materials		2,294 5.1%						2,069 11.1%
Electrodes		3,897 8.7%			177 11.4%			
Iron Feed				349 39.8%	51 3.3%			
Slag Formers				220 25.1%	109 7.0%			
Oxygen				61 7.0%	8 0.5%			
Alloy Additions				130 14.8%	130 8.3%			
Other Source	46 1.8%	466 1.0%	204 2.0%	35* 4.0%	68* 4.4%	2 0.0%	42 1.4%	622 3.4%
Total	2,506 100%	45,000 100%	10,558 100%	876 100%	1,556 100%	5,191 100%	3,135 100%	18,654 100%

* Refractories

Table 6-2

Recent Estimates of CO₂ Emissions
(lbs. and % CO₂ per ton commodity)

CO ₂ Source	Cement	Aluminum	Lime
Calcination	1,145 55.2%		1,570 56.0%
Elec. Energy	246 11.9%	23,290 70.0%	105 3.8%
Fuel	637 30.7%	872 2.6%	1,086 38.7%
Steam		3,229 9.7%	
Process Materials		2,295 6.9%	
Electrodes		3,128 9.4%	
Other Sources	46 2.2%	465 1.4%	42 1.5%
Total	2,074 100%	33,279 100%	2,803 100%

American Iron and Steel Institute covers more than the production of the steel from the furnace - it includes all shaping and treating steps up to the shipping of final products (e.g. sheet steel) from the steel plant. For comparison, it should be noted that the total energy used by the primary aluminum industry, only 83% was used in 1985 to produce aluminum metal from the Hall cells.

In discussing Table 6-1, it should be noted that improvements in technology and improved efficiencies will help reduce carbon dioxide from most of the sources. However, there is one - decomposition of carbonate minerals - that cannot be changed. This is a significant source of carbon dioxide emissions. In 1987, it accounted for 750,000,000 tons added by world production of Portland cement and quicklime.

On the other hand, these commodities have benefited from significant improvements in energy utilization in the last decade or so. Both Portland cement and quicklime processing have lowered energy use of about 20%. This has lowered carbon dioxide emissions 10%, or about 150,000,000 annual tons of carbon dioxide.

According to the Aluminum Association, energy utilization has improved 22% since the Battelle report (1) was released. Much has been accomplished with heat recovery and conservation, but the greatest improvement has been in the reduction process, which uses immense quantities of electricity. In recent years the efficiency of the reduction cells has been increased from 30% to between 40% and 50%. Of further benefit to the carbon dioxide situation, much of the expansion in the industry has taken place in regions of the world where abundant hydroelectricity is generated.

Future improvements in the carbon dioxide emissions related to aluminum might come from several factors:

- * Greater use of electricity from sources that do not use fossil fuels. This means a reassessment of the Nation's position on nuclear power. In 1988, only 19.5% of the U.S. power generation was nuclear. On the other hand, both France and Belgium both have well over 60% nuclear power generation.

- * Use of permanent anodes in the reduction cell. This would replace the carbon anode manufacturing step, and lower carbon dioxide by 10%.

- * A different processing route, such as aluminum chloride reduction in a non-carbon bipolar cell would lower carbon dioxide emissions 10%.

Energy reduction recently in the steel industry has not been dramatic, but it has been significant - on the order of 10-15% - with a consequent reduction in the

carbon dioxide emissions. This has been accomplished with improved heat recovery and fuel efficiency.

A major processing change in the steel industry has been the increased use of mini-mills to make new steel from recycled scrap using electric arc furnaces. Table 6-1 shows that, while this is economically attractive and conserves materials, this process path produces 178 percent of the carbon dioxide that the BOF does using ore processed in a blast furnace.

Recycling metals does indeed lower some carbon dioxide emissions. IC 8781 (9) showed that scrap aluminum used only 6.2% of the energy that primary aluminum required to produce alloy 380-type ingot. There is a comparable energy reduction (and consequent carbon dioxide reduction) from recycling can stock. However, all aluminum cannot be recycled because of the problems of mixing alloys. Purification to pure aluminum is almost as difficult as producing primary metal from ore.

For copper, two areas present opportunities to reduce carbon dioxide emissions:

- * Transportation in mining accounts for 2.7% of the carbon dioxide. Better materials handling, such as belt conveyors, could lower this figure significantly.
- * In-place leaching could have a major impact. This would be even greater if the carbon dioxide factor for electricity (for pumping) were lower by increased use of nuclear power generation.

TABLE A-III
 CARBON DIOXIDE EMISSIONS FROM THE
 PRODUCTION OF PORTLAND CEMENT

	UNITS	UNITS PER TON OF PORTLAND CEMENT	LBS OF CARBON DIOXIDE RELEASED PER UNIT	LBS OF CARBON DIOXIDE NET TON OF CEMENT
RAW MATERIAL PREPARATION				
LIMESTONE				
MINING (1.37 TON/TON)	MM BTU	0.0630	164.0000	10.3
TRUCK TRANSPORTATION (3 MILES)	TON-MILE	4.3000	0.3980	1.6
DRYING, NATURAL GAS	CUFT	222.0000	0.1340	42.9
SUBTOTAL				54.8
CLAY AND SHALE				
MINING (0.144 TON/TON)	MM BTU	0.0100	164.0000	1.6
TRUCK TRANSPORTATION (3 MILES)	TON-MILE	0.4320	0.3980	0.2
SUBTOTAL				1.8
SAND AND MISCELLANEOUS				
MINING (0.057 TON/TON)	MM BTU	0.0340	164.0000	5.6
TRUCK TRANSPORTATION (3 MILES)	TON-MILE	5.7000	0.1110	0.5
SUBTOTAL				6.2
CRUSHING AND MILLING				
CRUSHING	KWH	9.0000	1.8180	16.4
MILLING	KWH	30.0000	1.8180	54.5
OTHER	KWH	2.0000	1.8180	3.6
SUBTOTAL				74.5
SUBTOTAL OF RAW MATERIAL PREPARATION				137.4
CLINKER BURNING				
LIMESTONE CALCINATION	TON	1.3700	835.4400	1144.6
COAL	TON	0.0908	5,771.0000	524.0
COAL TRANSPORTATION (400 MILES BY RAIL)	TON-MILE	36.3000	0.1110	4.0
RESIDUAL FUEL OIL	GAL	6.8224	26.2000	179.0
NATURAL GAS	CUFT	2,636.0000	0.1340	353.2
REFRACTORIES	TON	0.0010	5,245.0000	5.2
ELECTRICAL ENERGY	KWH	12.0000	1.8180	21.8
ELECTRICAL ENERGY (COOLER FAN)	KWH	7.0000	1.8180	12.7
SUBTOTAL				2244.6
AIR POLLUTION CONTROL				
ELECTRICAL ENERGY	KWH	5.0000	1.8180	9.1
SUBTOTAL CLINKER BURNING				2253.7
CLINKER MILLING				
ELECTRICAL ENERGY	KWH	50.0000	1.8180	90.9
OTHER	KWH	4.0000	1.8180	7.3
GYPHUM	TON	0.0480	225.7000	10.8
GYPHUM TRANSPORT	TON-MILE	4.8000	0.1110	0.5
GRINDING BALLS	LBS	2.0000	2.8700	5.7
SUBTOTAL CLINKER MILLING				115.3
TOTAL				2,506.4

APPENDIX C

CONVERSION FACTORS FOR CO₂ EMISSIONS

Item	unit	lbs. CO ₂ to produce per unit	lbs. CO ₂ from C per unit	lbs. CO ₂ emissions per unit
<u>Fuels and energy source</u>				
Anthracite Coal, 85% C	ton	92	6,239	6,331
Bituminous Coal, 78% C	ton	46	5,725	5,771
Bituminous Coking Coal, 78% C	ton	46	5,725	5,771
Metallurgical Coke 90% C	ton	391.3	6,606	6,997.3
Coke Breeze, 90% C	ton	391.3	6,606	6,997.3
Petroleum Coke (calcined), 90% C	ton	401.2	6,606	7,007.2
Wood, 49.5% C	ton	-	3,633	3,633
Cereal, 40% C	lb	-	1.47	1.47
Tar & Pitch, 90% C	gal	-	33.0	33.0
	lb.	-	3.3	3.3
Distillate Fuel Oil (Diesel)	gal	-	23.0	23.0
Residual Fuel Oil	gal	-	26.2	26.2
Gasoline	gal	-	17.48	17.48
Kerosine	gal	-	20.84	20.84
Natural Gas	ft ³	-	0.134	0.134
LPG	gal	-	15.68	15.68
Propane	gal	-	13.87	13.87
	lb	-	3.00	3.00
Propane/Butane	gal	-	14.78	14.78
Acetylene	ft ³	-	0.232	0.232
Coke Oven Gas	ft ³	-	0.051	0.051
Blast Furnace Gas	ft ³	-	0.045	0.045
Carbon Monoxide	ft ³	-	0.116	0.116
Hydrogen	ft ³	0.176	-	0.176
Other Fuels	Mil. Btu	-	-	164
Electricity	kwh	1.818	-	1.818
Steam (plant prod. from coal-fired and waste-heat boilers)	lb	0.252	-	0.252
Steam (saturated steam at 100 psi from coal- fired boilers)	lb	0.353	-	0.253

Oxygen (420 kwh/ton)	ton	763.56	-	763.56
Oxygen (17.4 kwh/1000 cu. ft.)	ft ³	0.0316	-	0.316
Argon	ft ³	0.0453	-	0.045
Helium	ft ³	0.086	-	0.086
Limestone (- 4 inches)	ton	39.69	835	874.7
Lime (for steelmaking)	ton	982	1,570	2,555
Fluorspar (for steel)	ton	63.5	-	263.5
Iron Ore	ton	120.5	-	20.5
Iron Ore Pellets	ton	437.3	-	437.3
Iron Ore Sinter	ton	686.2	-	686.2
Carbon Electrodes	lb.	5.49	3.67	9.16
Graphite Electrodes	lb.	11.06	3.67	14.73
Soderberg Paste	ton	363.4	7,739	8,102.4
Explosives (ammonium nitrate)	lb	4.92	-	4.92
Caustic Soda (solid)	ton	7,146	-	7,146
Pig Iron	on	441.0	-	441.0
Soda Ash (natural)	ton	46.0	926.0	972.0
(synthetic)	ton	-	830	830
Other Materials	Mil. Btu	-	-	16

Transportation

Truck	Ton-mile	-	-	0.398
Rail	Ton-mile	-	-	0.111
Water	Ton-mile	-	-	0.042

BASIS OF CONVERSION FACTORS FOR CO₂ EMISSIONS

The basis for calculating conversion factors for CO₂ emissions is "Energy Use Patterns in Metallurgical and Non metallic Mineral Processing" (1, 2, 3) and BuMines Inf. Circ. 8781 (9). Other sources of information for estimating CO₂ emissions related to the various processes are shown in the list of references.

It should be noted that typical fuels and materials have been cited rather than average ones.

Anthracite Coal

- Requires twice the energy to mine as bituminous coal (1, p. 4). Assume twice the CO₂ emissions

$$46 \text{ lbs. CO}_2/\text{ton bituminous coal} \times 2 = 92 \text{ lbs./ton anthracite coal}$$

- Assume carbon content is 85% (16, pp. 62, 279)

1 ton contains 1,700 lbs. C

$$1 \text{ ton yield } 1,700 \text{ lbs. C} \times 3.67 \text{ lbs. CO}_2/\text{lb. C} = 6,239 \text{ lbs. CO}_2$$

- Total CO₂ = 92 + 6,239 = 6,331 lbs. CO₂/ton anthracite coal.

Bituminous Coal

- Mining requires 250,000 Btu/ton plus 1.02 lbs. explosives/ton (1, p.175). Conversion factor for energy is the same as that for "Other Fuel" as a first approximation.

$$250,000 \text{ Btu/ ton coal} \times 164 \text{ lbs. CO}_2/\text{million Btu} = 41 \text{ lbs. CO}_2/\text{ton coal mined}$$

$$1.02 \text{ lbs. explosives/ton coal} \times 4.92 \text{ lbs. CO}_2/\text{lb. explosive} = 5.02 \text{ lbs. CO}_2/\text{ton coal mined}$$

$$\text{Total for mining} = 46 \text{ lbs. CO}_2/\text{ton coal}$$

- Assume carbon content is 78% C (11, p.241, 16, p. 62)

1 ton contains 1,560 lbs. C

$$1 \text{ ton yields } 1,560 \text{ lbs. C} \times 3.67 \text{ lbs. CO}_2/\text{lb. C} = 5,725 \text{ lbs. CO}_2$$

- Total CO₂ = 46 + 5,725 = 5,771 lbs. CO₂/ton bituminous coal

Bituminous Coking Coal

- Assumed to be the same CO₂ as bituminous coal

Metallurgical Coke

- Manufacture of coke - 391.3 lbs. CO₂/ton

This is from Table C-2, CO₂ Emissions to Manufacture Metallurgical Coke

- Assume carbon content is 90% C

1 ton yields 2,000 lbs. coke x 0.90 lbs. C/lb. coke x
3.67 lbs. CO₂/lb. C = 6,606 lbs. CO₂/ton coke

- Total CO₂ = 391.3 + 6,606 = 6,997.3 lbs. CO₂/ton coke

Coke Breeze

- Assumed to be the same as CO₂ as metallurgical coke.

Petroleum Coke

- Assume 90% C (13, p. 9-7)

1 ton yields 6,606 lbs. x CO₂/ton coke

- Calcination of raw-petroleum coke requires fuel and power that results in 401.2 lbs. CO₂/ton raw-coke calculated from "Calcination" steps of Table C-6, CO₂ Emissions to Produce Electrode Graphite.

- Total CO₂ for calcined petroleum coke = 7,007.2 lbs. CO₂/ton

Wood

- Assume 49.5% C (14, p. 75)

1 ton yields 3,633 lbs. CO₂/ton wood

Cereal

- Assume cellulose, which is 40% C
1 lb. cereal yields 1.47 lbs. CO₂/lb. cereal

Tar and Pitch

- Tar is 90% C (16, p. 73); its specific gravity is 1.2 (17, p.563).
 - 1 gal. tar weighs 8.345 lbs. H₂O/gal. $\times 1.2 = 10.01$ lbs.
 - CO₂ = 10.01 lbs. tar $\times 0.9 \times 3.67$ lbs. CO₂/lb. C = 33.08 lb. \times CO₂/gal. tar = 3.31 lbs. CO₂/lb. tar
- Assume pitch is 90% C; its specific gravity is 1.11 (17, p. 563)
 - 1 gal pitch weighs 9.26 lbs./gal.
 - CO₂ = 30.6 lbs. CO₂/gal. pitch = 3.30 lbs. CO₂/lb. pitch

Distillate Fuel Oil (Diesel)

- Specific gravity 33° API No. 2 fuel oil (Diesel) is 0.86 (13, p. 9-10). 1 gal. oil weighs 0.86 \times 8.345 lbs./gal. H₂O = 7.18 lbs.
- Diesel oil is 87.3% C
- CO₂ = 7.18 \times 0.873 \times 3.67 lbs. CO₂/lb. C = 23.0 lbs. CO₂/gal. oil

Residual Fuel Oil

- Specific gravity 12.6° API No. 6 fuel oil is 0.98 (13,p. 9-10) 1 gal. = 8.18 lbs.
- Low sulfur No. 6 fuel oil is 87.26% C
- CO₂ = 8.18 \times 0.8726 \times 3.67 lbs. CO₂/lb. C = 26.2 lbs. CO₂/gal. oil

Gasoline

- Specific gravity heptane = 0.68 (4, p. 7-238) 1 gal. = 5.67 lbs.
- Assume 84% C (12, p.2358)
- $\text{CO}_2 = 5.67 \times 0.84 \times 3.67 \text{ lbs. CO}_2/\text{lb. C} = 17.48 \text{ lbs. CO}_2/\text{gal. gasoline}$

Kerosine

- Specific gravity = 0.81 (6)
- 84% C (12, p. 2358)
- $\text{CO}_2 = 8.3453 \text{ lbs. H}_2\text{O}/\text{gal.} \times 0.81 \times 0.84 \times 3.67 \text{ lbs. CO}_2/\text{lb. C} = 20.84 \text{ lbs. CO}_2/\text{gal. kerosine}$

Natural Gas

- Reference 16 gives a typical natural gas with products of combustion that include $1.15 \text{ ft}^3 \text{ CO}_2/\text{ft}^3$ natural gas.
- Reference 10 says natural gas is at least 85% methane (p. 10). Typical analysis of a dry gas (p. 256) shows contents that will yield $1.15 \text{ ft}^3 \text{ CO}_2/\text{ft}^3$ natural gas.
- The specific gravity of CO_2 at 60° and 30 in. Hg is 1.5282 (air is 1.0) (16, p. 53). At the same conditions the weight of air is 0.076 lbs./ft^3 (16, p. 55).
- $\text{CO}_2 = 1.15 \text{ ft}^3 \text{ CO}_2 \times 0.076 \text{ lbs./ft}^3 \times 1.5282 = 0.134 \text{ lbs. CO}_2/\text{ft}^3 \text{ natural gas}$

LPG (Liquified Petroleum Gas)

- Byproduct in petroleum refining; butane, isobutane, propane, propylene, butylenes, and their mixtures (6).
- Calculate as butane
- Density = 38.59 lbs./ft³ (7, p. 2565)
 $38.59 \text{ lbs./ft}^3 \times 1 \text{ ft}^3 / 7.48 \text{ gal.} = 5.16 \text{ lbs./gal.}$
- Carbon content of C₄H₁₀ is 82.8%
- CO₂ = 5.16 lbs./gal. butane \times 0.828 \times 3.67 lbs.
CO₂/lb. C = 15.68 lbs. CO₂/gal. butane

Propane

- Density = 34.54 lbs./ft³ (7, p. 2565)
 $34.54 \text{ lbs./ft}^3 \times 1 \text{ ft}^3 / 7.48 \text{ gal.} = 4.62 \text{ lbs./gal.}$
- Carbon content of C₃H₈ = 81.8%
- CO₂ = 4.62 lbs./gal. \times .818 \times 3.67 lbs. CO₂/lb. C = 13.87 lbs. CO₂/gal.
propane

Propane/Butane

- Assume mixture of equal parts
- CO₂ = average of CO₂ for propane and butane = 14.78 lbs. CO₂/gal.
mixture

Acetylene (16, p.53)

- 1 ft³ C₂H₂ gives 2 ft³ CO₂
- CO₂ = 2 ft³ CO₂ \times 0.076 lbs. air/ft³ \times 1.5282 lbs.
CO₂/lb. air = 0.232 lbs. CO₂/ft³ C₂H₂

Coke Oven Gas (16, p. 57)

- Coke oven gas yields $0.438 \text{ ft}^3 \text{ CO}_2/\text{ft}^3$ coke oven gas
- $\text{CO}_2 = 0.438 \text{ ft}^3 \text{ CO}_2/\text{ft}^3 \text{ gas} \times 0.076 \text{ lbs. air}/\text{ft}^3 \times 1.5282 \text{ lbs. CO}_2/\text{lb. air} = 0.051 \text{ lbs. CO}_2/\text{ft}^3 \text{ gas}$

Blast Furnace Gas (16, p.57)

- Blast furnace gas yields $0.390 \text{ ft}^3 \text{ CO}_2/\text{ft}^3$ gas
- $\text{CO}_2 = 0.390 \text{ ft}^3 \text{ CO}_2/\text{ft}^3 \text{ BF gas} \times 0.076 \text{ lbs. air}/\text{ft}^3 \times 1.5282 \text{ lbs. CO}_2/\text{lb. air} = 0.045 \text{ lbs. CO}_2/\text{ft}^3 \text{ BF g}$

Carbon Monoxide

- CO yields $1 \text{ ft}^3 \text{ CO}_2/\text{ft}^3 \text{ CO}$
- $\text{CO}_2 = 1 \text{ ft}^3 \text{ CO}_2/\text{ft}^3 \text{ CO} \times 0.076 \text{ lbs. air}/\text{ft}^3 \times 1.5282 \text{ lbs. CO}_2/\text{lb. air} = 0.116 \text{ lbs. CO}_2/\text{ft}^3 \text{ CO}$

Hydrogen (15, pp. 98-102)

- H₂ frequently manufactured by electrolysis of alkalized water or by steam-hydrocarbon reforming

In the steam-hydrocarbon reforming process:

- 35 lbs. CO₂/1,000 ft³ H₂ is produced

- To produce 1,000 ft³ H₂ by low pressure reforming requires:

0.5 kwh power
240 lbs. steam
215,000 Btu fuel

- CO₂ for operation:

Power: $0.5 \text{ kwh} \times 1.818 \text{ lbs. CO}_2/\text{kwh} = 0.909 \text{ lbs. CO}_2/1,000 \text{ ft}^3 \text{ H}_2$

Steam: $250 \text{ lbs. steam} \times 0.353 \text{ lbs. CO}_2/\text{lb. steam} = 88.72 \text{ lbs. CO}_2/1,000 \text{ ft}^3 \text{ H}_2$

Fuel: $250,000 \text{ Btu} \times 0.00006876 \text{ lbs. C/Btu} \times 3.67 \text{ lbs. CO}_2/\text{lbs. C} = 54.3 \text{ lbs. CO}_2/1,000 \text{ ft}^3$ (Source 17,p.549) + $0.909 + 88.72 + 54.3 = 143.9 \text{ lbs. CO}_2/1,000 \text{ ft}^3 \text{ H}_2$

- Total CO_2 from operation as well as that produced from the operation
 $143.9 + 35/1,000 = 0.179 \text{ lbs. CO}_2/\text{ft}^3 \text{ H}_2$

• In the electrolysis of alkalized water:

- $7 \text{ ft}^3 \text{ H}_2$ are produced per kwh

$\text{CO}_2 = 1.818 \text{ lbs. CO}_2/\text{kwh} \times 1 \text{ kwh}/7 \text{ ft}^3 \text{ H}_2 = 0.260 \text{ lbs. CO}_2/\text{ft}^3 \text{ H}_2$

- $3.5 \text{ ft}^3 \text{ O}_2$ are also produced

- Prorating CO_2 yields $0.260 \text{ lbs. CO}_2/\text{ft}^3 \text{ H}_2 \times 2/3 = 0.173 \text{ lbs. CO}_2/\text{ft}^3 \text{ H}_2$

• Average CO_2 for the two processes is $0.176 \text{ lbs. CO}_2/\text{ft}^3 \text{ H}_2$

Other fuels

• Battelle reports give only Btu value for "other fuels". It is reported to be function of dollar values.

• Using heat of combustion data from U.S. Steel (16,p.53), one can calculate the fraction from C in each fuel:

<u>Fuel</u>	<u>%C</u>	<u>% BTU's From C</u>
Diesel Oil	87.3	65
Bituminous coal	78.0	88
Natural Gas	74.5	45
Gasoline	84.0	59

- If "other fuels" are assumed to be equal parts of each, the average is 64.25% of the heat of combustion from C.
- For this report, assume 65% of the heat of combustion of "other fuels" is from C, which is the same as diesel oil.
- Using Vilbrandt's interconversion table for units of energy (17, p. 549).

$$1 \text{ Btu} = 0.00006876 \text{ lbs. C/Btu} \times 0.65 \text{ Btu from C/Btu} \times 3.67 \text{ lbs. CO}_2/\text{lb. C}$$

$$= 163.6 \times 10^6 \text{ lbs. CO}_2/\text{Btu "other fuels"}$$

$$\text{CO}_2 = 164 \text{ lbs. CO}_2/10^6 \text{ Btu "other fuels"}$$

Electricity

- 1988 Power Generation

<u>Source</u>	<u>Million kwh</u>	<u>%</u>
Coal	1,538,203	56.9
Petroleum	148,819	5.5
<u>Natural Gas</u>	<u>252,779</u>	<u>9.4</u>
Subtotal	1,939,801	71.8
Hydro	222,938	8.3
Nuclear	526,901	19.5
<u>Other</u>	<u>11,983</u>	<u>0.4</u>
Total	2,701,623	100.0
Imported (Canada & Mexico)	35,000	1.3
Exported	6,000	0.2

- 1988 fossil fuel steam generation heat rate = 10,253 Btu/kwh

Battelle used 10,500 Btu/kwh in 1973

- 1988 fossil fuels used for power generation:

- Coal, 757,520,000 tons

Assume 78% C

CO₂ factor = 2.82 lbs. CO₂/kwh from coal

- Petroleum, 247,768,000 bbls: plus petroleum coke; 409,000 tons

Bunker "C" fuel oil with a typical analysis (Sun Oil Co.) (16, p. 73):
88.60% C, 7.935 lbs./gal.

Petroleum coke, 90% C

Carbon from fuel oil = $72,354 \times 10^6$ lbs.

Carbon from petroleum coke = 736×10^6 lbs.

CO₂ factor = 1.80 lbs. CO₂/kwh from petroleum

Natural gas, 2,634,804,000,000 ft³

CO₂ factor = 1.21 lbs. CO₂/kwh from natural gas

- Combined CO₂ factor per 1988 U.S. Kwh:

0.539 kwh from coal x 2.82 lbs. CO₂/kwh = 1.605 lbs. CO₂

0.055 kwh from petroleum x 0.180 = 0.099

0.094 kwh from gas x 1.21 = 0.144

Total 1,818 lbs. CO₂/kwh

Steam (plant production from coal-fired and waste-heat boilers)

- Battelle used industrial information (1 p. 182) for heat value of this steam, which is 1,000 Btu/lb.

- Using Vilbrandt's interconversion table for units of energy (17, p. 549):

1 lb. steam (from waste heat) = 1,000 Btu x -.00006876 lbs. C /Btu x 3.67
lbs. CO₂/lb. C

- CO₂ = 0.252 lbs. CO₂/lb. steam

Steam (saturated, 100 psi, coal-fired boiler)

- Battelle used steam table data for 100 psi saturated steam with enthalpy content of 1,190 Btu/lb. and corrected for a boiler efficiency of 85%. Resulting value was 1,400 Btu/lb. steam (1, p. 182).

- Using Vilbrandt (17, p. 549)

1 lb. steam (100 psi, coal-fired) = 1,400 Btu \times 0.00006876 lbs. C/Btu \times 3.67 lbs. C/lb. C

- $\text{CO}_2 = 0.353 \text{ lbs. CO}_2/\text{lb. steam}$

Oxygen

- Energy equivalents taken from Battelle reports

- 420 kwh/ton is based on steel operations (1, p. 182)

$\text{CO}_2 = 420 \text{ kwh/ton O}_2 \times 1.818 \text{ lbs. CO}_2/\text{kwh} = 763.56 \text{ lbs. CO}_2/\text{ton O}_2$

- 17.4 kwh/1,000 ft³ is same basis (2, p. 96)

$\text{CO}_2 = 0.0174 \text{ kwh/ft}^3 \text{ O}_2 \times 1.818 \text{ lbs. CO}_2/\text{kwh} = 0.0316 \text{ lbs. CO}_2/\text{ft}^3 \text{ O}_2$

Argon

- This report estimated 801.9 lbs. CO₂/ton Ar, or 0.401 lbs. CO₂/lb. Ar.

- Ar density is 0.0017824 g/cc (4, p. 4-24), or 0.1113 lbs./ft³

- $\text{CO}_2 = 0.1113 \text{ lbs./ft}^3 \text{ Ar} \times 0.401 \text{ lbs. CO}_2/\text{lb. Ar} = 0.0453 \text{ lbs. CO}_2/\text{ft}^3 \text{ Ar}$

Helium

- Battelle (3, p. A-1) used Bu Mines L.C. 8018 to estimate energy for He at 640 Btu/ft³
- Using 1,000 Btu/ft³ natural gas, one can calculate:

$$\text{CO}_2 = 640 \text{ Btu/ft}^3 \text{ He} / 1,000 \text{ Btu/ft}^3 \text{ CH}_4 \times 0.134 \text{ lbs.}$$

$$\text{CO}_2/\text{ft}^3 \text{ CH}_4 = 0.086 \text{ lbs. CO}_2/\text{ft}^3 \text{ He}$$

The basis of conversion factors for CO₂ emissions for the following materials are based on appendix tables in the Battelle reports (1, 2, 3):

Limestone (minus 4 inches)
Lime (for steelmaking)
Fluorspar (for steelmaking)
Iron ore
Iron ore pellets
Iron ore sinter
Graphite electrodes
Soderberg paste

Those tables revised for CO₂ emissions follow this section of this report.

Carbon Electrodes

- CO₂ for this material is the same as that for graphite electrodes without the graphitizing and machinery steps.

Explosives

- The Battelle reports gave only the energy for explosives as 30,000 Btu/lb.
- Assume that the "other fuels" conversion factor of 164 lbs. CO₂/10⁶ Btu will give a first approximation.
- CO₂ = 30,000 Btu/lb. explosives x 164 lbs. CO₂/10⁶ Btu 4.92 lbs. CO₂/lb. explosives

Caustic Soda (solid)

- This report estimates 6,146 lbs. CO₂/ton caustic soda in a 50% solution.
- Solid NaOH require removing 1 ton H₂
- Using Vilbrandt's interconversion table for units of energy (17, p. 549) and assuming 100% efficiency, this would require 490 lbs. CO₂/ton H₂O removed.
- Assume approximate 50% efficiency, so that CO₂ would be 1,000 lbs. CO₂/ton H₂O removed.
- Total CO₂ for solid NaOH would be 7,146 lbs. CO₂/ton caustic soda.

Pig Iron

- Pigging operations as determined by a major producer of merchant pig iron (1, p. 101) required 60,000 Btu/ton for electricity, lime, cast steel molds, lubricants, refractories, etc. Using the "other fuels" CO₂ factor of 164 lbs. CO₂/10⁶ Btu, the CO₂ is 9.84 lbs. CO₂/ton pig iron.
- Blast furnace hot metal (from this report) is 431.2 lbs. CO₂/ton.
- CO₂ for pig iron is 441.0 lbs. CO₂/ton.

Soda Ash (natural)

- CO₂ content of trona (Na₂CO₃·NaHCO₃·2H₂O) is 46.3% or 9265 lbs. CO₂/ton trona.
- Assume mining is same as bituminous coal, or 46 lbs. CO₂/ton.
- Total CO₂ is 972 lbs. CO₂/ton trona.

Soda Ash (synthetic)

- CO₂ contents of Na₂CO₃ is 830 lbs. CO₂/ton.

Other Materials

- Battelle (1, 2, 3) and IC 8781 (9) give energy content on many materials only in Btu values.
- A first approximation is made for these materials using the "other fuels" CO₂ conversion factor of 164 lbs. CO₂/10⁶ Btu.
- To confirm this approximation, the 49 Btu values for commodities in the Battelle phase 5 report (2) were converted to CO₂ values using the "other fuels" factor. 61 percent of these were+ 10% of the CO₂ values reported in this report. 90% were+ 20%.
- From this data, this "other fuels" factor appears reasonable to use for "other materials", especially because they are generally relatively small quantities.

Transportation

- Battelle (1, p. 174) gives the following energy values for transportation:

Truck = 2,400 Btu/ton-mile
Rail = 670 Btu/ton-mile
Water = 250 Btu/ton-mile

- Assume diesel oil fuel for each using 139,000 Btu/gal. oil.
- This report gives 23.0 lbs. CO₂/gal. diesel oil.
- Lbs. CO₂/Btu diesel oil:

$$23.0 \text{ lbs. CO}_2/\text{gal.} \times 1/139,000 \text{ gal./Btu} = 0.000166 \text{ lbs. CO}_2/\text{Btu diesel oil}$$

- Truck:

2,400 Btu/ton-mile x 0.000166 lbs. CO₂/Btu diesel = 0.393 lbs. CO₂/ton-mile

- Rail:

670 Btu/ton-mile x 0.000166 lbs. CO₂/Btu diesel = 0.111 lbs. CO₂/ton-mile

- Water:

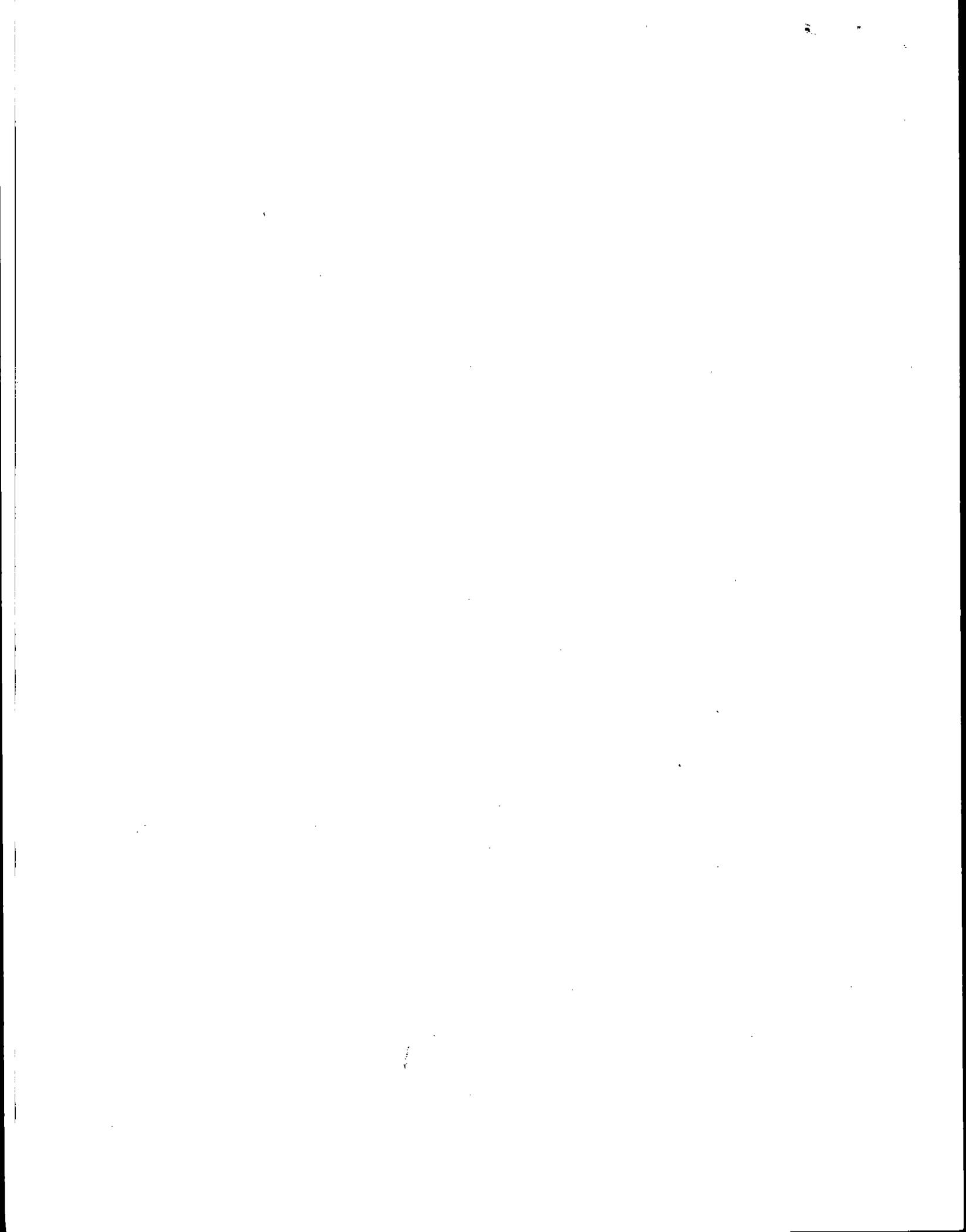
250 Btu/ton-mile x 0.000166 lbs. CO₂/Btu diesel = 0.042 lbs. CO₂/ton-mile

APPENDIX D

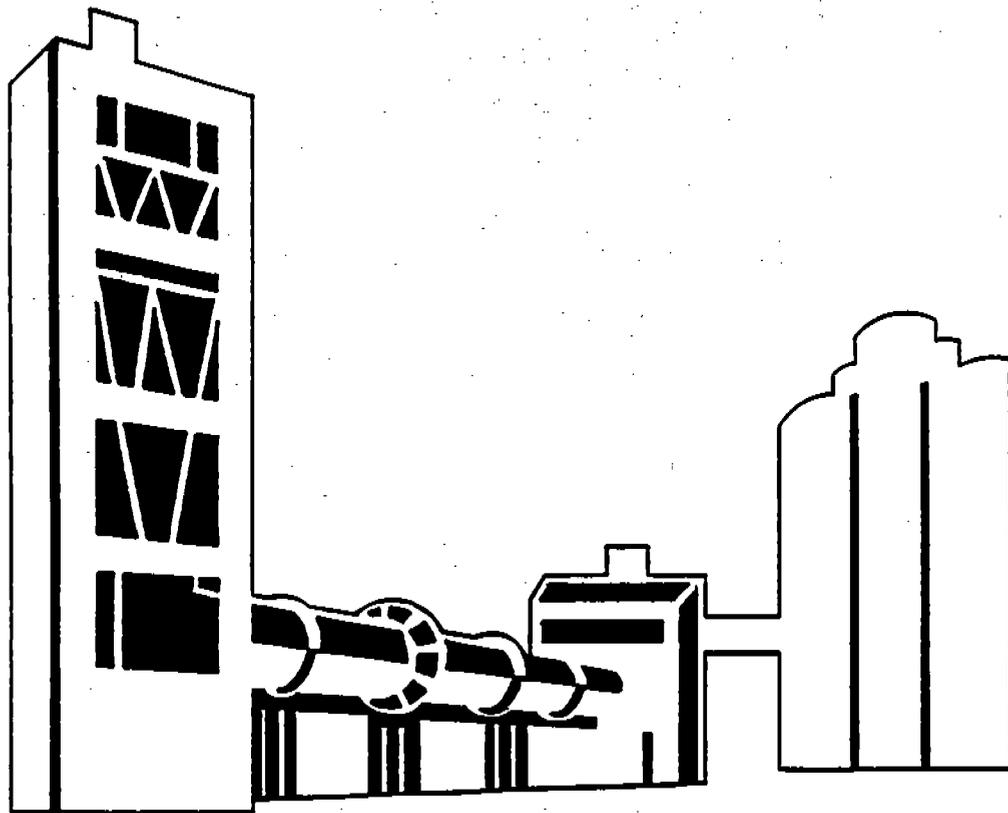
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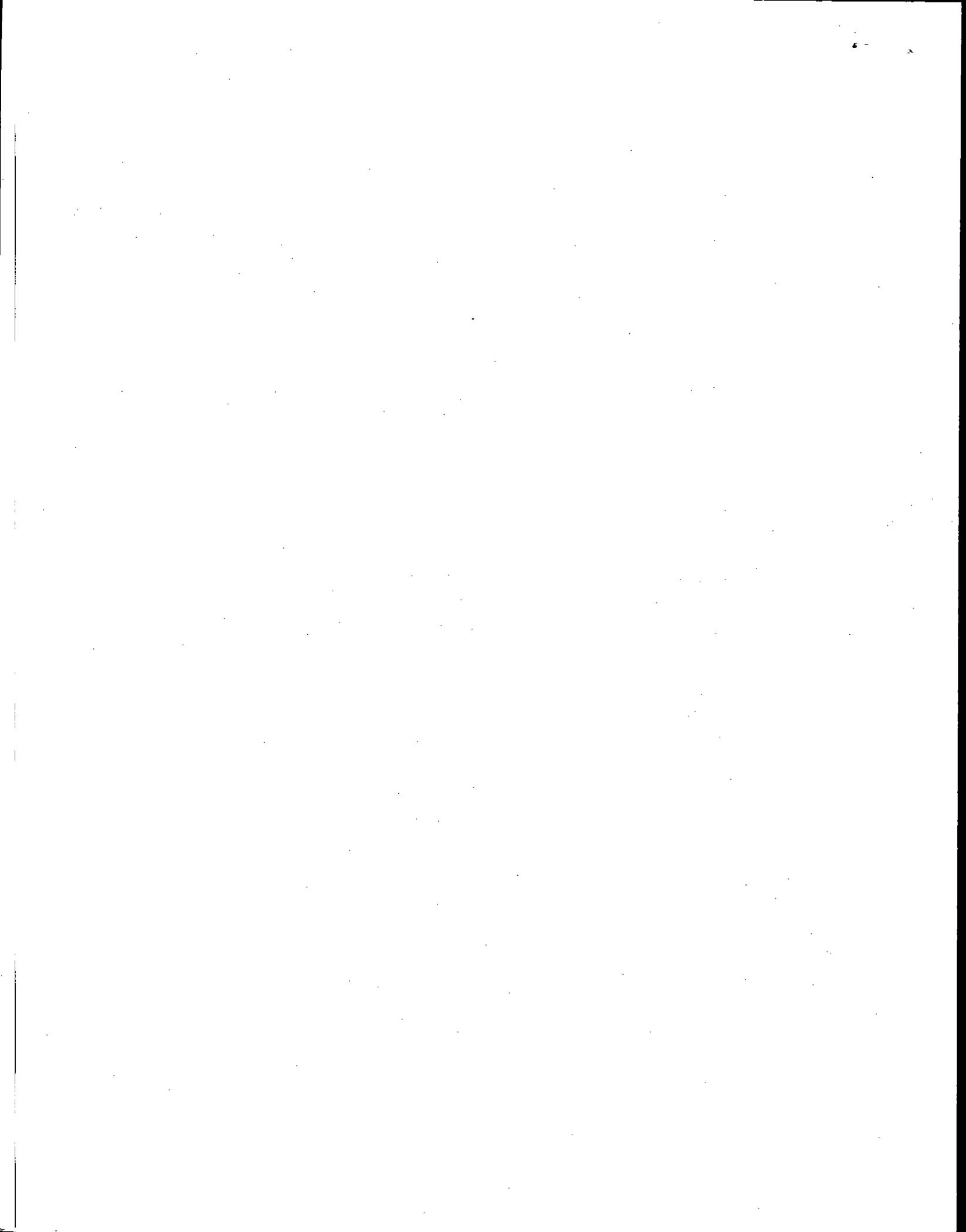


THE CEMENT INDUSTRY'S CONTRIBUTION TO CANADA'S GREEN PLAN



CANADIAN
PORTLAND CEMENT ASSOCIATION
ASSOCIATION
CANADIENNE DU CIMENT PORTLAND

JUNE, 1991



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APPENDIX IDENTIFICATION OF ENVIRONMENTAL IMPACTS

EXECUTIVE SUMMARY

The Federal Government's "Framework for Discussion on the Environment" challenged Canadians to set priorities on the protection of the environment through a consultation process occurring in 1990.

During that process, the Canadian Portland Cement Association (CPCA) committed itself to develop a comprehensive environmental plan for its industry. This plan identifies the effects of the industry on the environment, evaluates methods of reducing or eliminating them and draws attention to the opportunity for using the cement manufacturing process to recover the energy or chemical value of some of society's wastes.

CPCA has adopted the following Environmental Mission Statement:

"CPCA and its Member Companies will continue their high level of effort to produce economical, quality cement at optimum energy efficiency in an environmentally sound manner."

Consistent with this mission statement, seven principles have been adopted. The order of these principles does not imply a priority rating.

- I. **The safety and health of our employees, our neighbours, and our customers is our first consideration in the production and distribution of a quality product.**
- II. **CPCA Members will continue to implement effective controls which reduce or eliminate the release of pollutants to the air, to the land, or to water.**
- III. **CPCA Members will actively seek ways to manage wastes in a responsible and environmentally sound manner.**
- IV. **CPCA Members will pursue effective improvements in energy efficiency and promote the conservation of resources.**
- V. **CPCA Members will seek ways to beneficially and safely utilize recyclable wastes as raw materials, fuels and product components as part of their overall commitment to waste minimization and recycling.**
- VI. **CPCA Members will continue to conduct mining operations in a responsible and environmentally sound manner.**

VII. CPCA Members will participate with lawmakers, regulators, and other interested parties in the development of rational and effective environmental laws and regulations.

CPCA encourages its Member Companies, suppliers and users of concrete to carry out an environmental audit of their operations and to develop environmental plans to address issues of concern.

In this plan, the environmental effects of cement and its products were traced from "cradle to grave". The review started with quarrying raw materials and continued through cement manufacture, concrete production through to recycling, reuse or disposal of demolished concrete structures.

Seven key issues were identified.

Energy Options: The cement industry has demonstrated the ability to use a range of fuels over the past fifteen years as costs and availability have changed. When availability of fuels and environmental effects are considered simultaneously, there is little benefit to be achieved by altering the mix of conventional fuels for cement kilns. For this reason, atmospheric user fees are opposed by CPCA.

Energy Efficiency: Energy savings of 20% have been achieved in the past fifteen years. The achievement of further gains continues to have a high priority within the industry for both economic and environmental benefits. However, future gains will be technically more difficult to achieve and economically more difficult to justify than in the past.

Emissions Reduction: Cement plants emit carbon dioxide, nitrogen oxides, sulphur oxides and particulates. The industry is committed to reducing gaseous emissions resulting from the combustion of fuels by carrying out all economically sound process and energy conserving improvements in their plants.

Approximately 50% of the carbon dioxide produced in cement plants is released by the limestone, an essential step in the cement making process. This unique characteristic puts limits on the carbon dioxide reduction achievable in cement manufacturing. Nitrogen and sulphur oxides emissions are currently well below regulations and, with further improvements in energy efficiency, will be further reduced.

Management of particulates, both cement kiln dust and fugitive dust from storage of raw materials, has been a traditional challenge for the industry. Plants will continue to monitor and control particulate emission and make improvements as required.

Waste Management: The primary waste material generated by cement plants is cement kiln dust, recovered from the exit gases. Research will continue to reduce production of the waste and to develop environmentally friendly uses as a by-product.

The cement industry offers an enormous untapped potential to contribute to waste management. Cement kilns can safely recover energy from materials such as municipal garbage, scrap tires, spent solvents or waste oils. The proposal is compatible with present and future recycling programs. All levels of government are urged to evaluate industry proposals for recovering energy in cement kilns and to actively support this waste management/energy conservation proposal as an important component of waste management strategies.

The industry also offers potential for replacing a portion of the raw materials for cement kilns with inorganic wastes.

Energy Efficiency of Product Use: Almost all cement is used in concrete products which are the final end-use application. Cement is the energy intensive component of concrete. Concrete, including the energy used to make cement, has the lowest total energy component of all generally used construction materials other than wood or stone. Government is urged to carry out studies comparing the energy component for in-place construction using various construction materials to establish meaningful comparative measures of energy intensity.

The energy efficiency of in-place concrete construction has made substantial improvements by reducing energy in cement, by making more efficient use of cement in concrete, by replacing cement with supplementary cementing materials and by improvements in the design of concrete structures. Industry, Users and Government are urged to continue research on improving the energy efficient use of cement and concrete.

Reduce: Concrete durability is recognized as an area where improvements can extend the life of structures by decades. Although a great deal has already been learned, Industry, Users and Government are urged to continue research to improve the material properties of cement and concrete to enhance durability.

Reuse and Recycle: Beneficial reuse or recycling of demolished concrete structures has become feasible. Large pieces of used concrete are used, for example, as protection for shore lines. Old concrete can be crushed and recycled to produce aggregates for making new concrete or for bases for roads. Codes and standards bodies and specifiers are urged to accept recycled concrete as an alternative to fine and coarse natural aggregates.

To remain competitive in the global cement market, there is a limit to the costs that can be borne by a producer. While it is often technically possible to increase energy efficiency or reduce emissions, Canada's competitiveness in cement production would be threatened if new restrictions requiring major capital investment were imposed unilaterally in Canada. The Government must only introduce environmental controls in step with our major trading partners to maintain a level playing field on which to compete.

CPCA represents eight producers of Portland cement across the country representing 95% of Canada's production capacity of 14.5 million tonnes. In 1988 the cement industry employed 3,400 people with sales of \$938 million, exports of \$144 million and imports of \$56 million. An additional 20,000 people are employed in ready mixed concrete and concrete product industries. The combined sales of the three sectors is \$3.9 billion.

THE CEMENT INDUSTRY'S CONTRIBUTION TO CANADA'S GREEN PLAN

1.0 INTRODUCTION

1.1 Purpose

The Federal Government's "Framework for Discussion on the Environment" challenged Canadians to set priorities on the protection of the environment through a consultation process occurring during 1990.

In a June 28, 1990 letter to the Minister, the Canadian Portland Cement Association (CPCA) responded and presented its position on several environmental issues. In this response, CPCA committed itself to develop a comprehensive environmental plan for its industry.

In accordance with that commitment, this document was prepared identifying the effects of the industry on the environment, and evaluating methods of reducing or eliminating them. The document also draws attention to the opportunity for using the cement manufacturing process to recover the energy or raw material value of some of society's wastes.

Input was received from our member companies at meetings led by an environmental consulting group, and through consultation with the federal government.

This document will provide a basis for consideration by the many parties involved in the use of cement from cradle to grave, including the cement industry and its suppliers, concrete producers, contractors, owners and government, all of whom have an impact on the environment. The cement industry cannot commit other parties to action. It is their responsibility to identify the impact of their operations on the environment and to develop plans to address these effects.

CPCA encourages its Member Companies, suppliers, and users of concrete to carry out an environmental audit of their operations and to develop environmental plans to address issues of concern.

Because of the rapid evolution of conditions resulting from world events, technological developments and improved understanding of environmental response priorities change. Thus, this plan will require periodic review and modification.

1.2 The Industry

The Canadian Portland Cement Association represents eight producers of Portland cement across the country. Members represent 95% of Canada's production capacity.

The cement industry has been in existence for over 100 years in Canada and during that time has built the productive capacity to 14.5 million tonnes per annum. The industry employed 3,400 persons in 1988 with sales of \$938 million, exports of \$144 million and imports of \$56 million. An additional 20,000 people are involved in the ready-mixed concrete and concrete products industries. The combined sales of the three sectors is \$3.9 billion. Cement is a global commodity, unprotected by tariffs in Canada, and to remain globally competitive, the manufacturing costs must be controlled.

The cement industry depends upon relatively plentiful raw materials such as limestone and clay. The manufacturing process involves grinding these raw materials, carefully selected for their chemical makeup, to a fine powder which is then fed into rotary kilns and heated to over 1400 degrees Celsius. The resulting clinker is ground with gypsum to produce Portland cement, one of the ingredients in concrete, a universal building material.

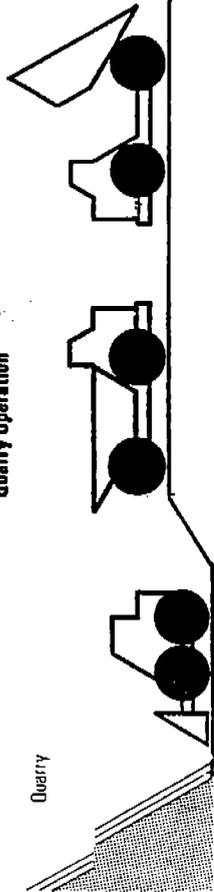
About 88% of the energy used to make cement is for fuel to fire the kilns. The remainder is electrical energy required for motors to drive the grinding mills, rotate the kilns, transfer materials and to power electrical devices for cleaning exhaust gases.

The kiln operation is the major source of emissions from a cement plant. In the kiln, coal, petroleum coke, gas, oil or a combination are burned to generate the high temperatures needed to produce clinker. Emissions from this process are predominantly nitrogen, carbon dioxide (CO₂) from the combustion of fuels and the calcination of limestone, water vapour and particulates from the ground raw materials along with a variety of minor components that occur in most combustion processes. A major difference between the cement kiln and other combustion processes is in the source of the CO₂. In other processes, CO₂ emanates primarily from burning the fuel. In the cement kiln, approximately 50% of the CO₂ is from fuel combustion and the remaining 50% from decarbonization of the limestone. Of the total carbon dioxide emissions from energy related sources in Canada, about 1% comes from fuel used by the cement industry. An approximately equal amount is released by the limestone.

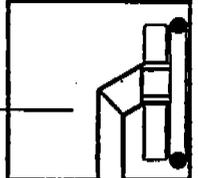
The cement manufacturing process

Quarry Operation

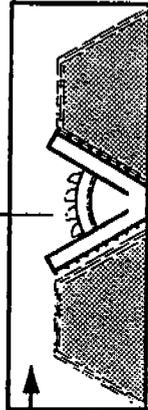
Quarry



Crusher



Pre Homogenization

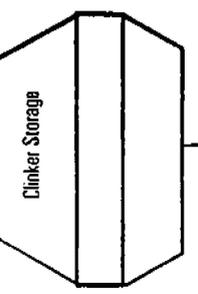


Timestone Bin

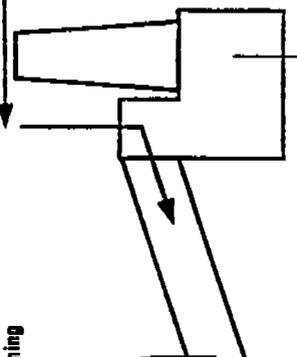


Burning

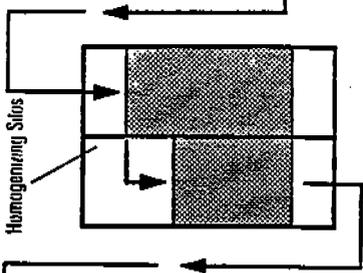
Clinker Cooler



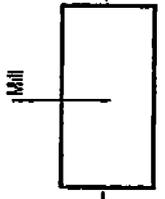
Kiln



Electrostatic Dust Collector



Raw Mill

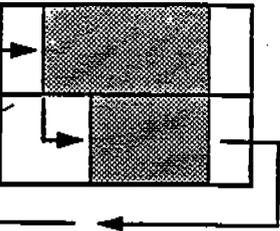


Additives

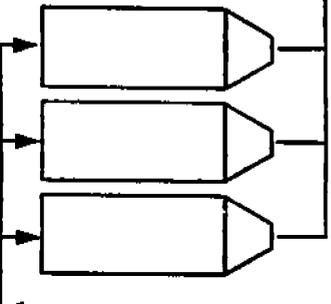


1 Mill

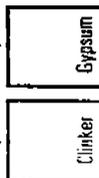
Homogenizing Silos



Cement Storage Silos



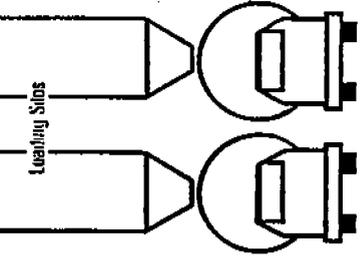
Clinker Grinding



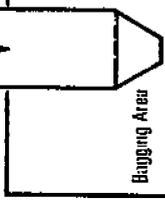
1 Mill



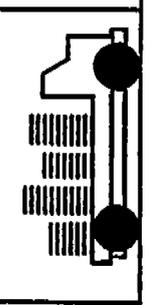
Loading Silos



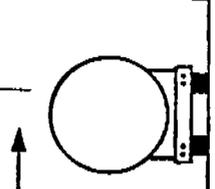
Shipping



Bagging Area

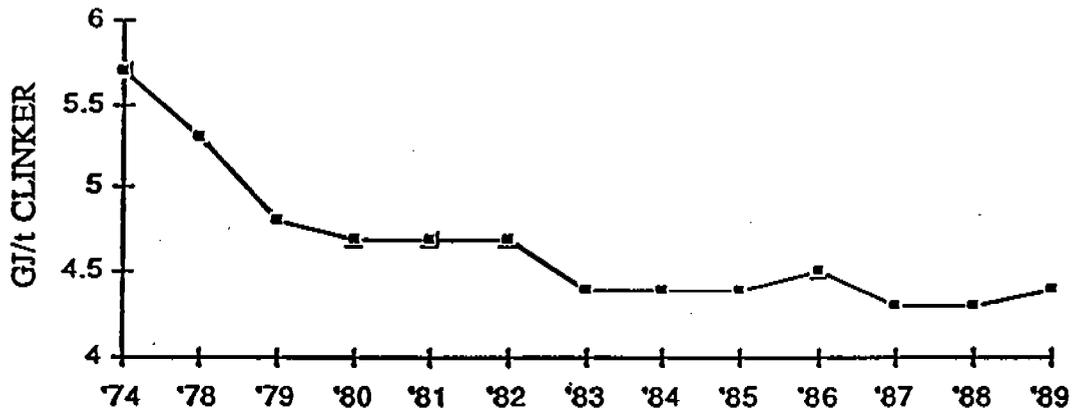


Loading Area for Railway Cars



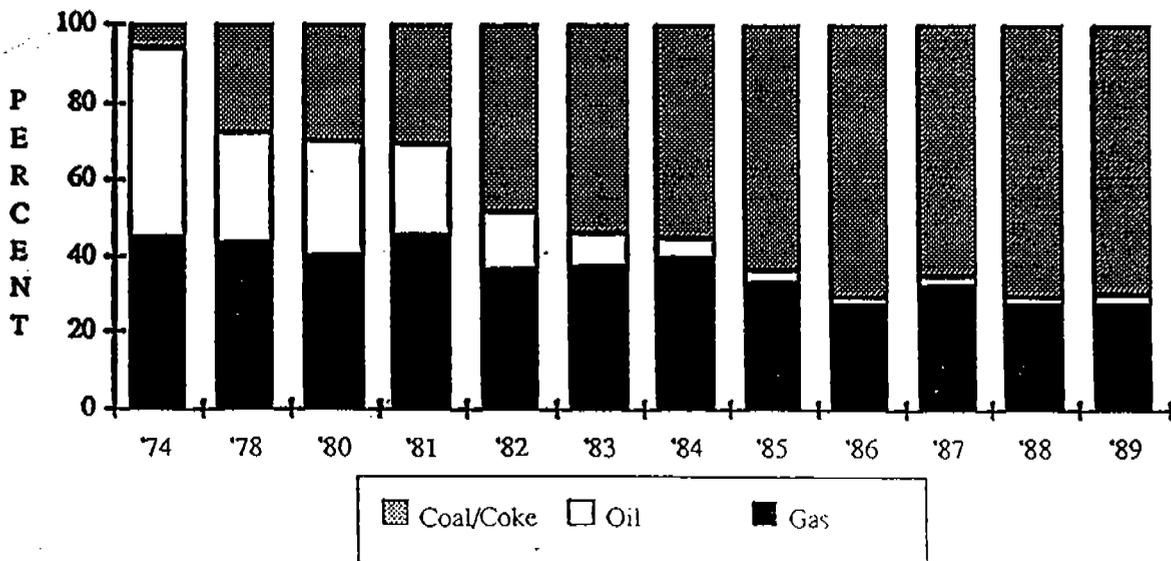
Within the cement industry, energy savings of 20% have been achieved in the past 15 years. These energy savings have, of course, reduced CO₂ emissions from combustion. Further gains, while possible, will be technically more difficult to achieve and economically more difficult to justify than in the past.

FUEL EFFICIENCY IMPROVEMENT



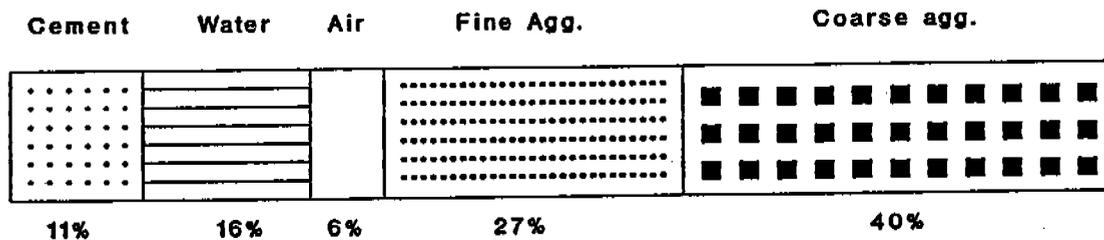
In this same period, initiated by the oil crisis in the mid 1970's, the use of oil as a kiln fuel dropped from 40% to 4% while the use of coal and coke rose from 11% to 70%.

COAL AND COKE HAVE BECOME PRINCIPAL FUELS



Although cement is considered an energy intensive material, it is not a final product and this should be taken into account when comparing energy intensities of construction materials. Concrete, the end use product, contains only 9 to 13% cement and is one of the most energy efficient construction materials available today.

Typical proportion of materials used in concrete



Substantial gains have been made in making concrete even less energy intensive by refinements in structural and material design. Further significant opportunities exist.

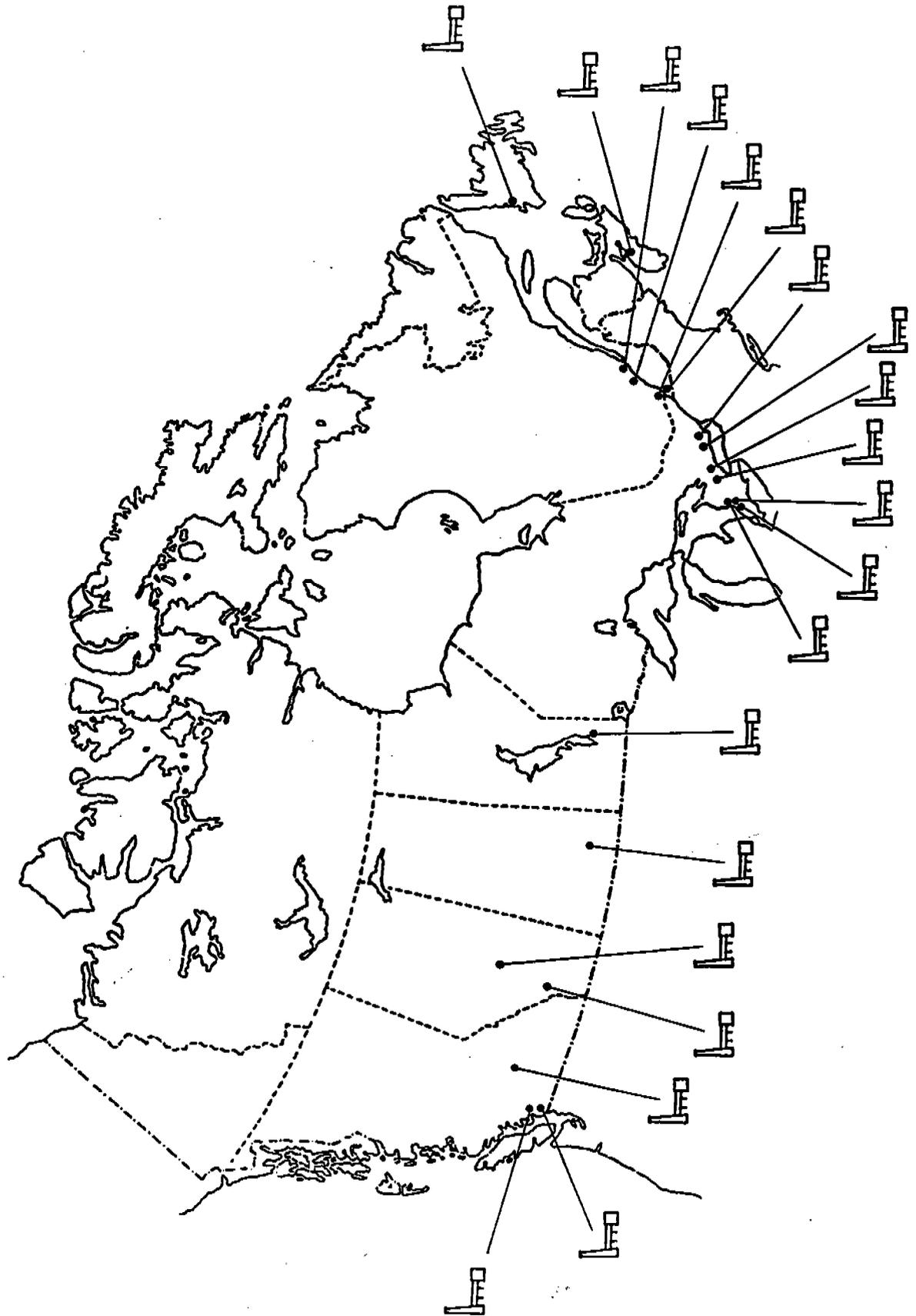
1.3 Consumer and Public Awareness

Concrete is the most widely used construction material in the world. In Canada, it is used at the rate of approximately 10 kg per capita per day. The consumption of concrete is directly tied to the economic growth of the country. Construction vital to Canadians, such as houses, factories, bridges, dams, electric power plants or sewage treatment plants cannot be built without concrete. Cement is the essential ingredient, the dry powder which in the presence of water, binds together sand and stone to produce concrete.

Twenty cement plants operate in Canada. The location of these plants is largely determined by the economics of transportation. The plants are built either at a limestone quarry or near a major cement market. Most were built on remote sites but as cities and towns have grown, residential development has edged closer to cement plants.

Dust from exhaust gases, and dust blown from stored materials such as coal, raw materials or clinker must be controlled. Modern cement plants operate in an environmentally sound manner and generally have good relations with their neighbours.

CANADIAN PORTLAND CEMENT PLANT LOCATIONS



3.0 CPCA ENVIRONMENTAL PRINCIPLES

Consistent with this mission statement, seven principles have been adopted. The order of these principles does not imply a priority rating.

- I. The safety and health of our employees, our neighbours, and our customers is our first consideration in the production and distribution of a quality product.**
- II. CPCA Members will continue to implement effective controls which reduce or eliminate the release of pollutants to the air, to the land, or to water.**
- III. CPCA Members will actively seek ways to manage wastes in a responsible and environmentally sound manner.**
- IV. CPCA Members will pursue effective improvements in energy efficiency and promote the conservation of resources.**
- V. CPCA Members will seek ways to beneficially and safely utilize recyclable wastes as raw materials, fuels and product components as part of their overall commitment to waste minimization and recycling.**
- VI. CPCA Members will continue to conduct mining operations in a responsible and environmentally sound manner.**
- VII. CPCA Members will participate with lawmakers, regulators, and other interested parties in the development of rational and effective environmental laws and regulations.**

4.0 ANALYSIS OF ENVIRONMENTAL ISSUES

4.1 Sustainable Development Analysis

In this section an overview audit is carried out tracing cement and its products and the environmental issues from "cradle to grave". The analysis begins with the quarrying of raw materials leading to the cement manufacturing process, the use of the product during concrete manufacture and construction and finally to the methods of reuse, recycling or disposal of the components of demolished concrete structures.

While the cement industry has direct control over many of the primary resource extraction and processing activities, it has only indirect involvement, or in many cases, no involvement in the production of concrete, construction, maintenance or demolition.

However all of these activities have been included in this overview in recognition of the holistic nature of sustainable development. The cement industry cannot assume responsibility for those operations beyond its direct control.

A table (see appendix) has been prepared to facilitate the review of environmental issues. Each issue has been identified with its accompanying environmental concern. These concerns are categorized as global, regional or local issues and they are rated low (L), medium (M) or high (H) as a measure of their importance. The key options available for reducing these concerns are identified and, if there is a barrier, it is identified as economic, technical or regulatory. Additional comments are included as clarification.

The overview identified seven key issues.

- **Energy Options** - nature of available fuels and their relative impact on the environment.
- **Energy Efficiency** - implementation of measures to reduce energy consumption per unit of product.
- **Emissions Reduction** - areas where changes in fuel use or technology can be effective.
- **Waste Management** - opportunities to consume organic wastes as partial fuel replacements and inorganic wastes as raw material feed.

- **Energy Efficiency of Product Use** - advances in reducing the energy component of put-in-place concrete construction and the opportunities for further reductions.
- **Reduce** - opportunities to increase the life cycle of concrete structures by addressing durability issues to reduce the need for reconstruction.
- **Reuse & Recycle** - opportunities where waste concrete from demolition can be re-used as concrete or recycled as aggregate.

A discussion on each of the issues and the opportunities for improvement in relation to environmental concerns follows.

4.2 Assessment of the Issues

As outlined in Section 1.2, numerous improvements have already been made by the cement industry. Although the accomplishments to date are impressive, some potential exists for further improvement. However, broadly speaking, the most economically attractive opportunities have been taken and many of the remaining possibilities have high capital costs and long payback periods.

In keeping with the level of influence of these issues, options for improvement are suggested with a view to reducing environmental effects. These options range from programs and policy changes to modification of technology.

4.2.1 Energy Options

Coal

In 1989, 52% of the fuel used to fire cement kilns in Canada was coal. Coal and coke are the principal fuels used in Eastern Canada because of current economics. In 1974 the use of coal was insignificant, with gas and oil being the predominate fuels at that time.

Coal is in abundant supply. Both low and high sulphur coals can be used in cement manufacturing. Of all industries, the cement industry has the greatest advantage in burning high sulphur coal because of the scrubbing action of the raw materials which absorb sulphur during the manufacturing process and incorporate it in the final product. If an electric utility were to burn the same coal without flue gas desulphurization, emissions of sulphur dioxide would be much higher per tonne of coal burned.

Additionally, there is no ash disposal problem in cement kilns because the ash becomes part of the product. CO₂ and sulphur oxides (SO_x) emissions are higher when burning coal than when using natural gas, but nitrogen oxides (NO_x) emissions are lower.

Natural Gas

In 1989, 28% of the kiln fuel used was gas. Gas is the principal fuel used in Western Canada because of current economics. In 1974, 50% of the kiln fuel used in Canada was gas. While the increased use of gas would reduce the emissions of CO₂ and SO_x, the emissions of NO_x would increase. Except in the Atlantic Provinces, where gas is not available, it would be possible to convert the industry to natural gas. While appealing, from a "clean" burning fuel viewpoint, both natural gas and coal will be required to meet Canada's energy needs.

Oil

In 1989, less than 1% of the kiln fuel used was heavy oil. In 1974 oil represented 40% of the total. The cement industry converted from oil to coal and coke as part of the "off oil" policy in the 1970's. While it is technically feasible to switch back to oil, limited supplies of bunker C grade are available and the supply and price is subject to international events beyond the cement industry's control.

Use of oil would reduce the emissions of CO₂ relative to coal.

Coke

Petroleum coke accounted for 17% of the industry's fuel in 1989. Coke is a by-product of the petroleum industry.

Biogas

The collection of biogas (methane) from landfill sites is practical for cement plants located close to landfill sites. The fuel is clean burning, conserves other fuels and reduces the greenhouse effect from uncontrolled release of methane from landfill.

Plasma arc

This technology for cement manufacturing is at the conceptual stage. The process would eliminate some of the products of combustion at the cement plant. However, the use of electricity would increase dramatically along with the emissions related to the electricity generation. Unless electricity is generated by hydro or nuclear plants, there will be no net environmental benefit. The process is not economically viable at current energy prices and is questionable in the future.

Summary

Although the cement industry has the capability to use a range of energy sources, there is little environmental benefit to be achieved by altering its mix of conventional fuels and this is not considered to be a fertile area for improvement.

Energy Recovery

There is an enormous potential to recover lost energy through safely burning combustible wastes such as spent solvents, used oils, scrap tires, and refuse derived fuels. The industry supports government's recycling programs. For materials which cannot be economically recycled or where markets for the recycled product have not yet or cannot be generated, the cement industry provides a solution. The solution is compatible with recycling programs. As recycling markets increase over time, the quantity of wastes directed to energy recovery may be reduced. The advantages of recovering energy from waste are fourfold:

- . reduction in the consumption of non-renewable fossil fuels. The potential exists in Canada for replacing the equivalent of nearly one million tonnes of coal per annum, a significant percentage of which is imported.
- . reduction in the cost of manufacturing cement. Some waste fuels have an energy content close to coal but are available at a fraction of the cost.
- . complete destruction of the organic fractions of wastes is assured because of the high temperatures and long retention times necessary to make cement clinker. Metals and other inorganics are incorporated as part of the product.
- . a contribution is made to proper management of combustible wastes which create an environmental hazard when stored indefinitely.

There is no significant change in emissions from cement kilns when waste derived fuels are used. When wastes are burned in a conventional incinerator, emissions from the incinerator are added to the atmosphere. When these same wastes are burned in a cement kiln, the resulting emissions replace those produced from burning fossil fuels.

Canadian cement producers compete in a global market. Most countries against which Canada competes in cement trade permit wastes to be burned as an alternate fuel, thereby reducing their fuel costs. Approval to burn wastes accompanied by appropriate emission standards and safeguards is necessary if Canadian cement producers are to maintain their competitive position.

Atmospheric Users Fees

The concept of allocating varying user fees on certain fuels, such as a coal tax or a carbon tax, has been suggested. The purpose of these taxes is to discourage use of fuels which produce higher levels of greenhouse gases.

From the cement industry perspective, these taxes would cause some shift of fuels, create higher demand and possibly shortages of the cleaner burning fuels, increase the manufacturing cost of cement and reduce the competitive position of Canadian cement. As previously stated, unlike most combustion processes, the raw materials in a cement kiln absorb the sulphur from high sulphur fuels, such as coal, eliminating the need and cost of scrubbers for SO_x reduction.

The concept does not consider that some industries, such as the cement industry, can burn coal with less environmental impact than other industries and that CO₂ emissions are but one of many considerations.

The cement industry has demonstrated its ability to use a range of fuels over the past fifteen years as costs and availability have changed. The industry opposes the introduction of atmospheric user fees unilaterally in Canada without the introduction of similar fees in other countries because these fees would seriously hamper the ability of the Canadian cement industry to compete in a free trade era.

Sound environmental regulations should be established without reference to fuel choice. Market forces should continue to be the mechanism to govern fuel selection.

4.2.2 Energy Efficiency

While much has been done to reduce energy consumption, the achievement of further reductions continues to have a high priority within the industry. Successful energy conservation projects have both economic and environmental benefits.

Initiatives by some specifiers to encourage the production of low alkali cements, as one solution for alkali reactivity problems, are counter-productive to the industry's ability to conserve energy and reduce emissions because of increased kiln dust wastage. This contradiction between cement properties and energy conservation points to the need for careful consideration by all stakeholders before implementing policies or standards.

Process Modifications

The conversion of plants using the wet process to the dry process is the most identifiable opportunity for energy conservation. This opportunity has nearly been exhausted. In 1989, 82% of the cement produced was from dry process plants. In 1991, by the conversion of one more plant, 90% of Canada's production capacity will be dry process. Advances along this line will be slow because some of the remaining wet kilns are effectively used for specialty products, low alkali cements or are used only during peak demand periods.

Cement Processes Comparative Energy Efficiencies

<u>Process</u>	<u>Energy Efficiency (GJ/t clinker)</u>
Wet	5.0 - 6.0
Dry	3.6 - 4.5
Preheater/Precalciner	3.3 - 3.6

Preheater or precalciner kilns offer increased fuel efficiency. A preheater transfers the heat from the exhaust gas from a dry kiln and transfers the heat to the raw material.

In precalciner kilns an additional combustion vessel is added at the bottom of the preheater tower to further heat the raw materials prior to introduction to the kiln. The capital cost of both preheaters and precalciners is high and electrical energy requirements are increased.

Further technological improvements in pyro-processing are being studied. The fluidized bed cement kiln is one of those concepts which offers future potential for more efficient heat recovery and low NO_x and SO_x emissions. Developments in this technology will be closely monitored.

Development of low tricalcium silicate (C₃S) cements offers the potential for energy reduction. High-lime clinkers require more fuel to process than low-lime clinkers. However, low C₃S cements have slow setting times and low early concrete strength. Research is needed into additives for such cements, to counteract these undesirable characteristics.

Substitution of industrial inorganic wastes for raw materials

Another approach to energy conservation is the substitution of materials which require less energy to make clinker. These energy savings may be in the quarrying, crushing or burning operations. Examples of possible raw material replacements are bottom ash or fly ash from electricity generating stations or from municipal incinerators.

Cement kiln flue gas scrubbing technology is in the developmental stage and, if successful, could enable complete recycling of cement kiln dust as raw kiln feed in some plants.

The industry will continue to review the potential for replacing raw materials with wastes and by-products of other industries.

Substitution of organic wastes for fossil fuels

As previously discussed, recovery of energy from organic wastes conserves fossil fuels.

Operational procedures

A number of in-plant activities provide opportunities for energy/environmental improvements. These improvements have been incorporated to varying degrees in Canadian cement plants.

Large electrical motors are required to rotate kilns, grind materials, drive fans and transfer materials. Incentives are being offered by some electrical utilities to encourage the installation of high efficiency motors.

The comminution (grinding) of materials by conventional ball mills in all industries is recognized as being energy intensive. High efficiency classifiers and roller presses in clinker grinding circuits offer increased efficiency. Improvements in grinding aids, grinding media, mill liners and the use of more complex grinding circuits have all made small but significant gains. However, even after all these improvements are incorporated, comminution will still be a relatively inefficient use of energy.

Computer control equipment for switching off motors or equipment not in use can reduce electrical consumption.

Efforts to use off-peak electrical power, by grinding at night and on weekends, aid in the efficient use of electrical power generation. This is a current practice at most plants today.

Although energy losses from the exhaust gases and coolers decrease as heat recovery systems are added to kilns, co-generation of electricity from waste heat is a possibility that may become more economically attractive as technology is further developed.

The industry will include an assessment of the environmental-economic benefits when making process or operational improvements to their plants.

4.2.3 Emissions Reduction

The cement plant stack emissions of concern are CO₂, NO_x, SO_x and particulates. This section describes available options to reduce them.

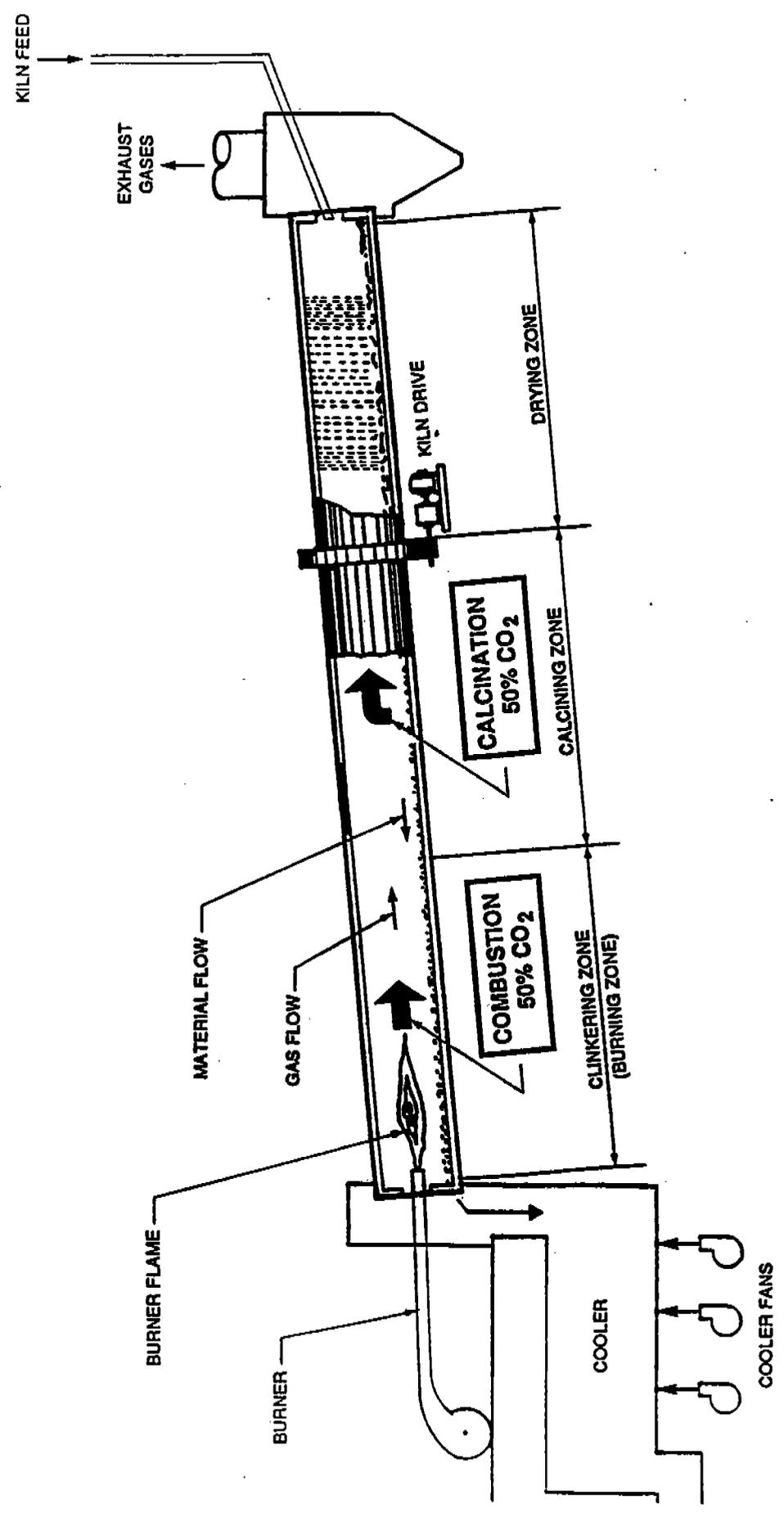
Carbon Dioxide (CO₂)

As was previously mentioned, a critical factor in understanding carbon dioxide emissions from cement manufacture is that approximately 50% of the CO₂ comes from the decarbonization of the limestone (see page 2). Decarbonation or calcination is an absolutely necessary process step which must take place regardless of the cement making process. Therefore, it is important to remember when evaluating CO₂ strategies that only the portion related to combustion has any real potential for reduction.

The following are potential CO₂ reduction options:

- improve energy efficiency to reduce products of combustion.
- convert coal to gas - an option which ignores the economic advantage of coal in Eastern Canada at the present time.
- burn organic wastes as partial fuel replacement. While still generating CO₂ as a by-product of the combustion process, this would represent a net reduction if these same wastes were disposed of at commercial incinerators or accidental dump fires where the heat energy is not recovered.
- use lime wastes as partial replacements for limestone in the raw feed as a means of lowering CO₂ generation from the calcination of calcium carbonate as well as lowering the CO₂ from fossil fuel combustion by reducing energy consumption.
- produce low C₃S cements. Further research is required to improve the performance of low C₃S cements.
- use supplementary cementing materials as partial cement replacements in concrete - fly ash, cementitious slag and silica fume are currently being used for this purpose. Limits on the degree of implementation are imposed by durability, performance, and strength gain characteristics of concrete products.

CARBON DIOXIDE SOURCES IN CEMENT MANUFACTURE



Considerable research has been done by the industry to find markets for CKD. A portion of the CKD produced is currently being used for fertilizers, for the treatment of municipal sewage, as soil sweeteners and as a stabilizing agent for soils and sludges. There is also potential for its use in neutralizing acid lakes. Further research, demonstration projects and market development are required.

Another promising development is the "CKD and flue gas scrubbing" technology, now under development in the United States. This technology offers significant potential benefits, including re-use of kiln dust as raw kiln feed; reduction of sulphur dioxide and nitrogen oxides in flue gases; as well as operational savings, including production of marketable potassium sulphate for sale as a fertilizer.

The cement industry will continue to carry out research to develop environmentally friendly uses of cement kiln dust.

Some kilns use a refractory brick which contains chromium. If chromium brick is used, the spent brick must either be crushed and mixed with the raw feed for incorporation into cement clinker or be disposed of in an environmentally acceptable manner.

Combustible Wastes

The cement industry offers an enormous and untapped potential to recover energy from organic wastes. The energy recovery benefits were discussed under section 4.2.1.

Municipal waste is generated at the annual rate of about 16 million tonnes. If the entire Canadian cement industry replaced 15% of its fuel with refuse derived fuel, it could burn about 700,000 tonnes of refuse derived fuel extracted from about 1.6 million tonnes of garbage or about 10% of Canada's municipal waste production. The production of refuse derived fuel from the non-recyclable portion of municipal waste is compatible with curbside recycling programs.

Hazardous industrial waste is generated at the annual rate of about 6 million tonnes. Generators treat about 3.7 million tonnes on site. Of the 2.3 million tonnes requiring off-site treatment, approximately 1.0 million tonnes is combustible. If the cement industry in 1988 had replaced 47% of its conventional fuels with combustible hazardous wastes, it could have disposed of 100% of the 1.0 million tonnes requiring treatment. These wastes include spent solvents, waste oils, miscellaneous chemicals and organic sludges.

Scrap tires are generated at the rate of about one tire per capita or 26 million tires per year. If the cement industry replaced conventional fuels with scrap tires to the technical limit, it could dispose of about 30 million tires annually.

Because of availability of waste materials, and location of cement plants, the economics of waste fuel will be different for different plants.

Non-Combustible Wastes

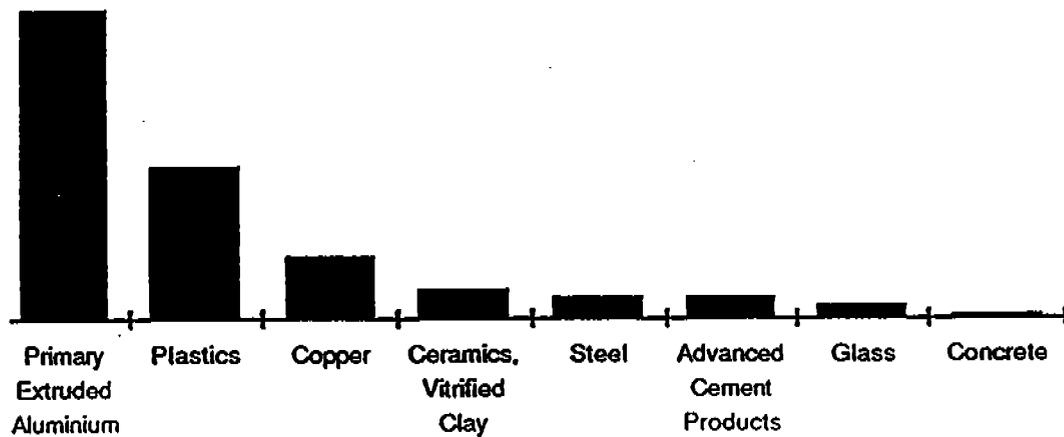
Inorganic wastes which require treatment before they can be safely landfilled can, in some cases, provide a partial replacement for the raw feed for cement kilns. The raw feed normally consists of limestone, clay, shale, iron ore, silica sand and other materials. By-products from foundries, fly ash or bottom ash from coal fired generating stations or municipal incinerators, iron wastes such as mill scale, contaminated soils or sludges can potentially replace a portion of the raw feed. Replacement of raw materials with partially calcined by-products such as lime wastes from foundries and ashes will help to reduce CO₂ emissions. There may or may not be a combustible component from these materials. Technically the limiting factor in the use of these wastes is the chemical composition of the waste materials and the resulting effect on the chemistry and performance of the cement. Economically the limiting factor is the cost of modifying the material handling and storage facilities for an additional raw material.

4.2.5 Energy Efficiency of Product Use

Cement is sometimes identified as an energy intensive product. It must be realized that cement is seldom used by itself. Almost all cement is used in concrete products which are the final end-use materials of the construction world. Very little energy is required to produce concrete or to carry out the activities to complete concrete construction. As such, concrete has the lowest total energy component of all generally used construction materials other than stone or wood. Construction materials such as steel, aluminium, plastics and glass are all more energy intensive.

RELATIVE ENERGY REQUIREMENTS

(per unit volume)



Although the cement industry has reduced its energy intensity by 20% in the past fifteen years, the energy efficiency of in-place concrete construction has improved much more by reducing the cement used per unit area of concrete construction.

Contributing factors arise from:

- improved performance of cement allowing reduced cement content.
- increased use of admixtures allowing reduced cement content.
- increased use of supplementary cementing materials such as slag cement, fly ash and silica fume which replace a portion of the Portland cement in concrete. These supplementary materials are all by-products of other industries and require little energy for their use.
- improvements in quality control of concrete production permitting a reduced margin for error in developing mix designs (i.e. a lower cement content can be justified).
- improvements in design of concrete structures allowing smaller members to bear loads.

Quantifying these improvements is very difficult, but over a twenty year period, the energy per unit volume of completed construction has decreased by at least 50%.

The government is encouraged to carry out studies comparing the energy component of in-place construction using various construction materials rather than the practice of comparing the energy of intensity of manufacturing processes which is a flawed and irrelevant comparison.

Industry, Users and Government are encouraged to continue research on improving the energy efficient use of cement and concrete in construction.

4.2.6 Reduce

Concrete durability is recognized as an area where improvements can extend the life of structures by decades. Currently, structures deteriorating from freezing, thawing and de-icing chemicals or structures suffering from alkali-aggregate reactivity are being repaired or replaced before the functional life of the structure has been reached. Research continues to make improvements in understanding and solving the problem. Recently, the development of high performance concrete has been recognized as a breakthrough in both durability and structural applications. As an example of the enthusiasm towards this product, the Ministry of State for Science and Technology has provided a \$6.4 million grant for a Network of Centres of Excellence on "High Performance Concrete" involving seven Canadian universities and two consulting firms.

Industry, Users and Government are encouraged to continue research on improving the material properties of cement and concrete to enhance durability.

4.2.7 Reuse and Recycle

Previously, when concrete structures were demolished, most of the concrete refuse was landfilled. With restrictions on landfilling, diminished supplies and increased cost of aggregate and large dimensioned stone in some parts of the country, beneficial reuse of demolished concrete has become economically feasible.

Large pieces of used concrete have replaced large dimensioned stone for protecting shore lines from wave action. Broken floor slabs or sidewalks are used for dry stone retaining walls as an alternative to quarried stone.

With the development of equipment for crushing concrete and removing reinforcing steel, both the concrete and steel can be recycled. The stone-sized and fine particles can be graded and recycled as aggregates for making new concrete or for bases for roads or buildings.

Sufficient reuse/recycling markets exist to consume all of the demolished concrete available. The main barrier to acceptance is economics.

Codes and standards bodies and specifiers are encouraged to accept recycled concrete as an alternative to fine and coarse natural aggregates.

5.0 ACTION PLAN SUMMARY

CPCA's Green Plan has reviewed issues associated with the cement industry from a sustainable development perspective. An environmental mission statement has been developed and is repeated below. Nine principles for CPCA Members, supporting the mission statement, have been adopted and are included in Section 3.0. Specific actions for CPCA, Industry, Users and Government, recommended in the body of this report are summarized in the following section.

CPCA and its Member Companies will continue their high level of effort to produce an economical, quality cement at optimum energy efficiency, in an environmentally sound manner.

General Recommendations

CPCA encourages its Member Companies, suppliers, and users of concrete to carry out an environmental audit of their operations and to develop an environmental plan to address issues of concern.

The industry is committed to continue to work with the community to increase the public's awareness of the role the cement industry plays in the community and the actions being taken to address environmental concerns.

The Government must only introduce environmental controls in step with our major trading partners to maintain a level playing field on which to compete.

Recommendations relating to Energy Options

The cement industry has demonstrated its ability to use a range of fuels over the past fifteen years as costs and availability have changed. The industry opposes the introduction of atmospheric user fees unilaterally in Canada without introduction of similar fees in other countries because these fees would seriously hamper the ability of the Canadian cement industry to compete in a free trade era.

Sound environmental regulations should be established without reference to fuel choice. Market forces should continue to be the mechanism to govern fuel selection.

Recommendations relating to Energy Efficiency

The industry will seek ways to beneficially and safely utilize wastes as raw materials, fuels and product components as part of their overall commitment to waste management and recycling.

All levels of Government are urged to evaluate industry proposals for recovering energy from wastes in cement kilns and to actively support these waste reduction/energy conservation proposals as an important component of waste management strategies.

The industry will include an assessment of the environmental-economic benefits when making process or operational improvements to their plants.

Recommendations relating to Emissions Reduction

The industry is committed to reducing gaseous emissions by carrying out all economically sound process and energy conserving improvements in their plants.

The government, in setting regulations, must recognize that only the carbon dioxide produced from the combustion of fuels can be reduced by current or foreseen technology. The carbon dioxide liberated from the limestone cannot be reduced significantly.

Governments must develop particulate regulations which recognize the difference in the composition and environmental effect between particulates from cement plants and the particulates from other combustion processes.

Recommendations relating to Waste Reduction

The cement industry will continue to carry out research to develop environmentally friendly uses of cement kiln dust.

Recommendations relating to Energy Efficiency of Product Use

The Government is encouraged to carry out studies comparing the energy component of in-place construction using various construction materials rather than the practice of comparing the energy intensity of manufacturing processes which is a flawed and irrelevant comparison.

Industry, Users and Government are encouraged to continue research on improving the energy efficient use of cement and concrete in construction.

Recommendation to Reduce Product Use

Industry, Users and Government are encouraged to continue research on improving the material properties of cement and concrete to enhance durability.

Recommendation to Reuse and Recycle

Codes and standards bodies and specifiers are encouraged to accept recycled concrete as an alternative for fine and coarse natural aggregates.

6.0 CONCLUSIONS

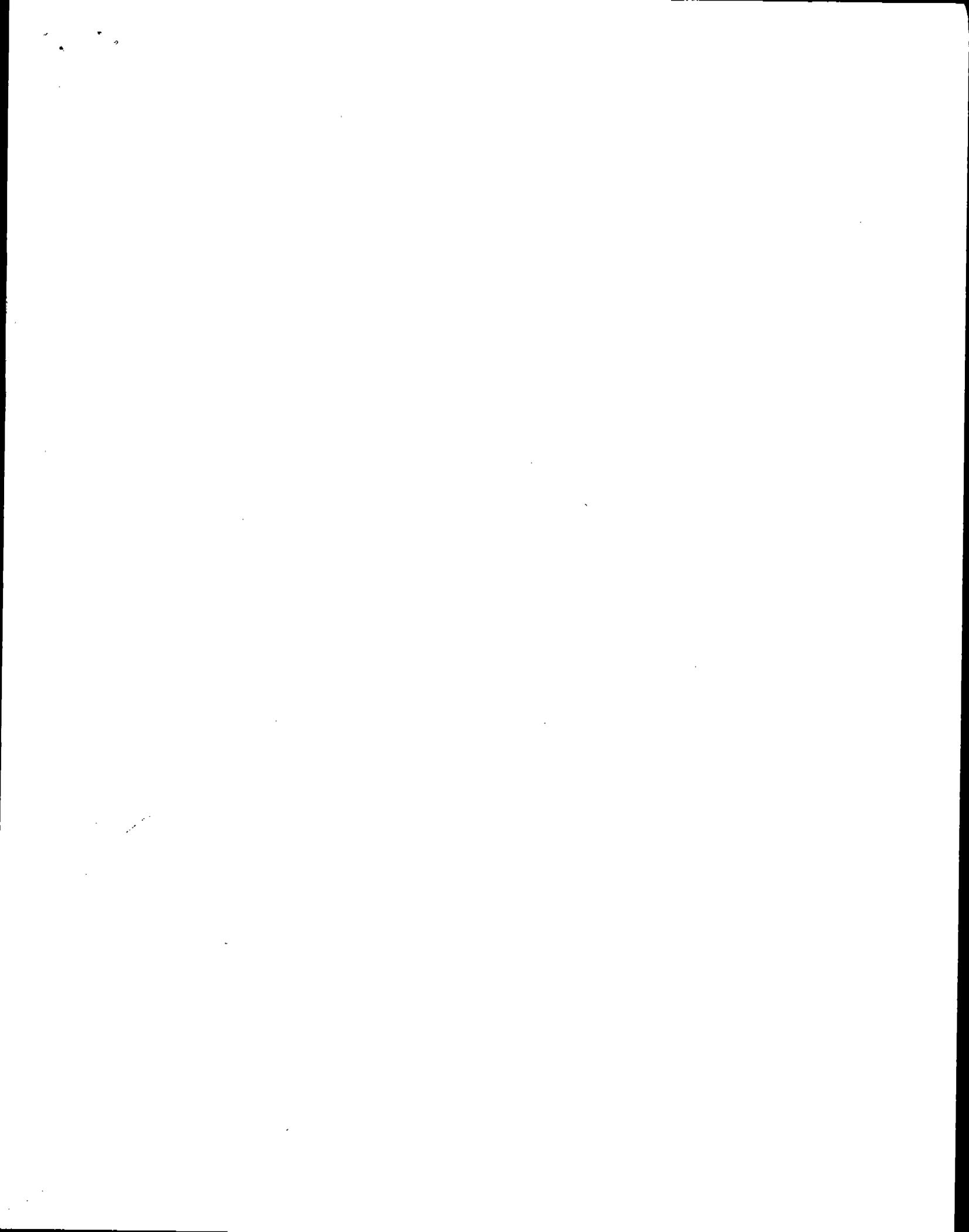
Increased use of concrete as an alternative to other construction materials would have environmental benefits because of the low energy intensity of concrete when compared to steel, aluminium, glass or plastics.

Cement is the energy intensive component of concrete. Great improvements have been made in energy efficiency in the past fifteen years. Modernization continues. Potential for further improvements are limited by the capital intensity of the major opportunities. While energy conservation reduces emissions from combustion, it is important to realize that approximately 50% of the carbon dioxide produced in cement manufacturing comes from a chemical reaction essential to the process and cannot be reduced significantly.

The energy efficiency of concrete has improved dramatically in the past several decades by more efficient use of cement, higher material strengths and more efficient structural design. Potential for further improvements exist. Further research is ongoing.

The cement industry offers a solution to the safe disposal of most organic wastes and selected inorganic wastes. The energy recovered from these wastes has the potential to replace up to 50% of the fossil fuels currently used or the equivalent of nearly one million tonnes of coal. This reduction would reduce the manufacturing cost of cement helping to maintain the competitiveness of the Canadian cement industry relative to cement producers in other countries burning wastes.

Portland cement concrete is a product which is absolutely essential to our economy. It is energy efficient, durable, inert during use and has the potential for 100% reuse or recycling.



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APPENDIX

IDENTIFICATION OF ENVIRONMENTAL IMPACTS*

ACTIVITY	ISSUE	ENVIRONMENTAL CONCERN	LEVEL OF INFLUENCE			IMPROVEMENT OPTIONS	BARRIERS TO OPTIONS	COMMENTS
			GLOBAL	REGIONAL	LOCAL			
RESOURCE EXTRACTION								
Quarrying & Stripping	Noise/Vibration	Irritant to neighbours close to quarry	.	.	L	Timing/distance Refinement in procedures	Economic	Most quarries are remote from residential areas
	Dust	Fugitive dust from blasting crushing, transportation and stockpiling raw materials is an irritant to neighbours	.	.	L	Refinements in procedures	Economic	" " "
	Groundwater	Affecting neighbours wells	.	.	L	Avoidance of Improper Kiln Dust Disposal	Economic	" " "
	Rehabilitation	Aesthetic, Safety	.	.	L	Controlled by Legislation	--	--

PROCESS ACTIVITIES

Kiln and Grinding Operations	Raw Material Supply	Sustainable Resource	L	L	L	Portion of Raw feed could be replaced by Calcium Waste	Economic	Limestones, silica & clay are some of the most common materials on the planet
	Dust	Fugitive dust from coal, raw feed and clinker storage	.	.	L	Indoor storage & management techniques	Economic	--
Energy Options	Major concern		H	H	H			
- Coal	Supply of dust (see above)		H	H	H	Convert to most available fuel	Economic	Ash is absorbed in cement making process SO ₂ mostly trapped by alkaline materials in kiln
	Sulphur Emissions (see below)							
	Higher CO ₂ than gas (see below)							
- Gas	Supply cost		H	H	H			Cement plants can use most fuels
- Alternatives			H	H	H	Burn waste derived fuels	Economic Regulation	Assists municipal and industrial waste management, serves as partial fossil fuel replacement.
Energy Efficiency	Fuel supply, electricity consumption, emissions		H	H	H			
- Plant Upgrading						Convert wet kilns to dry	Economic	Capital intensive - less than 20% of cement now produced in wet process
						Install pre-heater/precipitator towers	Economic	
						Electricity co-generation from waste heat	Economic/ Technical	

* Note: Transportation, which may be needed for raw materials, cement clinker, finished cement and ready mixed concrete operations, is not addressed in this Table.

Legend: L: Low environmental impact
M: medium environmental impact
H: high environmental impact

IDENTIFICATION OF ENVIRONMENTAL IMPACTS*

ACTIVITY	ISSUE	ENVIRONMENTAL CONCERN	LEVEL OF INFLUENCE			IMPROVEMENT OPTIONS	BARRIERS TO OPTIONS	COMMENTS
			GLOBAL	REGIONAL	LOCAL			
Product Modification	Grinding Operations	Energy Efficiency	H	H	H	Production of low C ₃ S cement	Technical/ Product Quality	Research required.
			H	H	H	Substitute high efficiency motors Use off-peak power at night Improve comminution	Economic	Implemented at many plants now
			H	H	H	Impr. Energy Effy. Capture and store CO ₂ Burn waste derived fuels	Economic/ Technical Regulation	Not feasible in foreseeable future Saves CO ₂ otherwise generated if waste is incinerated
			L	L	L	Replace coal with gas Replace limestone with lime wastes Convert to production of low C ₃ S cement	Economic Technical/ Product Quality	Would reduce CO ₂ generated by calcination of limestone
Emissions	CO ₂	NO _x	L	L	L	Impr. Energy Effy. Low NO _x burners Introduce Ammonia into kiln Replace gas with coal Staged combustion	Economic Economic	NO _x and SO ₂ level presently below regulated amounts
			L	L	L	Impr. Energy Effy. Scrubbers	Economic Economic/ Technical	
			L	L	L	Clean coal Technology	Technical/ Economic	
			L	L	L	Introduce new "C/D and flue gas scrubbing" technology	Technical/ Economic	Could reduce SO ₂ and NO _x emissions
Waste Reduction	Particulates	Organic wastes	L	L	L	Electrostatic precipitators Bag houses	Economic	In use
			H	H	H	Burn waste derived fuels	Regulation	Conserve Energy Help solve waste mgmt. crisis Reduce cement mfg. costs
			H	H	H	Use industrial wastes to replace raw materials for cements	Product Quality Product Quality Economics	Desirable characteristics of cement Limit acceptable wastes Disposal of ash from power plants or municipal incinerators
			L	L	L	Find markets for dust Recycle dust into cement Manage fugitive dust	Technical Technical Economic	How well controlled Increase cement alkali content
Waste Disposal	Dust	Cement kiln dust	L	L	L			

IDENTIFICATION OF ENVIRONMENTAL IMPACTS*

ACTIVITY	ISSUE	ENVIRONMENTAL CONCERN	LEVEL OF INFLUENCE			IMPROVEMENT OPTIONS	BARRIERS TO OPTIONS	COMMENTS
			GLOBAL	REGIONAL	LOCAL			
Waste Disposal	Dust	High pH from cement and solids on water quality	-	L	M	Introduce new "DXD flue gas scrubbing" technology	Technical/ Economic	Enables reuse of all CKD as kiln raw feed
			PRODUCT USE				Recycle into new concrete Treat wastes	Economic
Construction of concrete	Environmental	No direct environmental concerns	-	-	-			Concrete is an environmentally friendly product Cement is a caustic material. The eyes and skin must be protected.
	Worker safety	Cement burns	-	-	L	Safety regulations are in effect		
Performance of concrete	Energy Efficiency	Fuel consumption	L	L	M	Reduce cement consumption Refine Mix Design Refine Structural Design	Technical Technical Technical	Energy consumption of concrete is lower than competitive building and paving materials. Large improvements in last decade have already been made and further opportunities exist. Concrete products are noted for their long life span but further improvements are possible especially for freeze-thaw and alkali/aggregate durability issues. Concrete is an environmentally friendly inert material.
	Reduce	Reduce the demand for concrete by increasing the life cycle of concrete construction by addressing durability issues	M	M	M	Design Technical Improvement Construction Techn. Improvement Material Specification Enhancement	Technical/ Economic Technical/ Economic Technical/ Economic	
PRODUCT DISPOSAL	Demolition	Conservation of energy and resources	M	M	M	Re-use (instead of landfilling)	Economic	Large quantities of concrete are presently re-used for retaining walls. Restoration of deteriorated concrete is a viable alternative to demolition and reconstruction. Is currently being used in moderate quantities. Ultimately all demolished concrete can be re-used or re-cycled.
						Rehabilitation	Economic	
						Disposal	Economic	