



Chapter 7

Historical Overview of Lime Burning

Lime, Cement, Mortar, and Concrete

What is lime? What is the difference between lime, concrete, mortar, and cement? Any child knows the answer: lime is that little green fruit that makes such great-tasting 7-Up. Concrete is what she roller-skates on. A mortar is a small cannon, and cement holds model airplanes together. It is not all quite that simple, of course. Yet lime, concrete, mortar, and cement all have one very important thing in common: they are all made from limestone.

Lime is made by the process of calcining limestone, that is, burning the limestone without fusing (melting) it. Pure lime (quicklime, burnt lime, caustic lime) is composed of calcium oxide. When treated with water, lime gives off heat, forming calcium hydroxide, and is sold commercially as slaked (or hydrated) lime. It is used in the manufacture of paper, glass, and whitewash, in tanning leather, sugar refining, and as a water softener and a bleach. It is also used in making mortar and cement, and as an agricultural neutralizer of acid soils. Lime water, an alkaline solution of slaked lime in water, is used in medicine as an antacid and for other alkaloid uses. In earlier days, lime was used by gas companies to cleanse coal gas that was burned in lamps to light the streets at night.

Cement, commonly called portland cement, is made by combining limestone with clay, shale, or blast furnace slag that contains alumina and silica in proportions of 60 percent lime, 19 percent silica, 8 percent alumina, 5 percent each of iron and magnesia, and 3 percent sulfur trioxide. These are all ground together, heated in a kiln at temperatures in the 3,000° F range until fused, then quickly cooled into a "clinker" and ground into powder to be packed away for storage. Although cement dates to Roman times, the name portland cement dates to 1824 when an enterprising British cement maker decided to capitalize on the similarity between the color of his cement and that of portland stone, a much-used building stone in England at the time.

Mortar is a mixture of lime or cement with sand and water. Lime mortar consists of slaked lime and sand. Cement mortar is made by mixing cement and sand with water, and is the stronger of the two; the best is made by combining portland cement, sand, water, and a small amount of lime. Concrete is a mixture of cement and coarse sand, broken stone, gravel, or cinders. Better concrete is made with portland cement.

The words marble and limestone are many times used synonymously, although each is a name for a distinctively different stone. In an earlier time in Vermont it was the custom to call nearly all stone that was not granite marble if it could be carved or polished. This meant that even schist, which is more or less crystalline, was considered a marble at one time.

Some of Vermont's finest and most attractive marbles are not, technically speaking, true marbles. These include the limestones of Isle La Motte and Swanton; the breccias of Plymouth and Manchester; the dolomites of Swanton, Malletts Bay, and Manchester; the serpentine verde antique of Roxbury;

and others. All of these could be cut, polished, and sold as marble and were popularly regarded as such.

Marble is limestone that has been metamorphosed—that is, changed in nature due to the effects of heat and pressure deep within the earth. Limestone is an earlier phase of marble and it was formed under ancient seas from the residue of corals, shellfish, lime-producing plants, and lime carbonate. Limestone takes its name, therefore, from the large proportion of lime in the stone, which every lime burner knows (Perkins 1933:11-12).

Many of Vermont's early limestone quarries were opened for the intent of making marble. But as the nature of the stone was better understood and the market demanded true marble, some of these quarries switched from making "marble" to burning the stone for quicklime. And in time, even these pocket industries ceased as the demand increased for a high-quality lime and the kilns evolved into complex furnace-type operations.

The Lime-Burning Process

History does not share who first burned lime, when, or why. Lime burning certainly dates to antiquity, and it is thought that subsequent to the discovery of brick making ancient people arrived at the art of lime burning.

Assyrians and Babylonians used moistened clay as a cement but it is doubtful that they ever really used mortar. Egyptians used mortar in the construction of the pyramids. Scientists analyzed mortar used in building the pyramid Cheops and results showed that the Egyptians possessed nearly as much practical knowledge of the subject as did the mid-19th-century lime burners (Burnell 1870:1-2).

At some early period, the Greeks used compositions with lime as the base to cover walls constructed of unburned brick. And the Etruscans (700–500 BC) were the first Italians who employed mortar in building. The Romans probably derived all their knowledge of the arts from either the Etruscans or Greeks and added little to the general stock of knowledge regarding the use of limes.

Various early recorders of history acknowledged the subject of lime. One of the earliest was Marcus Vitruvius Pollio, a 1st-century BC Roman artilleryman who wrote 10 books on architecture (*De Architectura*). The oldest surviving work on the subject, its dissertations include architecture, engineering, and practical hydraulics. Pliny (the Elder, AD 23–79) and St. Augustine (AD 354–430) wrote occasionally about limes and cement, the former to complain of the malpractice of the builders, the latter to seek metaphysical comparisons.

Pure lime, or calcium, is chemically regarded as a metallic oxide, having strong alkaline properties. It is caustic but it never occurs in nature. It is found in the state of a bicarbonate, the carbonate and sub-carbonate of lime. Commercial lime is obtained by calcining these carbonates and the process consists of driving off the carbonic acid gas with which it is in combination.

The mineral that contains this carbonate of lime is given the generic name of limestone, and there are many and various

forms in nature. Limestones are generally composed of carbonate of lime, magnesia, oxide of iron, manganese, silica, and alumina, and are combined in variable proportions. They are also found with a mechanical mixture of clay, of quartzite sand, and of numerous other substances. The name limestone is more especially applied to such of the above mixtures that contain at least one-half their weight of carbonate of lime. Mineralogists make a distinction between the subdivisions of limestones, which are characterized by varieties of form and structure. This nomenclature is important because every description of limestone yields a lime of different quality, distinct in color and weight, its avidity for water, and especially in the degree of hardness it is capable of assuming when made into mortar. But the physical and mechanical natures of limestone are far from being certain guides as to the quality of the lime it can yield. A chemical analysis frequently gives different results from those obtained in practice (Burnell 1870:9-10). When found in a pure state, for example, Vermont limestone contains about 56 percent quicklime and about 44 percent carbonic acid (Hitchcock et al. 1861:746).

Carbonate of lime occurs in nearly all the geological formations, but it is scarce in the primary ones. Limestone is worked largely for obtaining building stone or for burning and obtaining lime. Calciferous rocks (containing calcium carbonate) of the primary formations and of the early transition series furnish

the greater number of stones that are worked under the name of marble. Secondary and tertiary calciferous rocks contain mixtures of clay and other ingredients that render them most adapted to furnish lime.

After a calcining sufficient to free the carbonic acid gas, the limestone significantly diminishes in weight. The resulting material possesses the property of absorbing water, either with or without the influence of heat. It cracks and falls to pieces while combining with the water, or slaking (spelled slacking in older books), as the process of passing into the state of hydrated lime is called. The principal characteristics of hydrate of lime are that it is white and pulverized and much less caustic than quicklime. It parts easily with the first portions of its water of combination if exposed to fire but requires a very high degree of heat to cause it to part with all of its water.

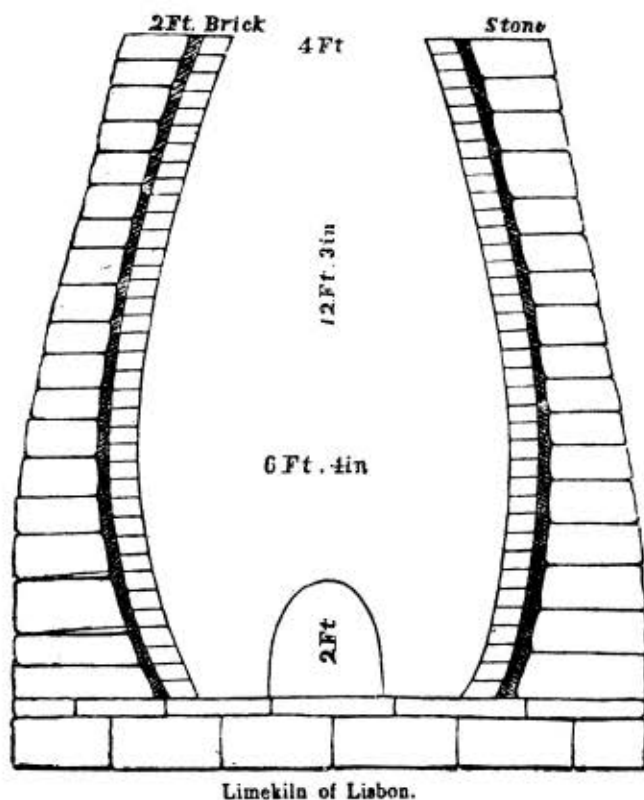
Calcining limestone can physically be done a number of ways, all of which have in common certain basic requirements. Carbonate of lime must be brought to a red-hot heat in order to free the carbonic acid gas. It must also be maintained in a continued and uninterrupted manner at that heat for several hours in order to allow all the gas to escape. The time needed for the complete expulsion of gas is in proportion to the size of the pieces of stone being heated. Large stones take a longer time; stones broken into smaller pieces, of a lighter nature, and moist take a shorter time.

The stones were broken into smaller pieces to allow the interior, insulated by the poor conductivity of the stone itself, to receive heat and to allow escape for the carbonic gas from the center of the stone. Lime burners watered the stone if prevented from using it fresh from the quarry. Moistening the stone caused the water to act on the carbonate of lime by formation of a temporary hydrate, which replaced the carbonic acid for a very short space of time in parts of the limestone first affected by the fire.

To obtain lime for water cement, the impure limestone should be broken into small pieces and subjected to a heat sufficient to expel the carbonic acid, which will require a high heat from two to five days. But care must be taken that the heat is not too intense, for if it is, the rock will become partially fused, and a glassy substance will result from the alkaline and silicious constituents of the rock. After calcination, the rock should be thoroughly pulverized and mixed with sharp sand, after which water may be applied till the mass assumes the consistency of common mortar, when it should be used immediately, especially if it possesses the setting property of some cements. The proportion of sand to be used with the cement, varies with the composition of the lime (Hitchcock et al. 1861:782).

When the limestone could not be broken into small pieces, the lime burner placed the largest blocks in the center of the kiln where they were exposed to the greatest heat. The temperature of the kiln was then raised to compensate for the larger stones. It became a question of economy—whether saving fuel compensated for the expense of breaking the stones into smaller pieces.

The color of the stone when in the kiln played an important part of understanding what was going on and when. Blue limestone became yellow if burned to a slight degree. Continuing



7-1. Cutaway view of a mid-19th-century, brick-lined, stone-type lime kiln that operated at Lisbon, New Hampshire (Jackson 1844:174). Compare with figure 2-11.

the process, the color passed to a deep yellow, an ash gray, and finally a slate blue when the heat was very intense. There was some controversy as to whether color played any part in determining quality of the product. Some burners felt that the best hydrated limes, when properly burned, were a light straw color.

It was important to determine the proper time to stop the calcination when it became apparent that some limes, if over-burned, lost all their useful properties and were, in the workman's phrase, killed. If under-burned, they had other undesired properties. Likewise, no comprehensive rule could be determined as to the fuel used, except that the choice of fuel was reflected in the design of the kiln. In areas where wood abounded, such as Vermont, kilns were made with hearths on which the wood was burned separately from the limestone. Wood, however, was not well-adapted for operation of running-type kilns, that is, kilns that were designed to be operated continuously (called perpetual kilns in Vermont). Fresh coal often caked, impeding calcination and contributing impurities to the lime. Coke was considered the best since it gave good heat nearly at once. To produce 35 cubic feet of lime it took about 60 cubic feet of oak, 117 cubic feet of fir, or 9 cubic feet of coal. Perpetual kilns required less fuel. Heavy smoke escaping from the kiln indicated wasted fuel.

Limestone was sometimes openly burned in large piles, called heaps, consisting of alternate layers of stone and fuel, similar to the mode of burning bricks in clamps. The same care was taken as in the latter in coating the sides of the heap with clay so as to retain as much heat as possible. The heap required strict attention to obtaining proper draft so that the whole mass would be equally burned. This method was usually restricted to coal-fueled kilns, due to the amount of fuel needed to compensate for radiated heat loss.

The Lime Kiln

There is not a lot of information available about the history and description of lime kilns. One archival source described lime kiln configuration in terms of "a cylindrical form," "inverted frustum of a right cone," etc. (Gillmore 1874:127). Another source, published in England, described lime kilns in terms of their shapes: rectangular straight prism, cylinder, cylinder surmounted by a truncated cone, reversed straight-sided cone or funnel, and a cone of different diameters (Burnell 1870:30-38).

Rectangular prisms were used for the purpose of simultaneously burning lime and bricks or tiles. Limestone occupied the lower half of the kiln; the upper half was filled with bricks or with the tiles placed on edge. Cylinder kilns were principally used in situations where large quantities of lime were required in a short time. They were rarely constructed for definitive use; rather, they were built cheaply for a short period of use. An archway was made first to form the hearth. A round tower was built atop to form the kiln itself, which was made of limestone, brick, or any material of those natures. The outside was coated with clay to stop all holes, and the whole was covered with a hurdle, which was a coating of earth, leaves, and/or branches that insulated it, taking care to leave a hole for access to the hearth. They were constructed of more solid materials and in



7-2. A 19th-century lime kiln with stone or brick walls, showing how larger pieces of charge were arched to hold up smaller stones above (Gillmore 1874:139).

a more permanent manner, and served only for burning lime. The largest stones were placed at the bottom of the kiln with smaller ones placed in the straight cylinder at the top. These kilns were superior to previous ones because heat reverberated from the sides and could not escape into the outside without producing its useful effect. The kilns were used mainly for intermittent burning where wood or rich coal was available for fuel.

Lime kilns were later classified by types of operation: intermittent or continuous. Intermittent kilns were those in which each burning of limestone was a separate operation, that is, the kiln was charged (loaded with limestone), burned, cooled, and emptied, and then the cycle repeated. The advantage here was that the kiln was operated only when a demand existed; the disadvantage was the irregular quality of the product from burning to burning. Intermittent kilns were usually small and were operated by local farmers as local demand required. These were the 19th-century so-called "pot kilns" that were the harbinger of new advances in the industry (Eckel 1922:100-109). In continuous kilns, also called running or perpetual kilns, limestone and fuel were charged in alternate layers, and as the burning progressed, burnt lime was removed from the bottom while fresh layers of limestone and fuel were added to the top. The process was similar to that of the blast furnace.

The inside walls of some early kilns were protected from the extreme heat by a lining of refractory stone, usually a good-quality sandstone. When the kilns were worked by intermittent fires, the limestone charge rested on arches built up from pieces of stone to be burned and laid dry. A small fire was lit below these arches toward the back. The fire gradually worked its way toward the front as the draft increased. The opening

was regulated to obtain the required degree of combustion and new fuel added as necessary to maintain the fire. Outside air, which entered through the fire door, carried the flames to all parts of the arch and gradually brought the whole mass of limestone to a state of incandescence. As the heat increased, the larger stones cracked and burst with loud explosions. The use of large stones was therefore avoided when building arches.

When the upper part of the kiln was smaller in diameter than the lower, the draft sometimes drove the flames out through the fire door. Very early kilns were built by trial and error, making the upper part larger or smaller, as required, to control the draft of the kiln. At some places, the lime burners placed pieces of wood vertically around and in the charge to facilitate the circulation of air and heat. These pieces of wood burned in the early stage of the process but left spaces that acted as miniature chimneys inside the charge. However, they also produced an unequal calcination.

The degree of heat required varied, depending on the density and humidity of the limestone. Likewise, the time necessary for perfect calcination was determined through trial and error. Such variables as the nature of the limestone, quality of the fuel, draft of the kiln, and direction and force of the wind all came into play. Before the process was complete, the charge in the lower part of the kiln gradually shrank. The stones that formed the arches cracked and the charge settled and lost from 15 to 20 percent of its height. Limestone generally lost about 45 percent of its weight by calcination through loss of water and carbonic gas. A simple way to determine if calcination was complete was to drive an iron bar down into the center of the charge. If the bar met with considerable resistance or struck firm, hard materials, the process was not yet complete. But if the bar penetrated easily, as if passing through loose, dry gravel, the process was considered complete. Another method was to draw a sample of the lime and directly analyze it, but this depended on where in the charge the sample was drawn.

As the character of the lime business changed from a local to a regional market, both the quantity and quality of demand increased. In many places, intermittent kilns were merely lined with firebrick and built a little higher to meet these new demands. In most places, however, kilns of new, technologically advanced designs were built.

These new kilns were 25 to 28 feet high with inside diameters of 5 to 6 feet at the top, 10 to 11 feet near the middle, and 7 to 8 feet near the bottom. The inside generally appeared similar to the inside configuration of early blast furnaces—like an egg standing on its fatter end. They were lined with regular brick or firebrick, set 14 to 18 inches thick into fire clay. Choice of firebrick was influenced by its ability to conduct as little heat as possible, yet retain the high-temperature heat. There was a 5- or 6-foot-high arched opening at the bottom through which fuel was loaded and burned lime was removed. About 1 or 2 feet above the bottom was an iron grate on which the fuel burned. The grate provided means for a good draft and space beneath for easy removal of ashes.

Limestone nearer to the fire still tended to over-burn while that near the top of the kiln might not be calcined enough. Then there was obviously a large loss of heat in intermittent kilns as the inside walls cooled while the lime was removed and the kiln was prepared for the next charge, as Vermont State

Geologist Charles B. Adams wrote in 1845:

In burning lime the intermittent kilns only are used in this State, so far as we have seen. There is of course a great waste of heat in cooling off the kiln for every charge of limestone. Where fuel is abundant, and the demand for lime is small, this may be the best method. Common bricks are found to answer for lining, although fire bricks, such as are made at Bennington, and may be made from any of the numerous beds of kaolin, would probably be best adapted to a kiln in constant use. Between the bricks and the outer wall there should be a space filled with ashes, to confine the heat and to prevent fracture of the outer wall by sudden heat.

The egg-shaped kiln is now preferred, having to some extent the properties of a reverberatory furnace.

The kiln should be built against the side of a cliff on which the stone can be drawn to the top; or on the side of a steep hill, raising the ground between the hill side and the kiln.

Where wood costs \$2.00 per cord, the expense of burning lime in an intermittent kiln is about 8 cents per bushel. But in a perpetual kiln . . . the expense is about 2 cents per bushel (Adams 1845:47-48).

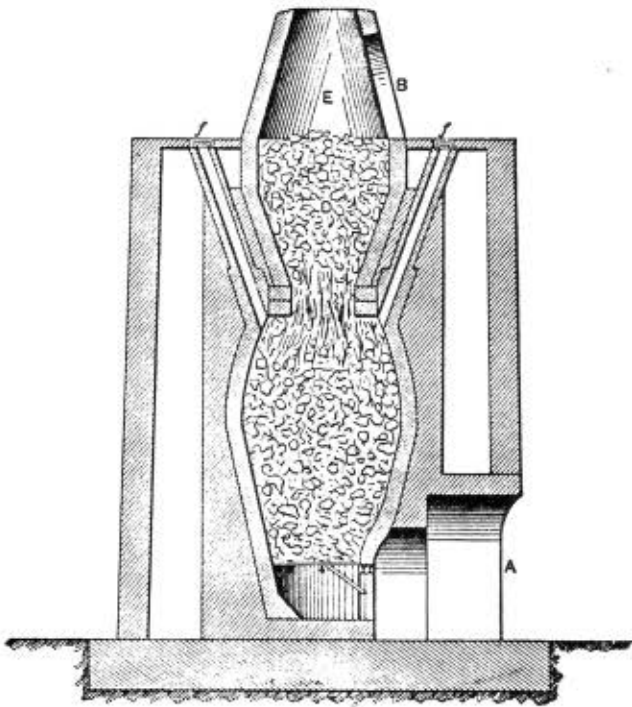
The problems associated with trying to increase the output of intermittent kilns while improving the quality of the product were solved in the 1860s by the introduction of perpetual kilns. These were categorized by their three types of operation: mixed-feed (limestone and fuel fed in alternate layers), separate-feed (limestone and fuel not in direct contact), and rotary kilns.

The advantage of mixed-feed over separate-feed kilns was that they were cheaper to build, were fuel-efficient, and yielded more product for the same size kiln. But lime produced by mixed-feed discolored through contact with the fuel, the fuel ashes were difficult to separate from the burned lime, and some ash formed hard clinkers on pieces of lime that prevented a satisfactory burning.

These [mixed-feed perpetual kilns in Vermont] are so constructed that fuel and the rock from which the quicklime is obtained are put in at the top, and the quicklime is obtained through a door at the bottom of the kiln.

The space in the kilns containing the fuel and stone is egg-shaped, or like two truncated cones placed base to base, by which shape the material in the kiln is supported or kept up while the removal of the quicklime is being carried on from an opening at the bottom. It is quite necessary that good draught be maintained during the time of burning, in order that the disengaged carbonic acid gas, which is heavier than common air, be carried off—hence an orifice should be left at or near the bottom for the entrance of air (Hitchcock et al. 1861:748).

At a 1920 mixed-feed lime plant in Pennsylvania it took six quarrymen to keep three kilns supplied, each kiln taking 24 tons of stone per day. The kilns burned 26 pounds of bituminous coal per 75-pound bushel of lime produced, or 34.7 percent on weight of lime produced. This was considered an enormous ratio since mixed-feed kilns were expected to produce lime with a fuel consumption of 15 to 25 percent per weight of lime burned.



7-3. The Aalborg lime kiln, showing side flues "f-f" leading downward to the combustion area in the middle of the kiln. Gate at bottom released burned lime and ash for removal at "A" (Eckel 1922:104).

One type design of mixed-feed kiln was known as the Aalborg (or Schöfer) kiln. In cross-section, this kiln appeared as two smaller egg-shaped chambers standing vertically atop each other. In the upper chamber the limestone was heated, dried, and partially calcined. Fuel combustion occurred at the juncture of the two chambers, and in the lower chamber the lime cooled. Angling downward into the juncture of the two chambers, in the middle of the kiln, were a number of narrow chutes which drew fresh outside air down from the top of the kiln. This fresh air, introduced directly into the narrow juncture of the upper and lower chamber, made the juncture the hottest part of the kiln, where the fuel was consumed and the lime was burned to completion. Aalborg kilns produced 15 to 20 tons of lime a day, consuming 220 to 260 pounds of coal per ton of lime, and making for an efficient 10 to 12 percent operation.

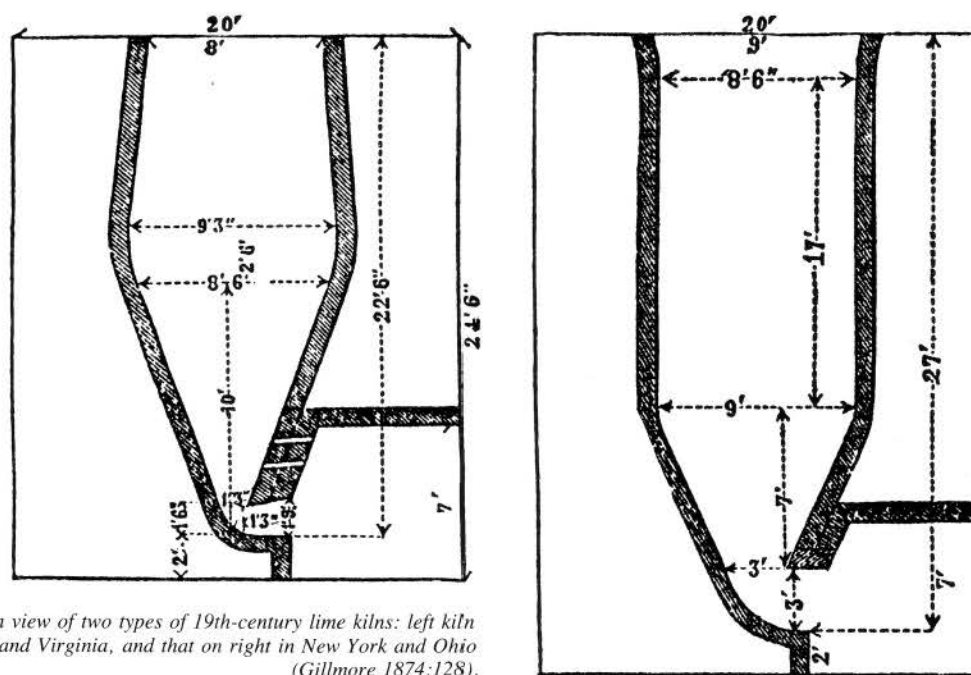
Mixed-feed kilns were the most difficult to manage with certainty, although when running favorably were the most economical. A mere change in wind direction (which affected the draft), a falling in of some inner part of the charge, or irregularity in the size of the pieces of limestone were some of the causes sufficient to retard or accelerate the draft and produce irregular movements in the descent of the charge within the kiln, causing either an excessive or defective calcination. At times, a kiln would act perfectly for several weeks, then suddenly be out of order for no apparent reason. A mere change in the nature of the fuel would produce so great a difference in the process that it defied all calculations of the lime burner. The practice of operating running mixed-feed kilns still resulted in little predictability of product quality.

The most favorable conditions to ensure a successful burning were: the thickness of the charge did not exceed 12 to 14 inches, the charge was not higher than the top of the kiln, and the fuel was well distributed through the charge. The supervisor of kiln operations had to carefully watch the top of the kiln and have fresh currents of air opened where gases did not pass. This was determined by noting whether the stones were blackened by the smoke escaping through the top, which could only take place in the direction of the escape of the gases. Wherever the stones of the charge were not blackened, therefore, the lime burner passed an iron bar through the charge to open a new chimney.

The second type of perpetual kiln, the separate-feed, became the first truly modern lime kiln, with its distinctive steel shell rising some 25 to 35 feet above the kiln base. The rusted steel shells of these kilns can still be seen among ruins at Leicester Junction, New Haven, Swanton (Fonda), across Lake Champlain at Chazy, New York, and at Cheshire, Massachusetts. These kilns rose from 35 to 50 feet in total height above ground level. The insides of the 5- to 8-foot-diameter shells as well as the kiln areas below were lined with firebrick. Around and outside the bottom of the shell were little furnaces, also known as fireplaces, in which the fuel was burned. Fuel in the furnaces was coal or wood, whose flames were directed through two large openings around the side of the shell and directly on the limestone passing downward past the openings. In this manner, the fuel and limestone did not come in contact. Fresh limestone was fed in at the top of the shell, at some plants by small cars that ran on tracks directly from the quarry to trestles on the tops of the kilns. Burned lime was removed through draw gates opened by turning a hand wheel at the bottom of the kiln; the burned lime fell through the draw gate into railroad cars that ran on the floor beneath the kilns.

One typical kiln of this type was called the Keystone kiln. Although this kiln did not have the fuel efficiency of the mixed-feed kiln, it did make a lime of much higher quality, with 90 percent being well-burned, clean, white lime (compared to the 75 to 80 percent from the mixed-feed kiln). The fuel burned being separate from the kiln also provided better control of the burning and the reduction of under- and over-burned material. Many patents were issued for improvements to various details of this lime kiln. One such patent was for boilers inserted in the kiln arches, utilizing the waste heat of the kiln to provide power to drive drills, hoists, crushers, and other machinery associated with the quarry operations.

One frequent problem associated with lime burning was "clinkering" or the burning of clay impurities—silica, alumina, iron oxide—in the kiln, caused by the high temperature reached in the kiln combining the limestone with these compounds. The result was the sintering of the clinkers with a portion of the product, which in reality was a form of natural cement called grappiers. In this country these over-burned portions were merely discarded; in Europe they were carefully saved and ground to make "grappier cements." Clinkering could begin at very low temperatures in lime with 5 to 10 percent clay impurities. It was also caused by combining the lime with the coal ashes in mixed-feed kilns. In some types of kilns, the high-temperature attack of the lime on the firebrick lining also caused clinkering.



7-4. Cross-section view of two types of 19th-century lime kilns: left kiln used in Maryland and Virginia, and that on right in New York and Ohio (Gillmore 1874:128).

Generally, the lime was drawn every morning and evening, day after day. When complete, the lime had to be drawn from the kiln with caution, otherwise the charge might drop unevenly and cause a bad shift of fuel in the remaining charge. The process continued on an average of three days and nights, but it varied according to local circumstances and weather.

By the 1860s, there were general rules for construction of a lime kiln. The lining of the inside should be made of firebricks, because this material resisted the action of the fire better than any other known material. The interior opening had to be high enough to allow the heat existing at the top to calcinate the stone placed there. Calcination was attained when the ratio of height to the largest diameter was in the order of 2:1 (2 feet of height to each foot in diameter at the widest). For perpetual kilns, this ratio increased to 3:1 or 4:1, with some kilns attaining 5:1. In intermittent kilns, the best upper opening was found to be about one-third the greatest diameter, and the fire opening about one-quarter of the same dimensions in both height and width. The thickness of the walls was not invariable, but walls had to be as thick as possible to maintain mechanical stability of the kiln and retain the greatest quantity of heat. It was unwise to scrimp in the construction to save costs since these savings would quickly be absorbed in heat loss and increased fuel costs.

The third type of perpetual kilns were rotary. These were an outgrowth of the portland cement industry, which required this distinctive kiln. Rotary kilns were essentially horizontal kilns, resembling a long, large-diameter pipe, which rotated slowly on driven rollers. The charging end of the kiln was slightly higher than the discharge end so the charge could slowly move through the kiln. Its chief disadvantage when applied in the lime industry was its high fuel consumption. For best operation, rotary kilns required that the limestone be crushed to fairly even size, preferably finely ground. These conditions provided

steady operation of the kiln with a large output. But it was difficult to maintain the heat inside the kiln at an economical temperature, reducing the amount of clinkers formed from impure limestone. The use of rotary kilns grew slowly and by the 1920s there were 30 in the country (one at West Rutland and possibly another at Colchester).

Early American Lime Kilns

An essential requirement in agriculture and industry, lime was made in the first American settlements by burning oyster shells that were plentiful along the seacoasts. With the discovery of limestone outcrops, lime was widely made by frontier farmers. By the end of the 18th century, lime burning began in earnest (Long 1972:469).

One of the earliest lime kilns in the country was operated in Rhode Island. It is described in old land records that mention the Indian name Setamachut, a hill on the west shore of the Wanasquatucket River near Manton, about three miles due west of Providence. Papers dated 1662 present Thomas Hackleton's request to the town to "burne lime" and to "take stones and wood for the same purpose." "I here present the dimensions of the kiln on Setamachut—16 feet diameter at the top; 13 feet diameter at the center; and 10 feet diameter at the bottom. It is 15 feet in depth. This was the earliest form used. . . . These facts show that the kiln at Setamachut is the rudest and most ancient now in existence in Rhode Island" (Rider 1904:266, 268).

Pennsylvania Governor Pownall reported in 1754 that there were lime kilns on every farm he visited in Lancaster County (Williams 1952:77-78, cited in Long 1972:469). In Vermont, many hillside outcrops of limestone in Clarendon and Wallingford have been found accompanied by remains of small lime

kilns used at one time by local farmers for fertilizing their fields. "There is plenty of limestone for manure on every field and it does not cost much labor or expense to come at it and it can be burned from the wood which we grub up when we clear the land" (Thompson 1884:317, cited in Long 1972:469).

Early-19th-century farmers built kilns for their own or local use either on a lot near the limestone quarry or on a woodlot, depending on the owner's judgement whether to carry the stone or the fuel to the kiln. It involved as much labor and expense to haul the wood as it did to haul the limestone. Lucky was the farmer whose kiln lay on the uphill edge of a quarry, yet downhill from a woodland so the wood cart could be rolled downhill to the site. Many lime kilns found in Vermont were on hillsides, at the edge of a quarry and downhill from forest. Lime not produced for one's self was a valuable barter item, although neither the raw limestone nor wood had as much value. Quarry workers received about 50¢ a day and the lime burner received about 75¢. Liquor was a common lubricant that kept everything running smoothly.

The early farm kiln was usually built into a hillside. Where no hillside was available, the stone kiln structure was banked up with earth, with an earth ramp leading to the top from the uphill side. Heights ran from 10 to 20 feet. Thickness of the stone walls were from 18 to 24 inches. Insides varied from square to round to rectangular and opened up from 8 to 9 feet inside diameter. Front (downhill) walls sometimes curved slightly inward at the edges according to the contour of the hill, and were laid up to the full height of the kiln in the middle to provide bank support for a road to the top of the kiln. The openings at the bottom varied in size and style. Earlier kilns had smaller openings, to protect the burning from sudden drafts lest the whole burn too rapidly. These openings were simple holes at the bottom of the front wall supported on the top by a heavy lintel stone. Later kiln openings were arched, similar to those of small blast furnaces. (Two Vermont kilns, at Jamaica (WD-68) and Wilmington (WD-89), display Gothic-style triangular openings with pointed tops.) A foot or two above the bottom of the shaft was an iron grate, above which the limestone was stacked and below which wood was piled for fueling the kiln. Grates were sometimes made so they could be shaken from the outside, as on a coal stove, to assist in removing burned lime from the stack. As the lime fell to the bottom of the stack, it was removed by hoe or shovel.

The shaft of the kiln was egg-shaped, with the larger diameter closer to the top; this was the reverse of the blast furnace, in which the larger diameter was nearer to the bottom. If a refractory stone such as sandstone was available, it was used for lining the inside. Mortaring was unnecessary if the kiln was constructed correctly and properly balanced.

The kiln was fired by placing a small pile of kindling on the grate at the bottom of the shaft. Firewood was placed on this about a foot high, then limestone in alternate layers with wood, being careful not to pack too tightly and choke the fire. When all was ready, the kindling was lighted, and the bottom and top openings were closed with an iron door or laid up with stone. All holes were mortared or plastered with clay or mud to control the draft. After running a week, depending on wind and weather, burned lime was removed from the bottom; fuel and stone were added to the top each day or two. The farmer

could count on a continuous supply of lime and still have time for farming.

It is unknown what temperatures were reached in these early lime kilns, but calcium carbonate will disintegrate at about 1,600° F, making the ideal temperature for burning lime in the range of 1,650° F to 2,200° F. Lime burned at the lower temperature proved to be the best, and the most efficient kilns burned lime at lower temperatures accompanied with steam forced into the kiln.

While vacationing in western Massachusetts in 1838, Nathaniel Hawthorne gathered ideas for a short story, titled "Ethan Brand," about a lime burner. To get his information, Hawthorne inspected some lime kilns in the vicinity of North Adams, possibly venturing north into Vermont.

September 7th.—Mr. Leach and I took a walk by moonlight last evening, on the road that leads over the mountain. Remote from houses, far up on the hill-side, we found a lime-kiln, burning near the road; and, approaching it, a watcher started from the ground, where he had been lying at his length. There are several of these lime-kilns in this vicinity. They are circular, built with stones, like a round tower, eighteen or twenty feet high, having a hillock heaped around in a great portion of their circumference, so that the marble may be brought and thrown in by cart-loads at the top. At the bottom there is a doorway, large enough to admit



7-5. A type of intermittent lime kiln in which the walls are firebrick-lined and the charge is still laid in an arch at the bottom. Fuel burned in compartment "b" and the lower compartment "a" provided unobstructed draft (Gillmore 1874:140).

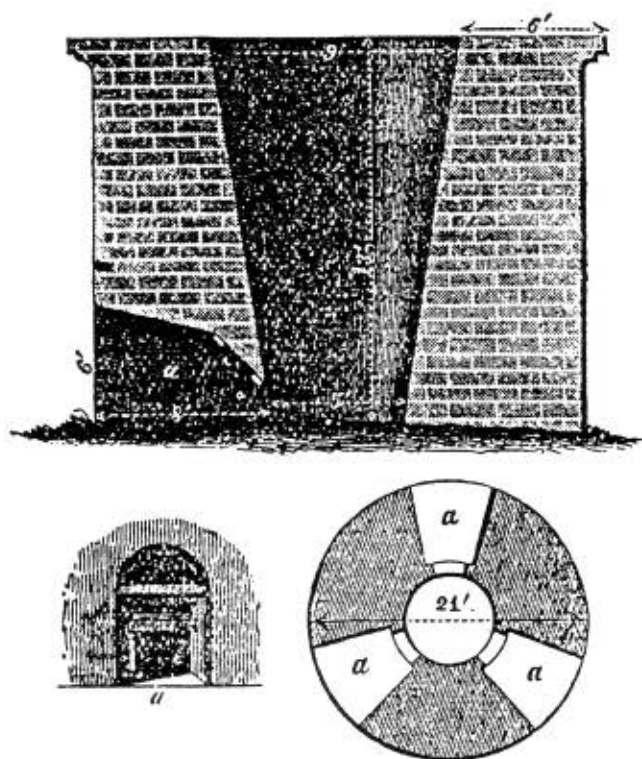
a man in a stooping posture. Thus an edifice of great solidity is constructed, which will endure for centuries, unless needless pains are taken to tear it down. There is one on the hill-side, close to the village, wherein weeds grow at the bottom, and grass and shrubs too are rooted in the interstices of the stones, and its low door-way has a dungeon-like aspect, and we look down from the top as into a roofless tower. It apparently has not been used for many years, and the lime and weather-stained fragments of marble are scattered about.

But in the one we saw last night a hardwood fire was burning merrily, beneath the superincumbent marble,—the kiln being heaped full; and shortly after we came, the man (a dark, black-bearded figure, in shirt-sleeves) opened the iron door, through which the chinks of which the fire was gleaming, and thrust in huge logs of wood, stirred the immense coals with a long pole, and showed us the glowing limestone,—the lower layer of it. The heat of the fire was powerful, at the distance of several yards from the open door. He talked very sensibly with us, being doubtless glad to have two visitors to vary his solitary night-watch; for it would not do for him to fall asleep, since the fire should be refreshed as often as every twenty minutes. We ascended the hillock to the top of the kiln, and the marble was red-hot, and burning with a bluish, lambent flame, quivering up, sometimes nearly a yard high, and resembling the flame of anthracite coal, only, the marble being in large fragments, the flame was higher. The kiln was perhaps six or eight feet across. Four hundred bushels of marble were then in a state of combustion. The expense of converting this quantity into lime is about fifty dollars, and it sells for twenty-five cents per bushel at the kiln. We asked the man whether he would run across the top of the intensely burning kiln, barefoot, for a thousand dollars; and he said that he would for ten. He told us that the lime had been burning for forty-eight hours, and would be finished in thirty-six more (*Hawthorne Chronicle* Dec. 1883:82-83).

Lime kilns also operated in New Hampshire at Haverhill, Lisbon, Franconia, and Lyme during this period. Limestone beds at Haverhill were near the base of Black Mountain, about 6 miles northeast of the village.

The country around is thickly wooded, so that an unlimited supply of fuel is readily commanded. The proprietor of the limestone owns 900 acres of woodland on the hill-side adjacent to the quarries, and he estimates the cost of wood fuel only at 50 cents per cord. His first kilns were badly constructed, and required from 18 to 20 cords of wood to burn a kiln of 60 tierces of lime; but the new ones, built according to the plan described to him, will require but 8 or 10 cords of wood to produce the same result. He makes two different kinds of lime, the first quality selling at \$1.50 per tierce, the second at \$1.25. Each tierce contains six bushels.

When it is considered that the principal expense of making lime consists in the cost of fuel, and that wood sells for \$3 per cord in Thomaston, Me., and \$5 per cord in Smithfield, Rhode Island, it will be perceived that the business of making lime at Haverhill, even at the low price above stated, cannot



7-6. An early attempt at continuous operation that provided three arches for the removal of burned lime (*Gillmore 1874:141*).

fail to be profitable, and that great advantages will accrue to the purchaser from the cheapness of the article. Heretofore the lime used upon the borders of the Connecticut River, in New Hampshire, was brought exclusively from Vermont, and immense sums of money must have been expended in its purchase. So long as it could be obtained at a lower price from the Vermont kilns, it was natural to depend upon them; but now Haverhill lime is destined to supply that region.

The kiln [at Lisbon] is egg-shape, and measures twelve feet three inches in height, four feet in diameter at the top, six feet four inches in diameter at the boshes (a little below the centre.) Arch for fuel, two feet high. The walls of the kiln are two feet thick, and are made of mica slate lined with common bricks. It cost \$150.

The common bricks soon glaze over on the surface, and withstand the heat sufficiently well. Four days and three nights are required for burning a kiln of lime, and ten cords of wood are consumed in the operation. From two to three men are employed. The cost of wood, cut, split and delivered at the kiln, \$1 per cord. The lime sells for \$2 per tierce at the kiln.

Mr. Oakes' quarry is situated two miles west from Franconia [iron] furnace, and is wrought to some extent for lime. This kiln is built like the one before described, but is of larger dimensions, containing 100 tierces of lime. It is built of common rocks found in the vicinity, and is lined with mica slate. The walls are from two to three feet in thickness,

and the lining one foot thick. He sells his lime for \$1.50 per tierce, without the cask, and for \$2 when packed in them. Wood, cut and delivered at the kiln, costs \$1 per cord. Fifteen cords of wood are required to burn a kiln of lime. Burning requires four days and three nights. Three men are employed at the kiln.

Estimate of cost and profits on one kiln of lime:

| | | |
|-------------------------------|-------|---------|
| Cost of quarrying and hauling | \$ 41 | |
| Breaking and filling in | 6 | |
| Filling out | 10 | |
| 15 cords of wood | 15 | |
| Labor | 7 | |
| 100 casks at 42¢ | 42 | |
| Interest and incidental | 5 | |
| Total costs | \$146 | [\$126] |
| 100 casks of lime sell for | \$200 | |
| Profit on one kiln of lime | \$ 54 | [\$ 74] |

Mr. Oakes has employed his lime successfully in agriculture, as a top dressing, in the proportion of one tierce to the acre. He has mixed it with compost manure and applied it to his potato crop, which, he says, appears unusually flourishing (Jackson 1844:172-175).

By the 1860s, burned lime was used:

[To] clarify the juice of sugar cane, generate heat and absorb the volatile gases in a compost heap; to purify the coal gas that illuminates our cities, bleach the rags of the papermaker and the cotton and linen fabrics of the manufacturer; to render potash and soda caustic in the soap manufacture, and used in water to restore health to the invalid; to free the hide from hair in the tanner's vat, and when mixed with litharge to dye the gray whiskers of the bachelor; to stop the stench that might arise from the slaughter-house, and to aid the chemist in his researches; and were the soil deprived of it entirely, large tracts of country now supporting luxuriant vegetation would become desolate and barren wastes (Hitchcock et al. 1861:746-747).

Although attractive on cold days for their warmth, lime kilns could be killers: "Deadly gases were frequently given off in the process of burning lime. A limeburner . . . told of a vagrant who was found dead from asphyxiation one morning near the shelter covering the shaft opening of the kiln on his father's farm. Although the area around the kiln shaft provided warmth on cold nights, the gases which escaped were extremely dangerous" (Long 1972:473).

Burned lime was usually sold by the bushel, the definition of which varied from place to place and time to time. In late-19th-century Pennsylvania, a bushel of lime measured 1 1/4 cubic feet which weighed about 80 pounds (Long 1972:481). In 1795 the Vermont General Assembly defined a bushel of lime, charcoal, or potash to be 2,592 cubic inches, which calculates to 1 1/2 cubic feet (Williams 1967:414). This law was repealed in 1816 in favor of a law that defined a bushel of lime, charcoal, or potash to equal 38 quarts of ale, or Winchester measure (*Laws of Vermont* 1816:139). By 1839, Vermont defined this bushel to be a standard bushel plus 3/4 of a peck (*Revised*

Statutes 1840:369). Bargaining between merchants and lime or charcoal burners in the 19th century must have been an ordeal with constantly changing standards.

Lime sold for 3¢ a bushel at the kiln in the 1700s and by 1800 rose from 8¢ to 12¢ at the kiln. A farmer could pay up to 25¢ if it had to be transported any distance, quite an expense for anyone not willing or able to produce his own (Long 1972:482).



7-7. Threaded ends of iron binding, with nuts and washers intact, extending out of the walls of a kiln ruin at Cavendish.

The lime was carried into the field in a wagon or cart, there unloaded in spaced piles as needed, and left for slaking, which caused a chemical reaction in the lime that sometimes gave off large amounts of heat. It was not uncommon for wagons of lime to catch fire if caught outside in the rain. John Catlin's house at Richville (Shoreham Center), Vermont accidentally burned due to the heat of some slaked lime stored in the building (Smith 1886:623). Piles of lime in the field gave off steam after a rain and sometimes glowed at night.

[Benjamin Hauer] started burning lime with his father Amos Hauer, when he was thirteen years of age and burned lime in kilns in the Harpers [Pennsylvania] area as late as 1951. He told that the burning lime was done primarily between farm chores. Usually, after seeding time in spring until hay making and from late summer until about Christmas, depending on the weather, the kiln was in continuous operation. He said they burned very little lime during the hottest and coldest months.

The time required to fill the shaft in preparation for burning depended on the help available. He stated that it took one and a half to two weeks and occasionally longer for his father and him to fill a kiln. He said they frequently filled in one or two layers a day depending on time available. The stones were usually found right on the farm; sometimes they were brought there from the surrounding areas. He stated



7-8. Variation of iron binding on the side of a kiln ruin in New Haven. The vertical plate connected the ends of the kiln-girdling iron rods and added support to the stone walls.



7-9. Broken wood beam that had supported upper wall section of the lime kiln ruin at Bristol.

that within one area the quality and color of the stone could vary considerably and that it was important for the lime burner to know the stone. The stone varied in hardness and in color from shades of blue to yellow and white. The quality of the stone determined to a large degree the amount of coal

required to complete the burning process. More or less coal was also required depending on the air movement and draft.

Occasionally, limestone was bought. He recalled paying one quarter cent per bushel or four bushels for one cent and from \$1.60 to \$1.85 a ton in later years. He stated it was

common practice for a farmer who had limestone on his farm to build a kiln near the outcroppings and then hire someone to burn the lime. The limeburner may have been paid for his services or there may have been a barter arrangement allowing him to sell some lime in return for his efforts.

He said he helped fill some kilns that had a capacity of only two hundred to three hundred bushels of lime and others that had a capacity of fifteen hundred bushels. The average capacity of the kiln at which he worked was three hundred to six hundred bushels. He told of removing as many as fifty bushels of lime a day from the kiln and as few as one or two wheelbarrows depending on combustion. He recalled that his father sold lime for five and one-half cents a bushel during his first years of burning and for eighteen cents a bushel in 1951, the last year he burned lime.

He related that lime was used in large amounts for mortar between stone and brick for the erection of the exterior walls of barns, houses, and out buildings. The stone were burned in the limekiln until they became fragile and calcified. The resulting lime when slaked in water made an excellent mortar and enhanced the appearance of masonry buildings.

Considerable quantities of lime were sold for white-washing, a common practice during earlier years. Since paint was scarce and expensive, walls, ceilings, stables, fences and tree trunks were frequently white-washed. As many as two hundred to three hundred bushels of lime were sold each year for white-washing. Some buyers bought as little as a peck at a time. Lime to be used for white-washing, he stated, was best obtained from good quality white stone.

He told of applying from seventy-five to one hundred bushels of lime per acre on their land and usually one field on the farm was limed each year. He recalled a Holstein cow that fell into a lime kiln and having to tear the bottom out of the kiln to remove the dead cow. [The owner of Maplebrook Farm in Timmouth, Vermont said the lime kiln ruin on his property had its front wall missing because he had to rescue a cow that had fallen into it. The kiln was built into the side of a slight rise at the edge of his pasture.] In addition to vagrants who slept by the kiln, he told of a basket maker who lived in and about the kilns during the decade of the forties.

Another informant told of a limekiln which was used for the storage of ice during his youth on his parents' farm. A peak roof was constructed over the shaft and ice from a nearby pond was stored in sawdust within the interior. He said the ice kept well from one season to the next.

The entire process of changing limestone to lime was an arduous task and frequently became a cooperative enterprise. It was not uncommon for neighboring farmers and friends to gather together and jointly share the task of hauling limestones and wood or attending the fire. This was particularly true when the kiln was located some distance from the quarry.

The area around the kiln frequently became a scene of many types of amusement and merriment during the early autumn evenings and nights. Corn roasts were common. Sometimes chickens were roasted and potatoes baked, making a suitable feast for a keen appetite at the end of a working day (Long 1972:474-481).

National Trends

The first national view of the lime business came about as the result of the 1900 U.S. Census. Statistics were gathered on lime plants throughout the country regarding operating expenses, production figures, fuel consumption, etc. Table 7-1 presents various statistics gathered for Vermont and four other New England states in the production of lime (Eckel 1922:114):

Table 7-1. Costs of Lime Manufacture during 1900

| | Conn. | Maine | Mass. | R.I. | Vt. |
|---------------|-----------|-------------|-----------|----------|-----------|
| No. of plants | 11 | 20 | 11 | 3 | 13 |
| Officials | 12 | 34 | 3 | 1 | 2 |
| Laborers | 171 | 582 | 130 | 40 | 182 |
| Capital | \$250,392 | \$1,942,007 | \$115,639 | \$26,150 | \$256,860 |
| Wages | \$ 71,938 | \$ 248,371 | \$ 69,823 | \$16,230 | \$ 57,257 |
| Limestone | \$ 86,759 | \$ 347,344 | \$ 67,826 | \$ 8,314 | \$ 36,804 |
| Fuel | \$ 59,005 | \$ 196,991 | \$ 54,257 | \$ 8,700 | \$ 45,112 |
| Freight | \$ 2,025 | \$ 68,803 | \$ 310 | — | \$ 6,000 |
| Product value | \$286,640 | \$1,226,972 | \$261,477 | \$48,089 | \$207,524 |

Analysis of table 7-1 in terms of total operating costs (not all the census data are included) resulted in learning that Vermont costs in 1900 ran close to the average of its New England competitors, as shown in table 7-2 (Eckel 1922:115):

Table 7-2. Percentages of Total Operating Costs

| | Conn. | Maine | Mass. | R.I. | Vt. |
|-----------|-------|-------|-------|------|------|
| Salaries | 3.6 | 2.3 | 1.3 | 0.8 | 0.8 |
| Wages | 26.8 | 21.9 | 33.3 | 36.1 | 32.9 |
| Limestone | 32.5 | 30.6 | 32.4 | 18.4 | 21.1 |
| Fuel | 22.1 | 17.3 | 25.9 | 19.3 | 25.9 |
| Freight | 0.8 | 6.1 | 0.1 | — | 3.5 |

In theory it took about 100 pounds of coal to burn a ton of limestone; in practice, however, fuel consumption was higher or lower depending on the design of the kiln and the skill of its operation. Table 7-3 shows the results of a survey of fuel consumption in the early 20th century (Eckel 1922:111). Table 7-4 shows the trend of the national lime industry from 1909 to 1920 (Eckel 1922:115).

Table 7-3. Type of Fuel Used at American Lime Plants

| Kilns Using | 1913 | 1917 | 1918 |
|-----------------------|-------|-------|-------|
| Coal | 1,334 | 1,138 | 885 |
| Coke | 123 | 189 | 151 |
| Coal and coke | 22 | 51 | 37 |
| Oil | 54 | 27 | 24 |
| Natural gas | 30 | 25 | 21 |
| Producer gas | 76 | 86 | 76 |
| Wood | 479 | 268 | 194 |
| Coal and wood | 220 | 182 | 182 |
| Total kilns reported: | 2,338 | 1,966 | 1,570 |



7-10. View of the binder assembly in the kiln ruin at Bristol, showing the flat iron binder extending out through the wall and its flat iron face plate held in place by beveled key inserted vertically through the binder hole.

Table 7-4. Lime Burned and Sold in the U.S. from 1909 to 1920

| Year | Tons of Lime | Value | \$/Ton | Plants |
|------|--------------|--------------|---------|--------|
| 1909 | 3,484,974 | \$13,846,072 | \$ 3.97 | 1,232 |
| 1910 | 3,505,954 | \$14,088,039 | \$ 4.02 | 1,125 |
| 1911 | 3,392,915 | \$13,689,054 | \$ 4.03 | 1,139 |
| 1912 | 3,529,462 | \$13,970,114 | \$ 3.96 | 1,017 |
| 1913 | 3,595,390 | \$14,648,362 | \$ 4.07 | 1,023 |
| 1914 | 3,380,928 | \$13,268,938 | \$ 3.92 | 954 |
| 1915 | 3,622,810 | \$14,424,036 | \$ 3.98 | 906 |
| 1916 | 4,073,433 | \$18,509,305 | \$ 4.54 | 778 |
| 1917 | 3,786,364 | \$23,807,877 | \$ 6.29 | 595 |
| 1918 | 3,206,016 | \$26,808,909 | \$ 8.36 | 496 |
| 1919 | 3,330,347 | \$29,448,553 | \$ 8.84 | 539 |
| 1920 | 3,570,141 | \$37,543,840 | \$10.52 | 515 |

Note that from 1909 to 1920 the tonnage of lime produced increased only about 2.5 percent, but the value of the lime through inflation caused by World War I increased 171 percent, while the number of plants producing the lime decreased by 58 percent. The industry was fast becoming highly competitive as kilns operated more and more efficiently.

Vermont Lime Kilns

The first comprehensive study of the Vermont lime industry was included in *Report on the Geology of Vermont* (1861) authored by Edward Hitchcock, his sons Edward, Jr. and Charles, and Albert Hager. In their 988-page, two-volume work, the authors stated that "to undertake the enumeration of all the places from which good material for quicklime could be obtained, would be a difficult task and one which will not

be attempted. Old limekilns abound in the vicinity of nearly all outcrops of limestone, but of late much of the lime manufactured is from perpetual kilns" (Hitchcock et al. 1861:748). Although some of the lime kilns already considered "old" by these authors in the 1860s have survived to the present day, it is too bad that some attempt was not made to record their locations while this information was still relatively current.

The earliest recorded lime kiln in Vermont (GI-27) was that at Isle La Motte, where the French burned lime to make mortar in 1664 or 1666. The date varies depending on the reference, although 1664 appears to be the date of the initial French settlement, and 1666 the construction date of Fort Sainte-Anne for which the mortar was used, and so also the lime kiln. The kiln operated to at least 1796 when it is recorded that "Royal Corbin of Windmill Pt., Alburgh, Vt., [told] Pliny Moore of Champlain, N.Y. to get some Lime at Fisk's" (Stratton 1984:118). The kiln, or at least modifications of the kiln at the same site, operated under the French, British, the Republic of Vermont, and the State of Vermont, which adds up to about 130 years of operation.

Although a marble quarry at Dorset lays claim to being the first in the country, there are many references to a quarry (later called Fisk quarry) at Isle La Motte being older (Adams 1845:45; Child *Grand Isle* 1883:226; Swift 1977:265; Meeks 1986:106). Meeks wrote: "Depending on how marble is defined, the earliest quarrying probably was at the south end of Isle La Motte as early as 1761." Stone might also have been taken from the Fisk quarry by the French in 1666 for construction of Fort Sainte-Anne. The confusion was probably caused by Fisk quarry operators calling its limestone a black marble. The Fisk quarry, however, was continuously worked longer than any other in Vermont (Perkins 1933:145).

Lime kilns started appearing in numbers with the opening

of farms and the discovery of good-quality limestone. The many small ruins found in the Vermont countryside bear witness to the amount of lime burning that took place in the early to mid-19th century. Lime kiln remains found in Vermont can be categorized, both by physical appearance and estimated use of the produced lime, as follows: farm, early and later commercial, early modern, and modern.

The farm kiln was built to fulfill strictly local demands for agricultural lime and building mortar. What surplus of production existed was sold for use in tanneries, paper mills, and chemical factories. The kilns were small relative to the size of later units, generally measuring about 6 to 8 feet inside diameter. They were built into the sides of a low rise near an outcrop of limestone and the sides of the kilns were covered with earth, leaving an opening in front to draw out the burned lime. The top kiln opening was level with the ground at the upper level, for ease in dumping limestone into it from an animal-drawn cart. Such kiln remains were found at Brandon, Tinmouth, Clarendon, and Wallingford and are some of the earliest types found thus far in the state, operating up to the 1840s.

Some kiln ruins found at Clarendon, Plymouth, Weathersfield, Jamaica, Cavendish, Whitingham, and Richford are in the early commercial category. They are somewhat larger and made with more massive-sized stones. Some, such as those in Plymouth, have front walls 8 to 10 feet high with wide ramps leading to the top from the uphill side. Plymouth limestone was considered a “very peculiar brecciated stone” which was formerly sawed and polished for marble, but later burned for

lime. It made strong and durable lime, but it was not very white (Perkins 1900:36).

Kiln ruins found at Arlington, Bristol, Castleton, Cavendish, Mendon, Benson, New Haven, Stratton, Weathersfield, Whitingham, Wilmington, and Jamaica are a later commercial-type lime kiln and start to hint at a more “furnace” appearance. These kilns still operated intermittently but were the final design before the advent of the early modern kiln. To the unwary field explorer, these squat, square stone structures could be confused with iron smelters due to their similarity in appearance. They usually displayed iron binding rods to reinforce the outer walls as in the blast furnaces. Some, however, also incorporated horizontal wooden beams built into the stonework to support the wall above the work arch, unlike blast furnaces. These kilns were most likely in operation during the immediate post-Civil War period, and up to the early 20th century.

Early modern kilns were those ruins found at New Haven, Swanton, Danby, Highgate, and Leicester. These are distinctive by their construction type and location, and have approximately 30- to 40-foot-square (or 30-foot-diameter) concrete and/or stone bases with up to 10-foot-diameter steel shells rising as high as 25 feet above the base. They are multi-unit operations and stand adjacent to railroads for access to out-of-state markets. The only truly modern-type lime kilns known to have operated in Vermont were the abandoned works at Winooski Park, razed for scrap in 1990.

Two variant modern-type kilns were Vermont’s only rotary kilns, which operated at West Rutland in the 1920s (RU-LK01)



7-11. A simple binder (right) in the corners of the kiln ruin at Amsden. This flat iron strip, bent downward at right angles at each end, lies diagonally across the corners of the kiln, holding the horizontal wooden sections in place. Hidden inside the corners, between the binder and the corner, are vertical iron rods that run the height of the stack and hold the binder tight against the horizontal wooden sections.



7-12. A few kiln ruins of a large lime-burning complex at Chazy, New York, inspected in 1982 before they were razed and used for fill in nearby Lake Champlain. In the ruin at the left, the shell was insulated with additional stonework. The bases of these kilns were of reinforced concrete. A quarry immediately to the south provided the raw limestone; the burned lime was carried away by railroad.

and possibly at Colchester (CH-284), and two concrete-section kilns at Highgate Springs (FR-225).

A large portion of limestone in the state is highly crystalline, which made the Vermont marble industry so successful. Attempts to make this particular kind of marble into lime in vertical kilns of any sort, however, usually met with failure. The difficulty was that the crystalline limestone, on being heated, broke into granular form instead of keeping its shape as ordinary limestone did when burned in the vertical kiln. The result was that the draft in the vertical kiln was choked and the burning stopped. The rotary kiln, which looked like a long smokestack laying on its side, provided the solution to this problem. It opened the way for burning waste marble for manufacturing lime. Nationally, rotary kilns were used in the cement industry, and the rotary process was tried for manufacturing lime as early as 1885. Not until 1916 did this new method of manufacturing lime become one of Vermont's industries, at West Rutland.

The cars loaded with blocks, spalls, or any suitable class of marble waste from the quarries and mills are delivered under a crane runway equipped with a twenty-five ton electric crane and this equipment unloads the raw material and delivers it to a 48" by 60" Superior jaw crusher. This crusher weighs 105 tons and is operated by a one hundred and fifty horse power motor. The swinging jaw moves only about three or four inches but this is sufficient to crush any block that will go into the four by five foot opening, at the rate of two hundred forty tons an hour or four tons a minute.

These chunks of marble that are discharged at the bottom slide directly into a gravatory crusher. The crushed stone is then elevated and discharged by a conveyor into two stone storage bins which permit a forty-eight hour supply of raw material ahead of the kiln.

The kiln, which measures eight feet in diameter by one hundred twenty feet long and resembles a huge stack on its side, was built by the Vulcan Company. It is constructed of $\frac{3}{8}$ -inch steel plates, and the kiln equipment complete weighs 118 tons. It is lined with firebrick and revolves on two bearings at the rate of about one revolution every three minutes, a thirty horse power variable speed motor furnishing the power. This motor regulation enables the speed of the kiln to be adjusted to suit the conditions of burning and the feed is operated by a rope drive on the same motor so that any change in speed of the kiln automatically changes the rate of the feed of the crushed stone to the kiln.

The heat for burning is furnished by a Chapman mechanical 10-foot gas producer, situated in a separate building. The incoming fuel is dumped through the car bottoms into a hopper under the track from which it is conveyed to coal crushing rolls. This crushed coal is elevated and discharged directly into the coal bin over the gas producer or into the large concrete storage building with a capacity of about 300 tons. From this storage building it may be withdrawn through tunnel gates and a belt conveyor to the original elevator and thus taken to the coal bin over the producer. The producer shell is in two sections. The bottom section, to which are fastened plows for the automatic removal of the ashes, re-

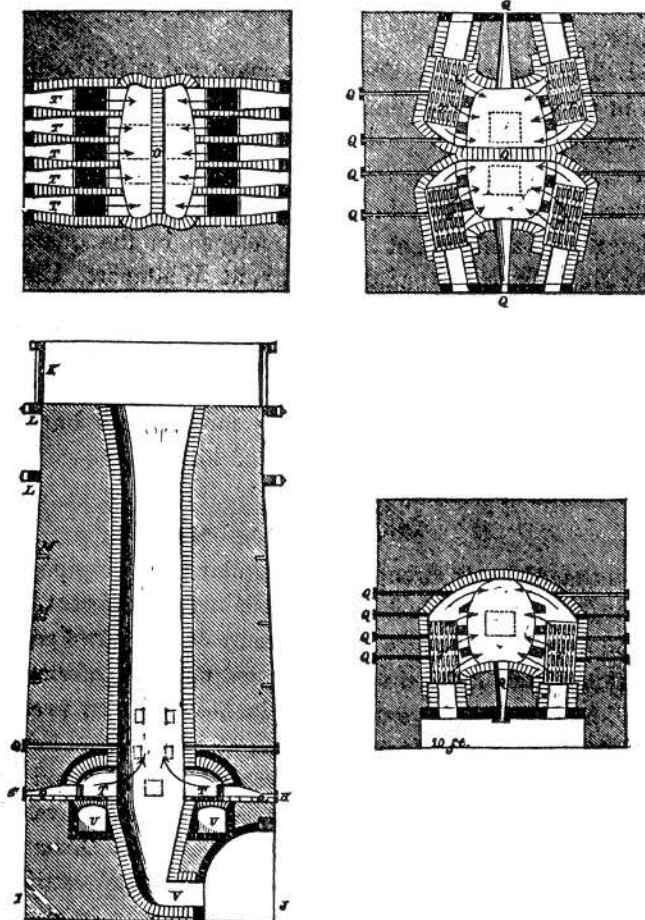
volves slowly while the top section revolves at a faster rate of speed. The twyre [*sic*] is stationary and through it a jet of steam is admitted. A mechanically water-cooled poker fastened in the stationary top, aided by the circular motion of the shell, keeps the mass of the fire agitated and compact. The whole is water-sealed and has a capacity of gasifying about one ton of coal an hour. One pound of coal when gasified will produce from three to five pounds of lime, depending on the quality of the gas and the character of the stone. From the producer, the gas is conveyed to the main building in a large steel flue, varying from three to four feet in diameter, and delivered into the lower end of the kiln where it ignites, producing a temperature of about twenty-two hundred degrees Fahrenheit. A Westmoreland County [Pennsylvania] gas coal is used in this process, the requirements being that the coal must contain not over 1% of sulphur and be very low in ash.

The kiln is set at a pitch of one-half inch to the foot. It can thus be readily seen that the mass of broken marble

being admitted at the upper end will gradually travel toward the lower end—it taking about four hours to pass through. Surface moisture is driven off early in the kiln and as the stone approaches the lower end the pieces are broken down and the balance of any moisture and the carbon dioxide gas is driven off and carried with the combustion gases up the stack. The actual burning of the limestone is probably limited to the last or lower thirty feet in the kiln known as the burning zone. A series of baffling walls in the stack chamber prevent the fine stone particles and lime from being drawn up the stack by the draft and any of this material which collects at the base of the stack chamber is removed by a screw conveyor and deposited in the stone bins, thus being returned to the kiln.

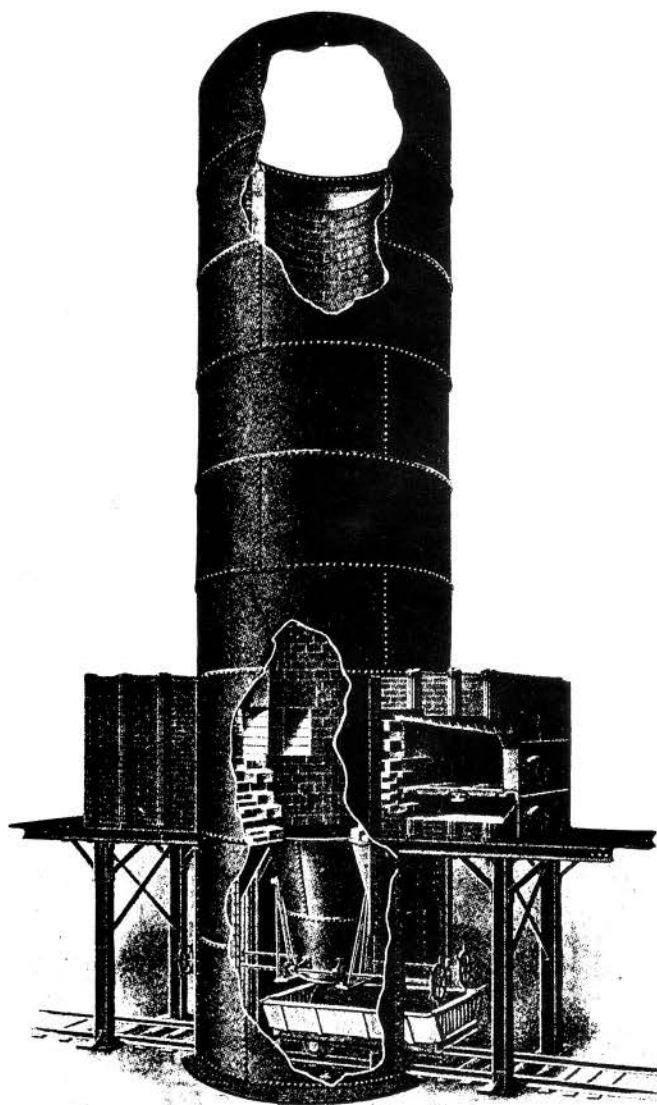
The lime oxide or burned lime discharges at the end of the kiln through a chute directly into a cooler situated at a lower level in the cooler pit. This is a stack-like cylinder on its side similar to the kiln but without any brick lining and measures five feet in diameter by fifty feet long. The cooler equipment weighs about 27 tons. Lifting angle irons are bolted to the inside of the cooler so that as it revolves the fine granular lime is raised and dropped through the air and thus the cooling operation is facilitated. A draft through the cooler is induced by the kiln stack and the burning process in the kiln and thus the air passing over the hot lime in the cooling process is preheated for the kiln. The cooler is mounted on two bearings pitched at the same grade as the kiln and operated by a ten horse power motor. The granular lime which entered the cooler at approximately twenty-two hundred degrees is discharged at the end sufficiently cooled so that it can be safely elevated to the two large steel oxide bins of approximately two hundred fifty tons capacity each. From these bins the quick lime can be loaded in bulk into cars or barreled as the trade demands.

From these bins the lime may be taken by still another elevator to the six cylinder Kritzer hydrator. This machine scientifically slakes the lime adding the proper amount of water to exactly hydrate and yet have the product come out exactly dry. The water is admitted in a spray to the stack of the hydrator through which the heat generated by the chemical reaction is carried off and this not only keeps the light hydrate from being drawn up the stack but the water in turn is preheated thus assisting the action of the hydration. Revolving beaters or paddles assist the movement of lime and water through the series of six cylinders thoroughly mixing the oxide with the water and insuring complete hydration and the absolute drying so that the material is discharged to a screw conveyor at the bottom as an impalpable flour. This passes to Raymond mills and beaters where any core, unburned material or foreign substance of any kind is separated and discharged permitting the pure, white, fluffy hydrate to be raised in the air separators to the storage bins from which it is bagged in valve paper sacks by an Urschell-Bates valve bagging machine. A dust collecting system at the bagger removes the fine material that is spilled in bagging. The paper sacks are made with no opening except for a small hole in a fold at one end. Through this hole a tube about one inch in diameter is inserted and through this the hydrate is forced into the bag. The flow of hydrate is auto-



7-13. Varieties of multiple-unit lime kilns. Left to right (top): cross-section view downward of an anthracite-fueled 10-kiln unit, and a 4-unit wood-burning kiln; (bottom): cross-section view of a wood-burning 2-unit kiln and downward view of same (Gillmore 1874:135).

matically stopped when the bag contains fifty pounds. No sealing or tying of the bag is necessary for the pressure of the contents seals the opening in the fold and then the bags are trucked and piled in the stock house.



7-14. Cross-section view of a Keystone lime kiln, showing firebrick-lined iron shell, fireplaces (middle), and hand-operated draw gates (Eckel 1922:106).

The capacity of the plant as it is now equipped is about 60 tons of oxide a day or 75 tons of hydrate. The operation is continuous night and day except for forced shutdown for repairs. As many operations as possible have been made automatic thus reducing to a minimum the item of labor (Smith "Description" 1916:102-106).

The preceding report also includes pictures of the rotary kiln,

jaw crusher, gravatory crusher, gas producer, hydrator, and valve bagging machine.

In addition to the five circular stone-type kilns that the Mis-sisquoi Lime Works operated at Highgate, the company must have experimented with kilns made of concrete sections, based on ruins found at the site in 1990. These concrete-type kilns were built in vertical half-sections that were held together with iron bands (only the impressions of the bands remain). The inside might have been lined with firebrick but none was found inside, possibly indicating that these "newer" kilns were never actually fired.

Regardless of the nationwide acceptance of the use of lime-stone in agriculture, 19th-century Vermont farmers were not to be immediately convinced that spreading pulverized lime-stone in their fields would increase crop yield. At a series of conferences held in 1871-1872 in Vermont, the recently formed Board of Agriculture, Manufactures, and Mining met and presented the following papers on the problems of farming in the state: "Exhaustion of Soils" and "Rotation of Crops" by Samuel W. Johnson of New Haven (Conn.) and William S. Thorp of Morristown; "Commercial Fertilizers" by Peter Collier of Cornwall; "The Relation of Science to Agriculture" by Henry M. Seely of Middlebury; and "The Fertility of Our Soil—How Lost, and How Restored" by Jonathan Lawrence of Passumpsic. All looked at what was happening to farming in the state, and how to turn the overused earth back into gainful production. As the nature of elements were studied, became better understood, and were more widely accepted, the nature of agriculture as a form of chemistry started taking hold. Soil exhaustion, once believed irreversible, was not necessarily the end of the world (Collier 1872:344-487). An understanding of soil nutrients and the chemistry of mineral replenishment were published in journals and preached to progressive-thinking farmers as the way to return once-dead fields to life. Henry Miles of Monkton wrote:

No soil is productive which does not contain a considerable proportion of carbonate of lime. A productive soil may be reduced to barrenness by abstracting its lime by incessant cropping. An unproductive soil may, in many cases, be rendered productive by the addition of lime.

The statement of Dr. Hitchcock is as follows: "First and most important of all, we think we have discovered the reason why Vermont so excelled all other New England states in the agricultural capabilities of her soil. It is the existence, in almost all her rocks, of lime in such a state that natural processes bring it out in just about the quantity needed by vegetation. This is the case in many parts of the state where inhabitants hardly suspect the existence of lime, and those places of the state most fertile are just the places where lime is most abundant and decomposable" (Miles 1876:271-273).

Another lime-related material that proved to be a valuable fertilizer when burned was marl. Usually found in the beds of ponds and bogs (not to be confused with peat), marl is a mixture of sand, clay, or silt that contains substantial amounts of calcium carbonate. The latter is known as shell marl and is the remains of shellfish deposited in layers in an ancient time when the area was the floor of a warm, shallow ocean. It was known as



7-15. Approximately 10-foot-tall concrete half-sections show innovation at work in new lime kiln designs by the Missisquoi Lime Works at Highgate Springs. These units were probably built in 1918.

marlstone when found in a solid form. Shell marl was dug and burned in a kiln the same as limestone. Important marl deposits were found in the early 19th century at Holland, Derby, Salem, Albany, Craftsbury, Glover, Greensboro, Hardwick, Walden, Sutton, Lyndon, Barnet, St. Johnsbury, Peachem, and Calais (Hitchcock et al. 1861:725).

Marl from Alburgh, Williamstown, Peachem, and Monkton was analyzed in 1847 and found to contain from 73 to 89 percent carbonate of lime, of particular value for use as fertilizer (Hitchcock et al. 1861:697).

Two marl beds worked profitably in mid-19th-century Vermont were at Marl Pond in Sutton, where digging and burning marl was a business for many years, and at Lime Pond (Limehurst Lake) at Williamstown. The marl was molded into bricks and dried; then the bricks were burned (Hitchcock et al. 1861:805).

The 19th-century Vermont farmer's ethic, however, was generally that "early rising and hard work" were the chief ingredients in the improvement of agriculture. It was especially hard to persuade him that simply broadcasting ground stone would profit where labor had failed. Despite the concentrated campaign to convince farmers that there was no real conflict between science and labor, as recently as 1929 only Maine was lower than Vermont regionally in the use of limestone for agriculture (Meeks 1986:149). And this at a time when the lime-burning industry in the state was also declining. (Today we think nothing of buying a bag of lime to balance the pH of our lawn or swimming pool; a century ago it was a revolutionary thought.)

By the 1890s, lime burning in the state became centralized at only a half-dozen operations. The discovery of the process of making hydrated lime in large quantities meant the product could be stored for long periods of time without suffering from the absorption of moisture and causing fires. The simple process

consisted merely of mixing quicklime with water and keeping the solution in constant agitation. The end result was a packaged powder product capable of withstanding long-distance shipment without losing its property for use as mortar or other industrial purposes. The production of hydrated lime led to the closing of many small kilns that once dotted the state. State Geologist Perkins reported production during this period as:

| Year | Value of Production | Year | Value of Production |
|------|---------------------|------|---------------------|
| 1893 | \$400,000 | 1896 | \$147,000 |
| 1894 | \$151,000 | 1899 | \$300,000 |

Perkins also stated that in 1894, six companies reported making 30,280 tons of lime; the next year eight companies made 38,720 tons.

Never in the major business category in Vermont, lime burning was most active from the turn of the century to the 1930s, reaching its peak in terms of kilns in operation in the 1920s. In 1900, the limestone quarries at Highgate and Swanton were among the oldest in the state, having been worked since the early part of the 1800s. The Highgate quarry was run by L. E. Felton and those at Swanton by J. P. Rich and W. P. Fonda. "All of these furnish the stone for extensive kilns in which lime is made" (Perkins 1900:32). The State Geologist reported the following as constituting the lime industry in Vermont during 1918: Missisquoi Lime Works (Highgate Springs), Fonda Lime Kilns (Swanton), Swanton Lime Works, Champlain Valley Lime Corporation (Winooski), Green Mountain Lime Company (New Haven Junction), Brandon Lime and Marble Company (Leicester Junction), Vermont Marble Company (West Rut-



7-16. Close-up view of the side draft vent design at the base of one of five kiln ruins near New Haven Junction, showing the double arch of firebrick and single support column in the middle. Vent hole today is choked with collapsed firebrick that formerly lined the inside of the tall iron shell above it.

land), and Pownal Lime Company. Notably missing are the Amsden Gray Lime Company (Weathersfield) which shows up in the 1924 and 1926 reports, and the Vermont Lime Products Company (Mount Tabor), which appears in no reports. By the 1930 report, only lime operations at Highgate Springs, Swanton, Winooski, New Haven, Amsden, Rutland, and Pownal are listed. That same year, the State Geologist wrote: "In going over Vermont in order to examine the ledges or outcrops, one comes across many old lime kilns of very simple construction and evidently used in old times for burning small quantities of limestone. Good limestone is not abundant in Vermont except in the vicinity of Lake Champlain on the western border. All of these primitive kilns have long since been abandoned, as new and far more efficient furnaces and new machinery have been invented and become available. It has required only a small number of these lime works to supply a much greater need than formerly existed and, of course, with far better results" (Perkins 1930:259).

By 1935 quicklime was made only at Swanton, Fonda, and New Haven, and hydrated lime at Winooski and West Rutland. Lime production varied during the seven years from 1929 to

1935 (Jacobs "Mineral Industries" 1937:19):

| Year | Short Tons | Value |
|------|------------|-----------|
| 1929 | 43,923 | \$362,169 |
| 1930 | 40,648 | \$319,108 |
| 1931 | 31,218 | \$236,508 |
| 1932 | 29,027 | \$194,359 |
| 1933 | 30,753 | \$200,582 |
| 1934 | 38,015 | \$252,731 |
| 1935 | 44,599 | \$286,006 |

Vermont Associated Lime Industries bought the quarries and kilns at Leicester Junction about 1947, at Winooski Park in 1948, and the Green Mountain Lime Company east of New Haven Junction in 1950. Whether a speculative venture or an honest attempt to consolidate the industry in Vermont so it could operate more efficiently, the company soon came apart. Operations at New Haven and Leicester Junction shut down in the early 1950s. Those at Winooski Park, the last lime kilns



7-17. *Hydraulically operated draw gates at the bottom of the lime kilns at Winooski Park. When these gates were opened, the burned lime fell into waiting railroad cars below. What might have been a rotary kiln is in the background.*

to operate in the state, were sold in 1960 and closed altogether in 1971 (Carlisle 1975:13).

At New Haven Junction, only a mile west of the ruins of the Green Mountain Lime Company's five lime kilns, the White Pigment Corporation (OMYA, Inc.) carries on a somewhat modern version of the 19th- and 20th-century lime-burning business. With sophisticated computer-controlled technology, calcium carbonate filler and extender is produced from limestone that comes from a quarry near East Middlebury for paint, plastic, paper, and foodstuffs. Limestone is crushed at its Florence plant, about 10 miles north of Rutland, where production capacity is 500,000 tons of the fine powder per year. Average particle size for the different products ranges from 0.000001 to 0.000021 inch in size, a very fine product similar to talcum powder. The beginnings of the company date to a time when lime and oil were mixed for whitewash and caulking. White Pigment is owned by Vermont Marble Company, itself a subsidiary of Pluess-Stauffer of Switzerland (James Stewart letter to author, Dec. 6, 1989).

At Swanton village, limestone is still quarried and processed by Shelburne Limestone Corporation (since 1987), although hydrated lime is no longer made and the kilns have long since disappeared. Giant computer-controlled machines now produce various grades of crushed stone (Douglas "Swanton Limestone" 1988:61). Only large circles on concrete platforms show where the tall kilns once burned lime.

Lime Kilns Outside Vermont

Lime kilns of all makes, ages, and states of survival dot the entire New York-New England countryside, and wherever limestone is seen in hillside escarpments or highway cuts, there is probably a lime kiln ruin or remain nearby. Some noteworthy

kiln ruins not far from Vermont are just across Lake Champlain in New York, about a mile south of the village of Chazy. Here stood the impressive ruins of a half-dozen early-20th-century lime kilns whose tall, rusted iron shells swayed and groaned in the lake-driven wind until they were toppled, leveled, and carted away for lakeside fill in the early 1980s. The property owner felt that an enlarged boat landing on the lake far outweighed the historical resource value of the site. Luckily, some measurements and photos along with a firebrick inventory were made only a year or two before. Point aux Roche, about five miles to the southeast, was known nationwide for high-quality limestone quarried here and burned for cement, but it is unknown if there are any kiln ruins or remains; the site has not been visited.

At the New York end of the Champlain Bridge from Chimney Point is the Crown Point State Historic Park, site of the ruins of Fort St. Frederic where the French burned some lime during their 18th-century occupation of this part of the country. In an open field about a mile south of the park's reception center and museum is the ruin of a more modern kiln where lime was burned for industrial interests at Port Henry. Remains of the railroad that ran from the kiln across shallow Bullwagga Bay to Port Henry are still visible. When the State of New York acquired the kiln property someone started demolishing the stack and managed to open the top half of the east wall before being stopped. That opening today exposes the colorful stone lining that would otherwise remain hidden to all (except the author, who braved spiders and bees' nests to crawl inside the kiln through its ground-level openings). The remains of the charging ramp to the top of the kiln are visible just uphill of the ruin.

Twenty-five miles west of Bennington is Bald Mountain, in the western part of Greenwich (Washington County), New



7-18. Collection of firebricks lying on the floor of the main kiln building at Winooski Park after having fallen out of the stacks above.

York, the site of a large lime-burning complex which started burning lime as early as 1785. By 1849 there were 16 kilns in operation (*N.Y. State Agricultural Society* 1850:851). Three years later, under new ownership, 10 new kilns were built, producing 160,000 barrels of lime a year (Johnson 1878:355). Two towering ruins were still standing when inspected in 1991.

At Adams, Massachusetts, 10 miles south of Stamford, Vermont, are the operating lime kilns of Pfizer, Inc. These tall, ancient-looking, but really modern concrete-wall kilns are gas-fired units that burn a particular quality limestone for a specialized product. Lime made here is used in soil stabilization, acid neutralization, and desulfurization of steel. It is also used in the treatment of industrial wastes and sewage and proved to be

a cure for an odoriferous problem at a nearby landfill. The better lime, called PCC, is used in sealants and plastics, papers, paints, rubber, and drywall compound and is sold worldwide ("Pfizer Completes a Major Face Lift" *Berkshire Eagle* May 14, 1991:D2).

A few miles farther south in the town of Cheshire, the ruins of a spectacular multi-kiln plant stand at the west end of the causeway near the south end of Cheshire Lake, at what was once known as Farnums. This plant closed about the same time as the one at Winooski Park (and might have been owned by the same firm), yet much can still be learned about the technology of the industry from the abandoned machinery that is now inhabited by birds and animals.



7-19. Four active lime kilns (background, right) at Adams, Massachusetts, operated by Pfizer, Inc.