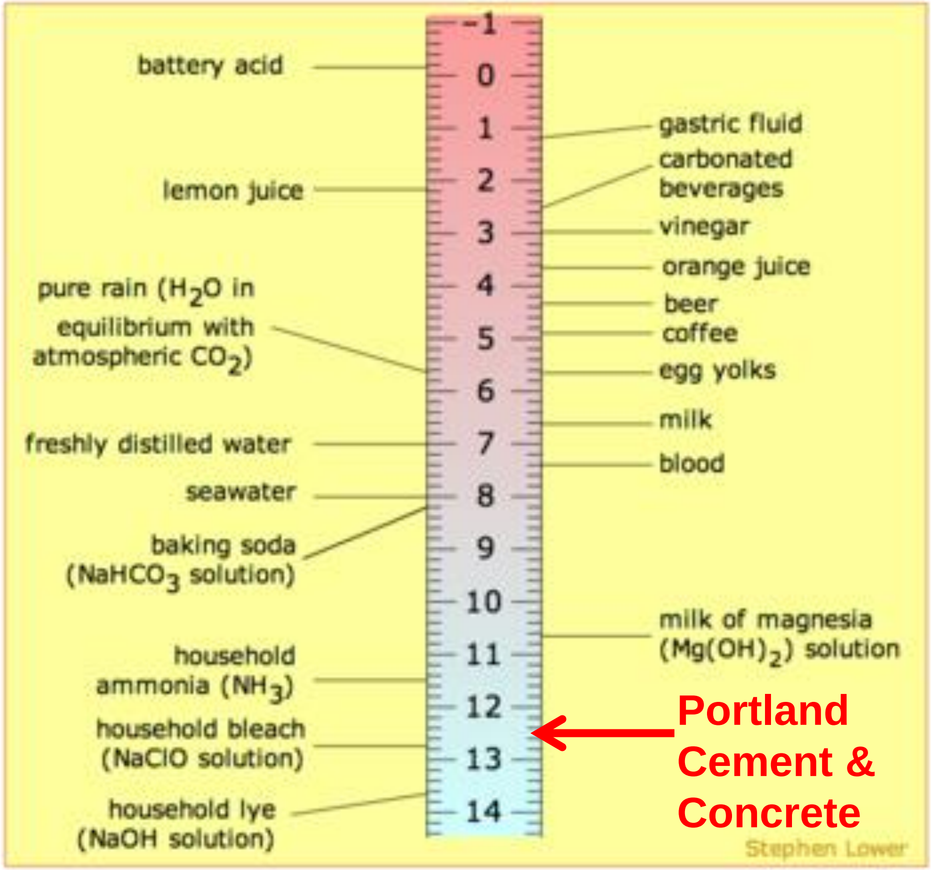
Cement and SCM

American Concrete Pipe Association

Safety First!

- Always wear proper personal protective equipment (PPE) when working with cement and concrete
  - Gloves
    - Cover all exposed skin that may come in contact with the cement or concrete
  - Eye protection
  - Respirator
  - Hearing protection
  - Safety shoes



Early Cement Works

Aspdin's early cement was nothing more than hydraulic lime, but in 1824 his patent gave him the use of the term *Portland* cement

Joseph Aspdin 1824

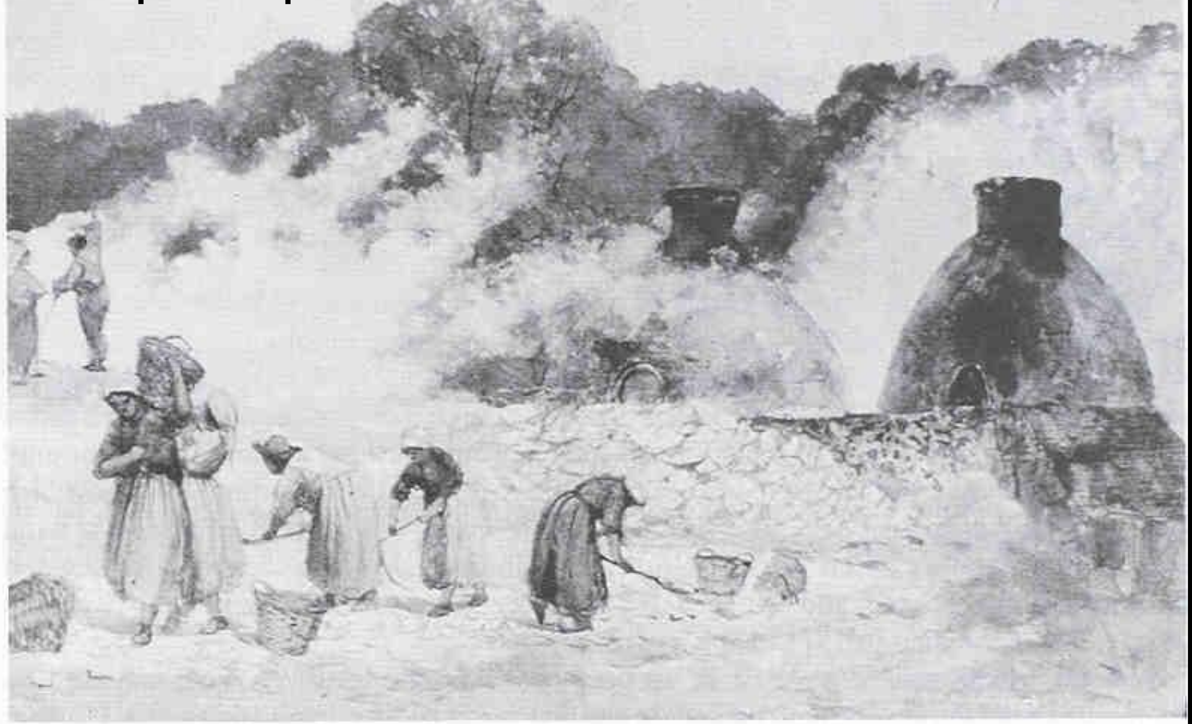


Fig. 1.3 Joseph Aspdin's first cement works at Kirkgate, Wakefield (*ca* 1828); proto-Portland cement was manufactured at this plant.

Lea's Chemistry of Cement

1885 *England*

Frederick Ransome patented a rotary kiln (18 inch X 15 ft)

U.S. Department of the Interior, National Park Service, Edison National Historic Site

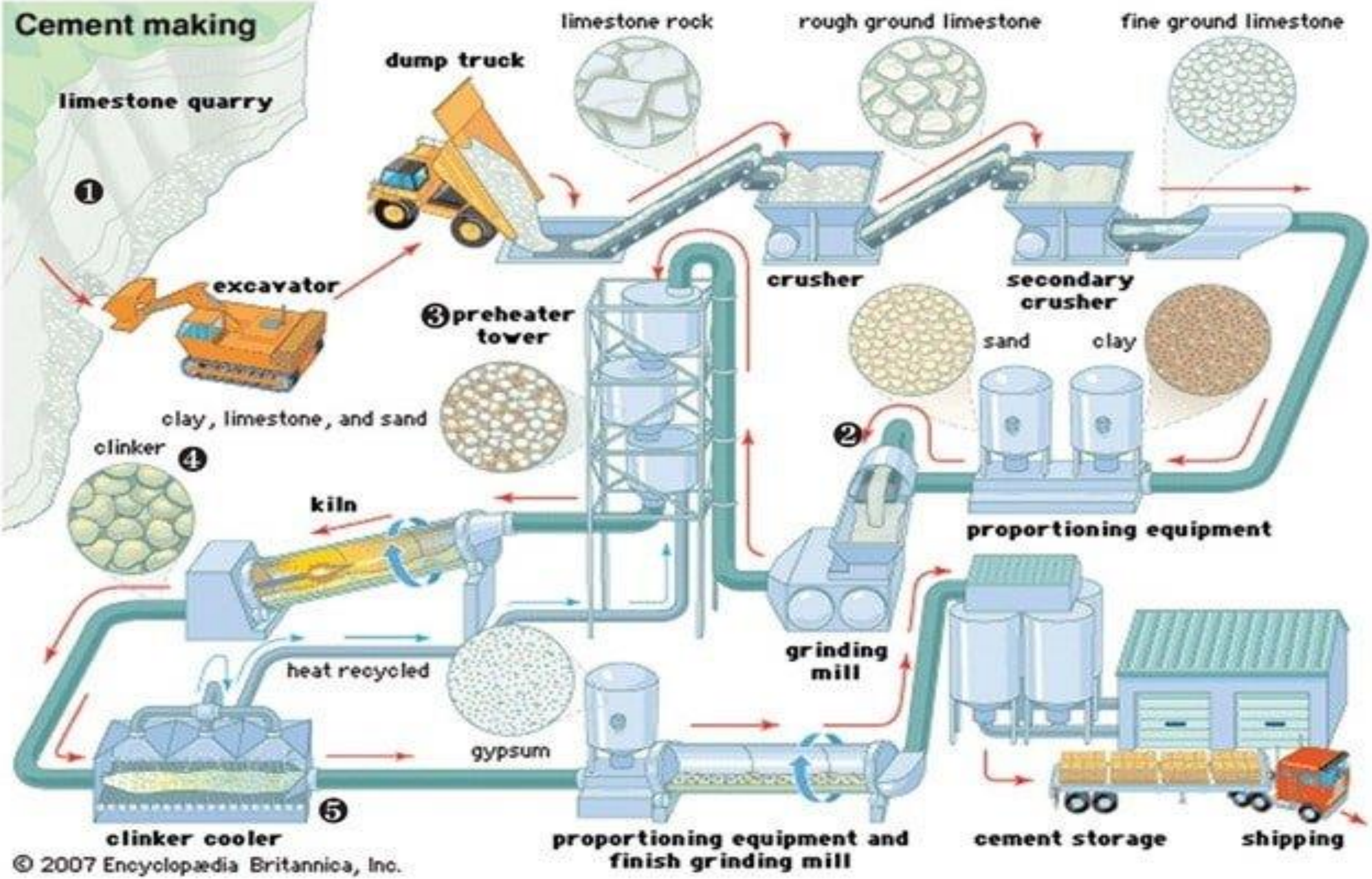
1900 - Thomas Edison takes advantage of the horizontal rotary kiln. Cement manufacturing changed from a batch process to a continuous process

Portland Cement - Definition

- Simple Definition

  The gray powder that reacts with water to create a glue-like material that bonds aggregates together to form concrete

- Hydraulic Cement


Cement making
limestone quarry
dump truck
limestone rock
rough ground limestone
fine ground limestone
excavator
crusher
secondary crusher
❸preheater tower
sand
clay
clay, limestone, and sand
clinker ❹
❷
kiln
proportioning equipment
heat recycled
grinding mill
gypsum
❺
clinker cooler
proportioning equipment and finish grinding mill
cement storage
shipping
❶
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Raw Material Components

Calcium	Silica	Aluminum	Iron

Limestone

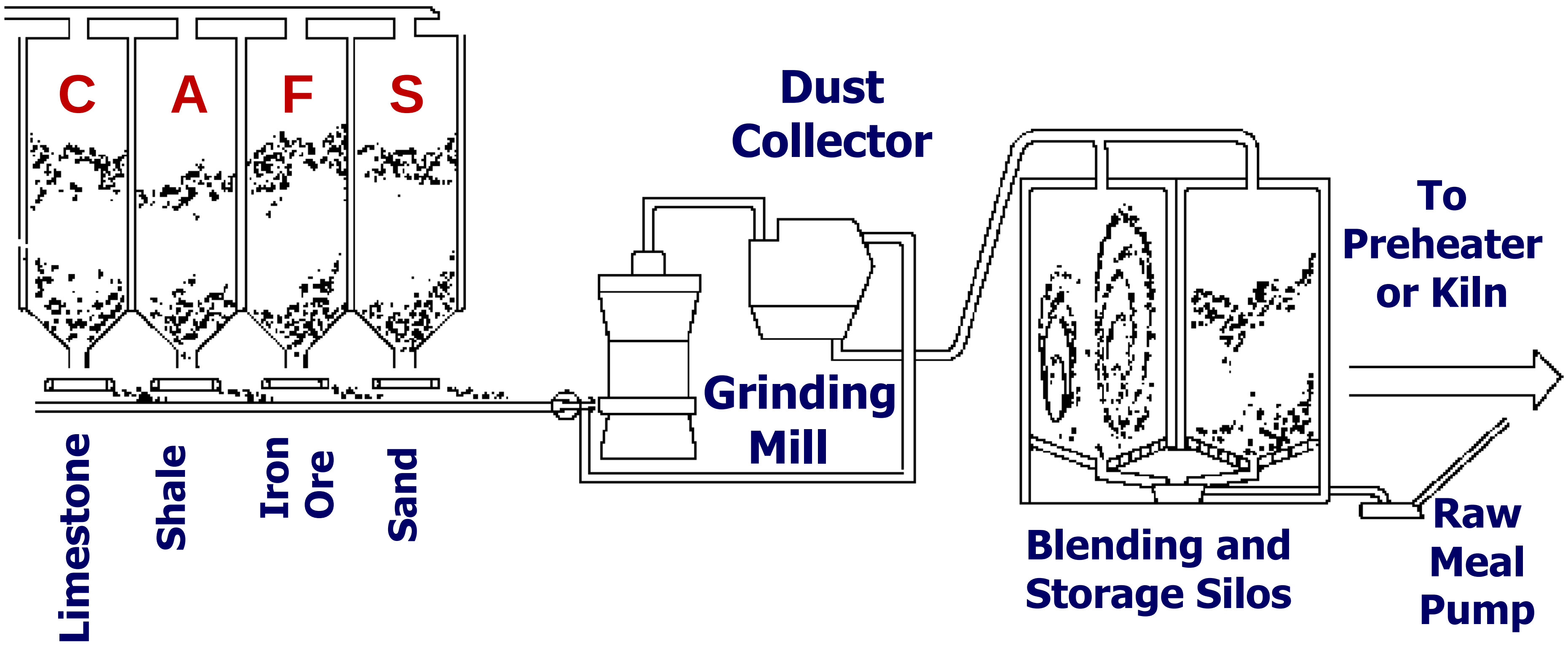
Silica Sand

Clay

Shale

Raw Material Mining & Processing

Raw Material Proportioning and Blending



Raw materials are homogenized by crushing, grinding and blending so that approximately 80% of the raw material pass a No.200 sieve

Two Types of Cement Kilns

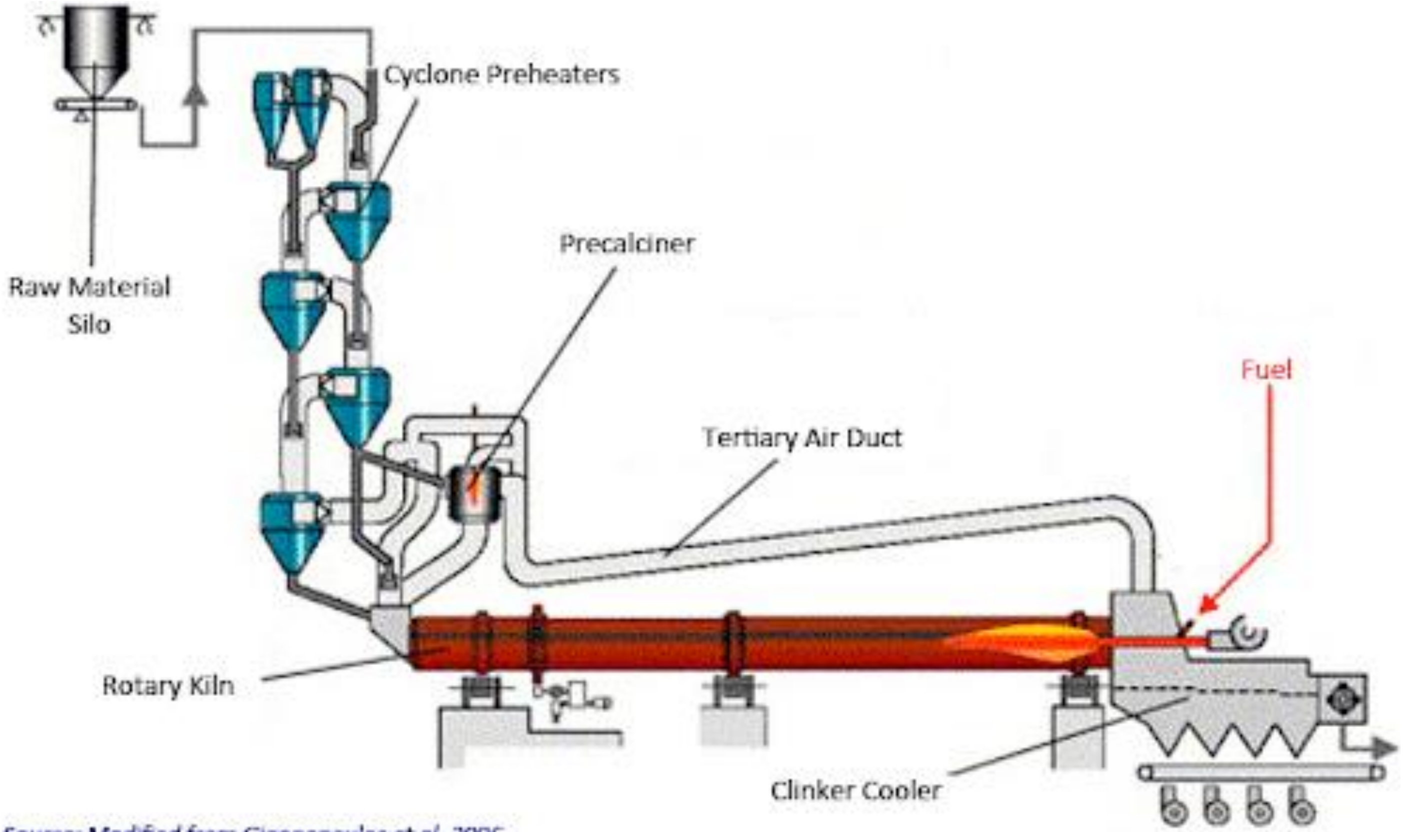
Wet Process

- Kiln Mix is a Slurry (30%-40% water)
  - Advantages
    - more uniform
    - raw material may already contain moisture
  - Disadvantage
    - higher energy use

Dry Process

- Kiln Mix is a Dry Powder
  - Advantages
    - preheating done outside the kiln
    - efficiency
    - shorter kiln length
  - Disadvantage
    - alkalies, sulfur, chlorides
    - tall, sophisticated

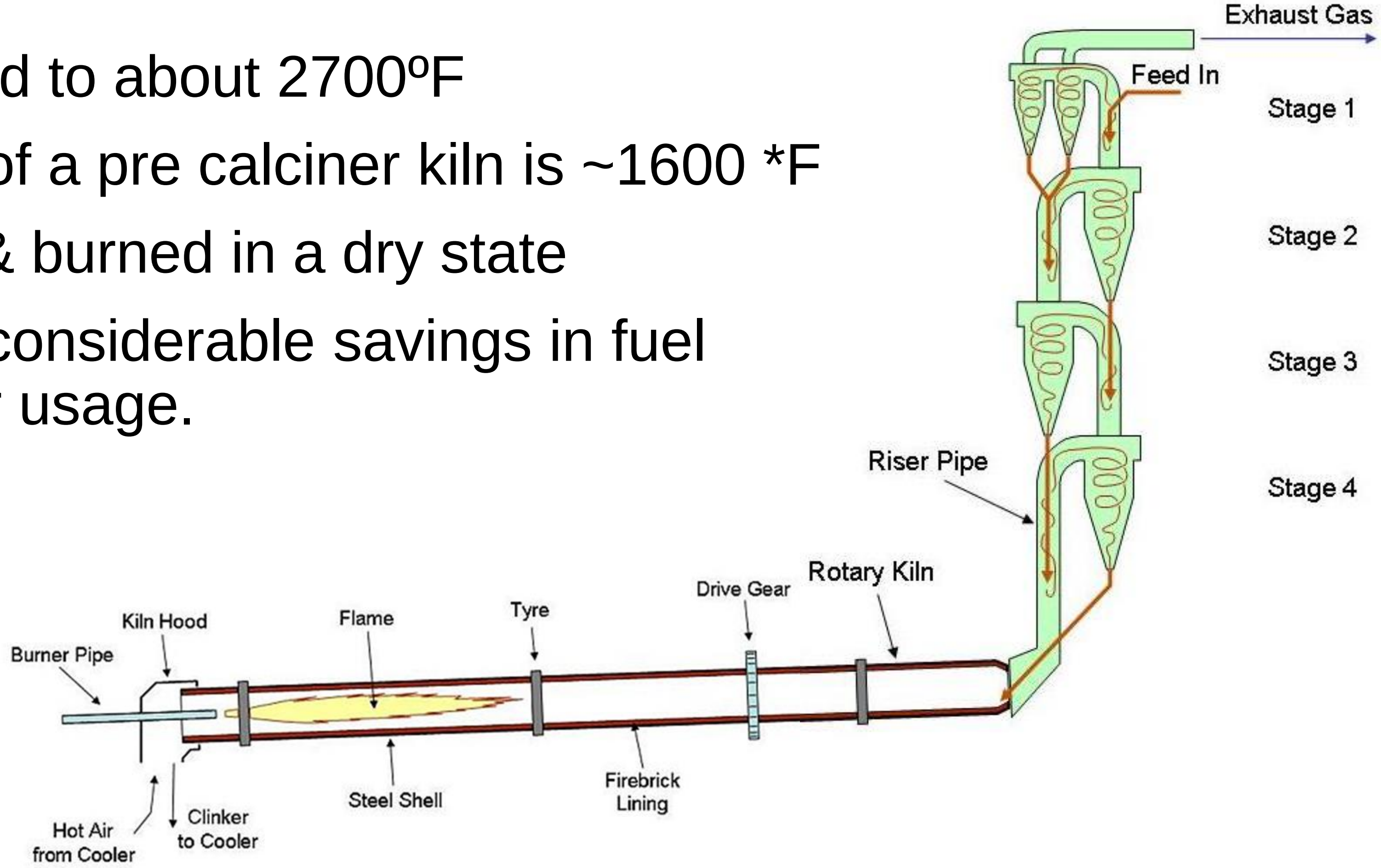
Dry Process Kilns



Source: Modified from Giannopoulos et al, 2006

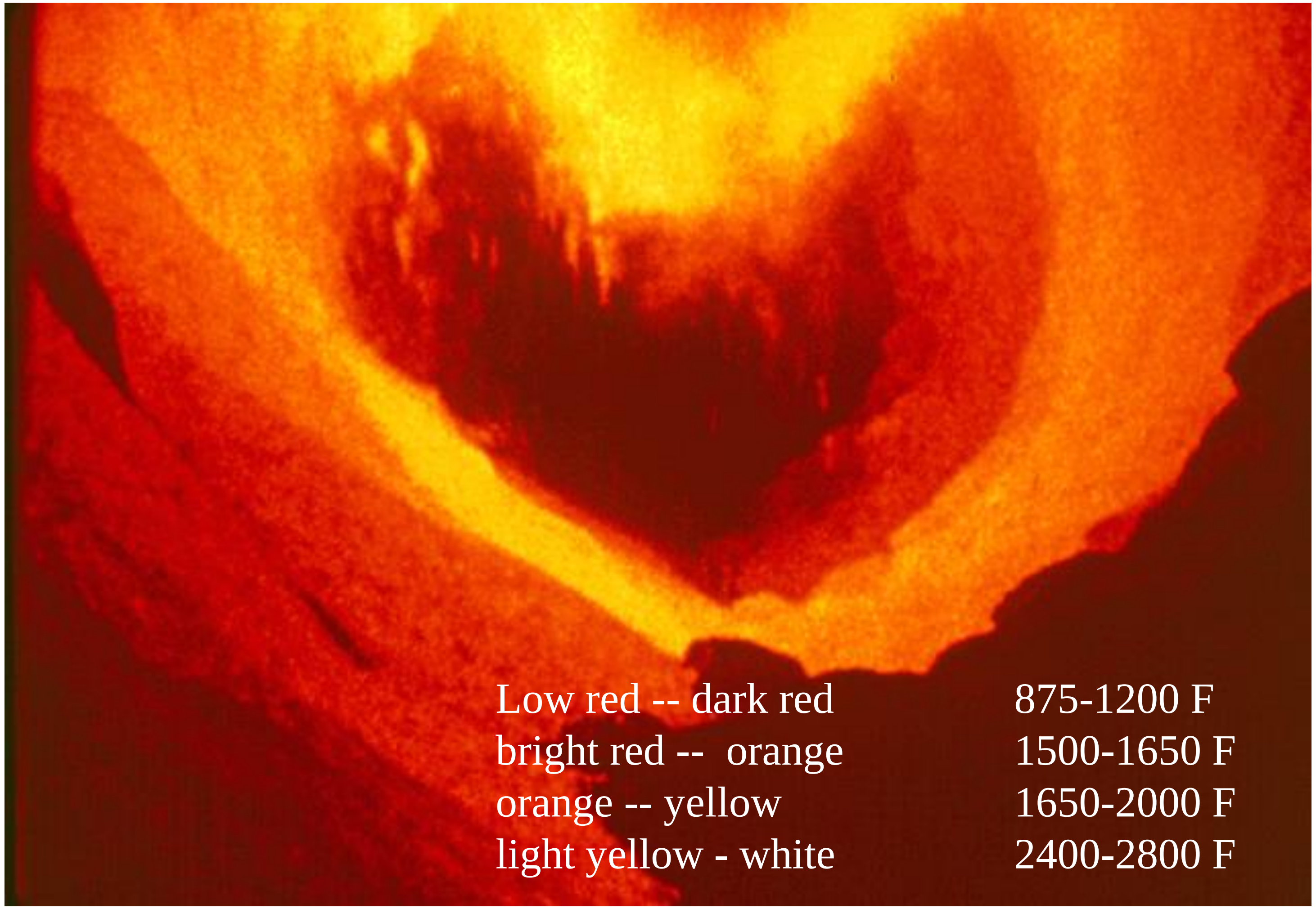
Dry Process Kilns

- Cement kilns are heated to about 2700ºF
- Final pre heater stage of a pre calciner kiln is ~1600 *F
- Mixture is fed into kiln & burned in a dry state
- This process provides considerable savings in fuel consumption and water usage.



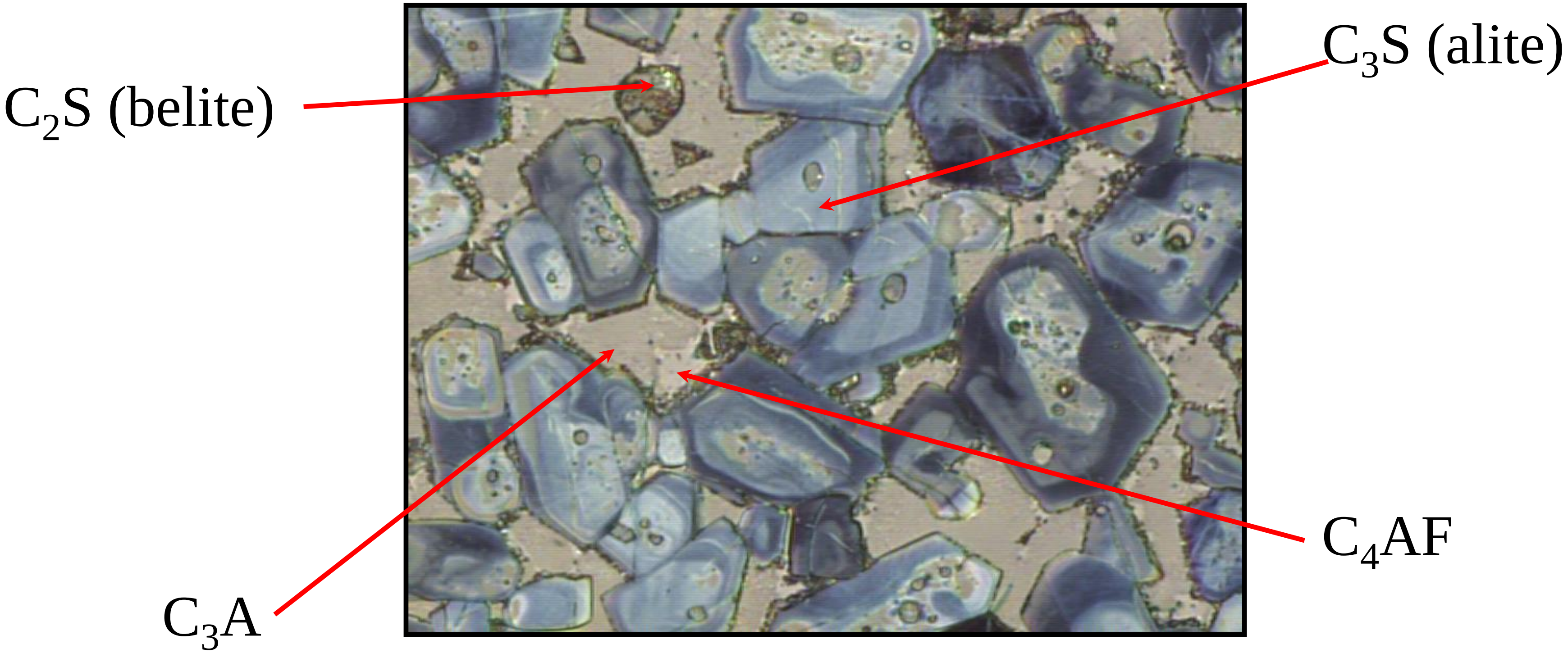
The Kiln

Heat Zones Inside the Kiln



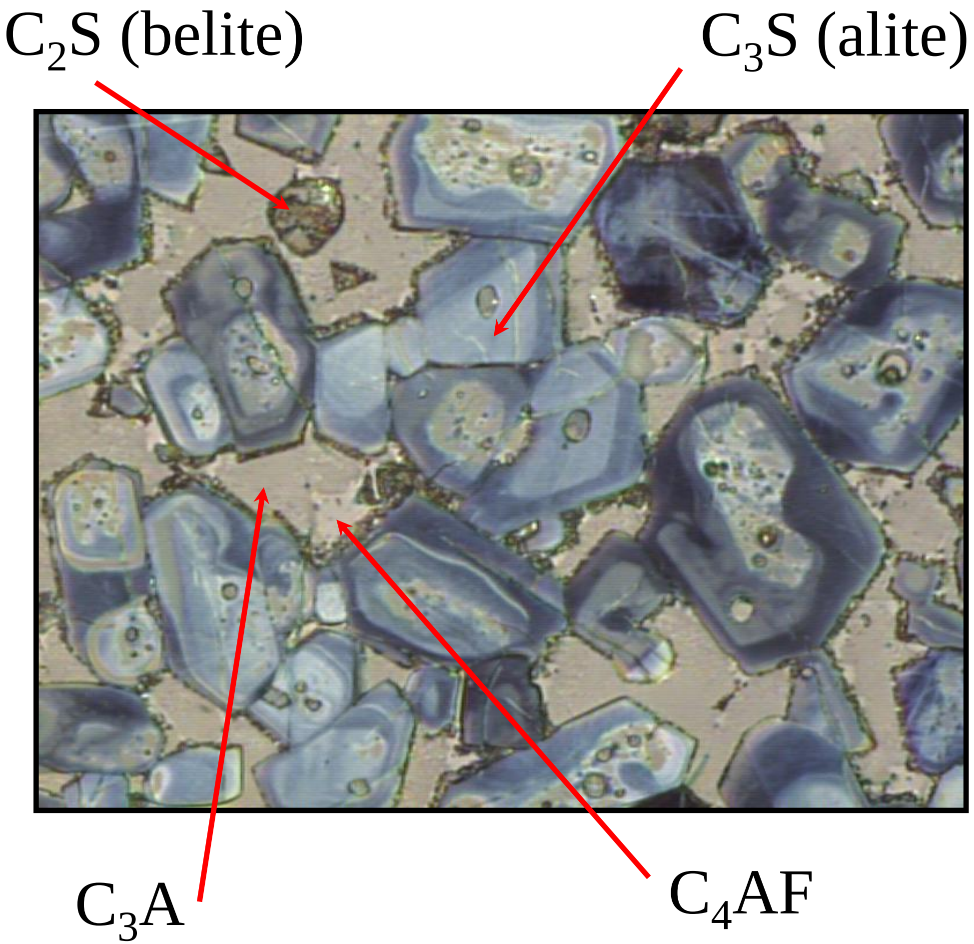
Clinker

Clinker (Cement) Compounds

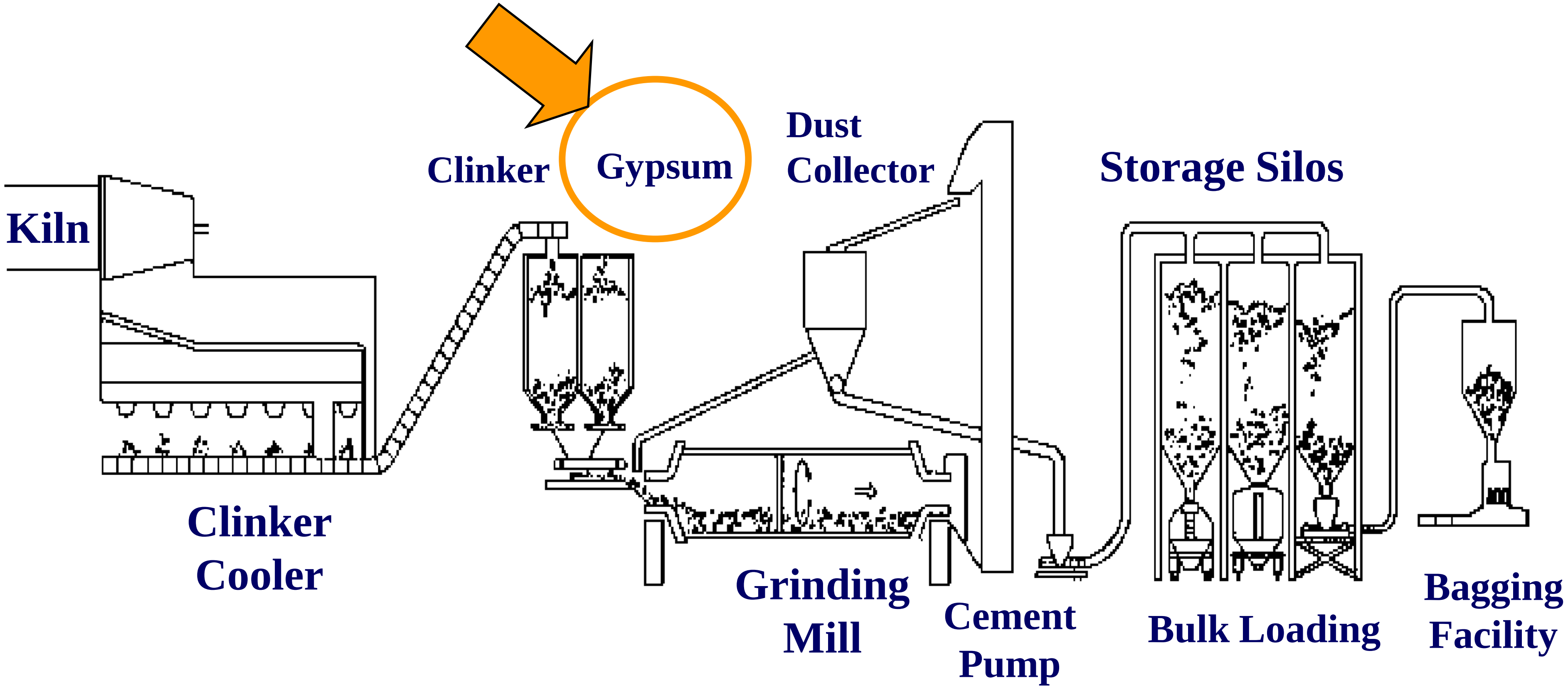


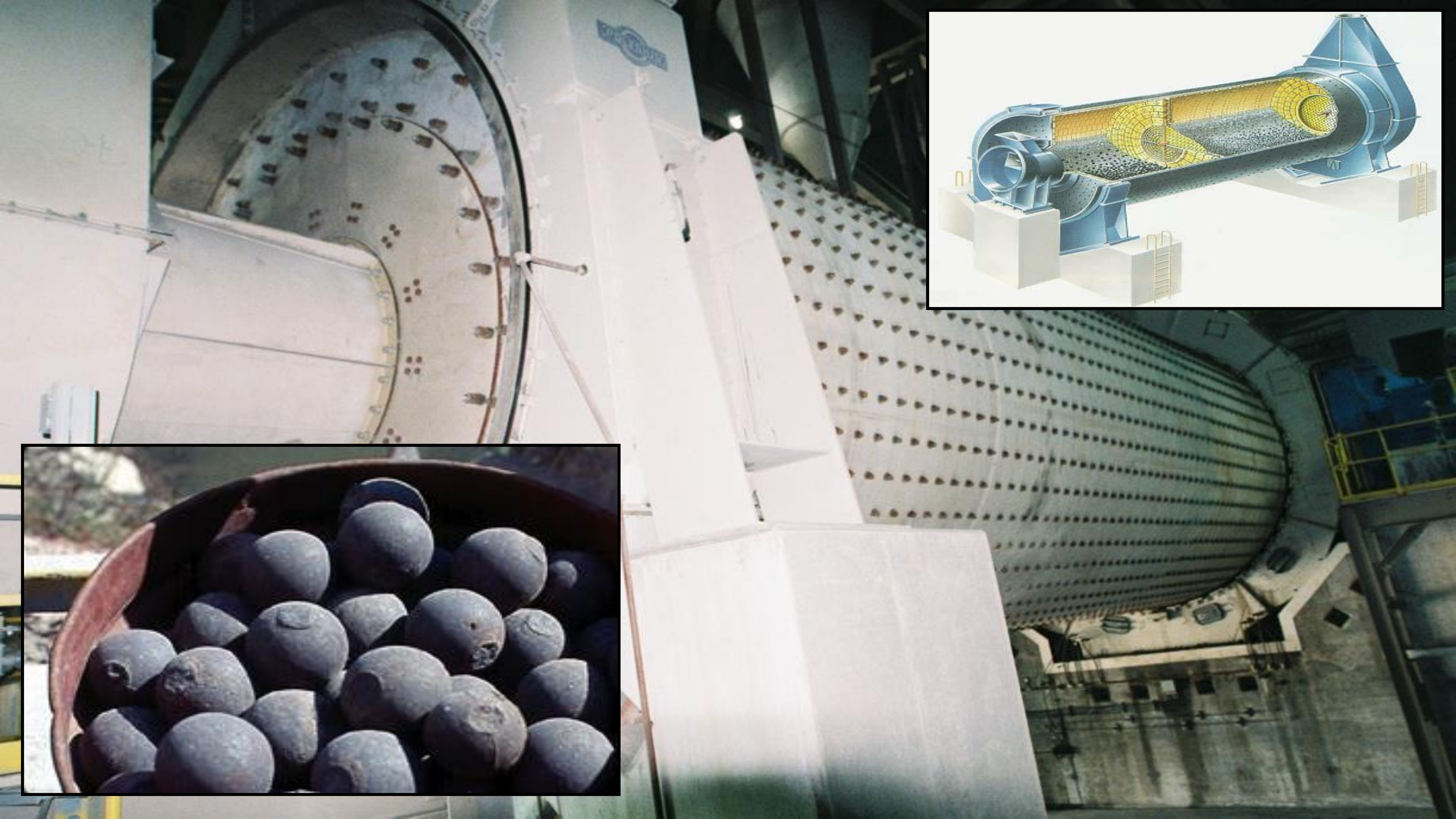
Clinker (Cement) Compounds

- Alite - C_3S (Tricalcium Silicate)
  - Lots of Heat Production and Early Age Strength
  - Controls Initial and Final Setting
- Belite - C_2S (Dicalcium Silicate)
  - Later Age Strength and Less Heat Production
- Aluminate - C_3A (Tricalcium Aluminate)
  - Lots of Heat Production
  - Contributes to very early Age Strength
  - Controls Sulfate Attack Resistance
- Ferrite - C_4AF (Tetracalcium Aluminoferrite)
  - Some Heat Generation but Contributes Little Strength
  - Responsible for Grey Color
  - Lowers clinkering temperature



Turning Clinker into Cement



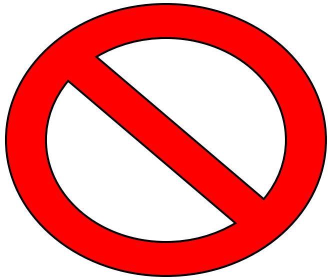


THE RECIPE

E.ORG

Cement Types

- Type I – General Use Cement
- Type II – Moderate Sulfide Resistance
- Type III – High Early Strength
- Type IV – Low Heat of Hydration
  - (No longer available)
- Type V – High Sulfide Resistance



No Type I/II

Type of portland cement	Potential Compound Composition,%				Blaine fineness m^2/kg
	C_3S	C_2S	C_3A	C_4AF	
I	54	18	10	8	369
II	55	19	6(max8)	11	377
III	55	17	9(max15)	8	548
IV	42	32	4	15	340
V	54	22	4(max5)	13	373
White	63	18	10	1	482

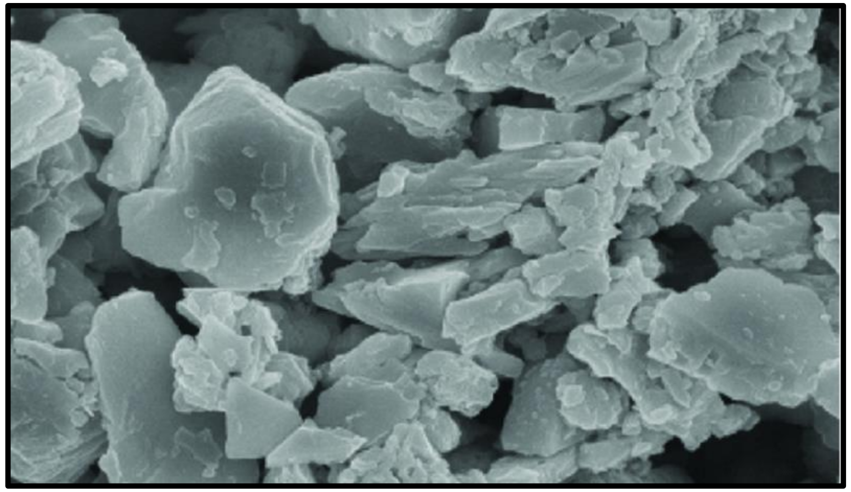
NO LONGER AVAILABLE

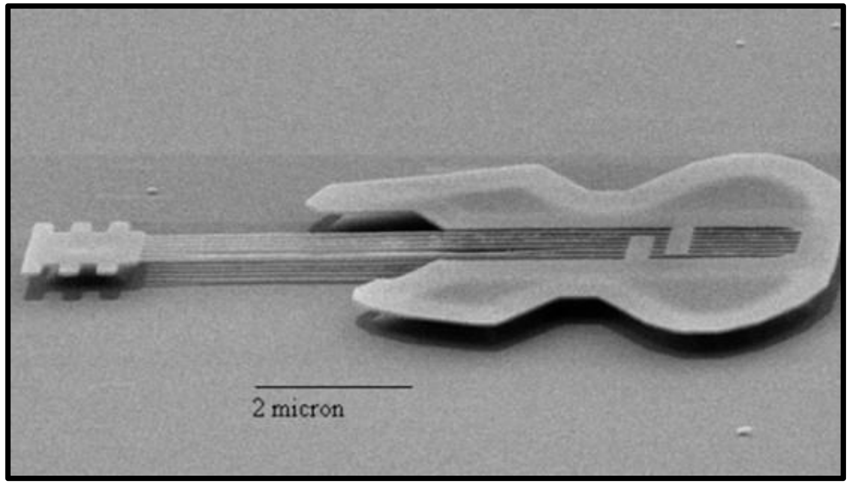
Cement Characteristics

- Specific Gravity: 3.15
- Amount Passing #325 Sieve (45 micron): ~95%
- Surface Area (Blaine):

  390-410 m^2/kg
- Median Particle Size:

  10 microns





Cement Standards

Hydraulic Cement

- ASTM C150 “Portland Cement”
- ASTM C595 “Blended Cement”
- ASTM C1157 “Performance Cement”

No AASHTO equal for C1157

AASHTO
American Association of State Highway & Transportation Officials
M85 / M240

AASHTO & ASTM are equal or similar specifications

State cement Requirements
CalTrans, Section 90-1.02B (2) (2010)

Material Certification Report

Material Certification Report

Material: Portland Cement
Type: I-II

Test Period: 01-Dec-2012
To: 31-Dec-2012

Certification

This cement meets the specifications of ASTM C150 for Type I-II cement, and complies with AASHTO M85 specifications for Type I-II cement.

General Information

Supplier:
Source Location:
Address:
Telephone:
Contact:
Date Issued: 15-Jan-2013

The following information is based on average test data during the test period.
The data is typical of cement shipped by ; individual shipments may vary.

Tests Data on ASTM Standard Requirements

Chemical

Item	Limit[A]	Result
SiO_2 (%)	-	19.7
Al_2O_3 (%)	6.0 max	4.6
Fe_2O_3 (%)	6.0 max	3.2
CaO (%)	-	63.9
MgO (%)	6.0 max	2.9
SO_3 (%)	3.0 max[B]	3.4
Loss on Ignition (%)	3.0 max	2.5
Insoluble Residue (%)	0.75 max	0.45
CO_2 (%)	-	1.2
Limestone (%)	5.0 max	3.1
$CaCO_3$ in Limestone (%)	70 min	89
Inorganic Processing Addition (%)	5.0 max	0.0
Potential Phase Compositions[C]:		
C_3S (%)	-	60
C_2S (%)	-	8
C_3A (%)	8 max	7
C_4AF (%)	-	9
$C_3S + 4.75C_3A$ (%)	-	91.3

Physical

Item	Limit[A]	Result
Air Content (%)	12 max	7
Blaine Fineness (m^2/kg)	260 min	375
Autoclave Expansion (%) (C151)	0.80 max	0.00
Compressive Strength MPa (psi):		
3 days	12.0 (1740) min	28.0 (4070)
7 days	19.0 (2760) min	34.9 (5060)
Initial Vicat (minutes)	45-375	89
Mortar Bar Expansion (%) (C1038)	-	0.008

Tests Data on ASTM Optional Requirements

Chemical

Item	Limit[A]	Result
Equivalent Alkalies (%)	0.60 max	0.58

Physical

Item	Limit[A]	Result
False Set (%)	50 min	87

Notes

[A] Dashes in the limit / result columns mean Not Applicable.
[B] It is permissible to exceed the specification limit provided that ASTM C1038 Mortar Bar Expansion does not exceed 0.020 % at 14 days.
[C] Adjusted per Annex A1.6 of ASTM C150 and AASHTO M85.
[D] Test result represents most recent value and is provided for information only. Analysis of Heat of Hydration has been carried out by CTLGroup, Skokie, IL.
Equavalent Alkalies (%) Minimum = 0.56, Maximum = 0.59
This data may have been reported on previous mill certificates.

Additional Data

Inorganic Processing Addition Data

Item	Result[A]
Type	-
Amount (%)	-
SiO_2 (%)	-
Al_2O_3 (%)	-
Fe_2O3 (%)	-
CaO (%)	-
SO_3 (%)	-

Base Cement Phase Composition

Item	Result
C_3S (%)	62
C_2S (%)	9
C_3A (%)	7
C_4AF (%)	10

Cement Hydration

$C_3S + C_2S + C_3A + H_2O$

(CSH)

(CAH)

Glue

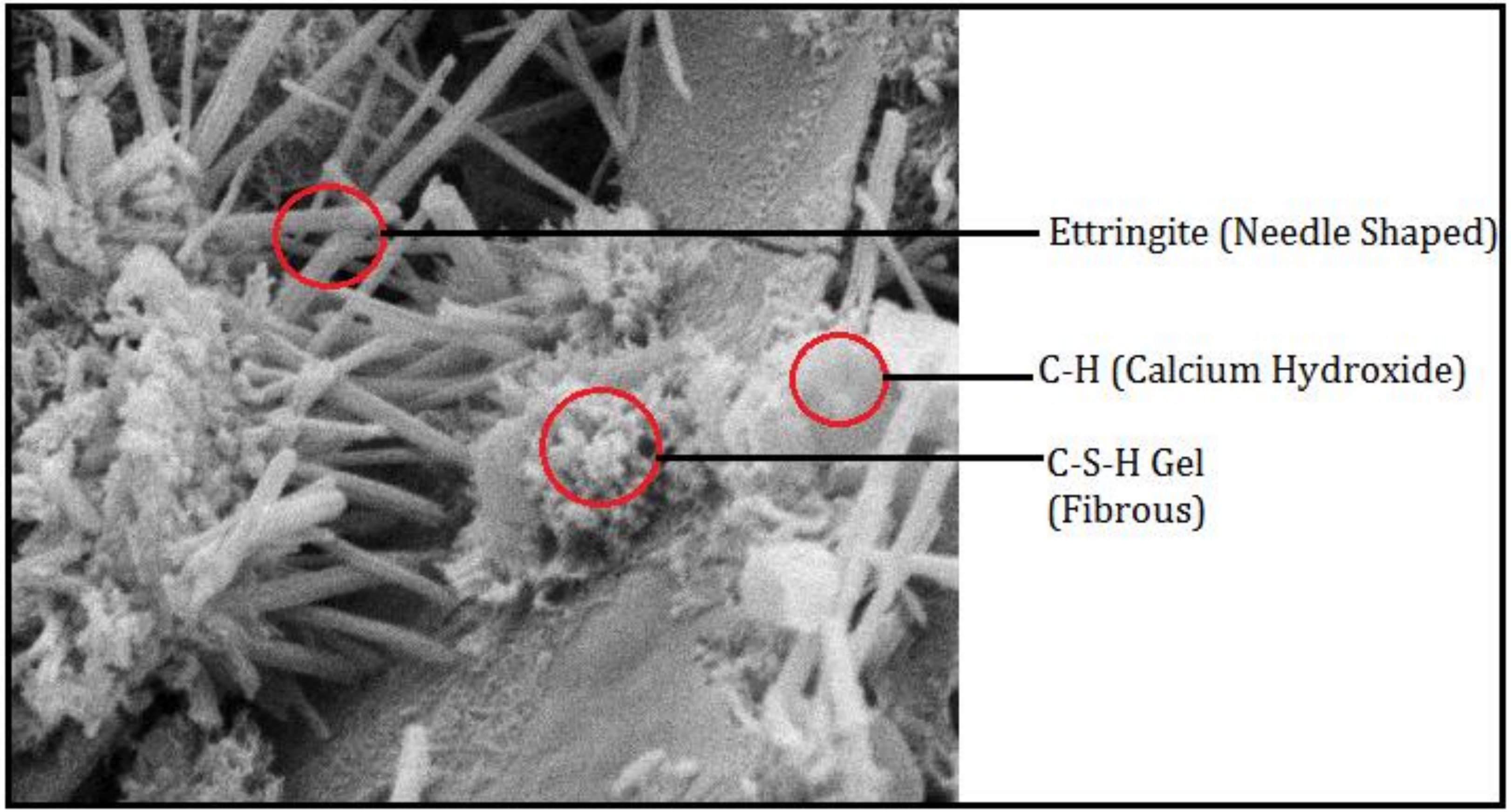
CS Hydrates

+ CA Hydrates

+ $Ca(OH)_2$ (CH)

+ heat

CSH gel is the glue that holds concrete together



<u>Hydrated Cement Paste -</u> Depending on the time of hydration and the Portland cement composition, several crystalline pictures can be observed in hydrated cement paste. A typical one contains CSH, calcium hydroxide and ettringite as shown in this picture.

Primary cement reaction (fast):

C_3S (and C_2S) + **water** = **C-S-H gel**

Byproduct from hydration = **Calcium Hydroxide**

Pozzolanic reaction (slow):

Fly Ash + Calcium Hydroxide = **C-S-H gel**

Supplementary Cementitious Materials (SCMs)

From left to right:

- Fly ash (Class C)
- Metakaolin (calcined clay)
- Silica fume
- Fly ash (Class F)
- Slag Cement
- Calcined shale

What is a Supplementary Cementitious Material?

- **Supplementary Cementitious Material (SCM)** - a material that, when used in conjunction with Portland Cement or Blended Cement, contributes to the properties of the hardened concrete through hydraulic activity, pozzolanic activity, or both.

- **Hydraulic Cementitious Material** - a material that sets and hardens by a chemical reaction with water.

- **Pozzolanic Material** - a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

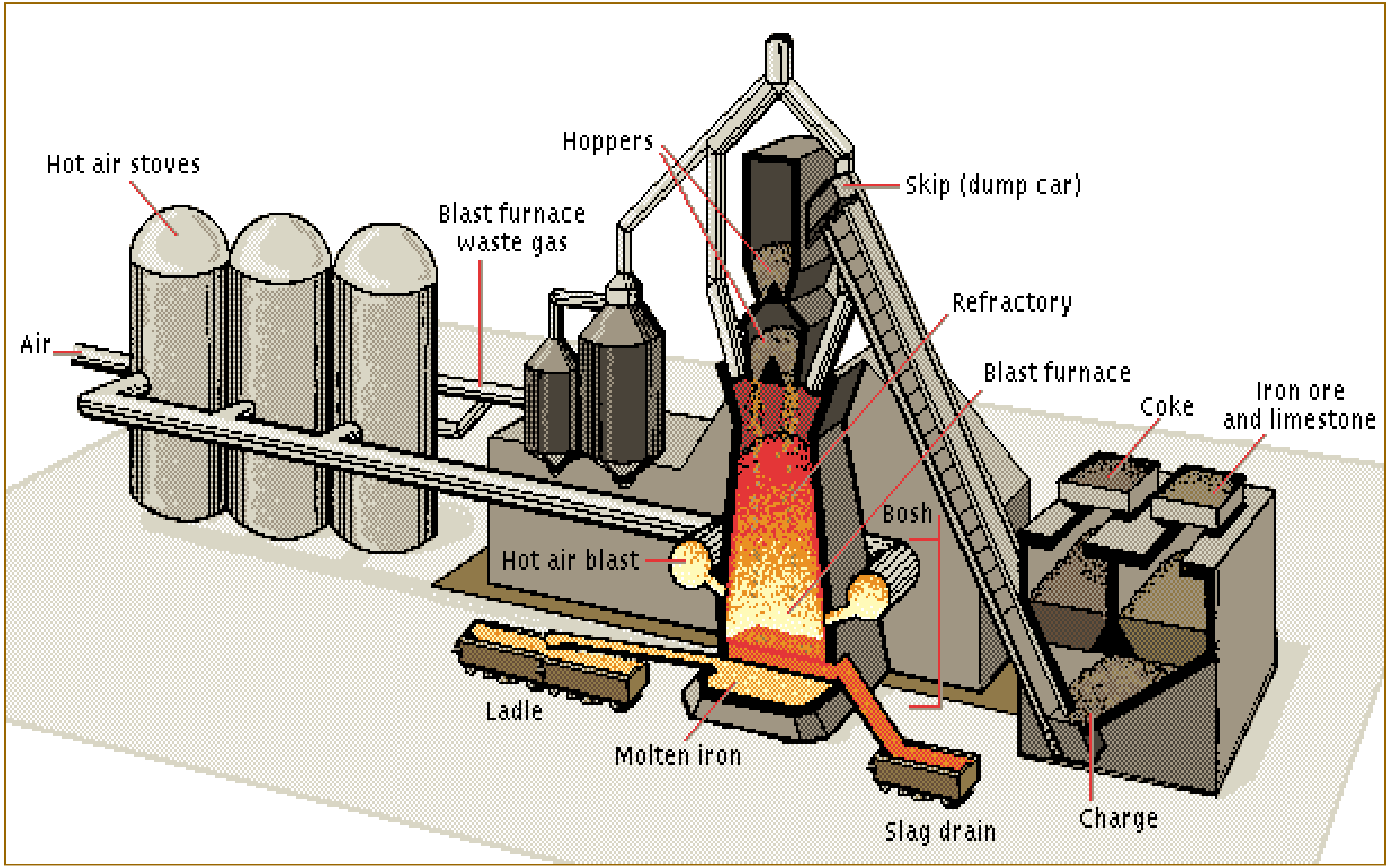
Slag Cement

Byproduct from the iron manufacturing process

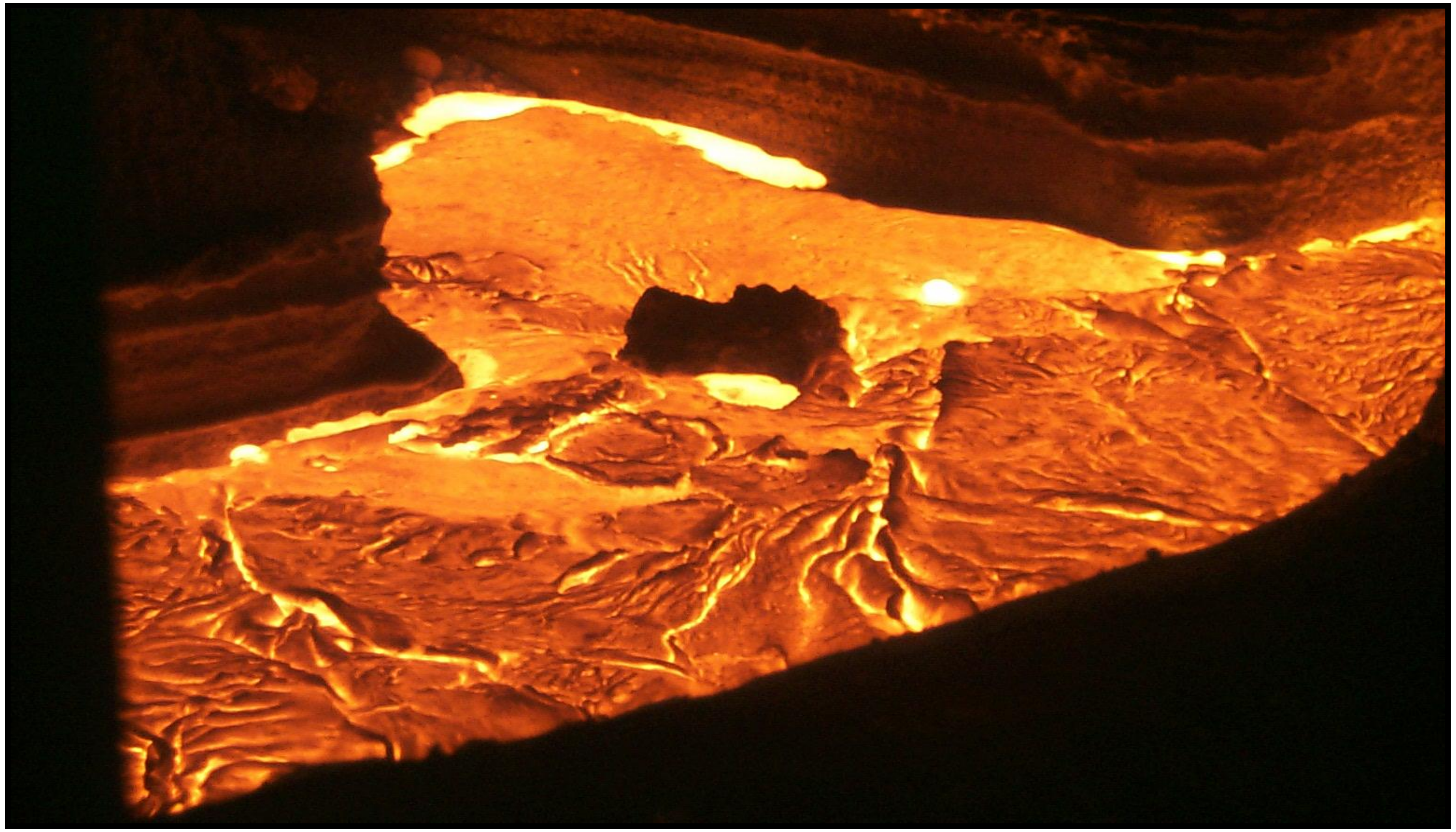
- **ASTM C 989** *Standard Specification for Slag Cement for Use in Concrete and Mortars* (classified by Strength Activity Index compared to a **reference** Portland Cement)
  - Grade 80 (SAI @ 28days = 75%)
  - Grade 100 (SAI @ 7days = 75% & 28days = 95%)
  - Grade 120 (SAI @ 7days = 95% & 28days = 115%)

Slag Cement is a hydraulic cement

Blast Furnace

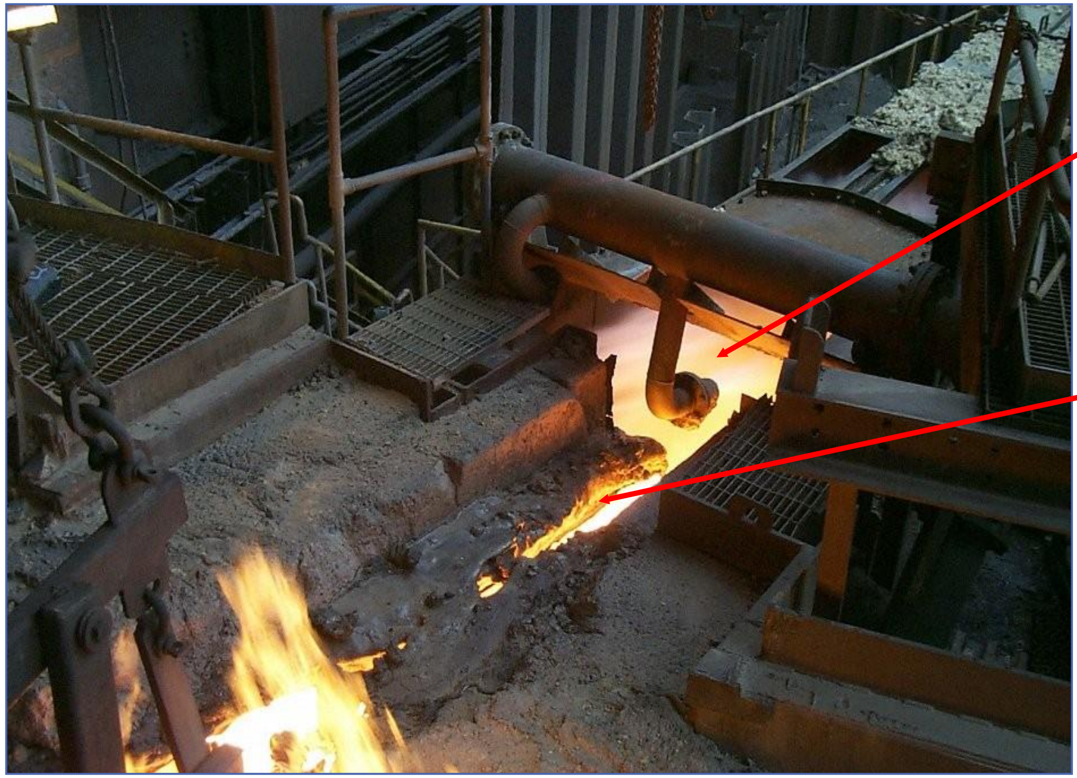


Molten Iron & Slag



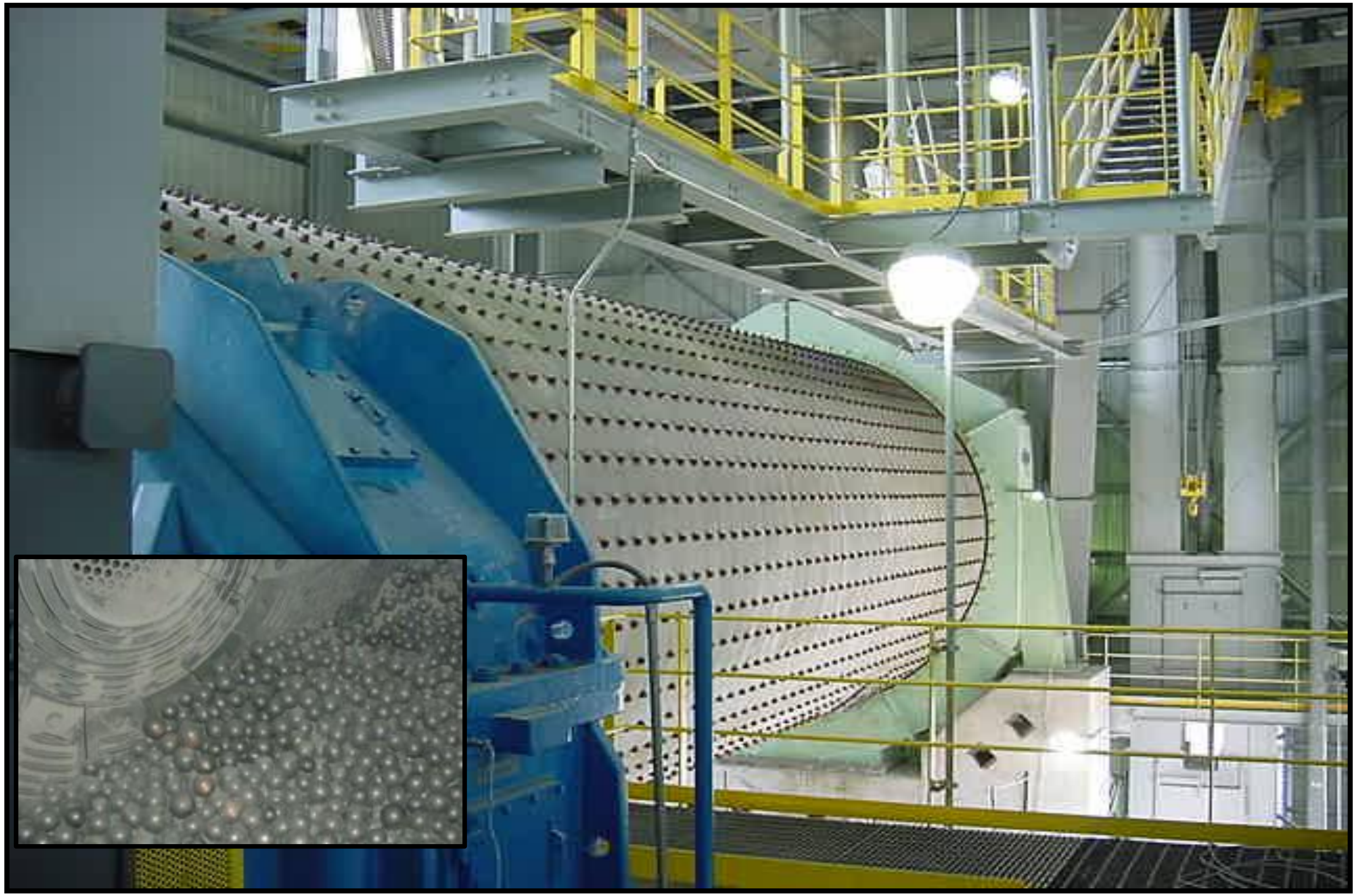
The slag is not as dense as the molten iron and floats on the top. It is separated by mechanical means and then granulated

Granulation



Rapid quenching with water at a ratio of 10:1 changes the hot slag to glassy, non-metallic silicates and aluminosilicates of calcium, known as granulated blast furnace slag

Grinding

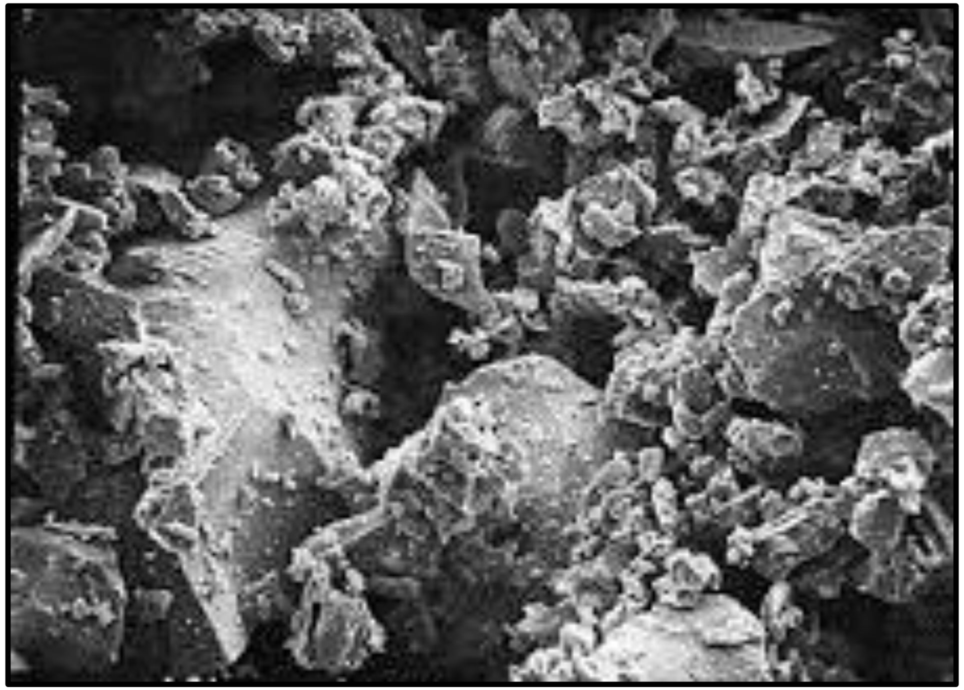


Slag Characteristics

- Specific Gravity: 2.6 - 2.9
- Amount Passing #325 Sieve (45 micron): ~95%
- Surface Area (Blaine):

  400 m^2/kg
- Median Particle Size:

  10 microns



Slag Cement

- Benefits for Hardened Concrete
  - Later age strength
  - Increased flexural strength
  - Lighter, brighter color
  - Reduced permeability and increased durability
  - Increased resistance to alkali silica reaction
  - Increased sulfate resistance (low alumina slag)

Cautions

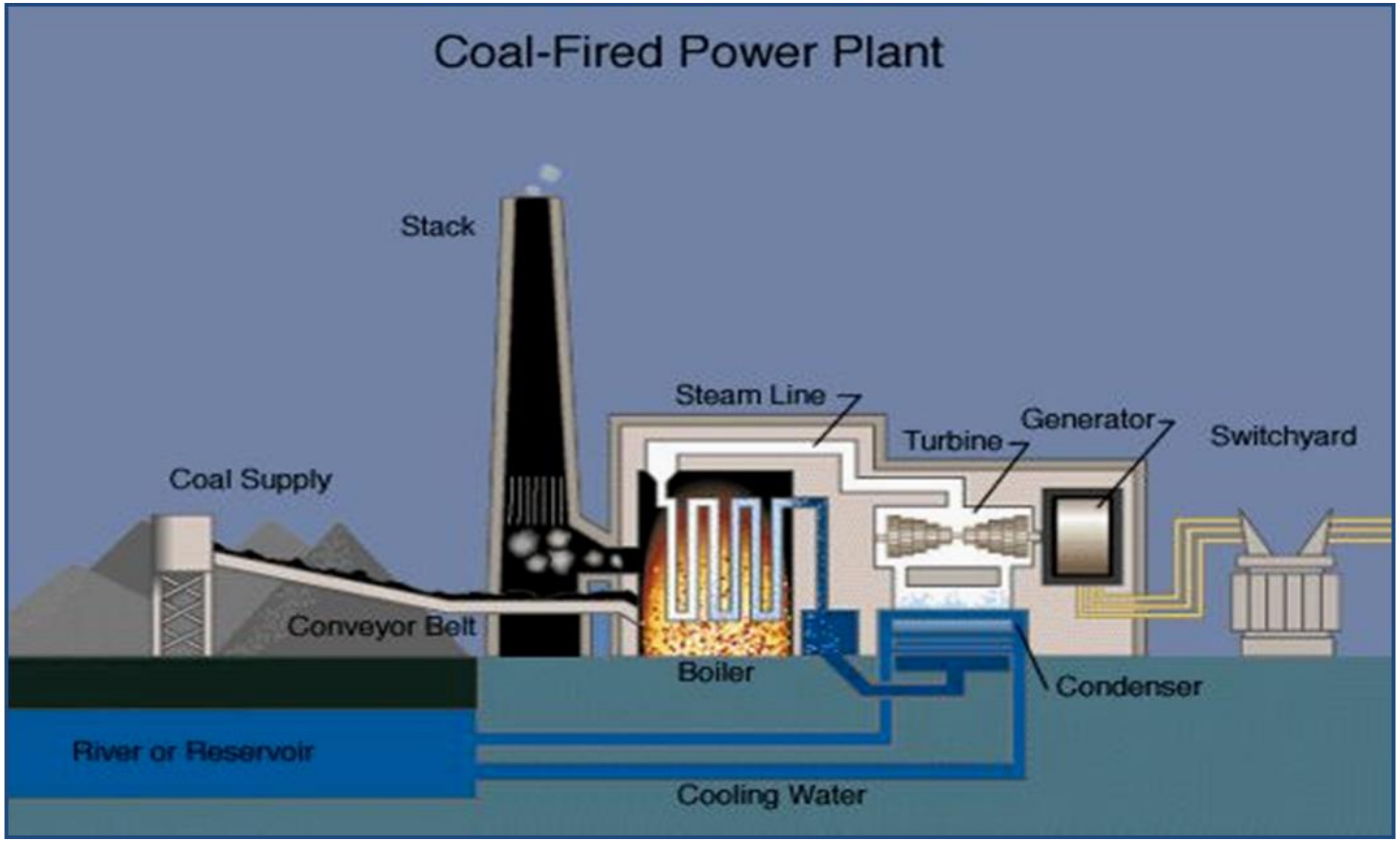
- As levels of unoxidized sulfide sulfur increase, a temporary greening of the hardened concrete may occur

Pozzolans (For example Fly Ash & Silica Fume)

- ASTM C618 Standard Definition
  - “pozzolan, *n.*
  - a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide to form compounds possessing cementitious properties”

Fly Ash Production

Coal/Source
↓
Coal Pulverizer
↓
Boiler
↓
Electrostatic Precipitation
↓
Fly Ash Silo
↓
Customers

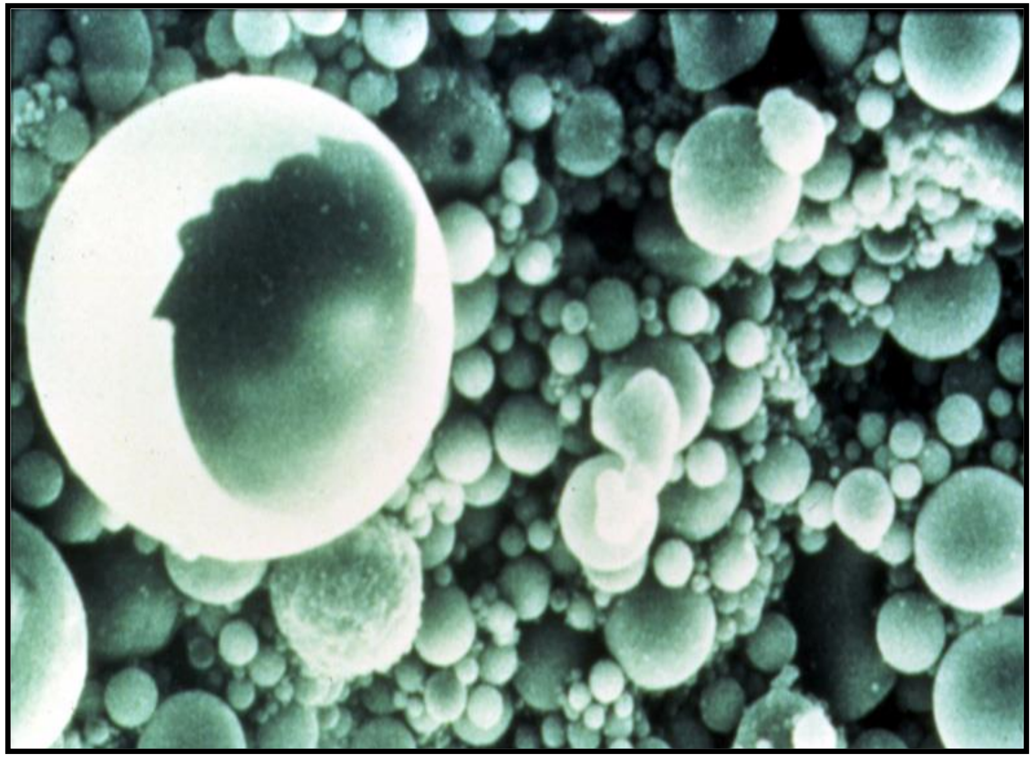


Fly Ash

- Class F
  - Produced from burning anthracite or bituminous coal
  - CaO content < 10%
  - Pozzolanic (no hydraulic properties, reacts to cement hydration byproducts only)
- Class C
  - Produced from burning of lignite or subbituminous coal
  - CaO content > 20%
  - Hydraulic and pozzolanic properties

Fly Ash Characteristics

- Specific Gravity: 2.1 – 2.9
- .Amount Passing #325 Sieve (45 micron): 85% - 98%
- Surface Area (Blaine): 420 m^2/kg
- .Median Particle Size:
  Class C = 5 microns
  Class F = 15 microns



Fly Ash

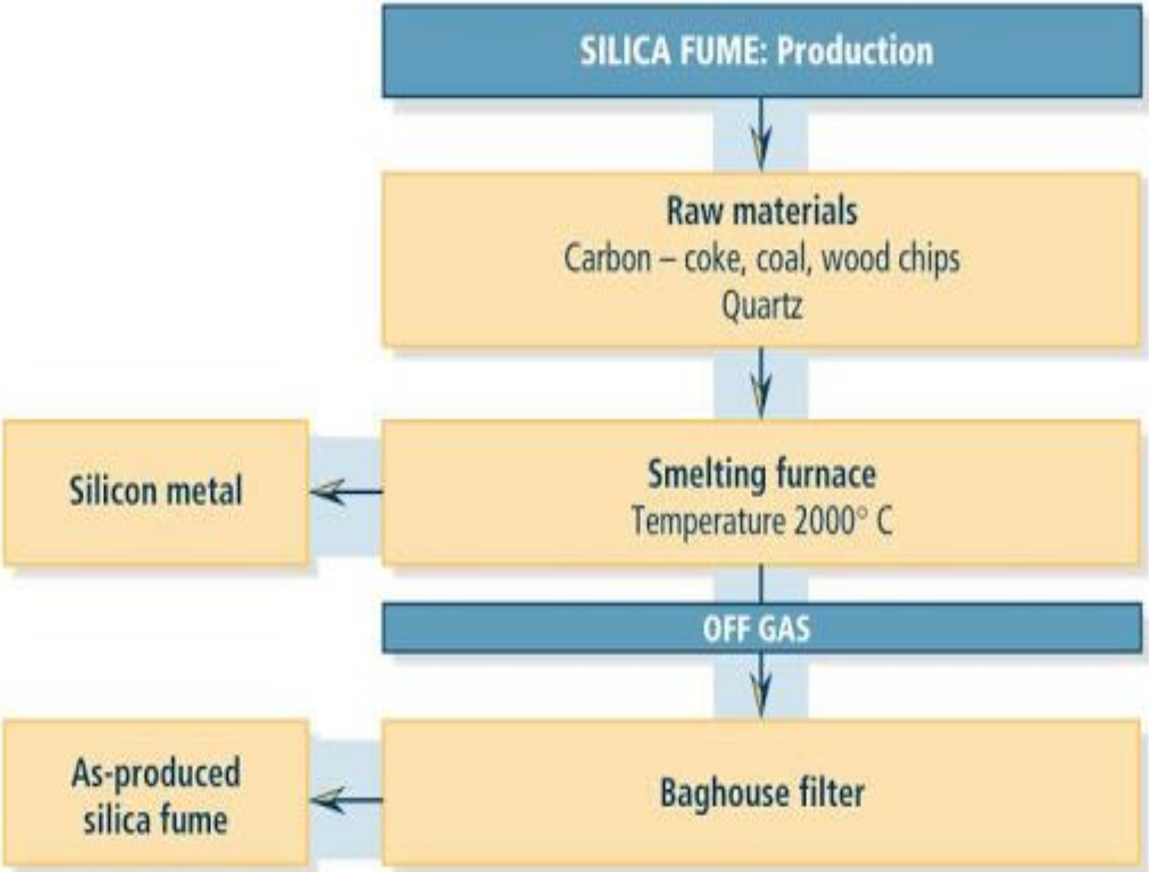
Benefits for Hardened Concrete

- Improve workability
- Lower mix cost
- Reduce heat
- Lower permeability
- Improve durability
- Mitigates ASR and DEF (Class F only)

Cautions

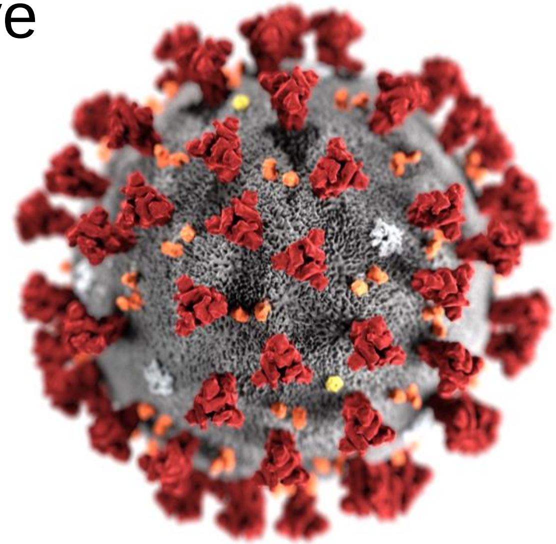
- Low early-age strength
- Increase set time
- Affects air entrainment (Class F)

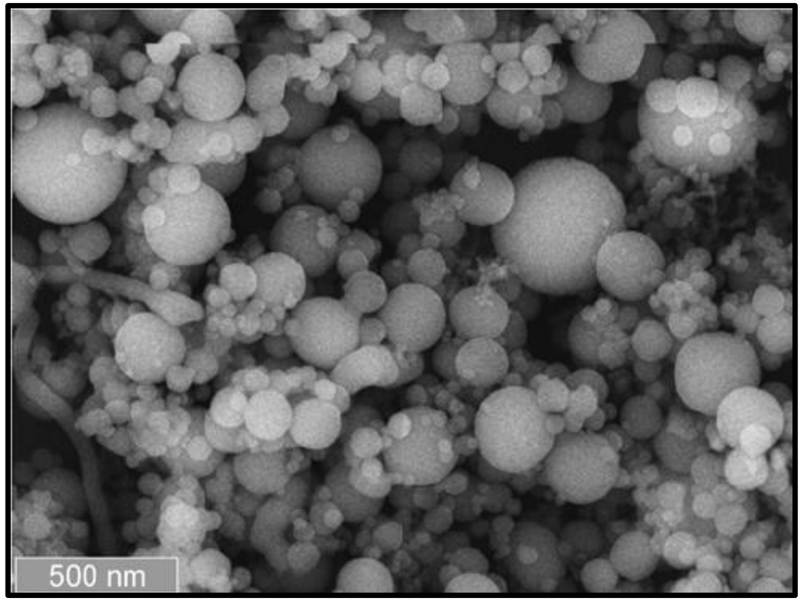
Silica Fume Production



Silica Fume Characteristics

- Specific Gravity: 2.2 – 2.3
- Amount Passing #325 Sieve (45 micron): 100%
- Surface Area (Blaine): 20,000 m^2/kg
- Median Particle Size: 0.15 microns





- Tobacco smoke has a surface area of 10,000 m^2/kg

Silica Fume Use

- First used in concrete in 1950’s. Modern usage started in the 1980s.
- Works on two mechanisms:
  - Purely pozzolanic because of the high silica content
  - Ultra fine filler material that fills the spaces between cement grains
- Very effective for very high strength / low permeability
- Typically used at 5-10% (by mass) replacement of cement
- Available in raw, densified, pelletized and slurry form

Silica Fume

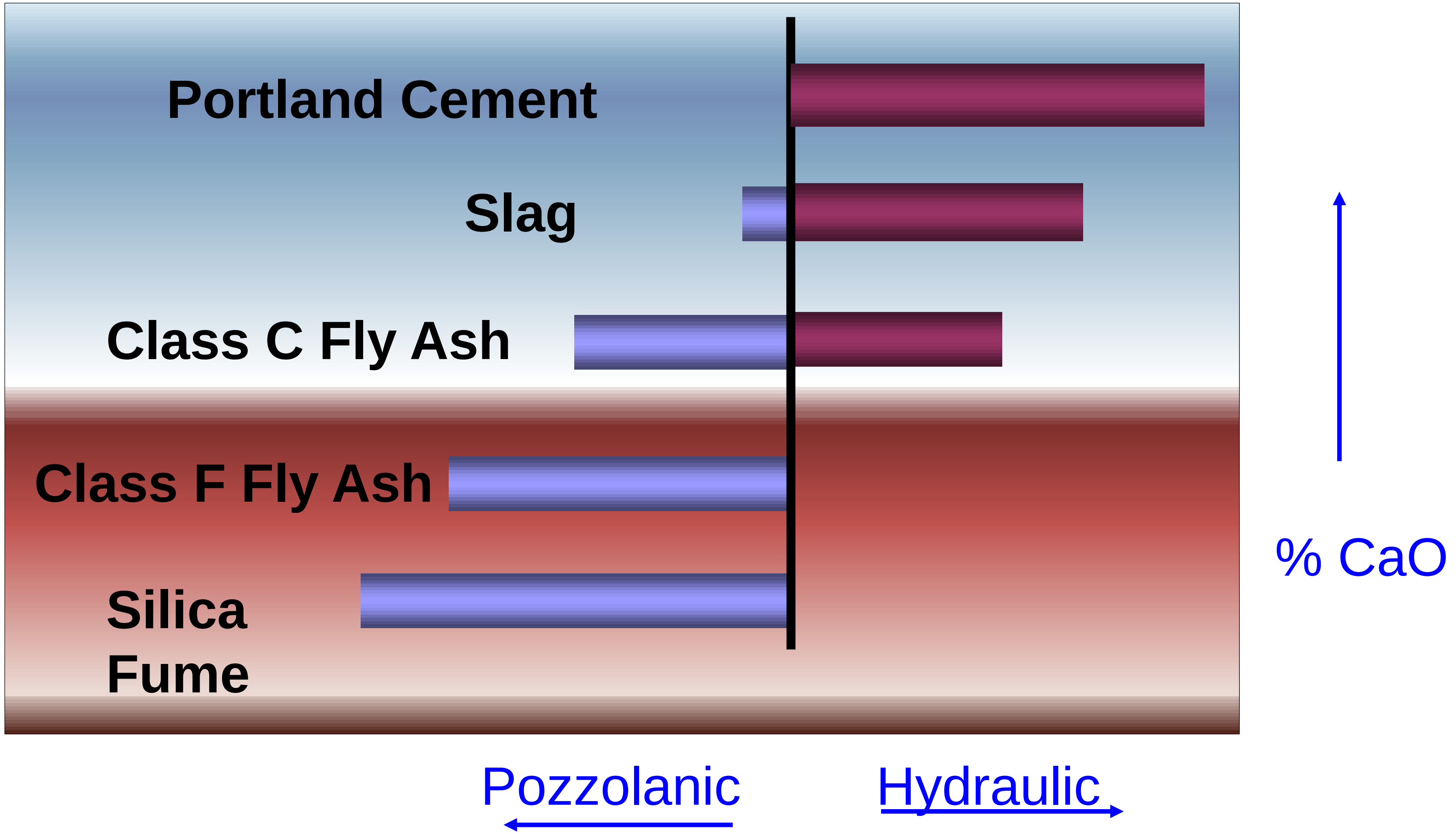
Benefits for Hardened Concrete

- Significant strength gain
- Reduces permeability
- Improves bonds strength to steel
- Reduces steel corrosion
- Improves freeze/thaw durability
- Excellent resistance to sulfate attack
- Significantly reduces Alkali-Silica reactivity

Cautions

- Concrete is more sticky
- Water demand of concrete will increase
- Affects Air Entrainment dosage
- Potential for plastic shrinkage cracking

General Reactivity Comparison



Conclusions

- Portland cement is a complex material that is manufactured from natural materials
- Pozzolans and Slags are by-products of manufacturing processes
- The use of SCM’s can benefit concrete by improving the desired engineering properties
- SCM’s also provides an environmental benefit


Thank You