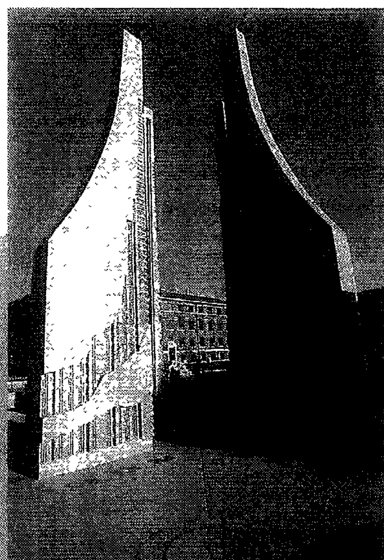
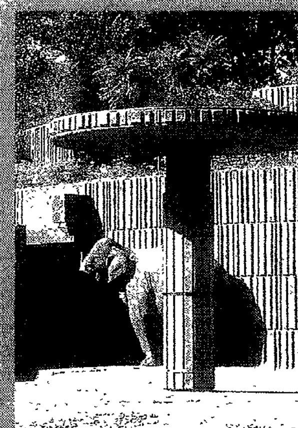
A NEW STONE AGE:

The Making of Portland Cement





A NEW STONE AGE:

The Making of Portland Cement

"These developments could bring about a high-tech stone age that will mean a civilization far less wasteful of energy, far less concerned with preventing fire and rust and far less subject to the disaster of dwindling resources."
Science writer Isaac Asimov, commenting on cement research, in "Back to Basics," *American Way*, April 1985

Building for a New Age

Imagine a building material strong enough for the tallest building or longest bridge, yet flexible enough to be molded into any size or shape. Our futuristic material would never rust or rot and would never need painting. It would resist fire and stand up to the ravages of weather and time–a material that would last for decades with only minimal upkeep.

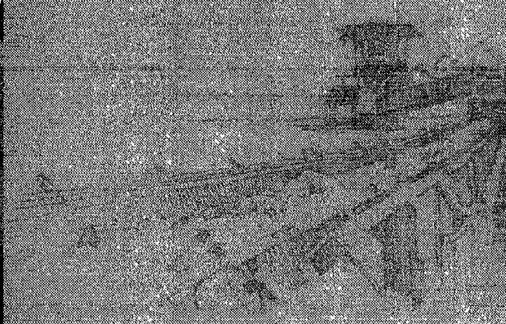
Moreover, it would be a natural material made of abundant, readily available resources. And the energy used to produce it would be much lower than for other construction materials.

Chances are, you walk over this remarkable material every day. For the future is here, and it's cast in concrete–a material with the natural properties of the stone from which it originates, plus its own unique qualities.

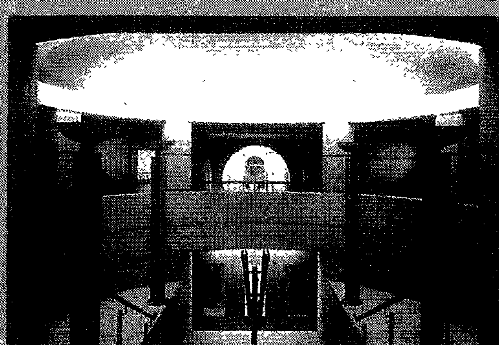
A

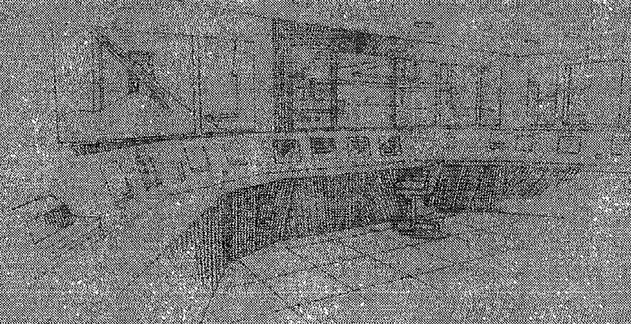
Photo captions and credits:
A. *Miracle on Fifth Avenue: Concrete—termed "artificial stone" by its inventor—forms a modern backdrop to an endearing counterpart, limestone. (Manhattan's 712-5th Avenue—Kohn Pedersen Fox)* B. *Exposed elegance. (Ryerson Polytechnical Institute, Toronto, Ontario—Lett/Smith Architects)* C&D. *Concrete is equally comfortable at home* (C) *or on the road* (D). *(C—J. Rodney Wyatt; D—Nicholson Construction Company)*
E. *Without peer on the waterfront. (Concrete Reinforcing Steel Institute)*

D



B





There's No Such Thing as a Cement Sidewalk

We're never far from something made of concrete. It's easily the most widely used building material on earth. We see it flow from the drums of ready-mix trucks and grow into skyscrapers, superhighways, or simply new sidewalks or patios. It forms our dams, water and sewage pipe, basements and foundations, blocks and bricks, streets and curbs, and a whole array of products from utility poles to railroad ties. The secret to this mixture of sand, stone, and water is a fourth key ingredient: portland cement.

Portland cement is an extremely fine gray powder manufactured from some of the earth's most common minerals. It's the glue that binds sand and gravel together into the rock-like mass we know as concrete. So there's no such thing as a "cement" highway, block, or sidewalk. They're all concrete.

"Portland" Is Not a Brand

Natural cement has existed since the Roman Empire. But its manufactured counterpart, portland cement, wasn't invented until 1824.

The term "portland cement" was coined by its inventor, English stonemason Joseph Aspdin. Aspdin heated a mixture of finely powdered limestone and clay in a small furnace to produce hydraulic cement–one that would harden when water is added. He called his new cement "portland" because concrete made from it resembled a highly prized natural building stone quarried on the Isle of Portland, off the English coast. "Portland" is not a brand name, then, but the generic term for the type of cement used in virtually all construction today.

Cement is essentially made up of minerals containing calcium, silicon, aluminum, and iron. Limestone, marl and chalk are the major sources of calcium. Clay, shale, bauxite, and iron ore provide the silicon, aluminum, and iron components. Other sources of raw materials include sea shells and industrial byproducts such as furnace slags, fly ash, and mill scale. Perhaps the most common combination of raw materials is limestone, clay, and sand.

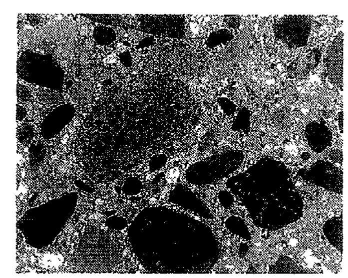
How Cement Works

When stone, sand, water, and portland cement are mixed together in the proper proportions, the water and cement form a paste that coats every stone and grain of sand and fills the spaces between them. The water triggers a chemical reaction called hydration. This reaction forms a gel which, as it hardens, binds the stones and sand into a solid mass that becomes stronger and stronger.

The cement's rate of hydration determines the setting and hardening time of the concrete. The initial reaction must be slow enough to permit workers to place and finish the concrete in its plastic state. Once in place, however, the concrete is allowed to harden into its finished form.

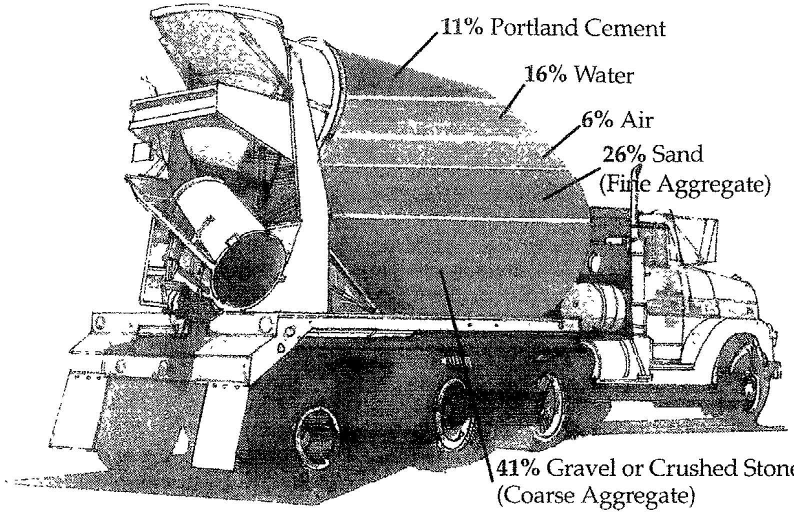
The rate of hardening can be precisely controlled. The gypsum ground into cement at the plant regulates setting time. Different types of cement have different setting times, and concrete additives are available to speed or slow setting. Temperature also affects setting time. The reaction of hydration itself releases heat–a boon in winter construction.

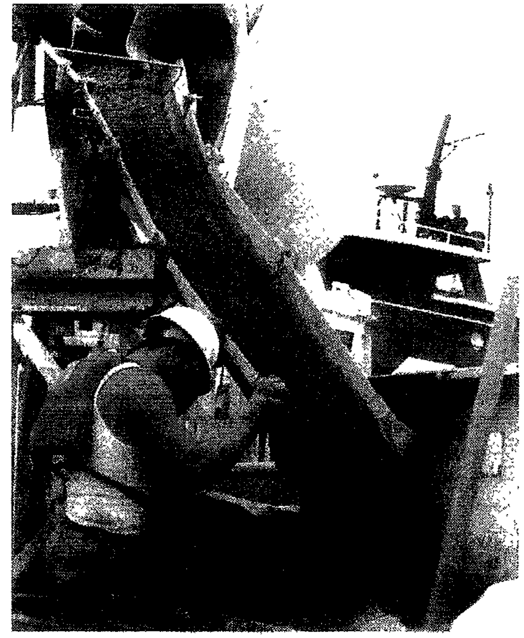
Although most strength development occurs in the first few days, concrete can gain additional strength for years if moisture is present and cement hydration is sustained.



The Right Mix

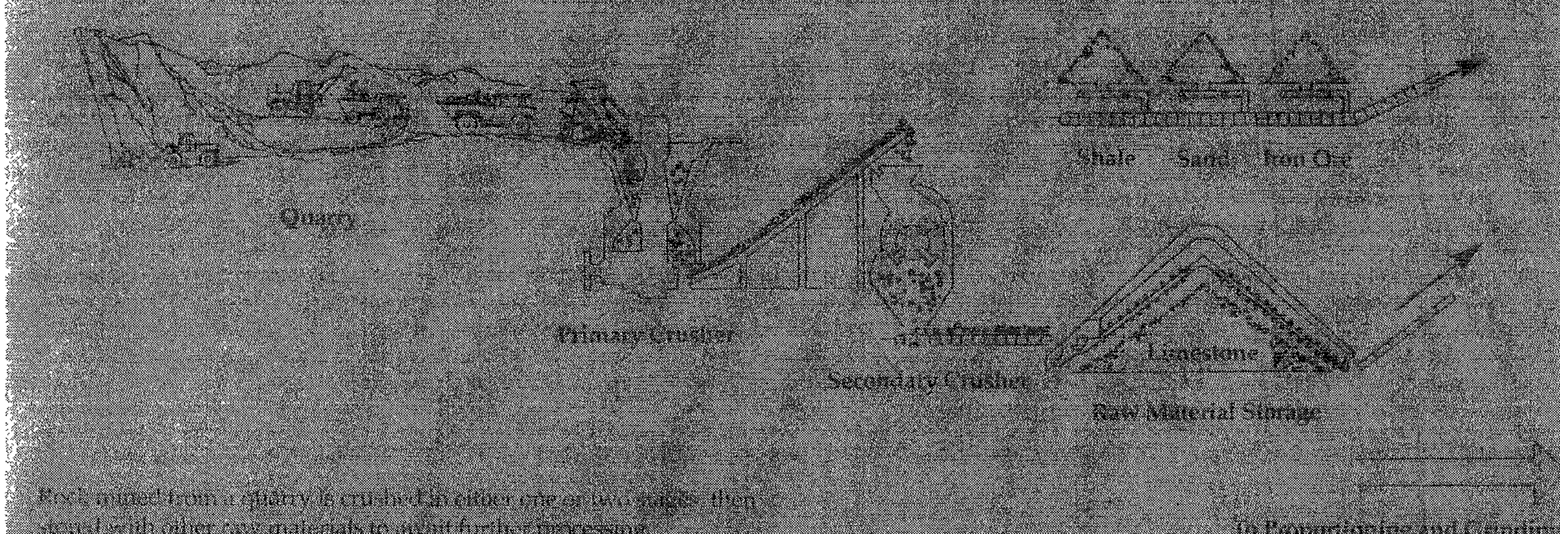
Components of Concrete



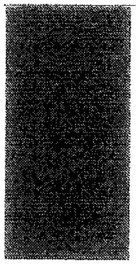


Upon this rock: From quarry to kiln to construction site, portland cement and its primary end product—concrete—are born of some of the earth's most common minerals.

It Starts with Stone



Rock mined from a quarry is crushed in either one or two stages, then stored with other raw materials to await further processing.



It Begins at the Quarry

Rock blasted from the quarry face is transported to the primary crusher, where the piano-sized rocks are broken into pieces the size of baseballs. A secondary crusher reduces them to the size of gravel. Some plants now crush materials in a single stage. The types of crushers used in a plant depend upon the types of raw materials processed. While the plant's quarry yields the primary ingredient, limestone, other raw materials are often brought in from outside sources.

In the plant laboratory, technicians analyze the raw materials and determine the correct proportions of limestone and other materials needed for the final cement product. At all manufacturing stages, the laboratory keeps a close watch on the raw materials to assure the quality and uniformity of the product.

The Daily Grind

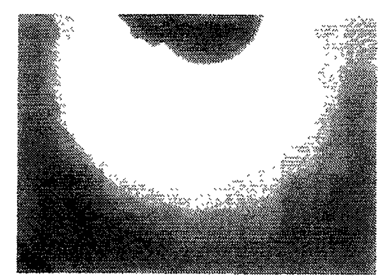
Once analyzed, the raw materials are blended in the proper proportions and ground even finer. Some cement plants use heavy wheel-type rollers that crush the materials into powder against a rotating table. Other facilities grind the raw materials in ball or tube mills–horizontal steel cylinders filled with thousands of steel balls. As the mill turns, the balls tumble onto the material and crush it into powder.

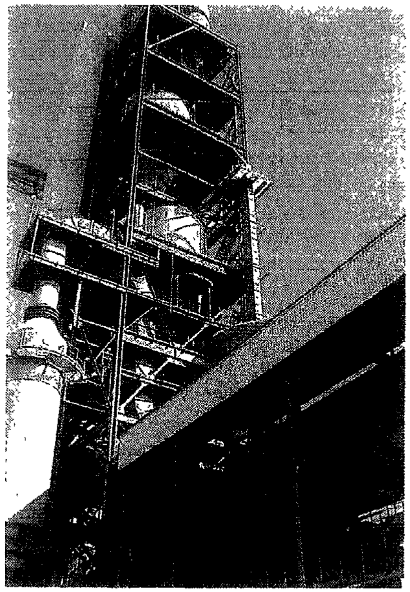
In the type of cement-making called the dry process, the raw materials are now ready for the kiln. In an older system known as the wet process, water is added to the raw feed during grinding, producing a creamy mixture called slurry, to simplify mixing and proportioning. After grinding, the slurry is stored in large, open tanks under agitation.

Kiln Chemistry

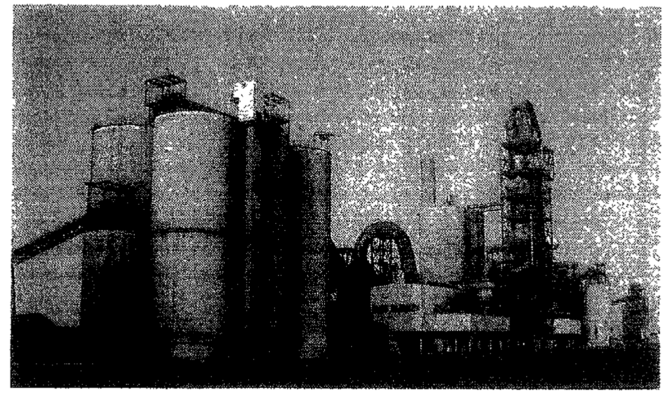
As the raw materials move down the progressively hotter kiln, they undergo complex chemical and physical changes requiring intense heat. Expressed at its simplest, the series of chemical reactions in cement-making converts calcium and silicon oxides into calcium silicates, cement's principal constituents. While kiln systems vary, there are three major zones:

1. Drying and preheating zone, 70°F to 1650°F (20°C to 900°C)
   Water is evaporated, and calcination–driving off carbon dioxide from limestone–begins.
2. Calcining zone, 1100°F to 1650°F (600°C to 900°C)
   Calcination is complete, removing carbon dioxide from calcium carbonate to produce the lime (calcium oxide) needed for subsequent reactions.
3. Sintering or burning zone, 2200°F to 2700°F (1200°C to 1480°C)
   Calcium oxide reacts with silica to form dicalcium silicates and alumina- and iron-bearing materials to form tricalcium aluminate and tetracalcium aluminoferrite. These two compounds, in liquid phase, meld solids together into the pellets called clinker. Remaining calcium oxide reacts with dicalcium silicate to form tricalcium silicate.

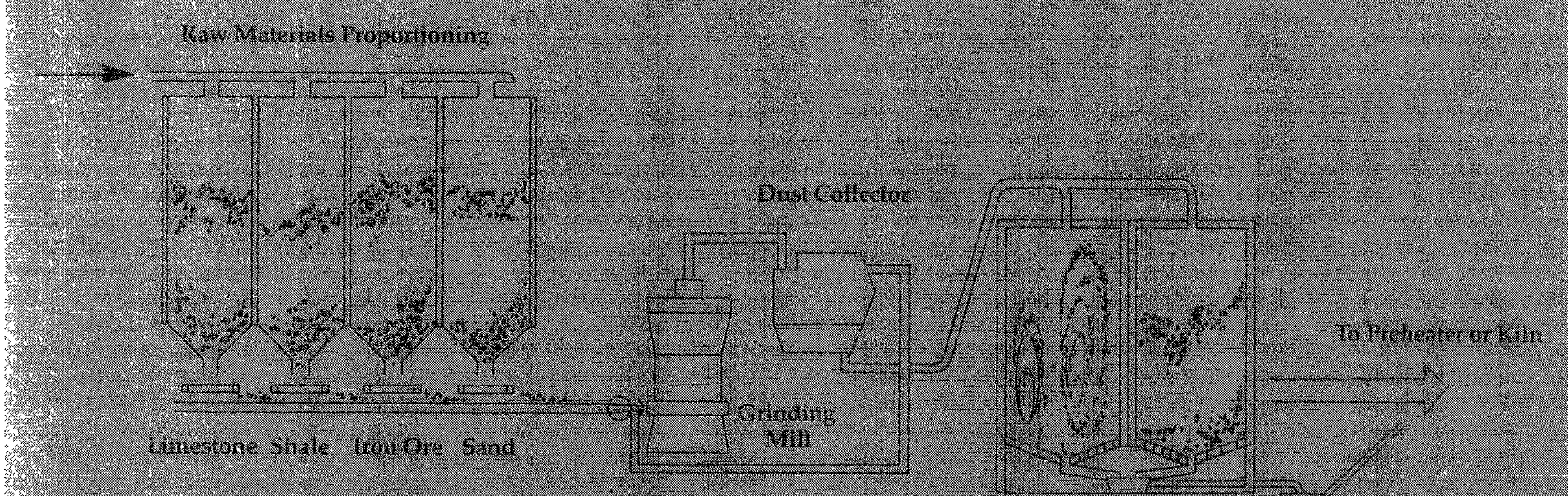




Belying cement's natural roots is a highly sophisticated, precise manufacturing process meeting rigid specifications.



A Precisely Mixed Grind



After analysis, the raw materials are proportioned, ground to fine powder, and blended. Some cement plants add water to the material during grinding, then blend and store it as a slurry.

Conversion by Fire

Whether in dry powder or slurry form, the raw meal is ready for the huge rotating furnace called a kiln. It's the heart of the cement-making process–a horizontally sloped steel cylinder, lined with firebrick, turning from about one to three revolutions per minute. The kiln is the world's largest piece of moving industrial equipment.

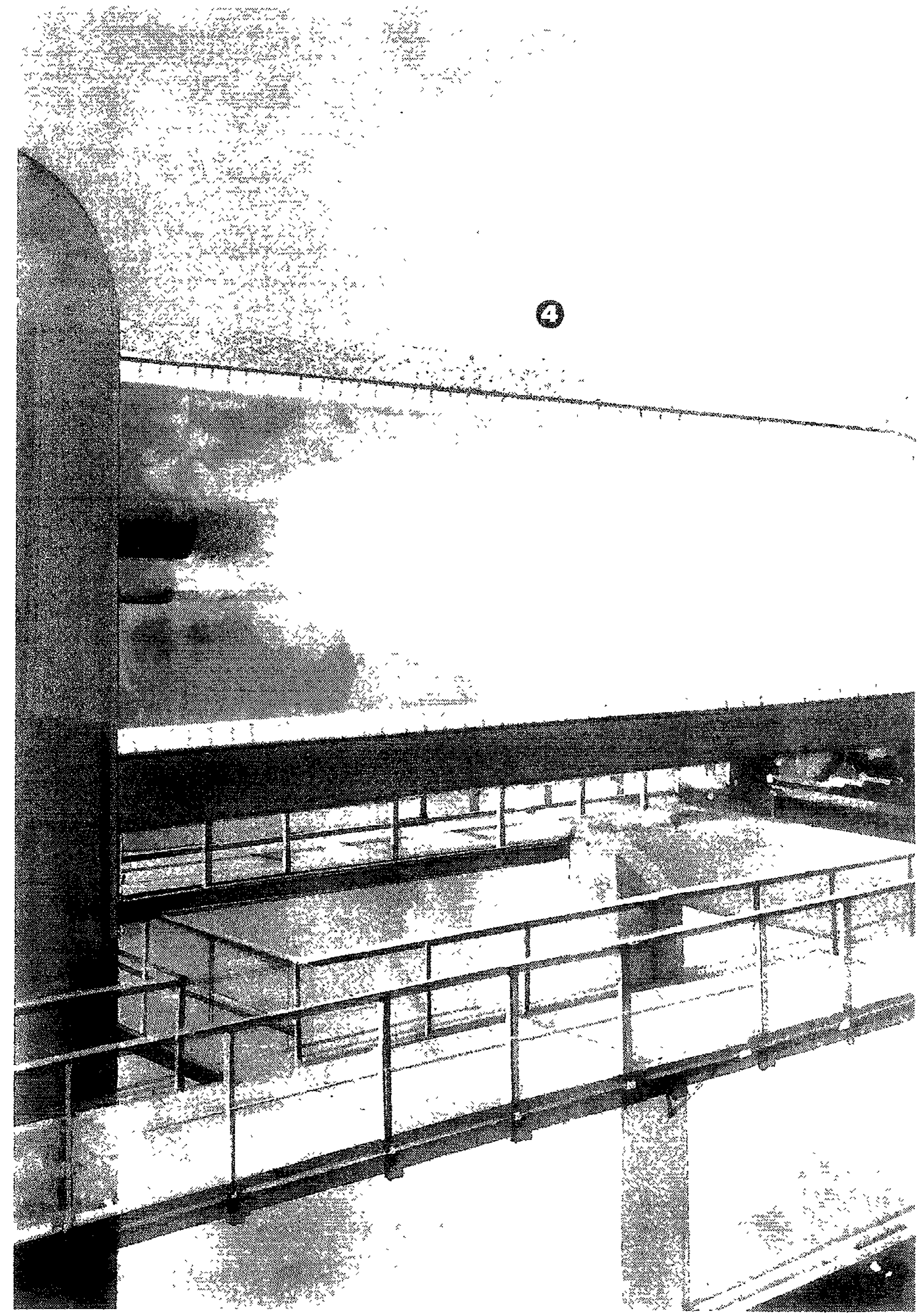
❶ To save energy, modern cement plants preheat the materials before they enter the kiln. The preheater tower dominates the landscape, rising more than 200 feet. The tower supports a series of vertical cyclone chambers through which the raw meal passes on its way to the kiln. Hot exit gases rising from the kiln heat the material as it swirls through the cyclones.

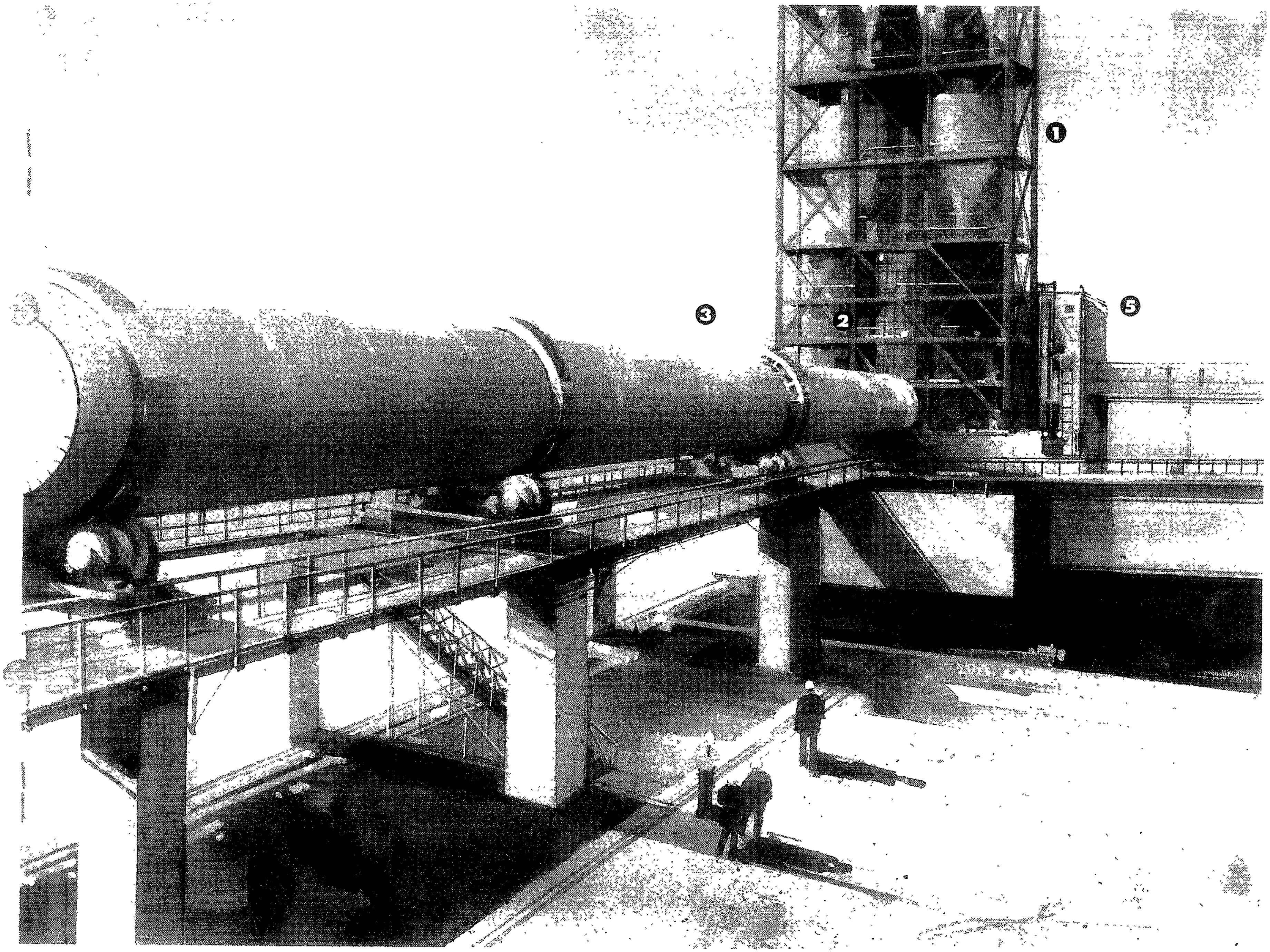
❷ Some preheaters contain a furnace or precalciner at the bottom of the preheater tower just before the kiln. Material from the last stage cyclone enters the precalciner along with hot combustion air and fuel. As much as 95% of calcination–the removal of carbon dioxide from raw materials–takes place here.

❸ From the preheater, the material now enters the kiln at the upper or feed end. It slides and tumbles down the kiln through progressively hotter zones toward the flame. Remaining carbon dioxide in the raw materials is driven off, and the intense heat triggers other chemical reactions.

❹ At the lower end of the kiln, powdered coal, natural gas, oil, or waste-derived fuels feed a white-hot flame that reaches 3400°F (1870°C)–one-third of the temperature of the Sun's surface. Here in the hottest zone, the materials reach nearly 2700°F (1480°C) and become partially molten. They emerge from the lower end of the kiln as a new substance: red-hot particles called clinker.

❺ Pollution control devices, such as electrostatic precipitators or fabric filters called baghouses, remove particulates from exit gases before they enter the atmosphere. This strict control of emissions enables cement plants to meet high air-quality standards. Many plants return all or a portion of the collected particles, called cement kiln dust, to the kiln as part of the raw feed. Cement kiln dust not returned to the kiln is responsibly managed or sold for uses such as liming or stabilizing agents.




1
2
3
5

The Final Grind

As the clinker leaves the kiln, it tumbles onto a reciprocating grate through which fans force cool air. The heat recovered as the clinker cools is returned to the kiln or preheater to save energy.

Once cooled, the clinker is ready to be ground into the familiar gray powder we know as cement. During final grinding, a small amount of gypsum is added to the clinker to control the setting time of the cement.

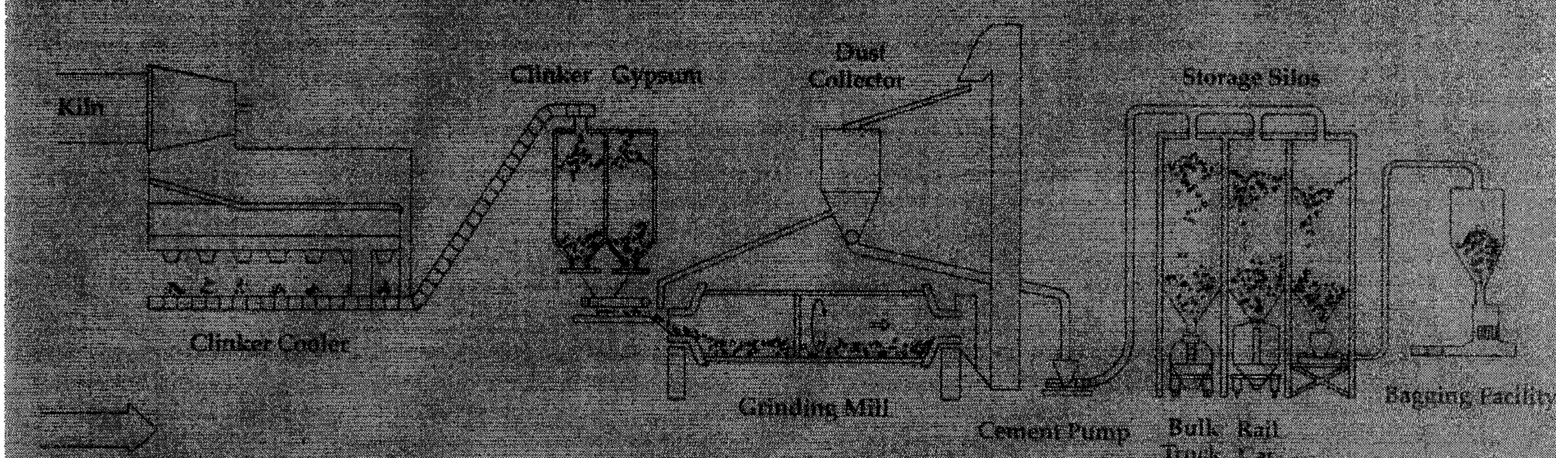
In ball mills, the clinker is ground to a super-fine powder composed of micron-sized particles as small as 1/25,000 of an inch. It can now be considered portland cement. The cement is so fine it will easily pass through a sieve that is fine enough to hold water.

Bagged or Bulk

From the grinding mills, the cement is conveyed to silos where it awaits shipment. Most cement is shipped in bulk by transport trucks, railroad cars, or barges. They're gravity-loaded at the storage silos by overhead equipment that can fill a large tanker in only a few minutes. A small percentage of the finished product is bagged for customers who need only small amounts of cement.

Although they may use different raw materials, fuels, equipment,

Cement So Fine



Once cooled, the clinker is ground with a small amount of gypsum. It's now portland cement–ready to be bagged or shipped in bulk.

and methods, cement plants produce portland cement of consistently high quality no matter where and how it is made. This is because cement is manufactured to rigid specifications that are carefully adhered to by all manufacturers. Cement produced in the United States conforms to the American Society for Testing and Materials Specification for Portland Cement (ASTM C 150).

From the plant, most cement is shipped to ready mixed concrete producers. It's combined with water, sand, and gravel to make the concrete delivered to construction sites in the familiar trucks with revolving drums.

Cement is also used for an array of precast concrete products–everything from pipe and concrete block to parking lot bumpers, and median barriers. It's also used in mortar for brick and block.

A Cement for All Reasons

Construction demands different types of cements for specific conditions and purposes. Most portland cement made today is a general-purpose cement known as Type I. Other specialty cements are produced from the same basic raw materials, but vary in chemical composition and physical performance.

One of the great advances in concrete technology was the development of air-entrained concrete in the 1930's. Scientists discovered that incorporating tiny bubbles of air in the concrete mix dramatically improves hardened concrete's resistance to deterioration from freezing and thawing. As moisture in the concrete freezes and expands, these bubbles act as expansion chambers, relieving stresses that could cause cracking.

Cement by Number

Different types of portland cement have special properties for specific uses. While their manufacture is similar, they differ in raw materials, proportions, and fineness. Under its C-150 specification, the American Society for Testing and Materials designates eight types of portland cement:

Type I– Normal, general-purpose cement found in nearly all concrete

Type IA– Normal, air-entraining cement

Type II– Moderate heat of hydration and moderate sulfate-resisting cement for concrete exposed to soil or water with sulfate contents, which can damage concrete

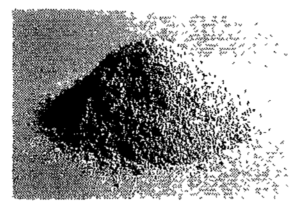
Type IIA– Moderate-sulfate-resistance, air-entraining cement.

Type III– High-early-strength cement for rapid-setting concrete

Type IIIA– High-early-strength, air-entraining cement

Type IV– Low heat of hydration cement for use when temperature rise is a concern–in hot weather or for massive concrete projects such as piers or dams

Type V– Sulfate-resisting cement for concrete exposed to severe sulfate action



The Case for Waste

Cement-making is ideal for recycling wastes by recovering their energy value. Many wastes, such as used motor oils, solvents, chemical byproducts–even scrap tires–have high energy content. As supplemental fuels, they replace significant quantities of traditional fuels such as coal and natural gas. Besides conserving scarce fossil fuels, burning waste in cement kilns safely rids society of undesirable and hazardous materials.

With its 3400°F degree flame, the rotary cement kiln provides the high temperatures and long burning time needed to completely destroy hazardous wastes. The U. S. Environmental Protection Agency requires incinerators and other waste processors to achieve 99.99% destruction efficiency. Cement kilns easily reach this destruction level and are often 100 times more efficient. And rather than simply destroying wastes, the energy is recovered to make portland cement.

Waste fuel burning does not affect the quality of the cement. In fact, some waste products can be processed as raw materials if they contain essential elements for cement. The rubber in scrap tires, for example, is completely consumed as fuel, and the steel belts provide iron, an essential ingredient of cement.

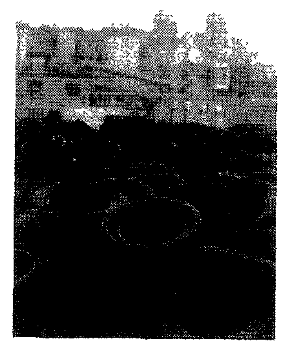
Cement plants must meet strict emission limits regardless of the fuel used. Using waste as supplemental fuel does not materially change air emissions. The tight controls over cement production processes assure that wastes are effectively managed and destroyed. And the final product–cement–does not contain any toxic organic compounds from waste fuel. Cement plants are thus contributing to a cleaner environment by safely destroying unwanted wastes while using the energy created to make a useful and essential product–portland cement.

What's in a Waste

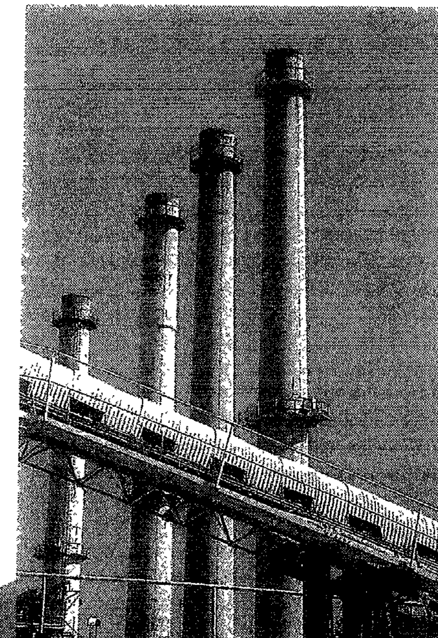
Cement plants can't just burn any waste–the materials must have fuel value and be compatible with the cement-making process. Any wastes not meeting these standards are rejected. Cement plants in the U.S. do not accept PCB's, dioxins, pesticides, or radioactive wastes.

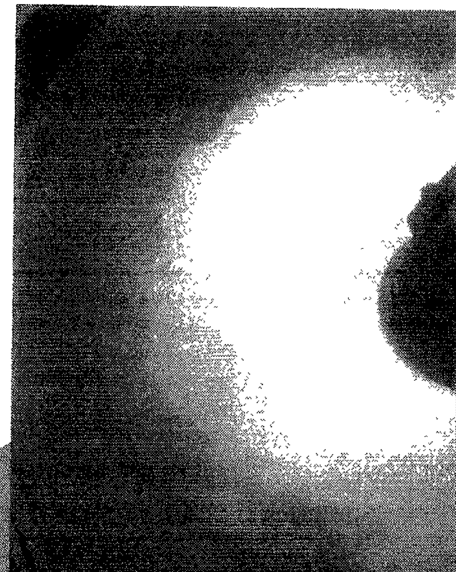
Most wastes recycled in cement-making are generated in the manufacture or use of everyday goods and services we all take for granted:

- Scrap tires
- Used motor oil
- Solvents and inks used to print newspapers and other publications
- Solvents used to recycle paper
- Dry-cleaning solvents
- Paint thinners and paint residues
- Sludge from the petroleum industry
- Agricultural wastes such as almond shells

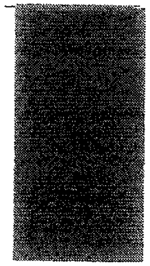


What happens to these wastes in the cement kiln? Organic compounds are burned as fuel, essentially destroyed. Inorganics, such as metals, become locked into cement's crystalline structure or are incorporated into cement kiln dust, a byproduct that is responsibly managed by waste-fuel users.





With a 2400°F kiln flame and highly refined process controls, cement plants offer the right synergy for waste-to-fuel recycling—residence time, turbulence, and temperature far beyond those of commercial waste incinerators.



The Shape of Things to Come

A steady stream of advances continue to build on concrete's traditional strengths and expand on its already considerable versatility.

A whole range of admixtures can customize concrete to flow like water, reduce setting time from days to hours, or dramatically increase strength. The last decade has seen breakthroughs that have pushed concrete's strength to nearly 20,000 pounds per square inch (140 MPa)–about 6 times that of a sidewalk or driveway. And in the laboratory, researchers have achieved strengths of 100,000 psi (690 MPa). For construction, this means taller and more economical buildings, longer and more durable bridges.

Other research is transforming Joseph Aspdin's "artificial stone" into wholly new products with properties that rival plastic, aluminum, and ceramics.

"Concrete is where metals were in 1960, when their strength shot up five or ten fold, and where ceramics were in 1970, when they did the same thing," says Francis Young, professor of civil engineering at the University of Illinois. "Concrete will go through an explosion of understanding in the 1990's. It's a material for the twenty-first century."

Yet for all its sophistication, modern concrete retains the stone-like properties that have made it the foundation of all we build–durable, fire-resistant, and immune to rot and rust. And it all begins with the fine gray powder called portland cement.

Cement Goes to Market

Use by Type of Construction

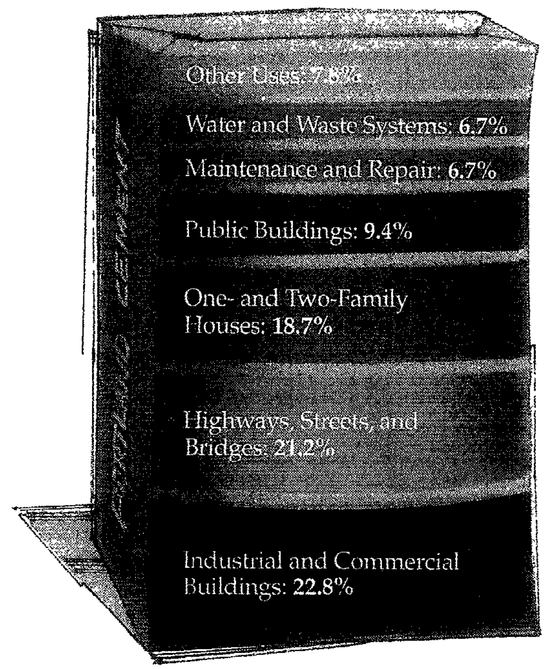
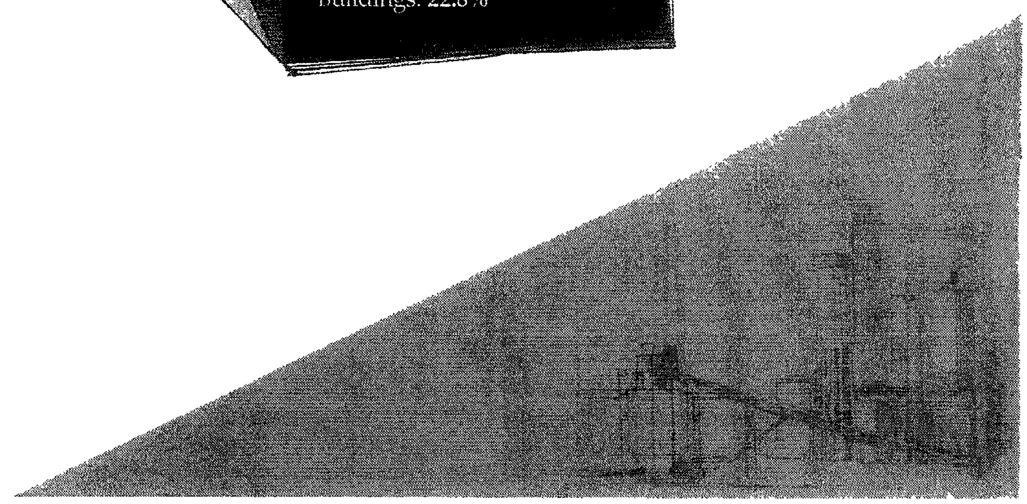
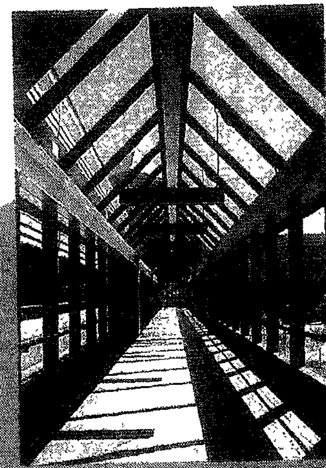
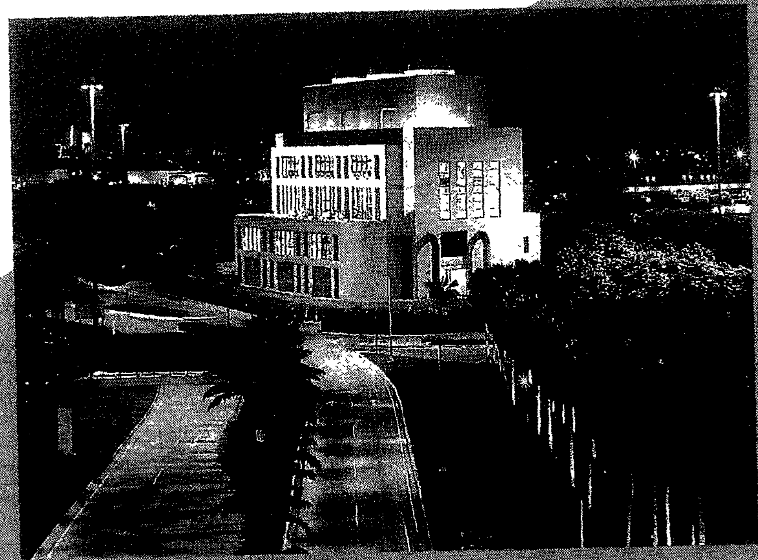


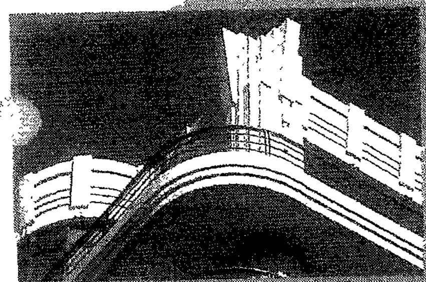
Photo captions and credits:
Three faces of concrete: architectural, utilitarian, and monumental. (Office building A—*Concrete Reinforcing Steel Institute; Chiller Plant in Dade County, Florida,* B—*Wolfberg/Alverez & Associates; San Francisco's Coit Tower,* C—*Interactive Resources, Inc.)* D. *Enlightened parking. (Blue Cross/Blue Shield of Connecticut's parking facility—Ellenzweig Associates)* E. *Span with elan. (The Skybridge in Vancouver, British Columbia—Precast/Prestressed Concrete Institute)*



D







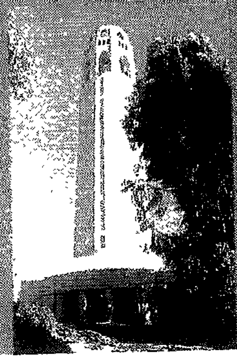


Exhibit B

LAFARGE
NORTH AMERICA

Lafarge's Experience with Meat and Bone Meal

LAFARGE NORTH AMERICA

Lafarge North America

- The largest diversified supplier of construction materials in the United States and Canada including:
  - Cement and cement-related products
  - Aggregates and asphalt
  - Concrete and concrete products
  - Gypsum drywall and a complementary line of finishing products

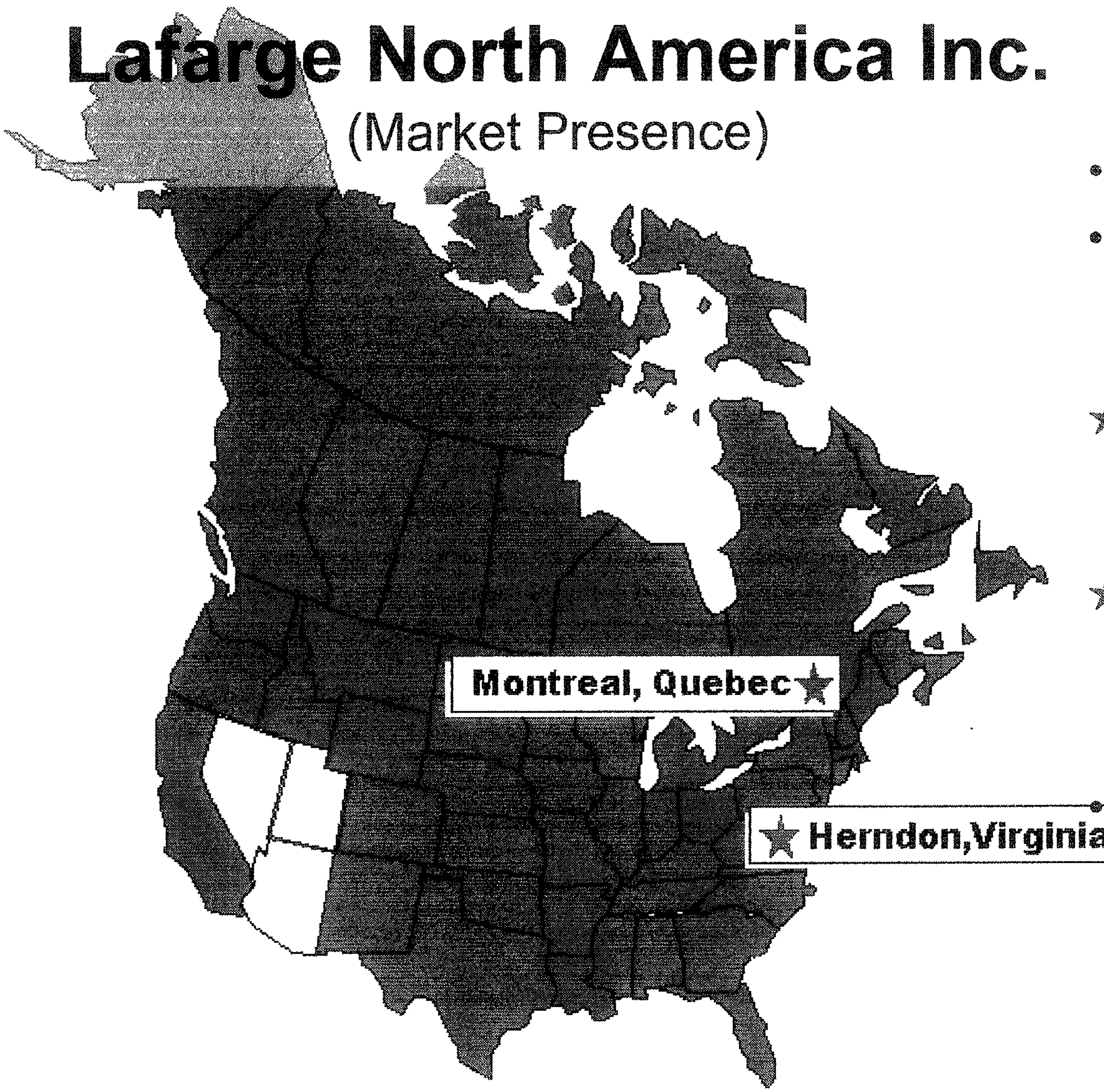
- Listed on the New York and Toronto Stock Exchanges (symbol:LAF)

- Part of the Lafarge Group, the world leader in building materials with 77,000 employees in 75 countries reporting €13.6 billion in sales for 2003.

LAFARGE
NORTH AMERICA

Lafarge North America Inc.

(Market Presence)



- Over 1000 operations throughout the U.S. and Canada
- More than 15,000 employees
- 2003 sales of USD $3.3 billion

★ North American Corporate headquarters, Herndon, Virginia

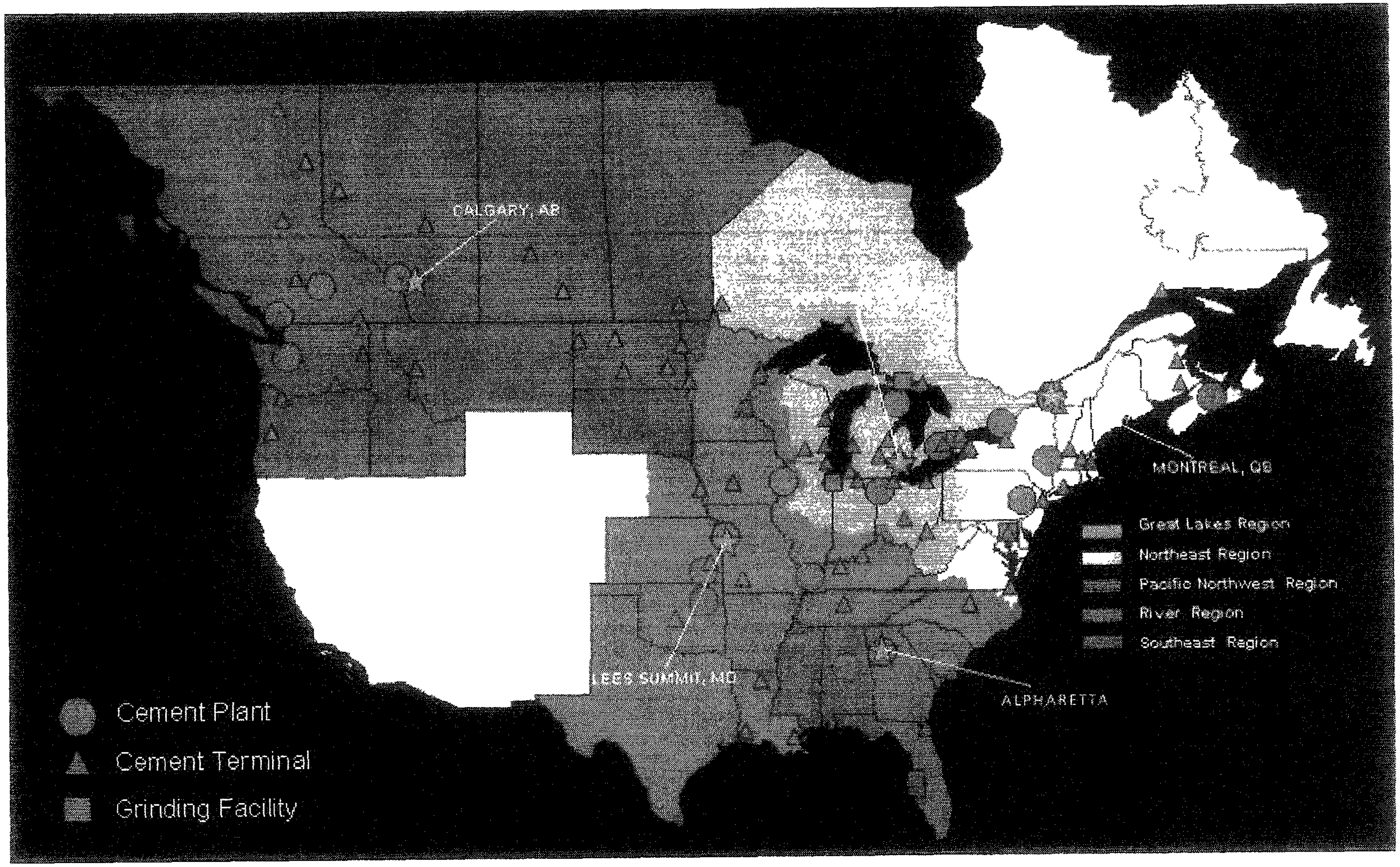
★ Lafarge Canada Inc. headquarters, Montreal, Quebec

3 main business segments:

- Cement and Cement-related products
- Construction Materials
- Gypsum

LAFARGE NORTH AMERICA

Cement and Cement-Related Products



LAFARGE
NORTH AMERICA

Environmental Standards

- Establishing policies, procedures, guidelines and practices to help us meet our responsibilities
- Auditing periodically our operating facilities and our performance
- Communication and cooperation with all levels of government
- Environmental outreach efforts
- Reduce, re-use and recycle by-products
- Sustainable development

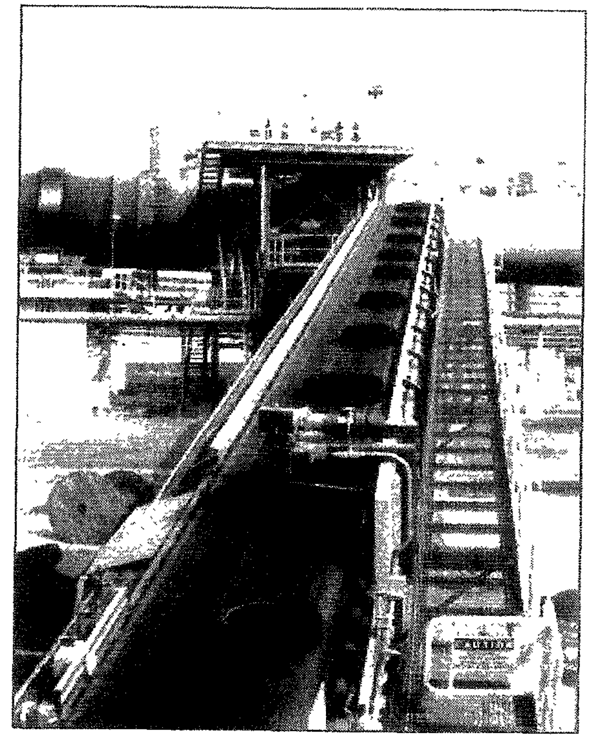
Alabama Brickyard

WWF | LAFARGE
Conservation Partner
Founding Member

LAFARGE
NORTH AMERICA

What is an alternative fuel to Lafarge?

- An alternative fuel represents a replacement BTU value in comparison to coal
- Examples include:
  - Fuel Quality Hazardous Waste
  - Tires
  - Carpet
  - Plastics
  - Spent pot liners
  - Animal meal
  - Used oil
  - Auto fluff
  - Coal tar fuels
  - Landfill Gas
  - Shredded diapers



Lafarge: A World-Wide Alternative Fuel Experience

Lafarge has plants with almost non-existant fuel cost in the United States, Europe, and South America

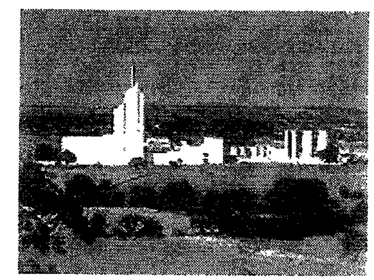
In North America: Harleyville, SC, St-Constant, Quebec, Brookfield, Nova Scotia, Paulding, OH, Fredonia, KS, Atlanta, GA, Whitehall, PA, Tulsa, OK, Richmond, BC, Seattle, WA, Kamloops, BC, Sparrows Point, MD are burning alternate fuels.

Hope Works, Derbyshire

- Recycled liquid fuel
- Tires
- Sewage pellets
- Packaging wastes
- Bone meal

Cauldon, Staffordshire

- Recycled liquid fuel
- Tires

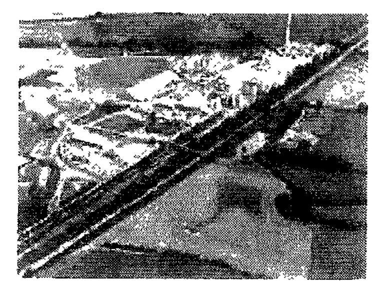


Dunbar, East Lothian

- Recycled liquid fuel
- Tires

Westbury Works, Wiltshire

- Recycled liquid fuel
- Tires
- Sewage pellets
- Packaging wastes
- Bone meal



LAFARGE NORTH AMERICA

Lafarge's Alpena Michigan Cement Plant

LAFARGE
NORTH AMERICA

Meat and Bone Meal

Lafarge's Experience

LAFARGE
NORTH AMERICA

History

- July 1996

  The French Ministry of Environment asks the Cement Industry to perform "co-incineration" tests

Le Ministre de l'Environnement

Paris, le 25 JUIL. 1996

Monsieur le Président,

Comme vous le savez, le Gouvernement a pris récemment la décision de retirer du marché les systèmes nerveux centraux de tous les ruminants abattus, les cadavres d'animaux et les saisies d'abattoirs. Ces dispositions complètent celles concernant le retrait des abats spécifiques de bovins nés avant le 31 juillet 1991.

L'ensemble de ces retraits concernent en période de production normale environ 400 000 tonnes de produits frais par an représentant de l'ordre de 100 000 tonnes par an de farines animales dégraissées et de 30 000 tonnes de graisses. Ces produits seront à incinérer.

Pour limiter au maximum le stockage de ces matières et les risques qui en résultent, l'importance de ces tonnages eu égard aux capacités d'incinération disponibles nécessite d'envisager l'incinération de ces déchets dans des installations de co-incinération.

A cette fin, je ne verrais que des avantages à ce que l'industrie cimentière réalise rapidement des essais d'incinération de ces produits dans des cimenteries déjà autorisées à incinérer des déchets au titre de la législation des installations classées.

Je vous prie d'agréer, Monsieur le Président, l'assurance de ma considération distinguée.

Bien amicalement.

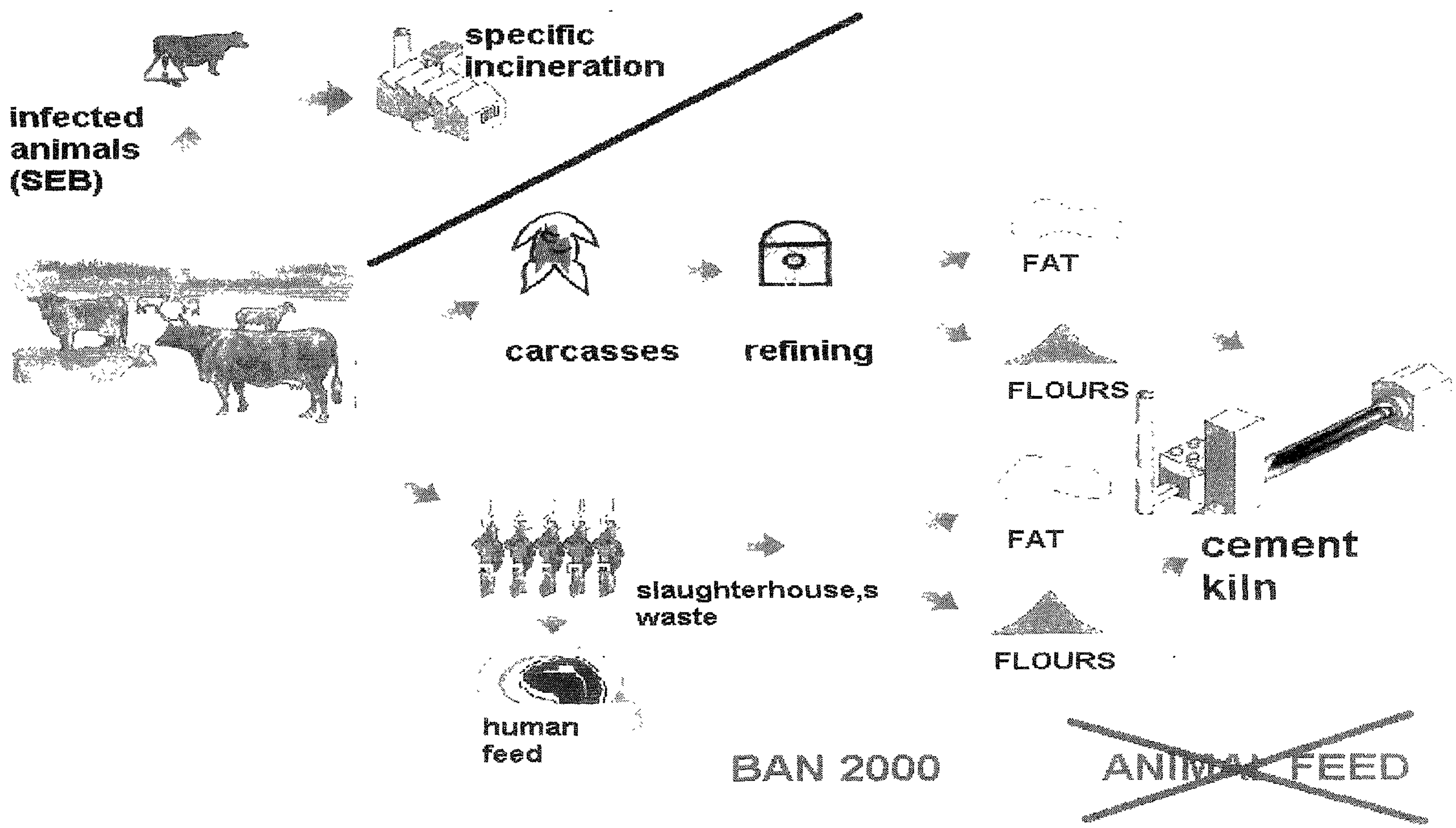
Corinne LEPAGE

Monsieur Antoine GENDRY
Président du Syndicat Français
de l'Industrie Cimentière
41, avenue de Friedland
75008 PARIS

20, avenue de Ségur - 75302 Paris 07 S.P. - Téléphone : (1) 42 19 20 21 - Télex Minenv 200312
Télécopie : (1) 42 19 11 23

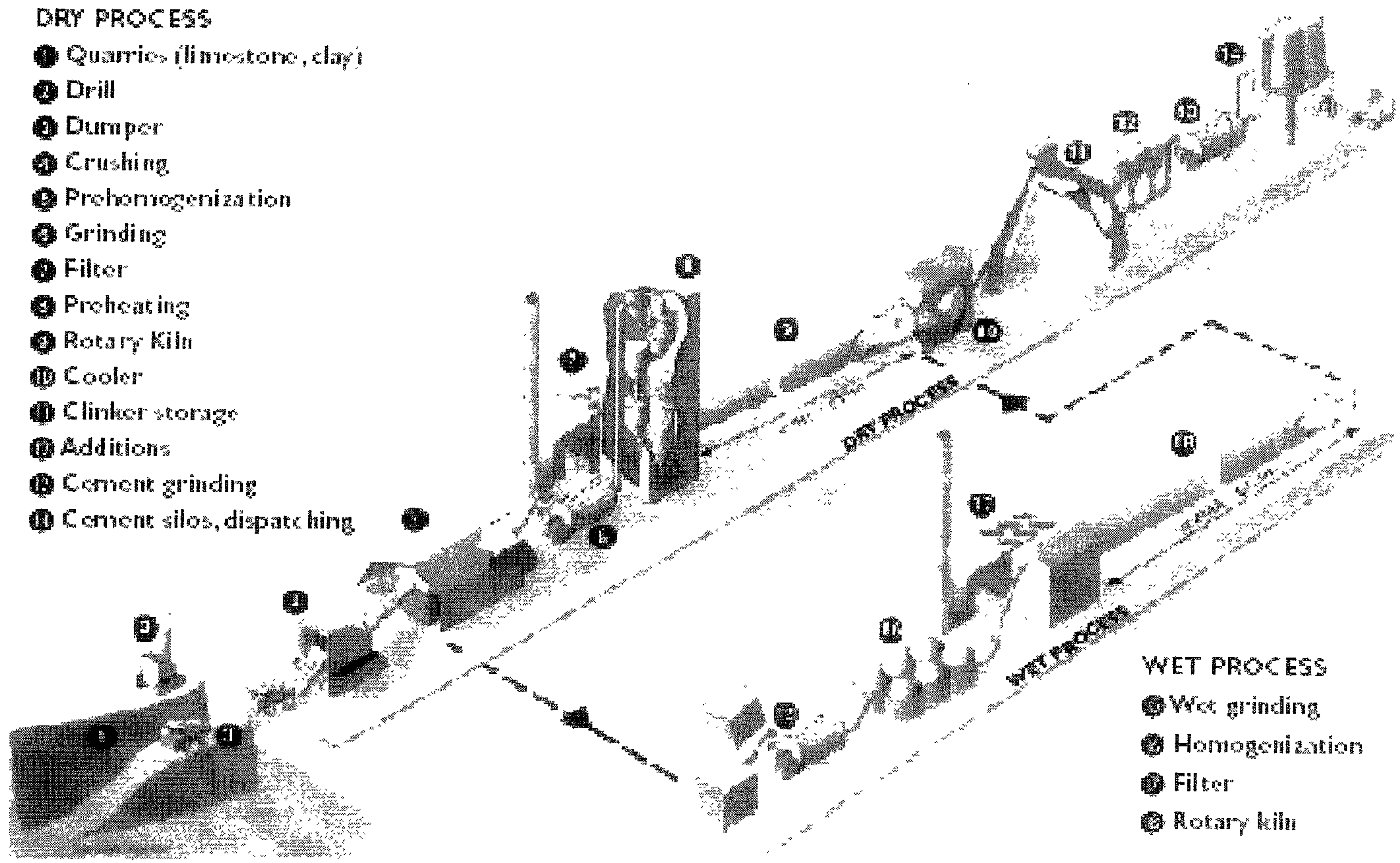
LAFARGE NORTH AMERICA

Europe's Situation



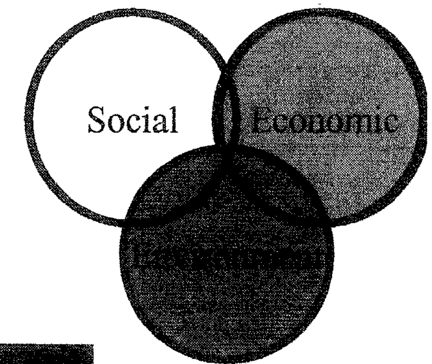
LAFARGE
NORTH AMERICA

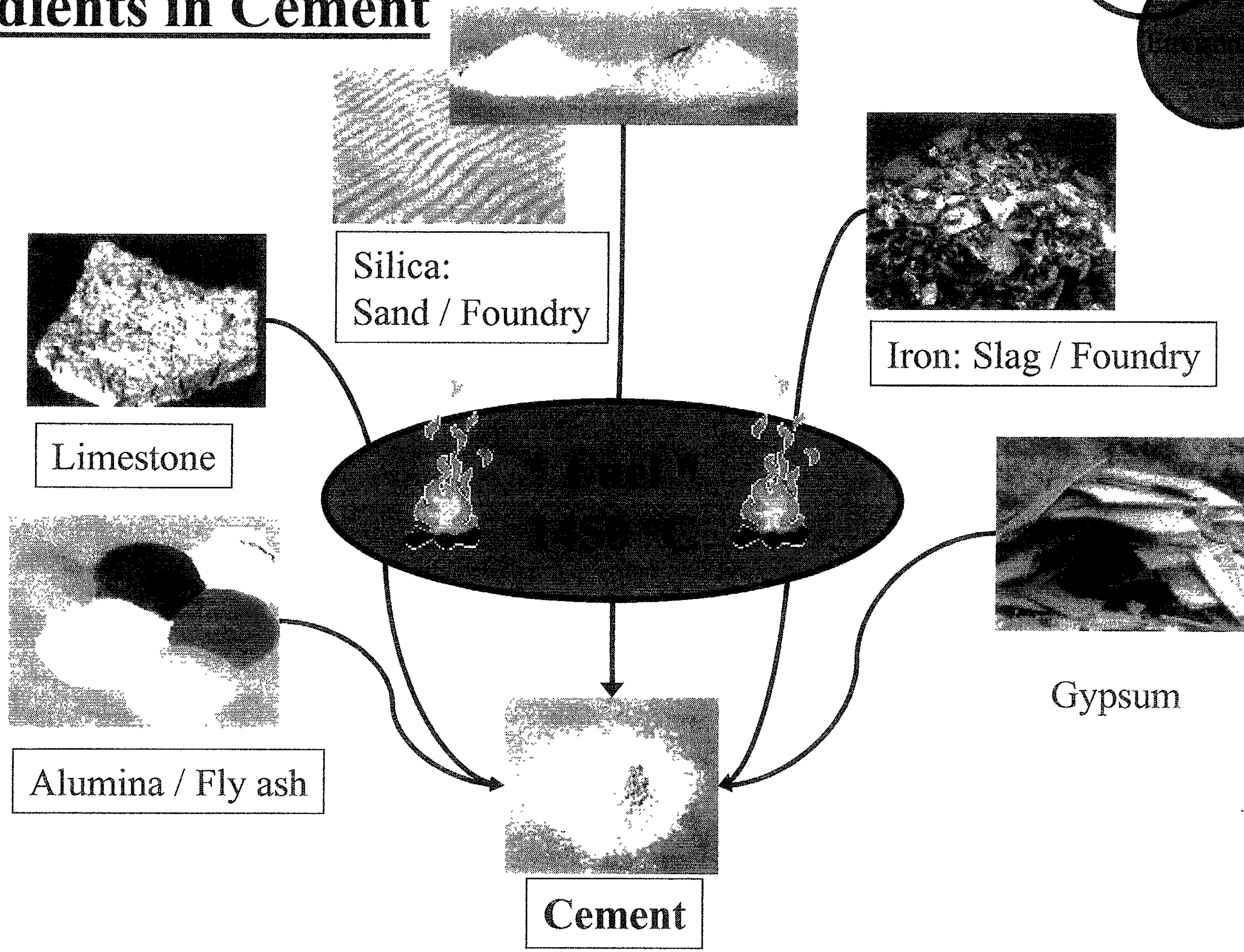
Cement Process



LAFARGE
NORTH AMERICA

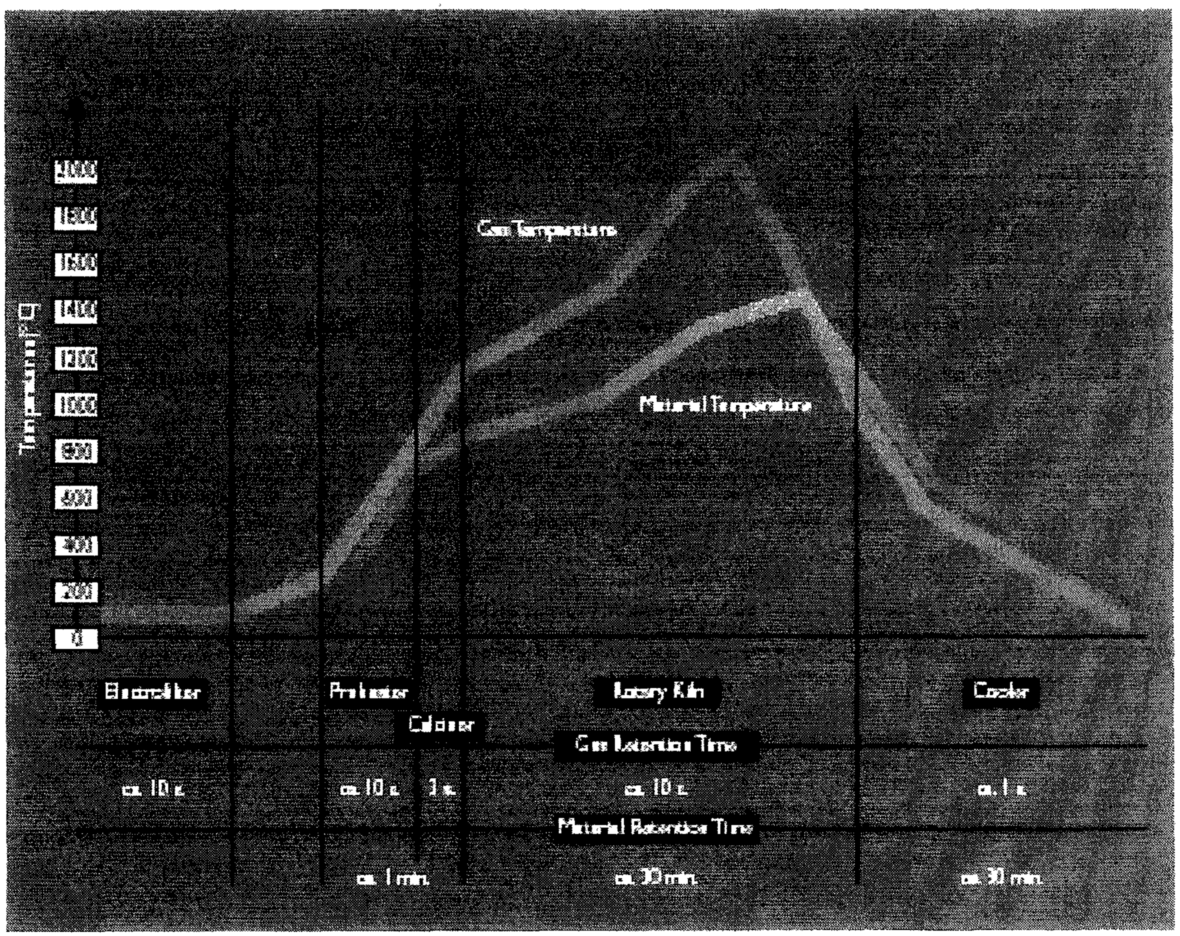
Ingredients in Cement





Ideal Conditions

Of particular importance, for the use of alternative fuels: high temperature, long residence time and an oxidizing atmosphere in a natural alkaline environment.



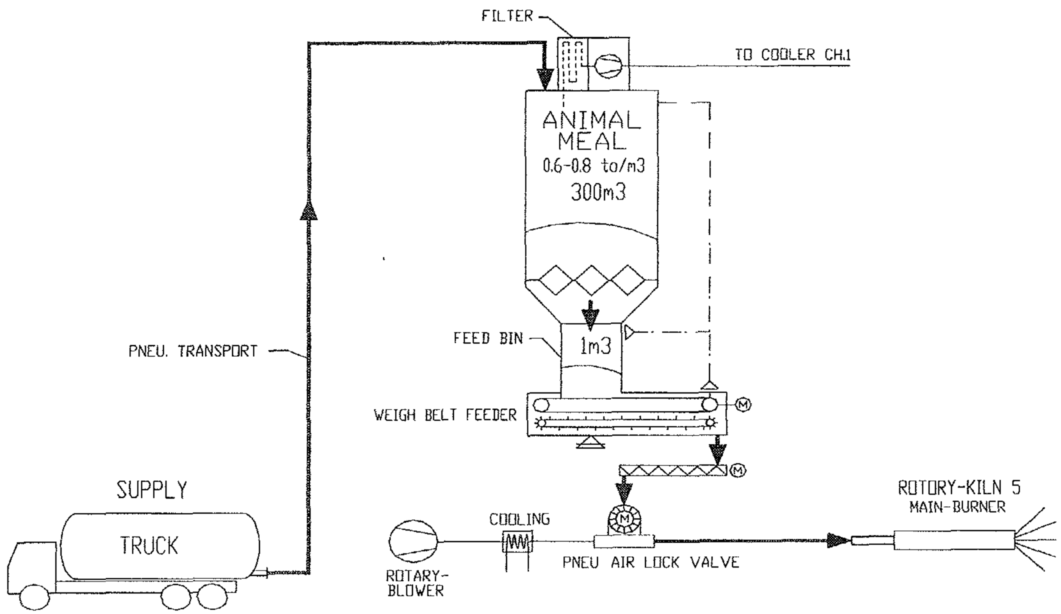
LAFARGE
NORTH AMERICA

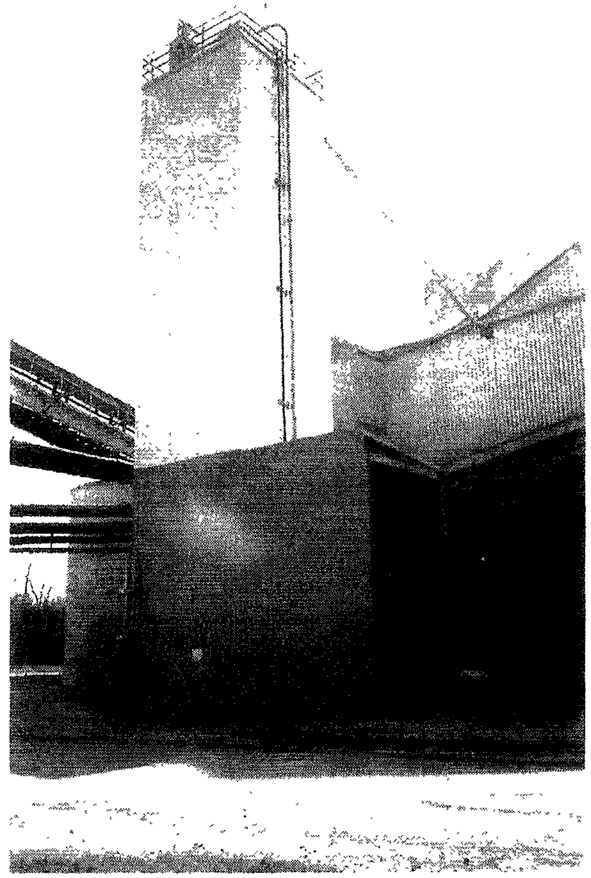
MBM Design Conception Best Practice

- Transport in enclosed trucks
- Silos dedicated to MBM
- Conveying to the kiln in fully closed circuits
- Direct injection into the main burner
- Personal protective devices
- Documentation and tracking
- Reduce odors by venting in the cooler

Retznei - Austria

- Reception Installation



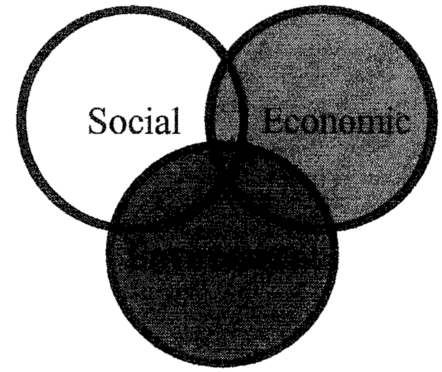


LAFARGE
NORTH AMERICA

MBM 2002 Lafarge's Experience

	Plants	Tonnes
• France	9/11	144,000
• Germany	3/3	61,300
• Austria	2/2	20,700
• Spain	2/3	15,200
• Czech Rep.	1/1	1,400
• Italy	2/2	6,900
• Japan	2/2	9,000

Local Issues



- Plant receiving process
- Employee and Stakeholder education
- Plant handling issues
- Capacity assessment
- Permitting and stakeholder issues being investigated

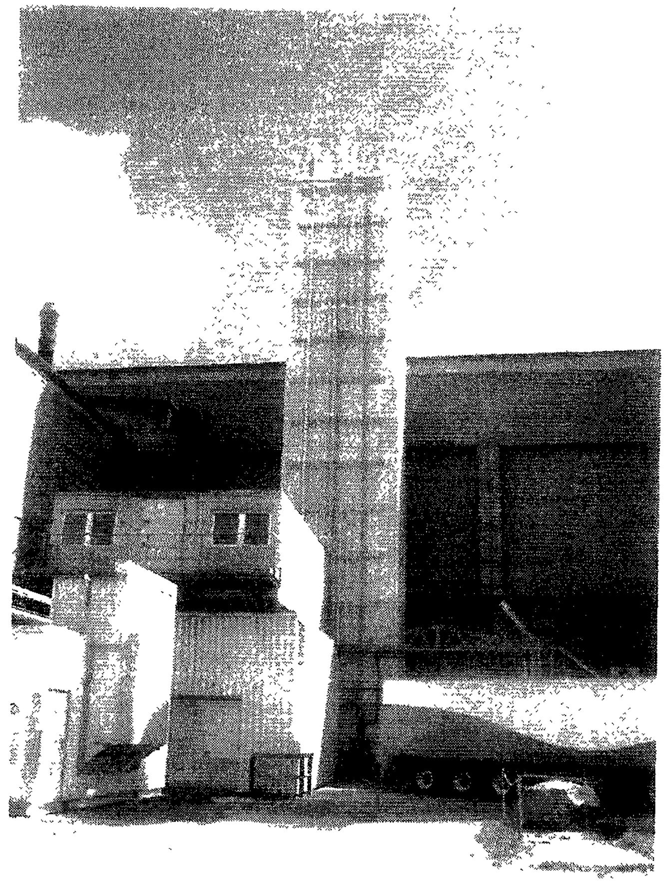
LAFARGE
NORTH AMERICA

Environmental Benefits

- Complete destruction of the organic portion
- No residue to landfill
- Replaces some conventional fuels (CO_2 emission reduction)
- Could use fat or animal meal
- Minimize Environmental Impact
  - Fully Enclosed Handling and Storage system
  - Draw on European Experience

Sottenich - Germany

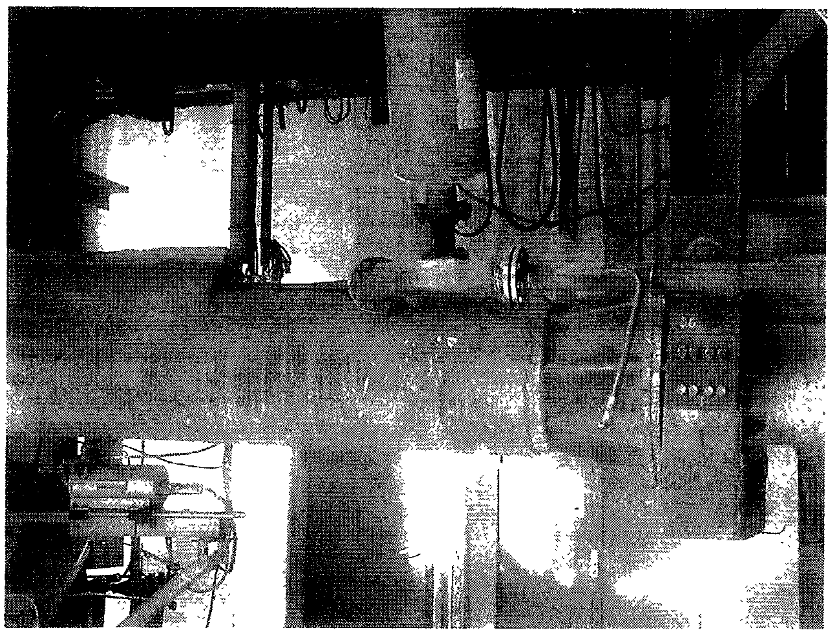
- Reception Installation

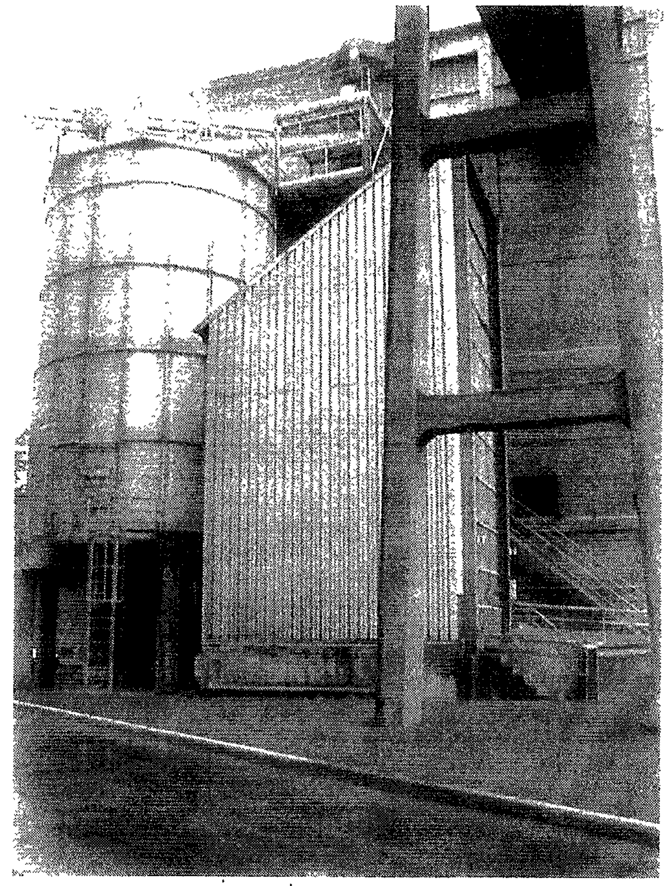


LAFARGE NORTH AMERICA

Martres - France

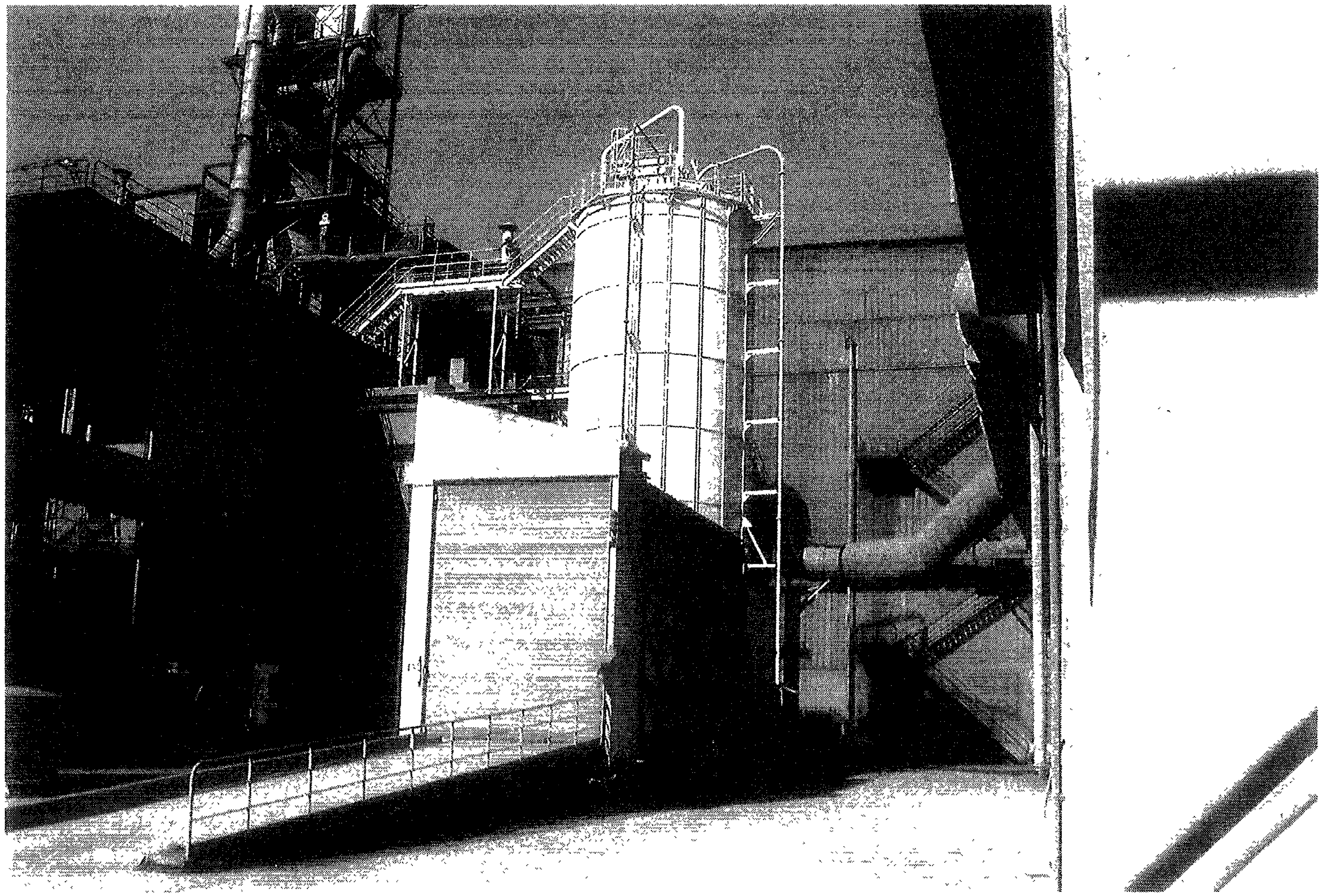
- Reception Installation and feeding the kiln



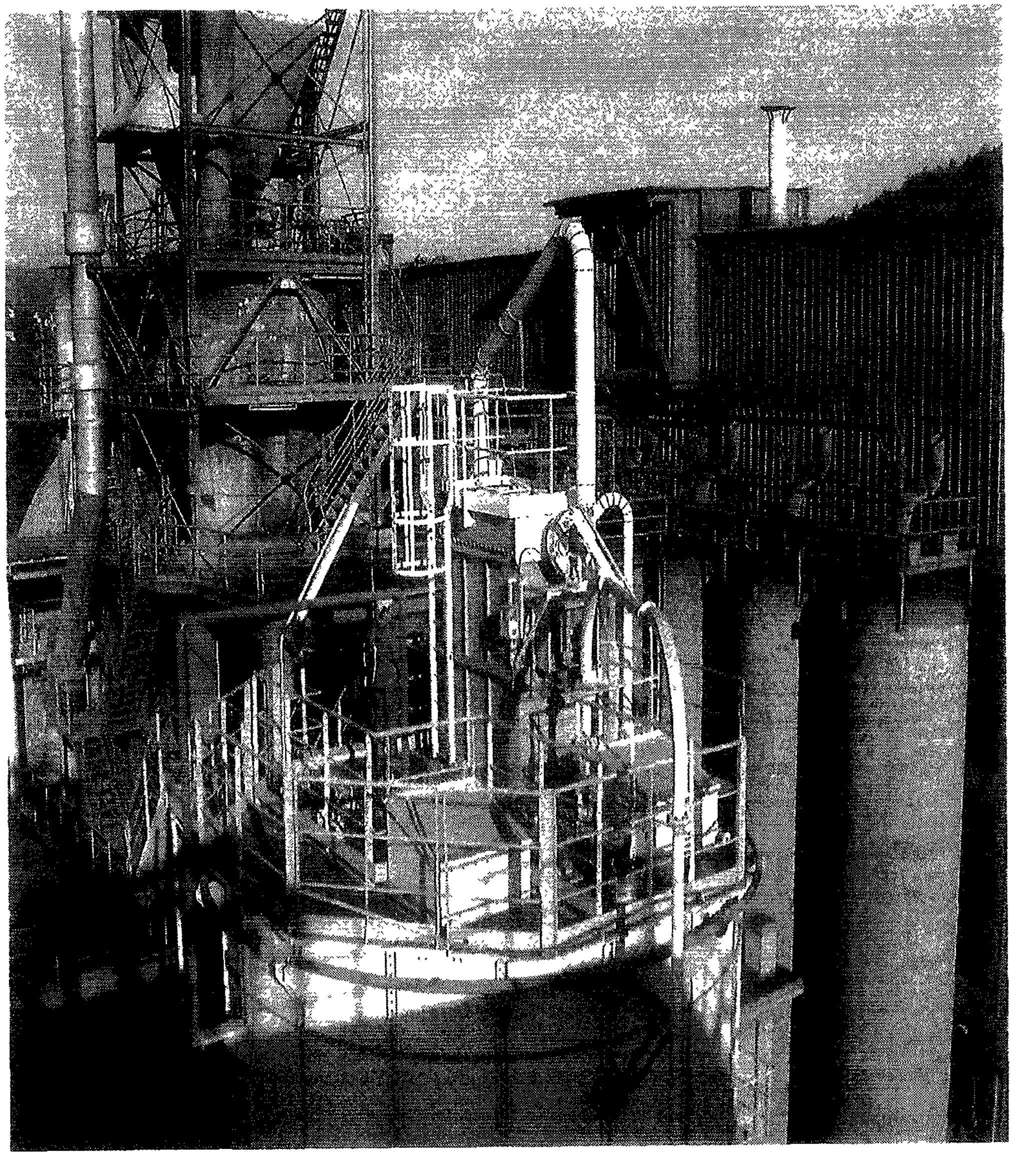


LAFARGE NORTH AMERICA

Val D'Azergues -- France



LAFARGE
NORTH AMERICA



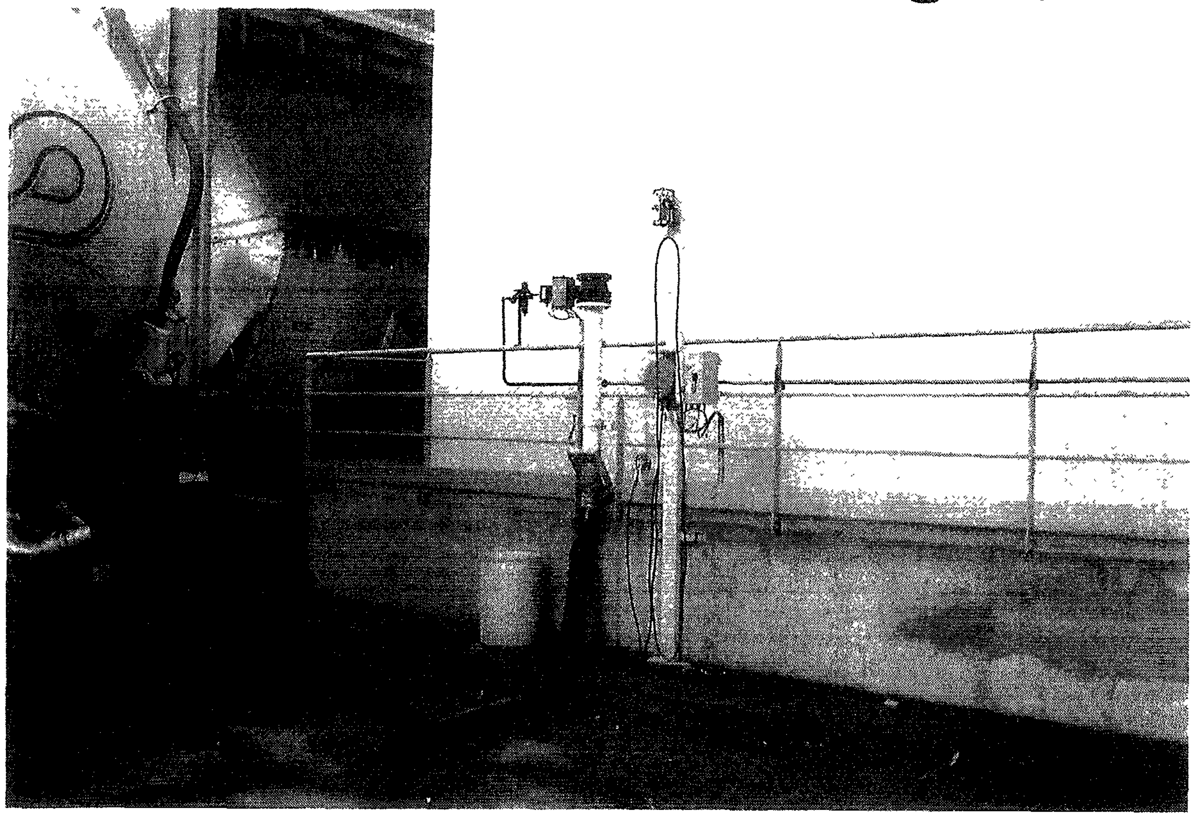
Val D'Azergues -- France

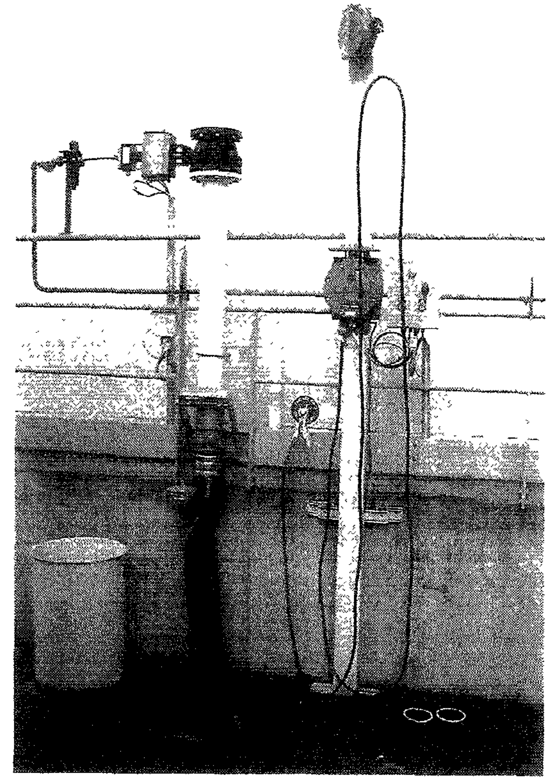
Storage tank

View of Silo top

LAFARGE
NORTH AMERICA

Val d'Azergue, France





MBM Reception - Pneumatic Unloading

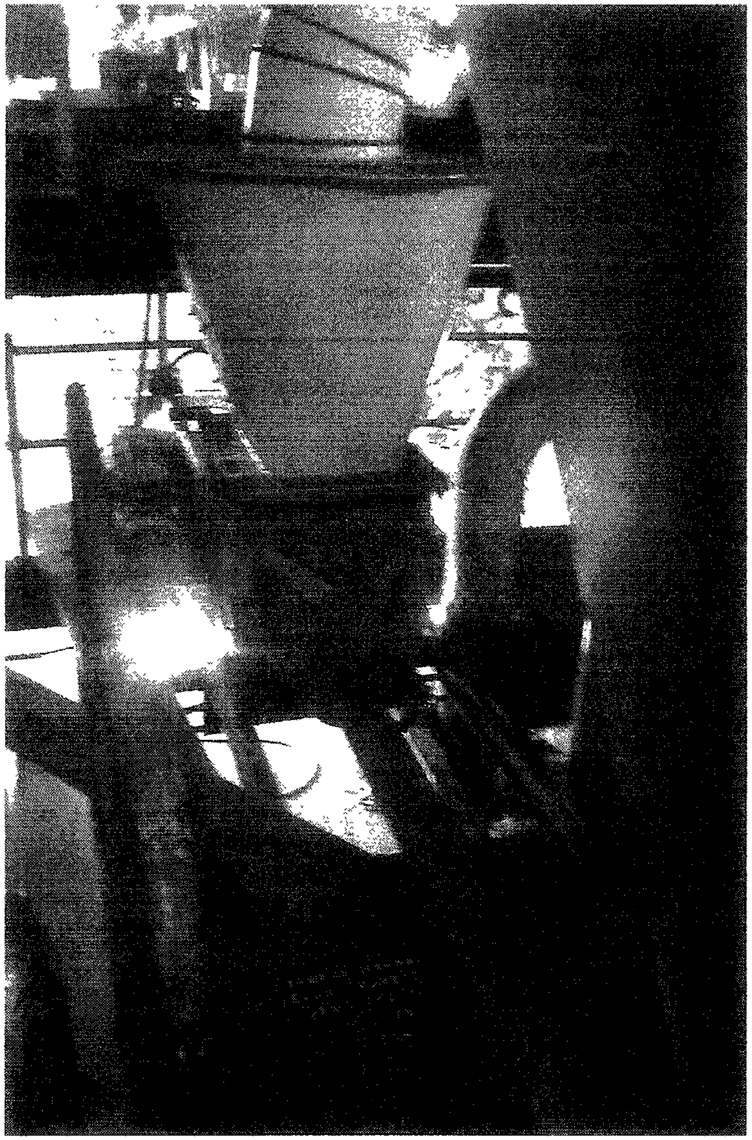
LAFARGE
NORTH AMERICA

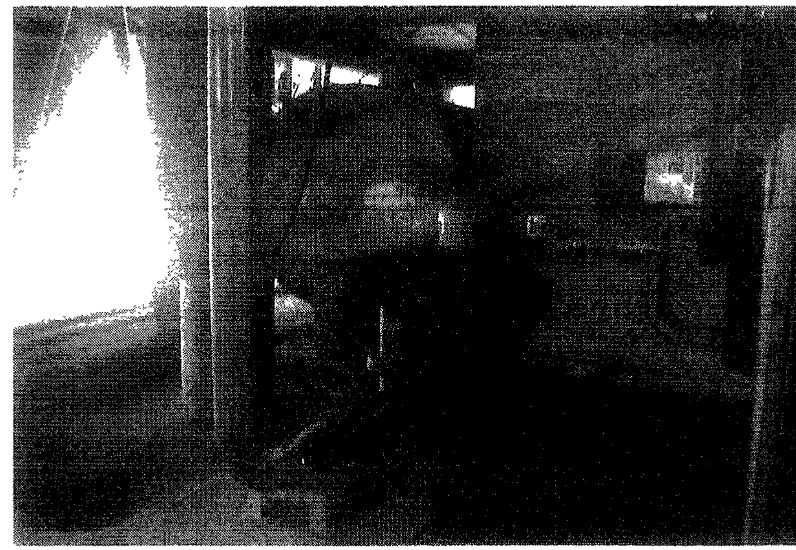
Val D'Azergues -- France

Silo extraction system (with isolation gate under).

LAFARGE
NORTH AMERICA

Val D'Azergues -- France





Air blower

Blow through rotary valve for alternative fuels injection, feed by a surge hopper