9 Limestone and Crushed Rock

Crushed rock is one of the most accessible natural resources and a major basic raw material. It is used in construction, agriculture, and other industries using complex chemical and metallurgical processes. Despite the low value of its basic products, the crushed rock industry is a major contributor to and an indicator of the economic well being of the nation.

Forms Of Crushed Rock

About three-quarters of the crushed stone production is limestone and dolomite, followed by, in descending order of tonnage: granite, traprock, sandstone and quartzite, miscellaneous stone, marble, slate, calcareous marl, shell, volcanic cinder and scoria.

Limestone, one of the largest produced crushed rock, is a sedimentary rock composed mostly of the mineral calcite and comprising about 15 percent of the earth's sedimentary crust. This mineral is a basic building block of the construction industry and the chief material from which aggregate, cement, lime, and building stone are made. For the purposes of this report, limestone will be used as a sample for crushed rock.

One product of limestone mining is lime. A wide range of industries use lime for a myriad of uses. It is used in many of the products and materials Americans use every day, including paper, steel, sugar, plastics, paint, and many more. The largest single use of lime is in steel manufacturing, for which it serves as a flux for removing impurities (silica, phosphorus and sulfur) in refining steel. It is used both in traditional basic oxygen furnaces (BOF) and the newer electric arc furnaces, as well as in secondary refining. Lime for use in the steel industry--both high calcium and dolomitic--must meet exacting specifications for physical and chemical properties. Without this high-quality lime, U.S. steel production would be crippled. Lime is also essential to producing metals other than steel. It is used to beneficiate copper ore, to make alumina and magnesia for use in aluminum and magnesium manufacture, to extract uranium, and to recover gold and silver.

The second leading use of lime is for environmental applications, involving air, drinking water, wastewater, and solid wastes. Industrial, utility, and mining operations rely on lime to comply with a host of environmental regulations. Lime is used to treat industrial and mining wastewater, in which it adjusts the pH of acidic waste, removes phosphorus and nitrogen, and promotes clarification. A growing use of lime is in the treatment of stack gases from industrial facilities, power plants, medical waste incinerators, and hazardous waste incinerators. Lime absorbs and neutralizes sulfur oxides from these gases, helping to prevent acid rain, and also reduces emissions of hazardous air pollutants, including mercury. Lime is especially vital to municipalities in meeting their environmental and public health responsibilities at a reasonable cost. First, lime is widely used for potable water softening and to remove impurities (such as lead) from drinking water. Second, it is a cost-effective method for treating sewage sludge. Third, stack gases from municipal incinerators are treated with lime to remove sulfur dioxide, hydrogen chloride and other contaminants. These applications of lime are important in maintaining a clean environment.

In construction, lime's traditional use is in mortar and plaster, because of its superior plasticity, workability, and other qualities. Lime's dominant construction use today is in soil stabilization for roads, airfields, building foundations, and earth dams, where it upgrades low quality soils into usable base and subbase materials. It is also used as an additive in asphalt to improve the cohesion of the asphalt, reduce "stripping," that retards the aging process. Dolomitic lime is also used in the production of masonry mortar and stucco, and high calcium lime is used in the production of aerated autoclaved concrete.

In addition to the uses described above, lime is essential to many other industries. For example, the chemical industry uses lime to manufacture sodium alkalies, calcium carbide, calcium hypochlorite, citric acid, petrochemicals, phenolates, stearates, naphthenates, nitrates, caseinates, calcium phosphates, propylene glycol, glycerin, and many others. These chemicals, in turn, go into virtually every product made in America. An important and growing use for lime is in the production of precipitated calcium carbonate (PCC), which is used in the production of paper, paint, ink, plastic, and rubber. The paper industry uses lime as a causticizing agent and for bleaching and, increasingly, for producing PCC for use in the paper manufacturing process.

9.1 Process Overview

9.1.1 Extraction

Most crushed and broken stone is mined from open quarries; however, in many areas, factors favoring large-scale production by underground mining are becoming more frequent and prominent.

Surface Mining

Surface mining equipment varies with the kind of stone mined, the production capacity needed, the size and shape of the deposit, estimated life of the operation, location of the deposit with respect to urban centers, and other important factors. Typically, drilling is done with tricone rotary drills, long-hole percussion drills, and churn drills. Blasting in smaller operations may be done with dynamite, but in most medium-to large-size operations, ammonium nitrate fuel oil mixture (AN-FO) is used as a low cost explosive. The rock is then extracted using power shovels or bulldozers.

Underground Mining

Underground operations are becoming more common, especially for limestone mining in the central and eastern parts of the United States, as producers increasingly recognize the advantages of such operations. By operating underground, a variety of problems usually connected with surface mining, such as environmental impacts and community acceptance, are significantly reduced. Underground room-and-pillar mines can be operated on a year-round basis and do not require extensive removal of overburden, producing a minimum of environmental disturbance.

The room-and-pillar involves extracting the rock by carving a series of rooms while leaving pillars of rock to support the mine roof. When mining reaches the end of a section of deposit called a panel, the direction of mining is generally reversed (called the “retreat”) in an attempt to recover as much of the rock from the pillars as possible. Pillars are mined until the roof is purposely caved. That section of the mine is then abandoned.

9.1.2 Processing

Stone

Processing activities include conveying, screening, secondary and tertiary crushing, and sizing. Screening is the single most important part of the processing cycle of crushed stone particles. A wide variety of screen types exist, and their selection is a function of the material processed and the final product required. Inclined vibratory screens are most commonly used in stationary installations, while horizontal screens are used extensively in portable plants. Large sizes of crushed stone, grizzly bars, rod decks, and heavy punched steel or plastic plates are used for screening. Woven wire, welded wire cloth, rubber, or plastic screens are used for smaller sizes. Stone is left by processing the crushed material across sizing screens where it is saturated with water, in order to remove unwanted material.

Lime Manufacture

In addition to being used as an industrial material, limestone is used to produce lime. Lime (CaO) is an important manufactured product with many industrial, chemical, and environmental applications. Lime production involves three main processes: stone preparation, calcinations, and hydration. Stone preparation includes crushing screening, and washing it removes impurities. Calcining is the heating of limestone to convert the calcium carbonate into calcium oxide. This process is typically carried out in a rotary or vertical shaft kiln. Required temperatures of the kilns exceed 1800 degrees. The product of calcining is quicklime which can be used as "pebble lime" or may be crushed or pulverized, depending on its intended use. The quicklime is then hydrated or combined with water, in continuous hydrators. The end product is a fine dry powder, or with excess water, pumpable milk of lime.

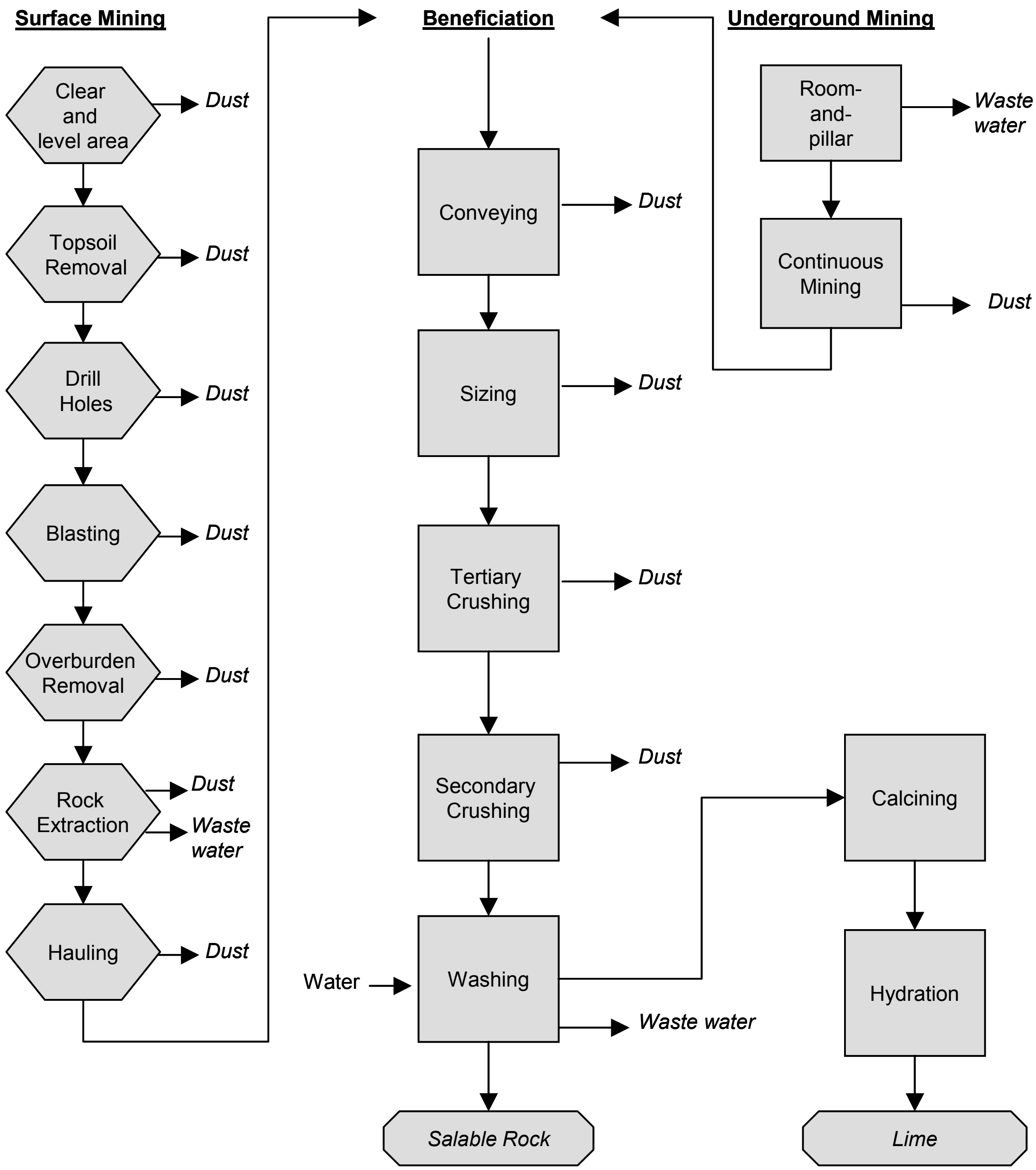
9.2 Inputs/Outputs

The following lists the inputs and outputs for limestone and other crushed rock mining and processing. Key inputs and outputs are:

Inputs	Outputs
Electricity	Dust
Fuels	Waste Water
Water	Carbon Dioxide

Figure 9-1 illustrates the steps in limestone and other crushed rock mining and processing with the inputs and outputs.

Figure 9-1. Crushed Rock Flow Diagram

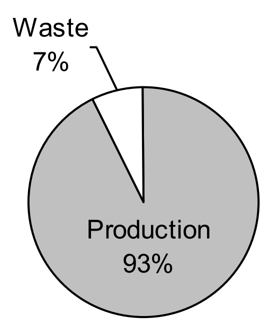


9.3 Energy Requirements

9.3.1 Materials Handled

Materials handled refers to the amount of ore and waste material that must be handled in mining. Figure 9-2 shows the amount of coal mined in relation to the amount of waste material produced in coal mining. When looking at energy requirements in mining and processing the tonnage of materials which must be handled drives energy consumption in mining operations. For example, in 2000 the amount of crushed rock produced was 1.7 billion tons. With an average ore recovery ratio of 94 percent, the amount of waste material produced was 130 million tons. This calculates to a total of 1.8 billion tons of materials handled in crushed rock mining.

Figure 9-2. Materials Handled for Crushed Rock Mining



Source: U.S. Department of the Interior, U.S. Geological Survey, *Mining and Quarrying Trends*, 1994, 1995, 1996, 1997, 1998, 1999, 2000

9.3.2 Energy Requirements

Major energy sources for limestone and other crushed rock include fuel oil and purchased electricity. In 1992, rock mining consumed 66.8 Btu. Table 9-1 shows the type and quantity of fuels consumed during rock mining as reported by the 1992 U.S. Census of Mineral Industries.

In 1978, the National Stone Association reported that out of 20 plants surveyed energy consumption ranged from 20,000 Btu per ton produced for a concrete stone plant to 54,000 Btu per ton for a plant producing fine agricultural limestone as well as grade stone. The average for the 20 plants was 33,500 Btu per ton. [1] Very few studies similar to the NSA report have been generated since that time.

Table 9-1. Limestone and Other Crushed Rock Production and Energy Consumed by Type [a]

	Units	1987	1992	1997
Limestone and Rock Production [b]	Billion tons	-	1.2	1.2
Energy Consumption				
Coal	Thousand tons	Withheld	78.5	43.0
Fuel oil [c]	Million bbl.	3.6	3.4	4.0
Gas	Billion Cubic Feet	1.7	3.2	5.4
Gasoline	Million Gallons	14.2	15.5	14.7
Electricity Purchased	Million kWh	3,500	3,500	4,600
Electricity generated less sold	Million kWh	Withheld	13.9	15.8

a Stone includes SIC Codes 1422, 1423, 1429 (1997 NAICS Codes 212312, 212313, 212319)
b Summation of stone and diatomeite
c Summation of distillate and residual fuel oil
Sources: U.S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census, Census of Mineral Industries, *Industry Series*, Crushed and Broken Limestone, Crushed and Broken Granite, Crushed and Broken Stone.
U.S. Department of the Interior, US Geological Survey, *Minerals Year Book*, Statistical Summary, 1997 & 1994

Due to a lack of current information, the energy requirements of mining and processing, the *SHERPA Mine Cost Estimating Model* along with the *Mine and Mill Equipment Cost, An Estimators Guide* from Western Mine Engineering, Inc., was used to calculate the energy required to mine and process limestone.

Table 9-2 shows the estimated energy requirements for a hypothetical surface limestone mine. The mine operates over 10 years with a 15 million-ton output at the end of its life. The mine runs 250 days per year with two shifts per day of nine hours, which gives it a

[1] National Stone Association, *Energy Conservation in the Crushed Stone Industry*.

daily production of 6,000 tons and a daily waste production rate of 300 tons. The distance the mined material must travel is 150 feet at a gradient of 7 percent.

The highest level of energy required in excavation is to operate the percussion drills. The drills run on diesel fuel and are the most energy intensive piece of equipment used in limestone mining. The percussion drills alone consume an estimated 24 percent of the total energy required per ton. Another large energy consumer is the hydraulic shovel. The shovel operates on diesel fuel and consumes an estimated 23 percent of the total energy required per ton by the mine. Transportation vehicles also operating on diesel fuel are a large consumer of energy. Rear-dump trucks, front-end loaders, bulldozers, water tankers, service, bulk and pick-up trucks combine to consume an estimated 50 percent of the total energy consumed per ton.

Table 9-3 shows the estimated energy requirements in a hypothetical limestone processing plant. The largest consumer of energy is the furnace for calcining. It is powered by natural gas and consumes an estimated 66 percent of the total energy per ton used in the plant. This process is only needed if the desired end product is lime.

The total energy required to mine and process limestone is 32,013 Btu per ton. Mining accounts for an estimated 71 percent of the total amount of energy per ton, with processing using the remaining 29 percent.

Table 9-2. Estimated Energy Requirements for a 6,000 ton/day Surface Limestone Mine

Equipment (number of Units)	Daily hours/ unit	Energy Consumption				
		Single Unit (Btu/ton)	All Units (Btu/hour)	All Units (Btu/day)	All Units (Btu/ton)
Percussion Drill [a] (6)	18.00	928	1,860,000	33,400,000	5,570
Hydraulic Shovel [a] (1)	14.00	5,140	2,200,000	30,800,000	5,140
Rear-Dump Truck [a] (3)	18.00	1,220	1,220,000	22,000,000	3,660
Bulldozer [a] (3)	18.00	1,030	1,030,000	18,600,000	3,100
Pick-up Trucks [a] (3)	12.00	679	1,010,000	12,200,000	2,040
Water Tanker [a] (1)	8.00	1,060	796,000	6,370,000	1,060
Service Truck [a] (2)	9.00	509	679,000	6,110,000	1,020
Lighting Plant [a] (4)	18.00	15	20,000	350,000	60
Front-End Loader [a] (1)	3.00	170	339,000	1,020,000	170
Bulk Truck [a] (1)	2.00	113	339,000	679,000	133
Pumps [b] (2)	18.00	1,020	679,000	12,200,000	2,040
Grader [a] (1)	0.10	6	339,000	33,900	6
Total			**10,500,000**	**144,000,000**	**24,000**

a Calculated at $0.535 per gallon of diesel fuel: average prices for sales to end-users in U.S. Petroleum Administration for Defense District No. IV, 1999

b Calculated at $0.556 per gallon of gasoline: average prices for sales to end-users in U.S. Petroleum Administration for Defense District No. IV, 1999

Note: Mine operates over 10 years with a 15 million-ton output at the end of its life. Assumes mine runs 250 days per year with 2 shifts per day of 9 hours, with daily production of 6,000 tons per day and a daily waste production of 300 tons per day. Assumes mined material must travel is 150 feet at a gradient of 7 percent.

Sources: BCS, Incorporated estimates (May 2000) using the Western Mining Engineering, Inc. *SHERPA Mine Cost Software* and *Mine and Mill Cost, An Estimators Guide*
Conversations with Industry Contacts

Table 9-3. Estimated Energy Requirements for Benefication of Limestone					
Equipment (number of Units)	Daily hours/ unit	Energy Consumption			
		Single Unit (Btu/ton)	All Units (Btu/hour)	All Units (Btu/day)	All Units (Btu/ton)
Tertiary Crushing [a] (1)	18.00	1,660	552,000	9,940,000	1,660
Secondary Crushing [a] (1)	18.00	995	332,000	5,970,000	995
Screens [a] (1)	18.00	332	111,000	1,990,000	332
Conveyor [a] (1)	18.00	165	55,000	990,000	165
Calcining [b] (1)	18.00	6,120	2,040,000	36,720,000	6,120
Total			**3,090,000**	**55,600,000**	**9,270**

a Calculated at $0.049 per kWH: average for Rocky Mountain Region, 1999
b Fuel by Natural Gas at 2,040,000 Btu/hr
Note: Mine operates over 10 years with a 15 million-ton output at the end of its life. Assumes mine runs 250 days per year with 2 shifts per day of 9 hours, with daily production of 6,000 tons per day and a daily waste production of 300 tons per day. Assumes mined material must travel is 150 feet at a gradient of 7 percent.
Sources: BCS, Incorporated estimates (May 2000) using the Western Mining Engineering, Inc. *SHERPA Mine Cost Software* and *Mine and Mill Cost, An Estimators Guide*
Conversations with Industry Contacts

9.4 Emissions

Dust emissions occur from many operations in stone quarrying and processing. Dust is released when rock and crushed stone products are loosened by drilling or blasting them from their deposit beds. Dust is also released when the loosened rock is loaded into trucks by power shovels or front-end loaders. Transporting the quarried material to the processing plant generates dust from the rock inside the truck and from the road. Sources of dust at the processing plant include the dumping of rock into primary crushers; primary, secondary, and tertiary crushing; screening; transferring rock by belt conveyor; loading rock onto storage piles from conveyors; and, wind blowing dust from storage piles and open conveyors.

Particulate matter produced during stone quarrying and processing is usually of relatively large particle size. The chemical composition of the dust tends to be homogeneous, since its ancestor is the rock formation from which the rock deposit was taken.

Air pollution control techniques for stone quarrying and processing plants include wetting the material and/or surfaces: covering open operations to prevent dust entrainment by the wind; reducing the drop height of dusty material; and using hooding, industrial ventilation systems and dust collectors such as baghouses on dusty processes. Dust recovered from air pollution control systems is often a valuable product used in road building and other construction operations.

Limestone and Dolomite

In 1997, approximately 15,288 thousand metric tons of limestone and 2,239 thousand metric tons of dolomite were used for various applications. Table 9-4 shows the carbon dioxide emission from limestone and dolomite use. For some industrial applications of limestone, it is heated to generate carbon dioxide. For example, limestone can be used as a flux or purifier in metallurgical furnaces, as a sorbent in flue gas desulfurization systems for utility and industry plants or as raw materials in glass manufacturing. Overall, both limestone and dolomite usage resulted in aggregate carbon dioxide emissions of 2.1 million metric tons of carbon equivalent.[2]

Table 9-4. Carbon Dioxide Emissions from Limestone & Dolomite Use (Million Metric Tons Carbon Equivalent)

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998
Flux stone	0.8	0.7	0.6	0.5	0.8	1.1	1.2	1.4	1.5
Glass Making	+	+	0.1	0.1	0.1	0.1	0.2	0.2	0.2
FGD	0.5	0.6	0.5	0.5	0.6	0.7	0.7	0.8	0.8
Total	**1.4**	**1.3**	**1.2**	**1.1**	**1.5**	**1.9**	**2.0**	**2.3**	**2.4**

+ Does not exceed 0.05 MMTCE
Note: Totals may not sum due to independent rounding.
Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1998*

Lime Manufacture

Lime production involves three main processes: stone preparation, calcination, and hydration. Carbon dioxide is generated during the calcination stage when limestone – mostly calcium ($CaCo_3$) – is roasted at high temperatures in a kiln and produces carbon monoxide and carbon dioxide. The carbon dioxide is driven off as a gas and is normally emitted to the atmosphere. Some of the carbon dioxide generated during the production process, however, is recovered at some facilities for use in sugar refining and precipitated calcium carbonate production.

Table 9-5. Net Carbon Dioxide from Lime Production (Million Metric Tons Carbon Equivalent)

1990	3.0
1991	3.0
1992	3.1
1993	3.1
1994	3.2
1995	3.4
1996	3.6
1997	3.7
1998	3.7

Note: Totals may not sum due to independent rounding.
Source: U.S. Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1998*

9.5 Effluents

There are no major effluents in limestone and other crushed rock mining and processing.

[2] U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1997, April 1999

9.6 By-products and Solid Waste

There are no major by-products or solid wastes in limestone and other crushed rock mining and processing.

9.7 Hazardous Waste

There are no major hazardous wastes in limestone and other crushed rock mining and processing.