DEPARTMENT OF COMMERCE ★ NATIONAL BUREAU OF STANDARDS ★

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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Possible Contributions of Cement and Concrete Technology to Energy Conservation

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Possible Contributions of Cement and Concrete Technology to Energy Conservation

Summary of the NBS/DOE Workshop held
October 3-4, 1977 at the National
Bureau of Standards, Gaithersburg, MD

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ABSTRACT

A workshop on Possible Contributions of Cement and Concrete Technology to Energy Conservation by the Year 2000 was held at the National Bureau of Standards on October 3 and 4, 1977. The purpose of the workshop was to identify and record ideas on possible contributions of cement and concrete technology to energy conservation in the near term and by the Year 2000. This included consideration of current technology as well as areas in which technological advances might be realized.

The workshop was divided into working groups on cement composition, cement production, blending materials, concrete production, efficient use of concrete, and institutional factors. The essential results from the six working groups were statements of Energy-Saving Opportunities, Research Needs, and Unresolved Issues. The statements, which are the major part of this report, are presented without critical analysis. They suggest, however, that there are a large number of possible opportunities which should be evaluated for their ability to contribute to energy conservation in the cement and concrete industries.

Key Words: Cement; concrete; research needs; energy-saving opportunities

EDITORS' NOTE

With the exception of Chapters 1 and 8 and the introductory sections of the other chapters, the views expressed are those of the workshop participants. They are edited versions of the written statements prepared by the working groups and their chairmen and they are presented without critical analysis. We hope our efforts to express them in a reasonably uniform style have not in any way changed or obscured the meanings of the statements.

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1. INTRODUCTION

1.1 Background

Concrete is the most widely used material of construction in the U.S. with more than 500 million tons being placed each year. The primary constituents of concrete are cement, sand, aggregate, and water with steel reinforcement being used in many structural applications. In addition, chemical admixtures are often used to modify characteristics of concrete such as rheological properties, air content and setting times.

More than 95% of the concrete placed in the U.S. contains portland cement as the main cementing material. In terms of the energy required to produce concrete, the manufacture of portland cement uses the largest amount. In 1975, the U.S. cement industry produced approximately 70 x 10^6 tons of portland cement and consumed about 2% of the energy used in the nation's industrial processes or about 6 x 10^{17} joules.*

Energy conservation in cement manufacture cannot properly be considered independently of the concrete industry which ultimately determines the efficiency with which the cement is used. Because of the interrelationships between the cement and concrete industries, and the desirability of being able to consider energy conserving options of both industries simultaneously, the Department of Energy and the National Bureau of Standards sponsored a two day workshop on the Possible Contributions of Cement and Concrete Technology to Energy Conservation by the Year 2000. The workshop was held at the National Bureau of Standards on October 3 and 4, 1977. A special effort was made to obtain the participation of well-informed persons representing a wide range of viewpoints and interests. The total number of participants was 95 with 12 being from foreign countries. As a precondition for participation, each had been required to submit in advance written ideas for discussion. The membership of the workshop steering committee is given in Appendix I and the list of participants in Appendix II.

1.2 Objective and Scope of the Workshop

As its name indicates, the objective of the workshop was to identify opportunties for energy conservation in the manufacture and use of cement and concrete in the near future and by the Year 2000. The workshop scope included modifications of cements and cement manufacturing processes, the replacement of a portion of the cement in concrete by waste or byproduct materials, and the more efficient production and

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* J.R. Clifton, P.W. Brown, and G. Frohnsdorff, Energy Conservation Through the Facilitation of Increased Blended Cement Use, NBSIR 76-1008, National Bureau of Standards, Feb. 1976.

use of concrete. An equally important part of the scope concerned institutional factors which might affect the use of energy-conserving technologies by the producers and users of cement and concrete. To promote discussion in these areas and bring out as many ideas as possible, six working groups were established within the workshop under the headings:

- Cement Composition
- Cement Production
- Blending Materials
- Concrete Production
- Efficient Use of Concrete
- Institutional Factors

The working groups were of roughly equal size and, as far as possible, assignments to them were based on the interests and expertise of the participants and the desire to have a broad range of viewpoints represented in each group. The working group chairmen (See Appendix I) had been selected in advance and they had been asked to work with their groups to discuss and prepare statements on the possibilities for energy conservation in their assigned areas. Between them, the working groups prepared 59 statements on energy-saving opportunities, and 67 on research needs; they also drew attention to 4 unresolved issues. Energy-Saving Opportunities referred to steps which the respective groups felt could be taken in the near term using current technology, while Research Needs related to further research which would have to be carried out if potential energy-saving opportunities were to be confirmed and exploited. Unresolved Issues indicated areas where it was felt, at least by some, that there might be opportunities for energy conservation though there was not now sufficient information to assess the potential.

This report includes six chapters detailing the outputs of the six working groups, and a final chapter giving a summary of ideas put forward by the working groups. It should be noted that the working groups were requested not to rank the ideas in order of importance. In view of the limited time available, it was decided it would be better to try to record all ideas and leave critical analysis and ranking for another activity.

We hope this report will stimulate energy-conservative actions and encourage the formulation of still other ideas for energy conservation in the cement and concrete industries.

2. CEMENT COMPOSITION

2.1 Background

Four main types of portland cement are currently produced in the U.S. Each of these cement types is composed of four primary compounds which approximate to the compositions: C_3S, C_2S, C_3A, and C_4AF, where C = CaO, S = SiO_2, A = Al_2O_3, and F = Fe_2O_3. The relative amounts of these compounds can, to some extent, be controlled by the manufacturer. This is done to meet specification requirements and to adjust performance. The four main cement types and their uses and special features may be summarized as follows:

ASTM Cement Type	Use or Special Characteristics	Salient Feature of Specification
I	General purpose construction	least restrictive spec.
II	Moderate heat of hydration or moderate sulfate resistance	$\leq$ 8% C_3A
III	High early strength	1-day strength $\geq$ 1800 psi (12.4MPa) 3-day strength $\geq$ 3500 psi (24.1MPa)
V	High sulfate resistance	$\leq$ 5% C_3A

2.2 List of Statements Prepared by the Working Group

Energy-Saving Opportunities:

a) Standard reference materials

b) High free lime clinker

c) Better matching of cement properties to use

d) Combined production of cement and other products

Research Needs:

a) Optimization of properties of blended cements

b) Nucleating agents for cement hydration

c) Low-lime clinkers and cement

d) Low-temperature processes for production of hydraulically-active dicalcium silicates

e) Hydrothermal pretreatments for activation of silicious materials

f) Lime-pozzolan mixtures as replacements for concrete

g) Autoclaved calcium silicate materials

h) Spurrite as a cementing material in autoclave processes

i) Cements containing large quantities of calcium sulfate

j) Cements for use with glass fiber reinforcement

2.3 Summary of the Discussions

The working group on cement composition considered how possible changes in cement composition could contribute to savings in energy and materials. Because the calcination of limestone consumes much of the energy used in portland cement manufacture, several suggestions were concerned with reduction of the lime content of cements; this could be done either by manufacture of portland cements of lower lime content or of blended cements containing significant amounts of other inorganic materials as partial replacements for ground portland cement clinker. Another group of suggestions recommended the use of silicious cements which, because they would not contain portland clinker, would require less energy to manufacture, though more to cure. The more efficient use of cements by better matching of properties to end use or by enhancement of performance through the use of nucleating agents was also considered. Because a reliable analysis of raw materials and products is necessary for close control of the cement manufacturing process, attention was drawn to the potential benefits of providing standard reference materials. The adjustment of cement compositions to minimize corrosion of other constituents of concrete (e.g., steel reinforcing bars and glass fibers) was considered worthy of research.

In reviewing the discussions, the working group chairman pointed out the desirability of learning how to increase the grindability of clinkers and of how to make satisfactory portland cements containing larger amounts of MgO or calcium sulfate than are presently accepted. He emphasized the importance of understanding the interactions between the ingredients of blended cements so that their performance could be optimized. He also said that, though no specific suggestions were made, the group had discussed possible uses of waste kiln dusts as cementing materials, neutralizing agents, fertilizers and replacements for gypsum in portland cement, and the collection of nitrogen compounds from kiln gases for possible use in fertilizers. Altogether, the working group prepared 4 statements of energy-saving opportunities and 10 statements of research needs.

2.4 Energy-Saving Opportunities

a) Standard Reference Materials

Variations in clinker composition due to variations in kiln feed cause increased use of energy in clinker production. Improved control of the composition of kiln feed has been assisted by the development of rapid analytical techniques, such as x-ray emission, but the use of these techniques could be simplified and extended if a larger range of standard reference materials could be made available. Standard reference materials are needed for shales, limestones, cement raw mixes, coals, and coal ash.

b) High Free Lime Clinker

Portland cement clinker is usually required to have a low free lime content. This helps insure satisfactory performance, but often at an increased energy cost. A recent patent issued in the Soviet Union suggests that energy savings of about 10% can be obtained in manufacture of clinker by making high free lime clinkers at temperatures not exceeding 1380°C. The benefits claimed are reduced fuel use in clinker formation, increased life of kiln linings, improved performance of blended cements made with the clinker, and easier grinding. This appears to offer an energy-saving opportunity provided the performance is satisfactory and appropriate standards are available.

c) Better Matching of Cement Properties to Use

The limited number of varieties of cement available hinders the matching of cement properties to user needs. This may lead to overdesign of concrete mixes with the use of unnecessarily large amounts of cement. More efficient use of materials could be obtained through the mixing of cements with blending materials such as certain types of slags, organic admixtures and reinforcing materials.

d) Combined Production of Portland Cement and Other Products

Portland clinker is usually manufactured as the sole product of the manufacturing plant. However, depending on the raw materials available, it is sometimes possible to manufacture portland clinker simultaneously with one or more of the following materials: alumina, sulfuric acid, phosphate fertilizers, and potash. Investigations should be carried out to determine whether processes involving the combined production of portland clinker and other products are energy-conserving.

2.5 Research Needs

a) Optimization of Properties of Blended Cements

For any specific blending material (e.g., granulated blast-furnace slag, fly ash, natural pozzolan) it is assumed there is an optimum portland clinker for use in making a blended cement. This might not necessarily be the best clinker for making a portland cement. There is a need for research on the effects of clinker composition and other factors on the performance of blended cements. If our resources are to be used most effectively, the effects that the phase compositions and particle size distributions of the clinker and the blended materials have on the performance of blended cements must be determined.

b) Nucleating Agents for Cement Hydration

It has been observed that the addition of certain hydrated calcium silicates, such as afwillite, to a paste of the cement compound alite, accelerate the hydration of the alite and the hardening of the paste. Further, the hardened paste shows only about half the drying shrinkage of the hardened paste without added afwillite. It has also been observed that the addition of ettringite can accelerate the hardening of a portland cement paste and increase its rate of strength gain. These effects are not well understood but it is assumed that the added materials act as nucleating agents for the hydration products of the cementing material. If advantage is to be taken of such phenomena in improving the performance of cements, the feasibility of accelerating cement hydration by means of nucleating agents should be investigated. Efficient use of all potential cementitious binders will only be realized when there is a fundamental understanding of the factors causing strength gain, when the reactivity can be measured and controlled, and when the optimum microstructure can be produced from each cementing material for the application in which it is to be used.

c) Low-Lime Clinkers and Cements

Preliminary research has indicated that cements containing larger quantities of alumina and SO_3 than portland cements can be made. They contain less lime than portland cements and, using $\overline{S}$ to represent SO_3, the phases present may include $C_4A_3\overline{S}$ but not C_3S. Cements of this type should be compared with portland cements from the points of view of performance and energy requirements for manufacture and use. There is a need to know whether the cements make durable concretes and whether they can be made from sulfur-containing industrial wastes.

d) Low-Temperature Processes for Production of Hydraulically-Active Dicalcium Silicates

β-Dicalcium silicate is one of the major cementing compounds in portland cements. However, it reacts much more slowly than tricalcium silicate. Recent research has shown that much more reactive β-dicalcium silicate can be made by spray-drying of gels at about 900°C. This suggests that a dicalcium silicate cement requiring little or no grinding might be made at a much lower temperature than portland cement. This possibility should be investigated.

e) Hydrothermal Pretreatments for Activation of Silicious Materials

It is suggested that the reactivity of siliceous materials, such as quartz, granulated slags, and fly ashes, might be improved through a pretreatment with high pressure steam or with alkali prior to their use as constituents in blended cements.

f) Lime-Pozzolan Mixtures as Replacements for Concrete

It is suggested that, for some purposes, lime-pozzolan mixtures could replace portland cement concrete. Improved understanding of the reactions between lime and pozzolans and new ways of controlling them should be sought. This research should include studies of the effects of low-pressure steam curing on lime-pozzolan mixtures.

g) Autoclaved Calcium Silicate Materials

In some European countries autoclaved calcium silicate materials are used on a scale comparable with portland cement concrete. The products include dense materials such as sand-lime block, and less dense ones such as aerated concrete. In some cases they are reinforced. It may be important that autoclaved calcium silicate products can be made using waste materials such as fly ashes, slags, mining wastes, and other industrial by-products. It is recommended that the potential energy saving from making autoclaved calcium silicate materials in the U.S. be evaluated. This would require the total energy requirements for manufacture of autoclaved calcium silicates and portland cement concretes to be compared taking into account all steps from the production of the raw materials to the completion of construction.

h) Spurrite as a Cementing Material in Autoclave Processes

Spurrite is a calcium silicate carbonate which might be a useful cement for use in autoclave processes. Since its manufacture would probably require less enegy than the manufacture of lime or portland cement, it should be determined whether spurrite is indeed viable as a cement for autoclaving uses and whether it can be economically produced both in terms of cost and energy use.

i) Cements Containing Large Quantities of Calcium Sulfate

Calcium sulfate dihydrate (gypsum) is an abundant naturally occurring mineral and also a common process waste. If a substantial fraction of the portland cement used in a variety of applications could be replaced by some form of calcium sulfate*, this would almost certainly save energy and help in the disposal of waste sulfates. Substantial quantities of calcium sulfate are used in supersulfated cements, but use of similar quantities in portland cements may lead to the disruptive expansion of concrete. If the factors causing expansion were understood, they might be controlled so that greater quantities of calcium sulfate could be used. There is, therefore, a need to carry out research on the factors which cause expansion in cements containing substantial quantities of any of the forms of calcium sulfate.

j) Cements for Use with Glass Fiber Reinforcement

There is considerable interest in the use of glass and other fibers for increasing the tensile strength of mortars and concrete. Although alkali-resistant glasses are available, there is still uncertainty about their long-term durabilities when used in portland cement concrete. Research is needed to aid the design of cement-fiber systems that are economical and durable. Research on such systems would have energy-saving potential because panels of fiber-reinforced materials could replace thicker panels of concrete or panels of metal such as aluminum or steel.

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* The main forms are anhydrite ($CaSO_4$), hemihydrate ($CaSO_4 \cdot 1/2\ H_2O$), and dihydrate ($CaSO_4 \cdot 2H_2O$)

3. CEMENT PRODUCTION

3.1 Background

The manufacture of portland cement is comprised of three major processing stages for which the approximate average energy requirements are:*

Process	Approximate Energy Requirement Btu/ton	Approximate Energy Requirement joules/Kg	Approximate Fraction (%) of Total Energy Requirement
Raw materials processing	1.0×10^6	1.0×10^6	13
Pyroprocessing	5.9×10^6	6.1×10^6	80
Finish grinding	0.5×10^6	0.5×10^6	7
Total	7.4×10^6	7.6×10^6	100

Raw materials processing includes quarrying, crushing, drying and grinding. Pyroprocessing shows the largest energy requirement largely because of the energy required for the calcination of the lime-bearing materials. In the finish grinding step, the cement clinker, along with the appropriate gypsum addition, is ground to cement fineness. The tabulated figures are averages for the whole industry. In general, the dry process for cement manufacture, in which the raw materials are kept dry while being prepared for pyroprocessing, uses less energy in the first two stages, while the wet process, in which the raw materials are ground and blended as slurries, uses more.

3.2 List of Statements Prepared by the Working Group Energy-Saving Opportunities:

a) Use of finely-divided raw materials

b) Metallurgical slags as raw materials

c) Simultaneous drying and grinding of raw materials

d) Dewatering of raw material slurries by filtration

e) Use of classifying mill liners and flow-controlling diaphragms to improve mill efficiency

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* Energy Conservation Potential in the Cement Industry, Conservation Paper No. 26. FEA, June 1975; NTIS No. PB-245.159

f) Substitution of combustible wastes for traditional fuels

g) Fuels derived from municipal and industrial wastes

h) Use of low grade fuels as partial replacements for high grade fuels

i) Use of mineralizers to lower the temperature of clinker formation

j) Improved methods for control of the clinkering process

k) New or modified pyroprocessing systems

l) Use of lower-grade heat

m) Cogeneration of electricity and/or steam with clinker

Research Needs:

a) Coal refuse as a cement raw material

b) Flue gas desulfurization wastes as cement raw materials

c) Sewage treatment waste as a cement raw material

d) Production of portland cement from high surface area lime

e) Separate grinding of raw materials

f) Dispersion of raw materials and clinker during grinding

g) Thermal comminution of limestone and other raw materials

h) Alternative methods of comminution

i) Electrical heating of kilns

j) Clinker as a by-product of coal-fired power plants

k) Low-temperature processes for cement production

l) Modeling of clinker production

m) Phase diagrams for portland cement compositions with mineralizers in kiln atmospheres

n) Measurement and control of clinkering by microscopic analysis

o) Improvement of clinker grindability by control of cooling history

p) Removal of undesirable volatile components from cement kilns by increasing exhaust temperatures

q) Reduction of dust generation in clinker manufacturing processes

r) High temperature dust collectors

s) Dust recycling and waste heat recovery

t) Effect of clinker structure on grinding energy requirements

u) Alternative to electrical energy for driving grinding mills

v) Improvement in efficiency of particle size classification

w) Cogeneration of electricity and clinker

x) Reduction of power requirements for cement production

Unresolved Issue:

a) Feasibility of complete recycling of dust when using high sulfur coal as fuel

3.3 Summary of the Discussions

The working group on cement production considered how cement manufacturing operations might be controlled or changed to bring about savings in energy and materials. It was suggested that certain finely-divided, or other highly-reactive, raw materials had potential for reducing the energy required in clinkering and that energy savings in raw materials preparation could be achieved through changes in methods of dewatering and drying raw materials. Suggestions were made as to how the amount of electrical energy used in grinding raw materials and clinker could be reduced and possibilities for use of lower-grade fuels were mentioned. The importance of controlling the cement kiln to obtain easily-ground clinker showing optimum performance in cement was touched on, and the possibility of using fluxes in the raw materials to lower the kiln burning zone temperature was noted. Improved heat recovery from kiln exit gases, which could be assisted if high temperature dust collectors could be made available, was seen to offer opportunities for further energy conservation. A related topic was the possibility of cogeneration of steam and electricity with clinker. It appeared there was still some need for new information on phase relationships in oxide systems relevant to cement manufacture, and the potential benefits of continuing development of mathematical models representing the kiln operation were noted. The group documented 13 energy-saving opportunities, 24 research needs, and an unresolved issue relating to the feasibility of complete recycling of kiln dust when high sulfur coal is used as the fuel.

3.4 Energy-Saving Opportunities

a) Use of Finely-Divided Raw Materials

Certain materials with potential for use in cement manufacture normally occur in a finely-divided condition. Examples are fly ash, aragonite, some silicates, and some forms of silica and alumina. The complete or partial substitution of these for more commonly used raw materials could lead to a reduction in the energy used in the grinding of raw materials.

b) Metallurgical Slags as Raw Materials

There are a number of metallurgical slags which have potential for use as cement-making raw materials. These include phosphate slags, iron blastfurnace slags, steel slags, foundry slags, and slags from nonferrous smelters. Although constraints to the use of some of these slags may be posed by their chemical compositions, variability, continuity of supply, and transportation and purchase costs, the fact that they have already undergone heat treatment means they would require less energy for conversion into clinker. It was recommended that information be published on all slag sources giving the slag chemistry and location in respect to cement plants. Computer programs should be developed to determine whether a particular slag could be used in combination with a cement plant's raw materials to give suitable cement compositions.

c) Simultaneous Drying and Grinding of Raw Materials

Using waste heat or supplementary heaters, grinding mills now available can simultaneously grind and dry materials initially containing up to about 20% of water. Such mills could save as much as 15% of the heat used in wet process cement manufacture. It is believed such mills could be installed (retrofitted) in most wet cement plants.

d) Dewatering of Raw Material Slurries by Filtration

Certain raw materials, such as chalks and clays, can only be used in the wet process. It is suggested that the slurries produced in grinding these materials should be dewatered by filtration to produce the driest practicable filtercake for feed to the kiln. It is predicted that about 20% of the energy normally required in the wet process could be saved through the use of filtration. (It should be noted that the separate grinding of alkali-containing materials and filtering them separately presents an opportunity for removing water-soluble alkalis with the filtrate water). The major restraints to installation of filtration equipment are likely to be space and availability of capital. Good maintenance of filters would be necessary for avoidance of problems.

e) Use of Classifying Mill Liners and Flow-Controlling Diaphragms to Improve Mill Efficiency

It appears that the efficiency of grinding mills can be increased through the installation and use of classifying mill liners and flow-controlling diaphragms. Increases in efficiency of up to 15% are claimed by manufacturers. Although several such systems have been installed in the U.S., documentation by impartial observers has not been made. It would be valuable in helping cement companies recognize the energy-saving potential of systems of this type, if the claims of the manufacturers could be verified.

f) Substitution of Combustible Wastes for Traditional Fuels

Several types of waste materials not currently used as fuels have potential for replacing the traditional fuels used in cement manufacture. Examples are waste crank-case oil, waste solvents, waste cellulosics, and by-product hydrogen. While there may be logistical and environmental difficulties in making the fuels available for cement manufacture, and while, particularly in the case of hydrogen, the flame characteristics may not be the optimum for heat exchange, it is recommended that the use of these waste materials as fuels be investigated.

g) Fuels Derived from Municipal and Industrial Wastes

There are a large number of possibilities for the production of fuels from municipal and industrial wastes. The fuels could be in solid, liquid or gaseous form. Although few of the production processes are commercially proven, several pilot plants are in operation. It is recommended that consideration be given to the possibilities for using these fuels for full or partial replacement of the traditional fuels used in cement manufacture.

h) Use of Low-Grade Fuels as Partial Replacements for Higher-Grade Fuels

Lower-grade fuels such as water gas, lignite, and petroleum coke, have a potential for at least partial replacement of higher-grade fuels for use in cement manufacture. Lignite and petroleum coke could be supplied to any cement plant and a water gas plant could be constructed on site with facilities for removing SO_2 and/or H_2S from the gas. The possibilities of using such fuels in cement manufacture should be investigated. Among the possible constraints are the availability of the fuel, the amount of air needed for proper combustion, and the low heat value of water gas. It is possible that, particularly in the case of water gas, new burning techniques such as oxygen enrichment would be needed.

i) Use of Mineralizers to Lower the Temperature of Clinker Formation

It is well known that there are mineralizers which lower the temperature of clinker formation. Examples are fluorides, magnesium compounds, and sulfate-containing compounds. Unfortunately, there is a lack of documentation on full and pilot scale tests to determine the energy savings per ton of clinker, the effects of mineralizers on kiln linings, the effects of mineralizers on the operation of suspension preheaters and various types of kilns and, most important, on cement performance. In view of the possibility of conserving energy through the use of coarser kiln feeds and shorter burning times, the use of waste materials containing fluorides and sulfates as mineralizers should be explored. These wastes include fluorosilicates, by-product gypsum, and sulfate scrubber sludges.

j) Improved Methods for Control of the Clinkering Process

Energy is wasted in the manufacture of portland cement clinker through irregularities in the operation of cement kilns. The use of improved methods of kiln control, therefore, has potential for energy savings. Although equipment suppliers should have an economic motivation to do research in this area and publicize the results, information on the technological advances occurring in the world does not seem to be adequately disseminated. Few cement manufacturing companies can spare the staff for the world-wide travel needed. There are two recent examples of the value of technology-gathering trips. These are the Kaiser Engineers trip around the world to study precalcining kilns in at least 24 plants and the European tour conducted by the PCA after the recent VDZ Congress in Germany. It is recommended that this type of activity be encouraged with the PCA being a possible focus.

k) New or Modified Pyroprocessing Systems

There appear to be several new or modified pyroprocessing systems which could result in reduced energy consumption in the manufacture of clinker. Examples are the fluidized bed process, the air slide kiln for calcining, the oscillating plate kiln for calcining and clinkering, the use of residual fuels in conventional kilns, and the use of a shaft kiln to preheat pellets before clinkering in a rotary kiln. Unfortunately, there are several constraints which hinder the full scale evaluation of new systems. They include the reluctance of the cement industry to accept the technical risk of using a virtually untried system, its reluctance to deal with small firms which may not be able to provide the long-term support needed, and the lack of capital in the industry. There is, therefore, a need for technical evaluation and demonstration of these systems in regard to energy use, first cost and operating costs, environmental factors, and process limitations. Between them, the new or modified systems have potential for processing of kiln dust, the cogeneration of power and clinker, the use of waste-derived fuels or other low-grade fuels, the replacement of existing or obsolescent suspension preheaters, and use in small plants. Some possible options for aiding exploitation of the opportunities are: provision of government or industry insurance against technical risks, government-instituted revolving loan funds with low interest rates, industry-sponsored investment systems and programs for development, higher cement prices, and the incentive provided by increases in fuel costs.

l) Use of Lower-Grade Heat

The use of the lower-grade heat which is usually wasted in the cement plant poses an energy-saving opportunity. New attention should be given to the use of the lower-grade heat for cement manufacture and the distribution of waste heat, or electricity manufactured from it, outside the cement plant. After the fullest use of energy in the manufacturing process, space heating would be the main use for heat at the lowest end of the temperature spectrum. Constraints on the distribution of heat and electricity outside the cement plant are the rate structures and regulations concerning feeding from non-regulated generators into a regulated net, and community attitudes towards industry. It is recommended that consideration be given to the use of the lower-grade heat for drying, in-plant space heating, heating of fuel and raw materials, community space heating, and process heating (as in paper plants using low pressure steam).

m) Cogeneration of Electricity and/or Steam with Clinker

Cement plants can burn lower grade fuel and convert it to electricity. This can be done with fuels which are not suitable for use by power companies. The availability of steam from waste heat boilers makes possible the use of direct drive equipment running on steam and other uses of steam which do not require conversion to electricity. Although many plants which once operated in this way were shut down for technical and economic reasons, these reasons may not be applicable today. The cogeneration of electricity and/or steam with clinker is most likely to be attractive in new processes where it can be integrated into the design. It may also be economic in existing modern plants, where preheaters and long kilns permit gases to leave at reasonably high temperatures, and in some older plants where it would increase fuel efficiency and use existing steam/ electric equipment.

3.5 Research Needs

a) Coal Refuse as a Cement Raw Material

Coal refuse contains fuel values as well as lime, silica and alumina. If it could be used in cement manufacture, it would help conserve natural resources, including fuel, and contribute to the disposal of coal mining wastes. Although the iron and alkali contents of coal refuse, and transportation costs, may hinder its use, it is recommended that research be carried out on the suitability of this type of refuse for use in cement manufacture, including studies of the effects of sulfur, alkalies and trace elements on phase equilibria and cement performance.

b) Flue Gas Desulfurization Wastes as Cement Raw Materials

Flue gas desulfurization (FGD) systems typically produce a $CaSO_x$ waste material. Although their contents of sulfate, sulfite and iron might be detrimental, it appears these wastes could be combined with fly ash to provide all the necessary oxide constituents for portland cement manufacture. If FGD wastes could be used in this way, it would help reduce a disposal problem and contribute to the conservation of natural resources. It is recommended that possibilities for manufacturing cement from FGD wastes be explored. Since the cement industry has no obvious economic incentive to support such development, the support would probably have to come from governmental or institutional sources.

c) Sewage Treatment Waste as a Cement Raw Material

Sewage treatment waste has a potential fuel value and it contains silica and lime. It can be generated in the form of a wet sludge or a dry incinerator ash. If this material could be used in cement manufacture, it would help to reduce waste disposal problems and aid in the conservation of fuel and other raw materials. It is recommended that the potential of this waste for use in cement manufacture be investigated. The research on the wastes should include investigations of the range of compositions, heating values, methods of handling, attendant environmental problems, and the economics of use.

d) Production of Portland Cement from High Surface Area Lime

High surface area lime can be produced by the rapid heating of calcium carbonate raw materials under a low partial pressure of carbon dioxide. It is believed that the high surface area lime would react more rapidly with silica, alumina and iron oxide in the formation of portland clinker, and with a lower requirement for energy. It is recommended that research be carried out on the calcination of calcium carbonates to form high surface area limes and that the energy costs and product quality be evaluated.

e) Separate Grinding of Raw Materials

The segregation of the components of the raw meal for cement manufacture can sometimes be traced to the variability in the grinding rates of the raw materials. Because of segregation, longer burning times are needed for the meal and more energy is used in clinker manufacture. Separate grinding of the raw materials to the optimum fineness with subsequent blending would probably reduce the energy requirement for clinker manufacture. Among potential benefits would be reduced fuel requirements, improved product quality, reduced dust generation, increased production, and conservation of materials by allowing use of lower-quality materials.

f) Dispersion of Raw Materials and Clinker During Grinding

Dispersing agents such as water, glycols, and other organic compounds with polar molecules are commonly used as grinding aids in the cement industry. In some cases, grinding aids tailored to a specific mill need have reduced the power required for grinding by 10 to 15 percent. Unfortunately, the benefits vary significantly with the application and the energy savings have seldom been quantified. This is because past studies have not been systematic and grinding aids have often been marketed in terms of their effects on the flow properties of the dry powder rather than on grinding efficiency. In order to help establish the energy saving potential of increased use of grinding aids, it is recommended that research be carried out to study the effects of grinding aids on energy requirements and product characteristics. The research should include studies of the dispersion phenomena in terms of their origin and the factors affecting them, e.g., electrostatic forces, heat, surface characteristics, etc. The results of such research could help the industry understand conventional and new types of dispersing agents, and increase the cement industry's ability to select the proper agents for optimum energy reduction.

g) Thermal Comminution of Limestone and Other Raw Materials

It has been observed that aragonite, one of the naturally-occurring forms of calcium carbonate, breaks up into micrometer sized particles when heated in a conventional rotary kiln. If the factors contributing to this reduction in particle size on heating were understood, it might be possible to reduce the energy requirement for clinker manufacture by inducing thermally-induced comminution within the kiln. It is recommended that research be carried out on this phenomenon exhibited by aragonite (which is abundantly available in the Caribbean and Persian Gulf areas) and on the possibility of extending application of the knowledge to other sources of calcium carbonate.

h) Alternative Methods of Comminution

The conventional ball mills used for grinding cement raw materials and clinker are very inefficient. It has been estimated that less than 5 percent of the energy put into the mill is actually used in surface area generation. The finish grinding of cement consumes about 40 percent of the electrical energy used in a cement plant equipped with a suspension preheater kiln. Because of the high potential for reducing the electrical energy used in cement manufacture if grinding could be made more efficient, it is recommended that fundamental studies of milling be carried out in the search for more efficient processes. Directions worthy of investigation might be suggested by analyzing the Snyder process, the torroidal steam autogenous mill, coal comminution processes, solvent processes, and processes developed by the Syracuse Research Corporation and by Russian technologists.

i) Electrical Heating of Kilns

It appears that several alternative energy sources could only be used for clinker manufacture if electric power could be used for heating a kiln. Among these alternative energy sources are nuclear, solar, geothermal, wind, tidal, ocean thermal, and photovoltaic. Unfortunately, with current technology, electrical heating is not economically attractive. In view of the importance of determining the possibilities of replacing fossil fuels with essentially renewable sources, it is recommended that research be carried out on the feasibility of using electric power for the production of clinker.

j) Clinker as a By-Product of Coal-Fired Power Plants

The fluid-bed process for combustion of coal includes the addition of limestone to the fuel bed to absorb sulfur dioxide. The possibility that the conditions in the bed could be controlled so that the lime would also combine with the coal ash to form a cementitious ash or an ash which was particularly suitable for the manufacture of cement clinker should be explored. Since such a process might have potential for lowering the energy requirements for manufacture of hydraulic cements, it is recommended that theoretical research be carried out to determine the feasibility of such a process and, if feasible, to extend the research to pilot plant and field trials to determine the range of application and the fuel efficiency.

k) Low-Temperature Processes for Cement Production

Although the present method of clinker production requires a large input of energy to heat the raw materials to high temperatures, there is some evidence that cements can be formed at much lower temperatures by mechanical action (grinding) between lime and silicates. Lime can also be produced at lower temperatures than are usually used. Because of the possibility of eliminating the traditional cement kiln with its high energy consumption, it is recommended that research be carried out on the feasibility of low-temperature formation of cementitious materials which could be substituted partially or completely for portland cement. The initial efforts should be focused on the low-temperature production of lime. If this is successful, the low-temperature production of cement should be investigated.

l) Modeling of Clinker Production

Changes in the distribution of the oxides in the raw materials for portland clinker production and changes in kiln operating conditions affect the physical character of the clinker, and the composition and distribution of the compounds in it. These changes in turn affect cement performance. An improved understanding of these relationships can be obtained through development of mathematical models. Certain aspects of this problem are fairly-well understood, particularly the basic gas-solid heat exchange equations and certain relationships involving raw material granulometry, chemistry and burning zone profile. However, research is needed on the conditions under which clinkering reactions take place and the critical factors in the formation of minor compounds. Research is also needed on the critical factors affecting the kinetics of coating formation and clinker formation, including the temperature profile. All of these should be integrated in a comprehensive model which would have importance for improving kiln design, and optimizing operations in regard to clinker quality, clinker grindability, refractory life, and fuel consumption.

m) Phase Diagrams for Portland Cement Compositions with Mineralizers in Kiln Atmospheres

It is generally accepted that the use of mineralizers (fluxes) in clinker production has potential for energy conservation. Although some phase "equilibria" data have been obtained for the calcium fluoride-portland clinker system, and for spurrite and its analogs occurring in the 1000-1100°C temperature range, there is a need for more detailed information on phase relationships in systems containing fluorides, chlorides, and sulfates with portland clinker compositions in kiln atmospheres. Information is also needed on the effects of mineralizers, individually and in the presence of others, on:

1. Alkali volatilization,

2. Minor components such as MgO,

3. Melt viscosity,

4. Calcination temperature,

This information is needed to help in the selection of mineralizers.

n) Measurement and Control of Clinkering by Microscopic Analysis

Improvement of clinker quality can lead to lower overall costs of cement. Methods have been developed to monitor clinkering so as to maximize the performance potential of the clinker. However, more research is needed to complete the evaluation of the methods. Research is needed to provide knowledge of the relationships between microscopic results and performance characteristics of the resultant cement, such as setting time, slump loss, rate of strength gain, and clinker grindability. If it could be developed, an automatic on-line sensor which functioned as an analog to a microscopic analyzer would have an important energy-saving potential. It is estimated that there is a potential for saving at least 20% of the energy required for cement manufacture.

o) Improvement of Clinker Grindability by Control of Cooling History

Portland clinkers can differ substantially in their grindability. The grindability is known to be affected by the rate of cooling. Clinker is usually cooled by a stream of air in reciprocating grate coolers, traveling grate coolers, or planetary coolers. A portion of the air is recovered for use as combustion air in pyroprocessing. The excess air is vented through a dust collector or is used as a low-grade heat source. Research is needed to determine if alternative cooling methods might be developed which could improve clinker grindability using thermal shock. Investigations should also be carried out to determine if cooling media more energy-efficient than air could be found in order to eliminate the capital and energy costs of air cleaning. The possible benefits are more easily ground clinker, more efficient cooling, and reduction or elimination of the need for air cleaning.

p) Removal of Undesirable Volatile Components from Cement Kilns by Increasing Exhaust Temperatures

Heat recovery from the exhaust gases of cement kilns is often hindered by the presence of undesirable vapors, such as those of alkali sulphates and chlorides in the gases. Because only low quantities of these salts can be tolerated in clinker, their vapors should not be allowed to condense on the incoming kiln feed. If the exhaust temperatures of the kilns could be increased, this could aid in the removal of the undesirable volatiles and help to optimize the total energy costs. Such a process modification could only be economical if an adequate heat recovery technology was available. Alternative energy sources or new processes may require higher exhaust temperatures so that systems with 100% separation (bypass) of the exhaust gases from incoming feed could be considered without causing an appreciable loss of efficiency. Research is needed to provide knowledge of the physical and chemical properties of high temperature gases leaving the clinkering environment. This knowledge would assist in the design of heat transfer equipment needed in the development of new processes.

q) Reduction of Dust Generation in Clinker Manufacturing Processes

Dust represents a substantial loss of the energy expended in quarrying, feed preparation, and, particularly, in pyroprocessing. There is, therefore, a need to carry out research to evaluate the following possibilities for reducing dust losses:

1. Separate preheating and/or calcining of raw material components

2. Separate grinding of each raw material component to minimize production of fines before entering the kiln

3. Better control of particle size in grinding the raw material mix to minimize the quantity of unnecessarily fine material entering the kiln

4. The use of mineralizers to allow the use of coarse raw feed

5. Reducing gas flows by oxygen enrichment or the use of noncombustion heat sources such as electrical or solar

6. Pelletizing the kiln feed, and

7. Using a fluid bed kiln.

r) High Temperature Dust Collectors

The need exists for the removal of dust from the exhaust gas stream of cement kilns without appreciable lowering of the temperature. For this purpose, it will be necessary to develop a dust collector which will operate in the range of 1500-2500°F (800-1350°C). The benefits of removal of dust from the hot stream will be much greater utilization of the heat in the stream.

s) Dust Recycling and Waste Heat Recovery

The ability to remove dust from hot gas streams will permit greater use of the heat in the stream. It should be possible to remove dust from cement kiln gases using a high temperature cyclone collector. Since the alkali will probably stay in the gas stream, this dust may be completely recycled. A waste heat boiler could then be designed to remove the alkali and recover the heat, the final dust collection being accomplished with a standard bag house collector. Research may be necessary to develop a high temperature cyclone for use with a specially designed waste heat boiler.

t) The Effect of Clinker Structure on Grinding Energy Requirements

Research has shown that the energy required for grinding is a function of the relation between the mean size of the crystals to be ground and the mean particle size of the product. Reductions of up to 25% in the amount of energy required for grinding have been demonstrated by control of crystal size. Research is now needed to determine the factors which govern the crystal size in clinker and to test pertinent theoretical explanations. Since the correlations between the crystallography and the grindability which are of concern are those which are found in the processing plant, research in the plant is needed with the results being documented and published. It is recommended that researchers be given the opportunity to work in a cement company to make plant level observations and correlate this data with laboratory grinds.

u) Alternatives to Electrical Energy for Driving Grinding Mills

Although electrical energy is most commonly used for driving grinding mills, other forms of energy could be used. For example, drives can be driven directly with steam from waste heat boilers and there are direct diesel drives. Because of the desirability of substituting waste energy for diesel fuel, modern technology for direct steam drives should be evaluated.

v) Improvement in Efficiency of Particle Size Classification

Particle size classification is used to increase the efficiency of grinding circuits. Present classifiers use air and the efficiencies attained are between 30-60%. Energy is lost in transporting the materials and as a result of mill inefficiency. Research is needed on mechanisms or devices for increasing the efficiency of particle size classification. This could include the use of additives. The benefits would be more efficient mill operation, reduced circulating loads in mill circuits, and reduced capital costs.

w) Cogeneration of Electricity and Clinker

The cost of electric power is rising because of increasing costs of fuel and plant investment. Cost penalties will be developed for use of peak period power. Because it may be necessary for the development of new pyroprocesses based on alternative energy sources (e.g., nuclear, solar), research is needed to provide knowledge of the physical and chemical properties of high temperature gases leaving the clinkering environment. This knowledge will assist in the design of heat transfer equipment.

x) Reduction of Power Requirements for Cement Production

The production of a ton of cement requires an average of 135KWH of electric power at a cost of about $4. The fuel requirement for production of a ton of cement is about 4 million BTUs at a cost of about $5. Although there are well-defined programs for reducing fuel consumption, there are none for power reduction. It is therefore recommended that research be carried out to determine how electric power requirements for cement production can be reduced, and how the efficiency of the equipment can be improved. A program similar to that which exists for reduction of fuel consumption should be established.

3.6 Unresolved Issue

a) Feasibility of Complete Recycling of Dust when Using High Sulfur Coal as Fuel

Increasing pressure is being placed on the cement industry to use high sulfur coal. This results in the generation of dusts with alkali and sulfur contents which are too high to be tolerated in the product. On the other hand, return of dust to the kiln is desirable for the sake of economy and efficiency. It is not yet clear what the ultimate resolution of this problem will be. It may depend on results of research on alkali and sulfur compounds in the clinker. It is also possible that a compromise on regulations regarding emissions and the types of fuel permitted will have to be reached between DoE and EPA.

4. BLENDING MATERIALS

4.1 Background

For the purposes of this workshop the category of blending materials included chemical admixtures and pozzolanic and latent hydraulic materials. Chemical admixtures are usually organic compounds or soluble inorganic salts added to concrete in small amounts to modify water requirement, air content, or setting time. Pozzolanic materials are solids which, though not cementitious in themselves, are capable of reacting with lime in the presence of water to produce cementitious products. Latent hydraulic materials are solids which will react with water to form cementitious products when activated, usually by exposure to a high pH environment. Pozzolanic and latent hydraulic materials are used in concrete in much larger proportions than chemical admixtures, usually as partial replacements for portland cement. When these materials are interground with portland clinker or blended with portland cement at a cement plant, the product is referred to as a blended cement. When they are to be added to concrete at a job site they are referred to as mineral admixtures.

4.2 List of Statements Prepared by the Working Group

Energy-Saving Opportunities:

a) Increased use of fly ash in cement and concrete

b) Increased use of slag in cement and concrete

c) Increased use of superplasticizers in concrete

Research Needs:

a) Standard test methods for chemical resistance of blended cements

b) Accelerated tests for pozzolanic reactivity

c) Mechanism of pozzolanic reactions

d) Quality control and beneficiation of fly ash

e) Elevated temperature curing of concrete products containing pozzolans

f) Reduction in variability of concrete performance through the use of slag

g) Slag activators

h) Use of slags other than granulated blastfurnace slags

i) Special clinkers for use in blended cements

j) Optimization of slag hydraulicity

k) Use of superplasticizers with blended cements

l) Cement-admixture interactions

4.3 Summary of the Discussions

The working group on blending materials considered both admixtures and materials suitable as partial replacements for portland cement. Based on the criteria of availability, compositional suitability, uniformity and cost, it was agreed that increased use of fly ash and blastfurnace slag could result in significant energy savings. The use of superplasticizers to reduce the water content of concrete mixes was also seen to have implications for energy conservation. None of the opportunities had been fully exploited because of lack of knowledge about reactions of the blending materials and the lack of adequate standard test methods for evaluating performance. Comments on these matters are contained in the three statements of energy-saving opportunities and twelve statements of research needs which the group prepared.

4.4 Energy-Saving Opportunities

a) <u>Increased Use of Fly Ash in Cement and Concrete</u>

Energy can be conserved through the use of suitable fly ash as a partial replacement for portland clinker in cement or for portland cement in concrete. The basic concrete mix design principles are known and neither the supply of suitable fly ash nor the economics of its use are limitations. However, among constraints to fly ash use are the sometimes unnecessary requirements for rapid strength development, inadequacies in standard specifications and test methods, uncertainties regarding the uniformity of fly ashes and the effects of their variability, and institutional factors such as consumer acceptance and industry apathy. Apart from use in conventional applications of concrete, other opportunities for use of fly ash in concrete include use in special applications such as k-crete and econocrete, and use in precast products cured at elevated temperatures. It should be noted that some lignite and subbituminous fly ashes have cementitious properties which might be exploited. The immediate need is for dissemination of information about fly ash use in concrete and research to increase knowledge of fly ash characteristics.

b) Increased Use of Slag in Cement and Concrete

Suitably granulated blastfurnace slags have latent hydraulicity. As a result, when ground granulated blastfurnace slags are properly activated, they can be used as partial replacements of portland cement. A major constraint on such energy-saving use is that the amount of granulated slag currently produced in the U.S. is very small.

c) Increased Use of Superplasticizers in Concrete

Superplasticizers can lower the water requirements for concrete and increase its strength. This has energy-conserving implications because lower water requirements result in improved concrete durability and make possible a reduction in the cement content of concrete. While the use of superplasticizers is growing, their use could probably be increased by improved dissemination of information about them.

4.5 Research Needs

a) Standard Test Methods for Chemical Resistance of Blended Cements

Concretes containing blended cements have often demonstrated chemical resistance and durability superior to that of concretes made with Type I portland cements. However, the use of blended cements in applications where chemical resistance is important has been limited by the inadequacies of standard specifications and test methods. This barrier could be overcome by the development of standard tests for the durability of cements, particularly in the areas of sulfate resistance, alkali-aggregate reactivity and soundness. New or improved standards would facilitate the use of blended cements by providing objective bases for comparison with the various types of portland cements.

b) Accelerated Tests for Pozzolanic Reactivity

Current tests for pozzolans for use in cement and concrete require 28 days for completion. This is much longer than is desirable for acceptance tests. It is recommended that research be carried out to provide the technical basis for the establishment of more rapid acceptance tests for fly ashes and other pozzolans.

c) Mechanisms of Pozzolanic Reactions

Understanding of the rate-controlling factors in pozzolanic reactions would almost certainly broaden the potential applications for pozzolans. It should lead to development of methods for increasing the rate of strength development of pozzolan-containing cements and concretes and make possible higher levels of cement replacement. It should also help in the identification of possibilities for benefication of fly ashes to obtain improved performance, the evaluation of pozzolanic potential of waste materials other than fly ash, and optimization of pozzolan use as, for example, by use of elevated curing temperatures.

d) Quality Control and Benefication of Fly Ash

Fly ash varies considerably depending on the sources of the parent coal. This variability hinders ash use in cement and concrete because of uncertainty about its effects. There is a need to quantify the effects of ash variability on the performance of concrete. This could lead to improved quality control, to improved beneficiation procedures for improving ash quality, and to higher levels of use of ash in cement and concrete.

e) Elevated Temperature Curing of Concrete Products Containing Pozzolans

Elevated temperature curing of concrete allows the use of higher levels of replacement of portland cement by pozzolan. Energy savings would result from research which would lead to guidelines for optimization of concrete mix designs taking into account the rates of strength development required and the curing conditions available. This could, in addition, encourage the use of waste and by-product materials not currently used in construction as replacements for traditional materials with a high energy requirement for their production, such as silica flour, and stimulate the development of new types of precast building materials.

f) Reduction in Variability of Concrete Performance Through the Use of Slag

There are indications that the blending of separately-ground, granulated blastfurnace slag with portland cement can decrease the variability in 28 day strength. Research is needed to confirm this effect and to provide a sound basis for its exploitation. This would allow more efficient use of concrete since less overdesign would be required. A current constraint is that suitable granulated slags are not produced in the U.S.

g) <u>Slag Activators</u>

The use of granulated blastfurnace slag in cement is limited in some applications because it tends to reduce the rate of strength development. Research needs to be carried out to identify improved activators for slag-containing cements so as to broaden their potential range of applications.

h) <u>Use of Slags Other Than Granulated Blastfurnace Slags</u>

The use of granulated iron blastfurnace slags in cement is well-established in many foreign countries. However, there appears to be additional potential for energy savings by using slags from other industries or the use of blastfurnace slags which are partially crystalline. Research is needed to evaluate other slags, such as phosphate slags and pelletized "air granulated" blastfurnace slags, for use as cementitious materials.

i) <u>Special Clinkers for Use in Blended Cements</u>

Slags and pozzolans differ in their chemical characteristics and reactivities. It is not known whether the compositions of currently produced portland cement clinkers are close to the optimum for use with them in blended cements. Higher free lime clinkers might offer a potential for more rapid strength development of blended cements while lowering the energy requirements for clinker production. Research is needed to confirm this and to assess its implications for energy conservation.

j) <u>Optimization of Slag Hydraulicity</u>

Performance of slags in cement and concrete is related to composition, glass content, and fineness. There is a need to investigate the relationship between slag fineness and strength development in slag-containing cements. The study should extend well beyond the range of finenesses normally used and should include assessment of the effects of the particle size distributions. The effects of fineness and particle size distribution on other properties such as air entrainment and workability should also be considered. This could increase the potential application of slag-containing cements by improving their rates of strength development and ultimate strengths.

k) <u>Use of Superplasticizers With Blended Cements</u>

The use of superplasticizers in blended cement concretes has the potential for increasing the rate of strength gain and for lowering the cement content needed. The use of less expensive blending materials, such as fly ash or slag, should compensate for the cost of the superplasticizer. Research is needed to develop a more complete understanding of the interaction of superplasticizers (and other admixtures) with cements, pozzolans, and slags and to explore ways of reducing admixture consumption by the unburned carbon usually present in fly ash. The research should include work on concretes containing superplasticizers.

1) Cement-Admixture Interactions

Admixture behavior in concrete depends on cement composition, temperature, time of addition, and dosage. Changes in these factors can lead to variability in setting behavior, water requirement and workability. In many cases these changes cannot be predicted. Research is needed to elucidate the mechanisms of water reduction to develop an understanding of the rheological properties of concrete of low water-cement ratio, and to elucidate the effects of admixtures on the chemistry of cement hydration, on the properties of the cement hydration products, and on the microstructure of hardened cement pastes and concretes in order to improve our capabilities for the prediction of concrete performance.

5. CONCRETE PRODUCTION

5.1 Background

Concrete is the most widely used construction material in the United States and accounts for about 75% by mass of all the construction materials consumed annually. The major constituents of concrete are cement, sand, aggregate, admixtures, and mixing water with significant amounts of steel being used in reinforced concrete. Roughly 65% of the concrete placed in the United States is proportioned at ready mix plants and transported to the sites of construction. Approximately 5% of the concrete placed contains mineral admixtures.

5.2 List of Statements Prepared by the Working Group

Energy-Saving Opportunities:

a) Optimization of the batching sequence

b) Test methods and compliance criteria

c) Production control methods

d) Improved thermal resistance through water reduction

e) Water-reducing, strength-improving admixtures

f) Specification of strength at the required age

g) Information on the performance of cement

h) Long-term cost and energy benefits of concrete

i) Maintenance of pavements and bridge decks

j) By-product and marginal aggregate materials

k) Unnecessary curing requirements

l) Energy-efficient design and maintenance of concrete plants

m) Heating and cooling requirements for plastic concrete

n) Conservation of heat contained in concrete aggregates

o) Conservation of heat contained in cements

p) Packaged forming and automatic self-curing systems for concrete castings

q) Thermal shock requirements for reinforced concrete

Research Needs:

a) Fuel use in concrete production

b) Energy requirement for mixing of concrete

c) Energy consumed in transporting concrete

d) Optimization of the transportation network

e) Energy required in placing concrete

f) Curing requirements for different end uses

g) Alternatives to accelerated curing in block manufacture

h) Reduction of corrosion of steel reinforcement

Unresolved Issue:

a) Incentives for cost-effective research and development in the cement and concrete products industries.

5.3 Summary of the Discussions

The working group on concrete production considered existing opportunities for saving energy in the production of concrete and research needed in seeking additional energy conserving possibilities. Attention was given to each of the operations inherent in the production, handling, and transportation processes. This included the use of optimized batching sequences in charging mixes and the use of well-designed, carefully-inspected production plants audited for energy consumption.

The possibilities for changing specification requirements to make more efficient use of materials and energy were discussed as were possibilities for the use of insulation to retain heat generated during cement hydration. The potential benefits from use of water-reducing and other admixtures, marginal aggregates, and the partial substitution of fly ash or ground granulated blastfurnace slags for portland cement were also considered. An unresolved issue concerned incentives for cost-effective research in the cement and concrete industries. The 17 energy-saving opportunities and the 7 research needs which the group identified are outlined below.

5.4 Energy-Saving Opportunities

a) Optimization of the Batching Sequence

The performance of concrete is affected by the sequence in which the ingredients are added to the mixer. For example, the effect of the addition of a chemical admixture can vary depending on the delay time following the first mixing of cement and water. It is important that the personnel of concrete plants should be properly trained so as to understand the effects of improper batching on the quality and performance of the finished product.

b) Test Methods and Compliance Criteria

Uncertain test results may lead to the rejection, demolition and rebuilding of supposedly defective concrete structures with a consequent waste of energy. To avoid this, improvements in the accuracy and precision of all concrete test methods are needed and realistic compliance criteria based on the test methods should be established. Problems are caused by a lack of understanding of the inherent variability of all tests for cement and concrete, the apparent belief by specifiers that results on test reports are indisputable, and the lack of standards of performance for testing laboratories. It is recommended that national and international standards be established which define the test methods and provide for regular verification of the methods. It is also recommended that standards for testing laboratories and facilities be established.

c) Production Control Methods

The quality of concrete made to a given specification is usually quite variable. As a result, there is a tendency to require concrete and its ingredients to be of unnecessarily high quality. Improvements in production control methods which would result in the production of more uniform concrete could lead to savings in energy by reducing the requirements for cement and processed aggregates. Related factors are the demand by specifiers for concrete and concrete materials of unnecessarily high quality and unrealistic code requirements which restrict the producer's options and prevent him from using his expertise. Among steps which could be taken to reduce the waste of energy are to seek recognition of existing production control principles in codes of practice and to provide training courses on production control methods. Improved production control could lead to reduction of design safety factors and more efficient use of materials, whether of low or high quality.

d) Improved Thermal Resistance through Water Reduction

The quantity of water in hardened concrete in the exterior of buildings is governed by the porosity of the concrete and should be minimized if advantage is to be taken of the inherent thermal resistance of concrete. This is because the thermal conductivity of water is higher than that of the other constituents of concrete. Unfortunately, construction practices and attitudes favor the use of relatively high water-cement ratios to obtain good workability. Other ways of obtaining good workability without such high water-cement ratios are through carefully-controlled additions of superplasticizers or fly ash to the concrete, or by vacuum de-watering after placing. To achieve the benefits of reduced water contents, it is recommended that changes be sought in the specification requirements and attention be drawn to the potential benefits through educational programs for concrete technologists, building owners and other decision makers. The energy savings will be cumulative throughout the life of the structure and will result in reduced life-cycle costs.

e) Water-Reducing, Strength-Improving Admixtures

In general, reduction in the quantity of water in a concrete mix increases the ultimate strength. For this reason, increased use of water-reducing, strength-improving chemical admixtures can save energy by reducing the required cement content of concretes. At present, about 50% of all concrete produced in the U.S. includes such admixtures and it appears the percentage can be increased much further. The principal constraints to increased use of these admixtures are prescriptive rather than performance specifications and the difficulty in predicting and controlling performance. With certain cement compositions, admixtures may do little to increase strength and may even cause strength reductions. The variability of cement-admixture performance resulting from variations in either the cement or the admixture is a frequent problem. Additional research is needed to identify appropriate selection and control procedures. Further, the possible energy savings from the use of admixtures should be considered in determining the composition of the cement produced. Although present U.S. cement specifications do not permit the inclusion of these chemical admixtures in the manufactured cement, this is not a major constraint since it is probably best to add the admixtures during the mixing of the concrete, even though a greater quantity of admixture per unit weight of cement may be required.

f) Specification of Strength at the Required Age

Present building codes and codes of practice traditionally use the 28-day strength of a concrete as the final quality control standard of its strength potential. This frequently leads to a requirement for unnecessarily high strength at 28 days when the structure may not be loaded for a much longer period. While recognizing that delay in acceptance of the concrete could cause some inconvenience if acceptance was based on strength at later ages, it is recommended that provision be made for structures which have long construction periods to be accepted on the basis of the 56-day, or other appropriate age, strength. This would require ACI to provide for use of different test ages for structures having construction periods of different lengths.

g) Information on the Performance of Cement

It appears that producers of concrete could adjust their mixes to produce concretes of more uniform strength if cement producers would supply them with more information. This is done in Australia where results of tests in the cement plant laboratory are sent by teletype to users as soon as possible following shipment. This would require cement companies to have concrete laboratory facilities, to keep records of the origin of individual shipments and, possibly, to store the cement for an extra day or two before shipment. The cement plant could use the accelerated tests now used in control of ready mix concrete, but the exact details of the tests would have to be developed. As an example, it might be possible to establish that a mill run composite of a silo yielded results representative of all shipments from that silo.

h) Long-Term Costs and Energy Benefits of Concrete

It is believed there are many applications where the total lifecycle costs and energy use of concrete structures are superior to those of competing materials. Examples are concrete building enclosures which benefit from the thermal inertia of concrete, underground housing, heat transfer and storage systems, and concrete pavements. However, because of the difficulty in quantifying the energy savings, no organized approach to their evaluation has been developed. It is therefore suggested that technical support efforts should be provided to document the long-term cost and energy benefits of specific applications of concrete.

i) Maintenance of Pavements and Bridge Decks

Traffic delays due to maintenance work on concrete pavements and bridge decks cause significant wastes of energy. The waste could be reduced if the repairs could be made more rapidly. The use of rapid-setting cements and special concrete formulations can help achieve this objective. Constraints to their use are state and other government specifications based on conventional concrete techniques, the high first costs of some products, and inadequate knowledge about the durability of others. Energy conservation would be assisted by more effective dissemination of information about the availability and properties of suitable materials. This could possibly be assisted through a Transportation Research Board-sponsored synthesis project.

j) By-Product and Marginal Aggregate Materials

Manufactured fine aggregates (sands) which are currently available can be used successfully in many concrete applications. In many cases, these aggregates are manufactured from by-product or waste materials and the processing required is usually less than for natural sands. Local specifications and lack of familiarity with the materials provide barriers to the use of the manufactured sands in concrete. It is recommended that acceptance of sands of this type be encouraged through dissemination of performance data, enlistment of the support of appropriate technical organizations, and revision of specifications.

k) Unnecessary Curing Requirements

The heat curing of concrete requires a considerable amount of energy. New developments in casting, curing and materials technologies make possible much shorter heat curing cycles than present specifications allow. If prescriptive specifications could be supplemented by performance specifications, this could lead to large reductions in fuel consumption. It is recommended that incentives be provided to contractors, precasters, state highway departments, etc., to investigate the use of new materials, new construction methods, and shorter curing periods.

l) Energy-Efficient Design and Maintenance of Concrete Plants

The plant layouts and the operating and maintenance procedures of many ready mix and pre-cast concrete plants result in waste of energy. Examples are the unnecessary handling and transportation of concrete, leaks in air and steam lines, uninsulated and leaky steam kilns, idling machinery, and inefficient means of heating and cooling. Unfortunately, the additional effort and maintenance required to reduce the energy losses, and the apparent low return on the investment, mitigate the effects of the effort made. It is recommended that programs be developed for carrying out energy audits of existing and proposed new plants to assist in identification of inefficiences and methods for their correction.

m) Heating and Cooling Requirements for Plastic Concrete

In many cases, plastic concrete must be heated or cooled by energy-intensive methods to meet specification requirements. Even though a combination of different curing conditions and chemical admixtures can reduce the energy expenditures while providing concrete of the required quality, current specifications and construction practices emphasize temperature control. It is recommended that specification writing bodies, especially ACI, be encouraged to include alternatives to temperature control in their specifications and to recommend construction practices which do not require temperature control.

n) Conservation of Heat Contained in Concrete Aggregates

Stockpiles of concrete aggregates are subject to seasonal changes in temperature. When an aggregate is moved from a stockpile to a storage bin, the material is usually taken from the exterior where the temperature variations are the greatest, rather than the interior where the variations are the least. Although additional capital expenditures are required to construct structures and equipment for withdrawing materials from the interior of a pile, it is recommended that this approach be promoted to minimize the need for cooling aggregates in summer and heating them in winter. This could be accomplished through publication of recommended practices and procedures for the storage of aggregates to minimize the effects of external temperature variations.

o) Conservation of Heat Contained in Cements

Good concrete practice suggests that hot cement should not be supplied to the job in summer although it could be desirable in winter. Using available technology, it appears that hot cement could be delivered to insulated bins at concrete plants to produce warmer concrete in winter. It should also be possible to use solar or other naturally-heated systems for heating water and other concrete materials in winter. This would be analogous to the practice in the asphalt industry of maintaining the temperature of hot asphalt during delivery so as to reduce the mix plant's energy use. The asphalt industry is also experimenting with the use of solar heat to keep surge bins and storage tanks hot.

p) Packaged Forming and Automatic Self-Curing Systems for Concrete Castings

The pre-cast concrete industry uses highly-insulated forms so that much of the heat liberated during the hydration of the portland cement is retained. This heat, which accelerates the strength gain, is available at no cost. Form manufacturers should be encouraged to market self-contained forming and curing systems which utilize efficient insulation. Such forming systems should include automatic systems (master-slave systems) for curing the quality control specimens under the same time-temperature history as the concrete in the insulated forms. Automatic master-slave curing systems should also be used for concrete structures and the associated quality control specimens at the construction site. Complete packaged forming and self-curing systems with master-slave curing systems for quality control specimens are available from electrical controls companies. Automatic curing systems can make possible much shorter curing periods through a combination of internal exothermic heating and external heating applied for a short time. Specifications will need to be modified to allow these shorter curing periods. Industry acceptance of such systems would be stimulated if they were recognized by state highway departments, since these departments have the most rigid specifications for casting, curing and quality control.

q) Thermal Shock Requirements for Reinforced Concrete

Limitations on the rate of cooling of winter concrete in cases where restraint of volume change is minimal or the content and distribution of steel is adequate for crack control should be reviewed. At present, the specifications do not properly distinguish between conditions where thermal shock is important and where its effects are minimal. It appears that the requirements could be modified to allow the use of energy-saving curing methods including the use of insulated forms, and shorter periods of high temperature curing and controlled cooling.

5.5 Research Needs

a) Fuel Use in Concrete Production

Energy conservation efforts relating to the production and use of concrete will be assisted if quantitative data can be made available on fuel use factors for all materials and operations. The opportunities can then be assessed on a rational basis. It is, therefore, recommended that research be carried out to identify the fuel use factors per unit mass of concrete and concrete materials. This should include the energy used in the production of the materials, and in transportation, processing, and storage. A data base on fuel use factors would enable private sector firms and government agencies to evaluate opportunities for energy conservation and reduction of materials and construction costs in the production and use of concrete.

b) Energy Requirement for Mixing Concrete

There are many different types of central plant mixers, truck mounted mixers, and non-agitating units for the mixing of concrete. However, the optimum combination of mixer and batching sequence for minimizing energy consumption is not yet known. It is recommended that research be carried out on mixers and batching sequences to identify ways of minimizing the mixing time and energy consumption. It is believed there are significant opportunities for energy conservation although the magnitude is not readily determinable. If it is assumed that the mixing function consumes ten percent of the energy used in the manufacture and delivery of ready mixed concrete, it is conceivable this could be reduced by at least half.

c) Energy Consumed In Transporting Concrete

Truck size, engine size and type, concrete capacity, and truck routing strategies are among the factors which influence the amounts of energy used in transporting concrete. In general, the relative importance of these factors is not known so the energy conservation benefits of changing concrete transportation practices and equipment cannot be assessed. It is recommended that research be undertaken to identify the quantities of energy consumed in various concrete transportation activities and the quantities of energy which could be saved through changes which might be effected. Since about 80 to 90 percent of the energy used in mixing and delivering ready mixed concrete is consumed in the transportation operation, it is believed this information could lead to substantial energy savings. In addition, improved practices in concrete transportation could increase the profitability of the ready mixed concrete industry, reduce costs for concrete construction, and retard inflationary price increases.

d) Optimization of the Transportation Network

Analysis of the total system of concrete and materials transportation is needed if energy is to be used most efficiently. Factors influencing energy use include the location of production facilities relative to material supplies and customers, methods of transportation available, and local environmental and zoning considerations. It is recommended that a methodology be developed for the analysis of the total transportation system for concrete and its constituent materials, and that it be used to determine the most efficient use of energy. This would lead to conservation of energy and increased efficiency in the transportation of concrete and related materials.

e) Energy Required in Placing Concrete

There are many techniques for placing concrete but little is known about the energy used in each. Further, the placing method affects the properties of the concrete and, therefore, the energy content of the constituent materials. It is recommended that the energy used in placing by pump, crane and bucket, belt, chute and buggy should be evaluated. The effects of mix proportions, mix properties, and the concrete materials necessary for successful application of the various placing methods should be taken into account since they affect the energy required in placing. It is believed that the physical placing methods, except for their effects on mix composition, only consume a small portion of the total energy used in concrete construction.

f) Curing Requirements for Different End Uses

Under certain conditions, satisfactory concrete can be obtained with little or no additional curing after placement. The exact conditions under which curing can be minimized or eliminated for a particular end use are generally not known and need to be delineated. It is, therefore, recommended that research be carried out to determine the conditions under which curing can be eliminated without adverse effects on the required strength, durability, appearance, and other characteristics of a concrete product or type of construction; the minimum curing necessary to obtain a particular level of quality should also be established. The establishment of criteria for minimum curing requirements would lead to more efficient use of materials and energy.

g) Alternatives to Accelerated Curing in Block Manufacture

Current practices in the manufacture of concrete block use energy-intensive methods of accelerated curing to achieve the early strength needed for the rapid cycling of production facilities. The curing accounts for five to ten percent of the unit manufacturing cost and it is believed that the energy requirements could be reduced by at least 50% through the use of alternative methods of curing. It is, therefore, recommended that research be carried out to develop ways of minimizing energy consumption in the concrete block curing process through new techniques in control of cement hydration. The benefits could be complete elimination of fuel used in the curing of concrete block, with attendant reductions in capital and maintenance costs.

h) Reduction of Corrosion of Steel Reinforcement

Significant losses due to the corrosion of reinforcing steel in concrete structures exposed to salt occur even when good concrete quality control has been exercised, since corrosion reduces the life of these structures. It has also been reported that corrosion of reinforcement in foamed concrete limits the continued use of this insulating concrete. It is therefore recommended that research be carried out to (1) develop improved guidelines for the quality of concrete and depth of cover required for reinforced concrete subjected to salt exposures, and (2) find ways of reducing the rate of corrosion of steel in concretes, such as foam concrete, which have a high permeability to air and moisture. Among the possibilities which should be investigated are alternatives to regular steel reinforcement or the use of organic and inorganic coatings on the steel.

5.6 Unresolved Issue

a) Incentives for Cost-Effective Research and Development in the Cement and Concrete Products Industries

There appears to be a lack of economic incentives for innovative, cost-effective research and development in the cement and concrete products industries. This is an important problem because cost-effective research would help stem the inflow of foreign capital and technology by the Year 2000 and would help reduce energy use in the manufacture and application of concrete products. Indeed, it impacts on the foundation of modern society since there is no alternative to a viable cement and concrete industry. By its nature, the industry is presently one of our most energy-intensive industries.* Factors which impact on the problem are:

- ° Inflow of foreign capital
- ° Fragmentation of the industry, both horizontally and vertically
- ° Adverse effects of some legislation and government regulation
- ° Inadequate tax legislation
- ° Depletion and depreciation
- ° Inadequate transfer of information to decision makers
- ° Possible adverse effects of government requirements and procurements
- ° Insufficient support by government of cost-effective basic research for the cement and concrete industry
- ° Restrictive effects of codes and zoning.

It is recommended that an in-depth business systems analysis be undertaken on the effects on profitibility of the introduction of energy-saving innovations into the system on a continuing basis. Research is also needed to develop in situ performance and durability standards for concrete to protect the consumer and establish life-cycle costs. A second workshop should be organized for high level government and industrial decision makers showing the result of this workshop in dollars and cents. A coordination center for cement and concrete research, technology development, and information documentation and retrieval should be established. Relevant solutions adopted in Europe and Japan, including low-cost loans and government cost-sharing in the development of innovative industrial processes should be examined.

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* It is the 6th most energy-intensive industry (Editor's note)

6. EFFICIENT USE OF CONCRETE

6.1 Background

Efficient use of concrete is closely linked with concrete production, cement production, and blending materials. Variability in any component of concrete ultimately results in variability in concrete performance. Because of the variability of concrete, concrete structures are frequently highly overdesigned. Efficient use of concrete requires careful consideration of both mix design and structural design, proper selection of cement, consideration of the trade-offs between site placement of concrete and the use of precast elements, and ensuring the required service lives of structures.

6.2 List of Statements Prepared by the Working Group

Energy-Saving Opportunities:

a) Application of generally-accepted practices and principles of concrete technology

b) Tailoring of concrete to meet functional and environmental needs

c) Accelerated testing

d) Certification for energy saving

e) Two-course construction

f) Innovative consolidation techniques

g) Use of ultra-rapid hardening cements

h) Very high strength concrete

i) Precast concrete

j) Concrete for special structures

k) Use of slags in concrete

l) Recycled concrete as aggregate

m) Fiber-reinforced cements and concretes

n) Autoclaved calcium silicates and other alternative materials for concrete

o) Polymer and sulfur concretes

p) Titanium alloy reinforcing bars

Research Needs:

a) Waste or by-product utilization

b) Recycled concrete as a source of cementitious materials

c) Fiber-reinforced concrete

d) Ferrocement

e) Polymer- or sulfur-modified concrete

f) New lightweight aggregates

g) Phase change materials

6.3 Summary of the Discussions

The working group on efficient use of concrete perceived that energy is wasted in the concrete industry chiefly by the failure to tailor concrete properly to its functional and environmental needs. This is apparent from several of the recommendations. Prescriptive specifications, which require the concrete to contain a specific (or exceed a minimum) cement content, have a large effect on the efficient use of concrete. Because the greatest opportunity for energy savings lies in the reduction of the cement content to the minimum required, such specifications prevent significant energy savings. If only the functional and environmental requirements of the concrete to be used in a particular application were specified, the producer could apply ingenuity to produce an acceptable concrete with minimum energy input. This tailoring concept is also evident in proposals for the use of two-course construction in which concrete of high quality, or of particular environmental resistance, is combined with other concrete not exposed to the aggresive environment; to extend the use of ferrocement, fiber concrete and polymer concrete; and to build special structures out of a sophisticated laminated system.

Although an obvious contribution of concrete to the conservation of energy is the use of the thermal properties of concrete in enclosing space in buildings, this was not considered in-depth since it was deemed to be outside the scope of the workshop.

Recycled concrete was regarded as a source of both aggregate and cement and was considered in detail, as was precast concrete. It was recognized that essential factors in the implementation of the proposed techniques would require technology transfer to the man in the field and the certification of workmen and inspectors. The working group identified 17 energy-saving opportunities and 7 research needs.

6.4 Energy-Saving Opportunities

a) Application of Generally-Accepted Practices and Principles of Concrete Technology

Failure to apply generally-accepted practices and principles of concrete technology often results in excessive use of energy. Examples of energy-intensive practices are (1) the use of higher cement contents than are needed to meet service conditions, (2) the limited use of blended cements and pozzolans, and (3) the requirement of low-alkali cements in the absence of proven reactive aggregates. Energy conservation will result from definition of different service conditions, whether for different structures or different portions of the same structure, and selective use of materials to meet these different conditions. Practices which improve the uniformity of concrete also conserve energy directly or indirectly. To take advantage of these opportunities, there is a need to transfer known technology but, at present, there is a lack of training materials and publications with an emphasis on energy conservation. A related problem is the lack of access to foreign literature. Steps which could be taken to promote the transfer of technology are the organization of seminars for specification writers, design engineers, local agencies, and concrete producers. The seminars could be organized by the ACI and industry groups. Agencies preparing recommended practices and technical documents should be encouraged to emphasize energy conservation. Well-informed technical representatives from industry and trade associations with field contacts (similar to those which the PCA had some years ago) would be useful. There is also a need for a foreign translation service.

b) Tailoring of Concrete to Meet Functional and Environmental Needs

Unnecessarily high cement contents are frequently used in concrete because of specifications requiring minimum cement contents. There is, in addition, reluctance on the part of concrete specifiers to select cement based on the environmental conditions to which the concrete will be subjected. If specifications permitted the tailoring of concrete to meet functional and environmental needs, this would avoid over-specification and reduce the use of cement. It is recommended that prescriptive specifications be eliminated so that determinations can be made for each project as to the type of concrete actually needed.

c) Accelerated Testing

Almost all codes and specifications require that concrete be evaluated by its 28-day strength; accelerated testing to assess strength development is not recognized. If earlier assessments of concrete acceptability could be made, the producer could react more quickly to changes in strength levels and allow a reduction in the margin of safety above the design strength. This would result in a savings of both cement and energy. It is recommended that codes and specifications be revised so that concrete may be accepted on the basis of accelerated tests when these tests have been correlated with 28-day tests using job materials. At the same time, design procedures should be changed so that design could be based on accelerated strength tests instead of 28-day strengths.

d) Certification for Energy Saving

Quality assurance of concrete would save energy by eliminating the waste which results from overdesign and overspecification. It would also reduce the overall costs of concrete and encourage the substitution of concrete for steel, which requires more energy to manufacture. As an essential part of the quality assurance program, it is recommended that a system of certification of field personnel (supervisors, foremen, inspectors, etc.) be established with a licensing system for those qualified to work with concrete. With such quality assurance, more use could be made of performance specifications through which concrete would be tailored to needs, thus savings materials and energy. Prescriptive specifications, which tend to be costly and wasteful, would become unnecessary provided adequate quality assurance was provided at the construction level. At present, it appears that the industry does not fully realize the waste of energy and materials caused by the present system. A possible approach to a certification program would be through political jurisdictions or professional societies.

e) Two-Course Construction

Normal concrete is relatively weak and the aggregates in it are unlikely to be superior in durability or other performance characteristics such as susceptibility to polishing. Better use of concrete materials can be made by using a facing concrete of the desired properties for the surface of a concrete member while using slightly inferior concrete for the interior which may account for as much as 75% of the total volume. Examples are (1) bridge decks of conventional concrete with a two-inch cover of latex-modified concrete for chloride protection, (2) highway pavements with a thick course of regular concrete overlaid with two-inches of high quality concrete containing aggregates which provide good skid resistance, and (3) concrete beams with flanges of fiber-reinforced concrete attached to webs of less expensive concrete. It is recommended that opportunities be provided for designers/constructors to be innovative in using different quality materials in sandwich-type configurations to produce the surface properties needed, while using less expensive fillers where the properties are less demanding. This could lead to significant savings of energy. However, it should be noted that the placing of such concretes requires exceptional care and inspection to see that the work is done properly. Cold joints can seldom be tolerated and the different concretes must be compatible, particularly in thermal properties, if premature deterioration is to be avoided. The principle of two-course construction has been used successfully in dams, panels with exposed aggregate surfaces, bridge decks, and pavements.

f) Innovative Consolidation Techniques

In the past, economic conditions have favored the use of workable concrete which minimizes manpower requirements and facilitates high rates of production. Unfortunately, the high water contents used to obtain workability can lead to requirements for high cement contents. Innovative consolidation techniques, such as the use of roller compactors, large internal and external vibrators, heavy drop tables, and vacuum dewatering devices, make possible the use of less workable concrete. The reduction in the water content of concrete leads to energy saving through reduction in cement use; however, these techniques will only be used if the savings in cement are sufficient to offset the costs of these special consolidation techniques.

g) Use of Ultra-Rapid Hardening Cements

Ultra-rapid hardening cements have potential for conserving energy in applications such as the rapid repair of transportation facilities and cold weather concreting where they may be used without the need for external heating. They are particularly useful for reducing the cycle time in precast concrete plants without the need for steam curing.

h) Very High Strength Concrete

Very high strength concrete can reduce the volume of concrete needed in compression members and some flexural members. Because of the smaller quantity of material used, the total energy required is below that for lower strength concretes. In addition, the use of high strength concrete extends the possibilities for replacement of other materials such as steel. The lower columns in high rise structures and the towers of cable-supported bridges are ideal uses of very high strength concretes. The use of very high strength concretes requires careful control of all aspects of production including material selection. High strength aggregates are required and the required concrete strengths may not be achieved for two or three months. Special consideration must be given in design to the control of deflections and it must be recognized that very high strength concretes may be much more brittle and notch sensitive than lower strength concretes.

i) Precast Concrete

Energy can be conserved by using precast concrete rather than cast-in-place concrete for many applications. Some of the constraints to the optimum use of precast concrete are (1) the need for research on materials quality, predictability, and methods of test, (2) the need for research on new materials to achieve weight reduction and architectural design flexibility, (3) the energy consumed in transporting elements cast off site, (4) lack of building designs providing repetition and simplified joinery, (5) reluctance by builders to accept the challenge and risk of innovation, and (6) the need to provide extra strength for temporary lifting during erection, as for thin walls. Among the benefits to be achieved are savings in the time taken to complete the work with resultant savings in the energy used in support activities; reduced needs for form materials; possibilities for incorporation of fiber-reinforced concrete and various polymer-containing concretes; reduced use of energy for curing which may be achieved by the use of ultra-rapid hardening cements; reduced use of energy for manpower support facilities; improved quality control resulting in more precise concrete design and reduced quantities of material used in equivalent elements.

j) Concrete for Special Structures

Although the amount of concrete used for special structures is comparatively small, the amount of energy which may eventually be saved may be considerable. In many cases, only the surface layer or other limited portion of a structure has to meet special requirements such as toughness or high erosion resistance. Energy savings may be achieved through use of specially-tailored composite concrete members. For example, the safety containment for a nuclear power plant could consist of a layered structure with an energy-absorbing outer cover to provide the necessary impact resistance, the whole requiring less energy than a conventionally-reinforced concrete shell. Another example might be in offshore and shore protection structures which require high erosion and cavitation resistance in the immediate vicinity of the surface. The bulk of these huge structures can consist of mass concrete of rather low quality provided the surface has the necessary qualities. A major constraint to the use of specially-tailored composite concrete members is the increased requirement for skilled manpower and the fact that each new application has to be considered separately. Close collaboration between materials engineers and structural engineers is essential.

k) Use of Slags in Concrete

There is a high potential for energy saving through partial substitution of ground granulated blastfurnace slags for portland cement in ready mixed and other concretes. In general, the concrete mixes should be redesigned. At present, the exploitation of this potential saving is hindered by lack of suitable granulated slags, lack of slag granulation plants, and lack of education of the concrete community. Steps which should be taken are the development of an educational program and a quality standard program, improvement of specifications and methods of test, and investment in slag granulation facilities.

l) Recycled Concrete as Aggregate

Concrete prepared using recycled concrete as aggregate is as workable as conventional concrete, has a compressive strength of at least 70% of that of conventional concrete, and a modulus of elasticity which is at least 60% of that of conventional concrete. Other properties such as resistance to freezing and thawing and volume stability are similar to those of conventional concrete. It is recommended that research be carried out to develop additional data about how the various parameters, such as time and water-cement ratio, affect the strength and durability properties of concretes containing recycled concrete aggregate and the sensitivity of mechanical properties to the properties of the recycled concrete aggregate. It has been established that, where recycling plants are competitive, energy savings are realized in the form of savings of transportation fuel. Specifically, for each hour of recycling plant operation, a saving of 180 gallons of fuel is obtained. At present, there are 15 recycling plants in operation while the market conditions permit the profitable operation of an additional 50 plants. Assuming that the research mentioned would trigger the establishment of 50 additional plants, the fuel savings would be of the order of 18 million gallons per year.

m) Fiber-Reinforced Cements and Concretes

The use of fiber-reinforced cements (FRC) and concretes can, at least in some cases, aid in the reduction of energy consumption on a construction project through (1) reducing the quantity of cement needed, (2) reducing the product weight, (3) eliminating or reducing the conventional reinforcement, (4) reducing construction time, (5) increasing service life, and (6) decreasing maintenance requirements. In precast products such as pipe, architectural panels, and underground utility boxes, the section thicknesses can be smaller because of the superior flexural strength of glass or steel FRC. Energy savings in production and transportation can result from the reduced quantities of material required, the reduced product weight, and the decreased dead load on structures. However, it should be noted that the fibers are energy-intensive materials such as steel, glass, and polypropylene, and the concrete mixes are cement-rich. There are also advantages to the use of shotcrete-applied FRC in slope stabilization. The FRC follows the slope contours, there is no minimum thickness constraint, no mesh is required, and the construction time is significantly reduced. Similar considerations apply to the use of FRC shotcrete mining and tunneling applications. If the full performance potential of fiber-reinforced concrete could be achieved, it is possible that the material costs in given applications would be less than those for portland cement concretes. Further development of the equipment required to handle fibers and fibrous concretes is needed.

n) Autoclaved Calcium Silicates and Other Alternative Materials for Concrete

Autoclaved calcium silicate products can be substituted for portland cement concrete in some applications. These include both dense products such as sand-lime block and less dense ones such as aerated concrete. Autoclaved products may also be reinforced. Other alternative products may be made using lime-pozzolan mixtures and low-pressure steam-cured lime-silica materials. Although such products and materials will only save energy relative to concrete in areas where there are favorable factors, the possibilities should not be overlooked. Restraints to the widespread use of autoclaved calcium silicate products are (1) the fact that they can, in general, only be used for precast work, (2) existing autoclave processes are probably not energy-efficient, and (3) a significant capital investment is required to establish a plant. Nevertheless, it is recommended that studies be made of possibilities for the use of autoclaved calcium silicate products and the institutional barriers to be overcome to exploit them. In particular, the possibilities for the use of autoclaved aerated concrete in regions where thermal insulation is important should be investigated. It is possible that cements which are unsuitable for normal use (e.g., cements which are high in MgO) could be used.

o) Polymer- and Sulfur-Concretes

Polymers and sulfur can be used in concrete to produce concretes of improved performance. It should be possible to reduce the overall energy costs associated with some structures if the service life can be increased and if less material is needed. Although it is known that great improvements in properties such as strength and durability can be achieved, it is not yet possible to determine the life-cycle costs. Field trials are urgently needed in applications such as structures,

p) Titanium Alloy Reinforcing Bars

The corrosion of steel reinforcement in waterfront structures leads to waste of materials and energy. The problems are particularly severe in tropical locations where seawater has to be used for mixing and where the only aggregates are corralline limestone. The durability and service life of such structures could be increased many-fold if titanium alloys instead of steel, were used for reinforcement. Reduced maintenance requirements would lead to a reduction in energy consumed in repairing or replacing the structure. The unit mass of titanium alloy is 44 percent less than that of steel, the thickness of concrete cover over titanium could be less than that over steel, the working stresses in titanium-reinforced concrete could be increased at least 100 percent over those for steel-reinforced concrete so that micro-crack development in the concrete cover would pose no problems, and the dead weight per unit volume of titanium-reinforced concrete would be appreciably less than that of steel-reinforced concrete. The reduced cross-sectional areas of the structural components, the correspondingly reduced dead weights, and the absence of spalling would compensate for the initially greater cost of the titanium alloy reinforcing bars. A strict analytical study of a concrete section reinforced with Ti-6Al-4V alloy is needed to determine the effects of titanium reinforcement on the structural behavior of slabs and piles including stiffness, strength, safety, ductility, and allowable working stresses. It would also be necessary to survey titanium alloy producers to ascertain the feasibility of commercial production of deformed titanium alloy reinforcing bars for use in all future construction of commercial and governmental reinforced concrete waterfront structures.

6.5 Research Needs

a) Waste or By-Product Utilization

Designers have become very selective and wasteful in choosing concrete materials. In part, this is due to the past low cost of concrete materials which made it possible to justify their selection on the basis that less inspection would be necessary. Today, the balance between labor and materials has changed so that less costly materials should be used when feasible. The use of less costly waste and by-product materials often contributes to energy conservation. A variety of waste and by-product materials exists, primarily at the local level, which can be used in concrete provided due care is excercised. These include incinerator wastes, slags, ashes, ceramic wastes, waste sludges, and building demolition products. Many of these wastes could be incorporated in foundations or similar structural uses of concretes. To facilitate their use, a guide book for operators of concrete plants should be prepared. The book should provide information on individual waste and by-product materials and precautions required in their use. Research which could provide the necessary data is underway at the Bureau of Mines and the Federal Highway Administration but large numbers of samples will need to be tested to develop suitable guidelines. Other work is needed to identify the types and quantities of materials available at the local level, particularly in areas which are short of aggregates.

b) Recycled Concrete as a Source of Cementitious Materials

The recycling of concrete as aggregate has been demonstrated. However, it has not been established whether the hydrated portland cement in recycled concrete could be reused as a cementitious material. Since it is likely that the dehydration of the hydrated cement could be accomplished at relatively low temperatures, it is recommended that the possibilities be investigated. The concept could be explored through a modest reserch effort.

c) Fiber-Reinforced Concrete

Most fiber-reinforced concretes are made with fibers which have no special provision for bonding or anchorage and which are distributed more or less uniformly throughout the concrete. If improved bonding or anchorage of the fibers could be obtained, and if fiber distribution and orientation could be optimized in areas of maximum tensile stress, wear or impact, performance equal to the usual fiber-reinforced concretes could be obtained with a much lower volume of fibers. A smaller quantity of fibers would permit less cement paste to be used in the matrix without loss of quality. Fiber contents for equivalent performance in many applications can be reduced by 75 percent and, with the associated reductions possible in the cement content, large reductions in energy requirements over conventional fiber-reinforced concrete can be achieved. Research needs are (1) determination of the bonding or anchorage of individual fibers needed to provide maximum strength without loss of ductility, (2) development of practical means for orientation of fibers, (3) determination of the mechanical behavior of sectional members reinforced by fibers only in the areas of maximum tensile stress, wear, or impact, (4) development of a rational means for measuring toughness by which various fiber-reinforced concretes can be compared, and (5) determination of those properties, other than strength and toughness, which distinguish individual fiber-reinforced concretes from plain concrete and how these properties should be measured.

d) Ferrocement

Ferrocement is a composite material consisting of a portland cement mortar reinforced with multiple, closely-spaced layers of reinforcement, such as wire mesh. This produces a relatively flexible, ductile concrete which lends itself to factory production. However, further work is needed to make this system competitive from an energy viewpoint and to provide information on performance characteristics required for designing ferrocement structures. Development of construction techniques in which the matrix is sprayed on to the preformed reinforcement is needed. Among the benefits are the replacement of more energy-intensive materials such as steel, the use of ferrocement as formwork which can be left in place, and ability to tailor systems to meet specific needs.

e) Polymer- or Sulfur-Modified Concrete

Within the last decade, much research has been devoted to various kinds of polymer and sulfur concrete composites. Interest has been stimulated by the improvements obtained in properties such as strength, ductility, stiffness, impermeability, and durability. More information is needed for potential users who must assess the initial and long-term costs of these types of concretes in relationship to performance in applications such as highways and structures. Research should be carried out to establish the cost-effectiveness and energy use requirements for all principle types of polymer- and sulfur-containing concretes. This should take into account (1) present and estimated lowest future costs of production and processing, (2) present and conceivable applications, (3) short and long-term performance and reliability, and (4) cost and energy benefits in comparison with conventional concrete, e.g., benefits of reduced maintenance costs.

f) New Lightweight Aggregates

The use of lightweight aggregate concretes in tall structures reduces the loads on columns, thus allowing smaller column sections. This results in savings in cement and energy. At present, lightweight aggregates are produced by bloating clays and shales in rotary or other kilns. With the increase in oil and gas prices, the cost of producing lightweight aggregate has risen considerably. Alternative, lower cost methods and materials are now needed for the production of lightweight aggregates. Research is needed on the use of coal wastes as sources of lightweight aggregate materials since the residual fuel value of the waste could be exploited. Other systems with potentials for energy savings should also be investigated.

g) Phase Change Materials

The storage of thermal energy at ambient temperatures is a central design feature of building structures which are to provide for optimal use of hybrid energy sources. These sources include active and passive solar systems and off-peak electrical energy. Methods for incorporating phase change materials in concrete-based composites should be developed. Two methods which should be evaluated are encapsulation and inclusion as an emulsion. The effect of the phase change material on the properties of the concrete should be investigated. It is estimated that the use of phase change materials could result in savings of 50 percent of the heating and cooling costs of new structures and about 30 percent in existing structures.

7. INSTITUTIONAL FACTORS

7.1 Background

Energy conservation in the cement and concrete industries is not a purely technical matter. Many institutional factors affect the generation, transfer and exploitation of the technical knowledge necessary for energy conservation. Examples are the societal climate, the availability of capital, the tax structure, transportation subsidies and tariffs, the educational system, the standards system, support for research and development, the technical information system, and environmental legislation. It was the purpose of the working group to consider if and how institutional factors might be employed to foster more efficient use of energy in the cement and concrete industries.

7.2 List of Statements Prepared by the Working Group

Energy-Saving Opportunities:

a) Use of cements with inorganic residues and wastes

b) Increased use of fly ash in concrete

c) Academic programs in cement and concrete technology

d) Educational cement and concrete energy reviews

e) Cost sharing in technological innovation

Research Needs:

a) Implementation of workshop output

b) Joint university-industry R & D

c) Collection of data on energy use in the cement and concrete system

d) Uniformity of specifications for cements

e) Performance acceptance testing

f) Mathematical model of the cement and concrete system

Unresolved Issues:

a) Adequacy of knowledge about raw materials reserves and resources

b) Societal impact of using by-products in concrete

7.3 Summary of the Discussions

The working group on institutional factors spent much of its time discussing general categories of institutional factors before turning its attention to specific energy-saving opportunities, research needs, and unresolved issues. This summary of its discussions is based on notes submitted by the chairman and co-chairman after the close of the workshop. The group identified 5 energy-saving opportunities, 6 research needs, and 2 unresolved isssues.

The working group decided to treat the institutional issues under five headings:

Economics

Education

Technical Matters

Materials Conservation

Societal Matters

Economics was given first priority because the rate and extent of implementation of energy conservation measures, and also the creation of vehicles for development of the necessary technology, depend upon the availability of sufficient capital. Education was given second priority, because sufficient knowledge must be made available for implementation of any major energy conservation program. Broad educational programs are also a prerequisite for progress towards creation of R&D-intensive cement and concrete industries capable of sustaining their own technical development. The discussion of Technical Matters of an institutional nature which impact directly on energy conservation concentrated on the standards system. Materials Conservation was discussed because it was recognized that energy and materials conservation are not always in harmony and may sometimes lead to conflict at the institutional level. Lastly, Societal Matters were discussed because of the necessity of ensuring that any actions taken to meet societal needs are understood by society.

International cooperation was recognized as an institutional factor with important implications for energy conservation. For example, post-war conditions in Europe had required serious attention to be given to energy conservation many years before the matter became crucial in the U.S. and a wealth of experience had been gained. European participants in the working group expressed their interest in cooperating on the issues raised.

Economics

The primary economic issue is the availability of capital. A report prepared by the Portland Cement Association (PCA) for the Federal Energy Adminstration* pointed out that the principal constraint to adoption of the more significant long-term energy conservation measures is the enormous requirements for investment capital. Estimates of the capital requirements of the U.S. portland cement industry were given in a PCA report submitted to the Cost of Living Council in March 1974. Based on the PCA figures, but with modifications to reflect new information, the total capital needs of the industry are estimated to be:

(1)	New capacity additions totaling 36 million tons of annual capacity required by 1980 at $70 per ton; (figures based on product demand forecast by the Boston Consulting Group).	$2.52 billion
(2)	Conversion where practicable of existing wet-process plants to more energy-efficient, dry-process preheater methods; (49.5 million tons at average conversion cost of $41 per ton of capacity).	2.03
(3)	Conversion of present plants utilizing petroleum fuels exclusively to permit use of coal; (39 million tons of capacity at estimated conversion cost of $3.20 per ton).	0.13
(4)	Capital expenditure to meet EPA 1975 standards for air and water pollution control.	0.28

* "Energy Conservation Potential in the Cement Industry," FEA Conservation Paper No. 26 (1975) NTIS No. PB-245-159.

(5) Replacement of obsolete plants (more than 40 years old) with new energy-efficient production facilities; (11 million tons at 1974-75 estimated of $70 per ton). 0.77

Total capital needs $5.73 billion

This figure, which is based on the industry's estimate of its own needs, is for "up-dating" the U.S. cement industry to use energy conservation technology already in use in other countries. The additional capital needed for industrialization of cement use in concrete, and for other means to conserve energy in the use of cement, is not on record. We also lack estimates of the additional capital which would be required for the U.S. cement and concrete enterprises to gain international leadership comparable to that of U.S. construction engineering.

The existence of legislative barriers which prevent invested capital from offering reasonable ROI's (returns on investment) was recognized; they hinder energy conservation efforts. Analytical studies on this issue were suggested. It was also suggested that wider use could be made of existing government support schemes for high-risk development projects. A study of European programs for support of high-risk projects was recommended. It was also recommended that the views expressed in the workshop should be brought to the attention of decision makers concerned with economic matters.

Education

The need for various levels of education to improve the technical knowledge base of the cement and concrete industries was discussed. It was recognized that there is a need for strong basic and applied research efforts to advance the cement and concrete industries, and a need for a system for the flow of knowledge from basic research, through development, into the commercial application and marketing of technology. These subjects could benefically have been discussed further. In the area of research management it was pointed out there is much useful information available from other industries; reference was made to studies of the Industrial Research Institute (IRI) and the European Industrial Research Management Association (EIRMA). The fragmentation of the cement and concrete industries, and of the relevant research activities, was recognized as a barrier against development of comprehensive research programs. The group agreed about the need to remedy this. The use of government-sponsored schemes for joint university-industry research was proposed as one way of strengthening the technical basis of the cement and concrete industries. Examples of European programs of this sort are those at Aston University in England, and at the Academy of Technical Sciences in Denmark. It was noted that studies of joint university-industry research activities had been performed by both IRI and EIRMA. On another matter, it was recommended that research should be carried out to compile data on energy consumption in the broad range of activities related to construction including the manufacture of materials, construction, use of buildings, transportation, etc.

Technical Matters

Two of the items discussed related to standards and specifications. They encompassed a broad range of energy-related constraints. First, the proliferation of specifications for hydraulic cements in the U.S. has been an obstacle to standardization of products; it has caused waste of energy and increased costs because of needs for additional storage and handling. Recent cooperative efforts have resulted in much closer conformity between ASTM and Federal Specifications, but there remains a divergence at state and local levels. Often, the differences in the specifications are not based on sound technical considerations. The Federal government could perform a valuable service by promoting uniformity of standards and specifications at all levels of government, and giving consideration to existing international standards. Secondly, it was suggested that use of performance acceptance testing should be encouraged. Current ASTM, Federal and AASHTO specifications for hydraulic cements are an amalgam of prescriptive and performance specifications. Prescriptive specifications tend to stifle innovative developments and to be wasteful of energy and resources. Whenever possible, prescriptive specifications should be replaced or supplemented by performance requirements. Where standard performance tests would not be practical for acceptance testing, because of the time factor, accelerated tests should be devised to supplement standard long-term tests. Performance specifications could encourage innovation in low-energy product development, and reduce the costs of manufacture and testing.

Materials Conservation

In the area of materials conservation, one of the most interesting ideas discussed concerned the establishment of a computer model of the cement and concrete manufacturing realm. This would enable simulations to be performed to investigate the impacts upon energy use and system economics of possible technological changes. The group felt this would be a prolific field with significance for the making of decisions on many levels including research and development, corporate operations, and governmental planning and policy making. It was also suggested that development of a comprehensive model would benefit from international cooperation, and the group recommended that this should be noted. In other discussions of materials conservation, a need for more knowledge on material resources for cement and concrete manufactured in the U.S. and their rates of depletion was pointed out. It was recognized that increased use of by-products, notably fly ash and slags, in cement and concrete could conserve energy and materials, and it was suggested that improvements in the durability of concrete would also help conserve energy.

Societal Matters

Although it did not propose any actions, the working group felt that the social impact of energy conservation, and of advances in cement and concrete technology, was obvious and that awareness of it should be promoted by industry, government, and the science and technology sector. Confidence in proposed actions must be won from the many segments of public opinion including politicians, students, and so forth, if the large programs needed in the U.S. are to be undertaken.

7.4 Energy Saving Opportunities

a) Use of Cements with Inorganic Residues and Wastes

The ability of concretes to be made with a wide variety of inorganic residues and wastes should be capitalized on. The potential benefits are the use of low-cost resources and the development of materials with unique performance characteristics. The constraints to the use of the residues and wastes include a lack of coordinated knowledge regarding the available residues and wastes and the lack of a comprehensive enterprising outlook which can cut across industry sectors. One way of attempting to exploit the opportunities would be to establish programs in research institutes, or in joint activities of businesses and universities, to identify and investigate candidate systems and estimate the developmental requirements and costs.

b) Increased Use of Fly Ash in Concrete

The amount of portland cement used in ready mixed and other concrete could be reduced by redesigning the mixes to use fly ash. It is recognized that care would have to be taken in selecting fly ash to ensure quality and uniformity. A factor to be taken into account is the lack of education of the concrete community (e.g., specifying agencies, purchasers and users) about the benefits of, and the technical requirements for, the successful use of fly ash. Among the steps which could be taken to promote increased use of fly ash in concrete would be development of an educational and quality standard program through cooperation between organizations such as the National Ready Mixed Concrete Association and the National Ash Association. The educational program would have to cover mix proportioning techniques and it would be essential for it to be supported by high quality technical service to the user. Other actions needed would be improvement of standard methods of test and specifications for fly ash. The use of government purchasing power could encourage increased use of fly ash in concrete. The effects of the freight rate structure on the competitiveness of fly ash may have to be taken into account.

c) Academic Programs in Cement and Concrete Technology

The optimum use of concrete material resources requires the availability of well-trained technicians. It is recommended that a full academic program be established at the university level leading to one or more degrees in cement and concrete technology. The program should cover cement chemistry, cement manufacturing processes, aggregate production, and the manufacture and delivery of concrete. It is recognized that there may be problems in generating student interest in such a program and in finding a university with the capability and willingness to undertake the program. There are also questions about the cost of establishing a viable program and assuring a job market for graduates. It is recommended that existing programs in foreign countries be reviewed and an industry committee be set up, perhaps by the PCA, to seek a major university to undertake establishment of the program, to guide curriculum development, and to assure job opportunities for graduates.

d) Educational Cement and Concrete Energy Reviews

There is an urgent need to centralize and disseminate energy information presently buried in miscellaneous publications, including untranslated articles. Because of the need for education and the promulgation of ideas, it is recommended that an educational quarterly or semi-annual cement and concrete energy review be published. It would consist of domestic and foreign articles on energy topics pertinent to the industry. The energy-related topics would cover general information, processes and equipment. It would also publish foreign translations (a current problem) and provide space for reader contributions including an idea forum. Constraints in establishing the publication might be competition from existing publications and the difficulty of obtaining funds and finding competent staff. Competent editing and selectivity in choosing items for publication would be essential. If Department of Energy funds were available, the review might be prepared by the Department staff and published by the Department or through a publishing house. An alternative might be to have it published under contract by an existing publication.

e) Cost Sharing in Technological Innovation

There is a need to stimulate technological innovations with energy-conserving potential. Innovations might, for example, relate to the use of process heat and the use of wastes and by-products, and their development might require cooperation between equipment manufacturers, raw material suppliers, cement and concrete producers, and end users. Cooperation between the industries might be encouraged if introduction and development of technological innovations could be carried out on a shared cost basis but, at present, it appears that cooperation is hindered by legal constraints and a lack of capital for joint developments. Among possibilities for stimulating technological innovation which should be considered are establishment by the industry of professional chairs in cement and concrete technology at some leading educational institutions, revitalization of existing cement and concrete associations, and various forms of government-industry interaction and government funding.

7.5 Research Needs

a) Implementation of Workshop Output

The study of energy conservation opportunities in the cement industry which was sponsored by the Federal Energy Administration served to codify the state-of-the-art. The present workshop documents the perceived need for new technology. It is recommended that the suggestions received be ranked in order of energy-saving potential and that high-potential projects be scoped out with a designation as to who should fund them, e.g., the private sector or the government. This would be an essential step in the implementation of the workshop output.

b) Joint University-Industry R and D

The U.S. cement and concrete industry is fragmented both horizontally (many cement companies) and vertically (cement manufacturers, concrete producers, contractors, and customers). This makes innovation difficult because carrying ideas from exploratory research through development, production, and marketing requires cooperation between successive stages of the vertically-fragmented industry. Fragmentation also leads to lack of research funding since no one segment expects to profit sufficiently from an innovation to justify research expenditures. It appears that government encouragement may be required to overcome the constraints to R and D. This might be through new educational programs or direct sponsorship of university-industry efforts to develop more energy-efficient cements, concrete production, and construction techniques. It is recommended that a government-sponsored, university-industry internship program should be instituted to train new R and D personnel. Also, programs of this nature which have been undertaken in Europe should be examined. Among the expected benefits would be an increased supply of highly-motivated, well-trained, technically competent R and D personnel capable of producing real innovation and successful market penetration for energy-saving products and construction practices.

c) Collection of Data on Energy Use in the Cement and Concrete System

If the highest benefit/cost ratio is to be achieved from energy conservation activities, it is necessary to know where, and how much, energy is being used. It is also necessary to know which energy uses are most susceptible to reduction by application of existing knowledge and by further research and education. It is therefore recommended that a methodology for computation of energy use be established and applied to data which would be collected for various segments of the industry and for various types of projects using concrete. The collection and analysis of the data might be done by industry organizations, trade groups, graduate students in engineering or economics, or a joint effort of industry and academe. Factors to be considered would be mining of raw materials, cement production, manufacturing of concrete, construction, transportation, and the maintenance and operation of completed concrete constructions. Secondary and tertiary effects would also have to be considered such as the energy cost of manufacturing the equipment that is used to transport, manufacture and construct concrete facilities. The data collection would best be done in a series of steps of limited scope and the results should be subjected to peer review. The project might include a mathematical model and use statistical sampling techniques to guide the field collection of data. The results would focus attention on areas using excessive amounts of energy and provide a rational method for designers and other users of concrete to reduce energy consumption.

d) Uniformity of Specifications for Cements

The various specifying agencies have been working to bring about closer conformity between their specifications. Recent experience has demonstrated the value of this standardization in helping both the producer and consumer use modern cement technology. It is recommended that the federal government promote guidelines and standards for uniform specifications at all levels of government such as state, county, etc. Such guidelines and standards should include consideration of existing international standards. The benefits would be improved opportunities for exploitation of innovative developments such as blended cements and admixtures; reductions in energy use; and reduction of the costs of manufacture, storage, and laboratory testing.

e) Performance Acceptance Testing

Current ASTM, Federal, AASHTO (American Association of State Highway and Transportation Officials) and state specifications for hydraulic cements are an amalgam of prescriptive and performance requirements. Efforts should be made to adopt performance tests for acceptance whenever possible, with accelerated methods being used to supplement conventional long-term tests in order to expedite earlier acceptance of products. There is a need to expand our knowledge of performance tests, accelerated tests, and the correlation between laboratory test results and field experience. While the cost of the required work is not known, the savings achieved would probably justify the research effort. The benefits would be improved opportunities for exploitation of innovative developments such as blended cements and admixtures; reductions in energy use; and reduction of the costs of manufacture, storage, and laboratory testing.

f) Mathematical Model of the Cement and Concrete System

In the conversion of raw materials into concrete in service, many processes take place. The processes include quarrying, crushing, grinding, mixing, pyroprocessing, mixing of concrete, placing of concrete, curing of concrete, and aging of concrete in service. Enough is already known about many of these processes to enable at least crude mathematical models to be developed. If a comprehensive model (macro-model) of the total system were developed, it would be valuable as an educational tool, and a tool for decision makers to use in studying the interrelationships between the diverse factors in the cement and concrete system which affect energy use and life-cycle performance. It is recommended that the mathematical models which have already been developed and which could be used in the development of a macro-model of the cement-concrete system should be identified. This should be followed by identification of additional models of portions of the system which would need to be developed to complete at least a rudimentary macro-model in a form suitable for further development. The model would be useful as an educational tool to help students understand the complex technical relationships between cement manufacture and cement performance in concrete; for aiding assessment of the energy implications of changes in the cement-making process and in other factors affecting the life-cycle performance of concrete; for aiding economic decisions; and for identification of research needs. Overall, it would help improve the education of our future decision makers and improve the quality of decisions relating to energy and materials conservation in the cement and concrete system. The development could benefit from, and contribute to, international cooperation.

7.6 Unresolved Issues

a) Adequacy of Knowledge about Raw Materials Reserves and Resources

There appears to be uncertainty as to whether there is adequate knowledge about reserves and resources of raw materials used for the production of cement and of other materials needed for the concrete industry. While the U. S. Geological Survey and the Bureau of Mines publish data about material reserves and use, it is not clear whether the figures are reliable and whether they take into account possible changes in the needs of the cement and concrete industries. If adequate knowledge is not available, we may eventually discover we do not have necessary materials in locations where they are needed (e.g., aggregates near urban centers). There is a question whether requirements for low-alkali raw materials and low-magnesia limestone are being considered in the projections for cement-making materials. It is recommended that experts from the cement and concrete industries review the status of the knowledge regarding the mineral resources needed by their industries.

b) Societal Impact of Using Wastes and By-Products in Concrete

There is uncertainty about the societal impact of using wastes and by-products in concrete with the aim of conserving energy, replacing depleted materials, and improving the energy saving in housing, etc. There is a need to make sensible use of wastes and by-products in order to save energy and materials, and to dispose of environmentally objectionable materials. Opposition, or lack of support, is due to lack of knowledge regarding the opportunities and to some conflicting economic considerations. In cooperation with governmental energy conservation agencies, the industry should explain the issue to a broad public.

8. SUMMARY

The recommendations of the six working groups covered a broad range of ideas for energy conservation. No attempt was made to rank the ideas in order of importance. The range of opportunities for energy conservation in the cement and concrete industries can be appreciated by reviewing the ideas presented.

The largest direct use of energy in the manufacture of concrete results from pyroprocessing to form portland cement clinker. Major opportunities for energy conservation, therefore, lie in reducing the energy requirement for the manufacture of clinker and in reducing the amount of cement used in concrete. The latter may be accomplished by partial replacement of cement by suitable waste or by-product materials or through the more efficient use of concrete. Suggested opportunities for reducing the amount of energy used in clinkering include the following:

- use of fluxes to lower the reaction temperature in the kiln
- permit higher free lime contents of clinker
- improve the uniformity and the particle size distribution of kiln feed
- select more reactive raw materials which will require less energy for clinker formation
- recover more heat from kiln exit gases
- improve ability to predict heat transfer and chemical reactions within the kiln.

Most of these items, like the others listed in this summary, imply needs for research as well as opportunities for energy savings.

Methods proposed for using concrete more efficiently include:

- increase the use of blended cements containing fly ashes, granulated blastfurnace slags, or other suitable waste or by-products
- increase the use of water-reducing admixtures in concrete to obtain strength benefits
- avoid overdesign by tailoring concrete properties to meet the needs of the application and by manufacturing concrete of greater uniformity
- develop more performance-oriented specifications
- develop improved tests for evaluation of performance of concrete and concrete constituents.

Although most of the energy used in the manufacture of cement is consumed in pyroprocessing, substantial amounts are also used in other processes. The grinding of the cement-making raw materials and the grinding of the clinker to make cement use large quantities of electrical energy. The inefficiency of grinding processes indicates that there are possibilities for improvement. Examples of suggestions for improving grinding efficiencies are:

- investigate factors affecting the dispersion of powdered materials in mill systems

- carry out an impartial evaluation of particle size classifiers and disseminate the results

- investigate the possibilities for improving the grindability of clinker through control of kiln and clinker cooler

- pretreat raw materials to improve their grindability

- select raw materials which require less energy for preparation.

The energy consumed in cement manufacture is also affected by the degree of control exercised on the manufacturing processes. For this reason, methods for the rapid and reliable analysis of raw materials and clinker are needed. Two specific suggestions concerning analysis were:

- develop a range of standard reference materials suitable for checking analytical procedures and calibrating analytical instruments

- develop improved methods for determining the quality of clinker.

Many operations in the manufacture and transportation of concrete offer potential for energy savings. Among the suggestions made were:

- remove unnecessary requirements for the curing of concrete

- carry out energy audits of concrete manufacturing plants

- develop storage and handling procedures to help retain the natural heat in concrete constituents

- use recycled concrete as aggregate in new concrete

- improve test methods and production control

- transfer more information from cement producer to cement user

- optimize the transportation network.

Although many technical opportunities for energy conservation were identified, it was apparent that there were serious institutional barriers to exploitation of the opportunities. These included availability of capital, education, technology transfer, standards and codes. Among the actions needed to remove barriers to, or provide incentives for, exploitation of opportunities for energy conservation were:

- provide training for cement and concrete technologists

- remove unnecessary restraints to use of innovative materials posed by prescriptive specifications

- provide government support or incentives for research and development
- identify capital requirements for exploitation of energy-saving opportunities
- promote dissemination of information on opportunities for energy conservation through cement and concrete technology
- stimulate cost-sharing in technological innovation
- stimulate joint university-industry R and D
- develop a mathematical model of the cement and concrete system.

The workshop produced a large variety of suggestions concerning the possible contributions of cement and concrete technology to energy conservation. The list of suggestions, though long, is undoubtedly incomplete. Nevertheless, it should draw attention to energy-saving opportunities for immediate implementation and suggest profitable areas of research. One of the suggestions made at the workshop was that the actions suggested should be implemented. The publication of this report is a step in this direction. It is hoped that further steps will be taken by its readers.

9. ACKNOWLEDGMENTS

By publication of this report we wish to acknowledge the contributions of all who participated in the Workshop and made the effort worthwhile. Their names are given in Appendix II. Particular thanks are due to the members of the Steering Committee and the Chairmen of the working groups (Appendix I) and to the following persons who, though not able to attend the Workshop, wrote in to contribute ideas for discussion: Harold Vivian, CSIRO, Australia; Stephen Gottlieb, Gorresen's Pty. Ltd., Australia; and Peter Hawkins, California Portland Cement Company.

We also wish to acknowledge the efforts of the many members of staff of the National Bureau of Standards who helped with the organization of the Workshop and assisted during the Workshop to make it run smoothly. These include Sara Torrence, Lynn Boggs, Anita Sweigert, Marie Dickey, Frank Davis and Nat Waters.

Last, we wish to acknowledge the support from the Division of Industrial Energy Conservation, Office of the Assistant Secretary for Conservation and Solar Applications, Department of Energy, which made the Workshop possible.

APPENDIX I

Workshop Steering Committee and Working Group Chairmen

Steering Committee

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Geoffrey Frohnsdorff, National Bureau of Standards, Chairman
Richard Gaynor, National Ready Mixed Concrete Association
Roy Grancher, Rock Products Magazine
Nathan Greening, Portland Cement Association
Robert Philleo, Office of Chief of Engineers, U.S. Army
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Working Group Chairmen

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Group 2, Cement Composition: Nathan Greening, Portland Cement Association

Group 3, Blending Materials: Francis Young, University of Illinois

Group 4, Concrete Production: Paul Klieger, Portland Cement Association

Group 5, Efficient Use of Concrete: Robert Philleo, Office of Chief of Engineers, U.S. Army

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APPENDIX II

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A workshop on Possible Contributions of Cement and Concrete Technology to Energy Conservation by the Year 2000 was held at the National Bureau of Standards on October 3 and 4, 1977. The purpose of the workshop was to identify and record ideas on possible contributions of cement and concrete technology to energy conservation in the near term and by the Year 2000. This included consideration of current technology as well as areas in which technological advances might be realized.

The workshop was divided into working groups on cement composition, cement production, blending materials, concrete production, efficient use of concrete, and institutional factors. The essential results from the six working groups were statements of Energy-Saving Opportunities, Research Needs, and Unresolved Issues. The statements, which are the major part of this report, are presented without critical analysis. They suggest, however, that there are a large number of possible opportunities which should be evaluated for their ability to contribute to energy conservation in the cement and concrete industries.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Cement; concrete; research needs; energy saving-opportunities.

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