Conserving Resources, Saving Lives: Strip Mining Coal in America, 1880-1945

By
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Our coal mining wastes . . . one-half our coal, which is absolutely indispensable for our present industrial life.
—Gifford Pinchot, 1908

Stripping methods [of mining coal] furnish complete conservation.
—Eli Conner, 1911

Gifford Pinchot became the first chief of the United States Forest Service in 1905. Like other Progressives, Pinchot worried about the costs of laissez faire, and he is usually remembered for his life-long advocacy of forest preservation. But Pinchot's concerns extended beyond forests to include, among other resources, coal. At then-current rates of consumption, he warned a public audience in 1907, "our supplies of anthracite coal will last but fifty years." The next year President Theodore Roosevelt called a governors' conference to discuss the conservation of natural resources. The conference led to a subsequent National Conservation Commission. Its three-volume report, issued in 1909, documented widespread, apparently needless, waste of forests, coal, oil, natural gas, and other resources, and warned that the nation might run out.[1]

Suddenly people saw the need for conservation everywhere. Nor was interest limited to scientists, politicians, and scribblers. It appears to be a natural human need to imagine you are doing good while doing well and so businessmen and -women soon adopted the new cause as their own. Wood preservers denounced a tariff on creosote as antithetical to conservation. For the International Railway Fuel Association, founded in 1909, saving railroad coal was also doing a public good. The nascent work safety movement spoke of conserving workers' lives.

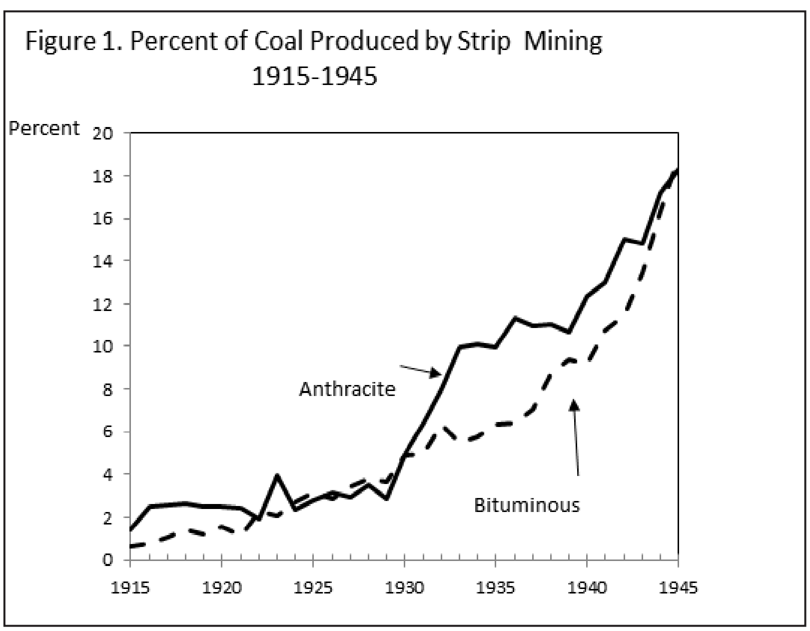
Publicists for the railroads urged stricter penalties for trespassing to conserve human life as well, while illuminating engineers explained that better lighting conserved vision. The "fundamental aim" of studying fatigue, efficiency experts Frank and Lillian Gilbreth explained, "is conservation." Scientific management, tractors, and machines all conserved labor in the workplace, while new household appliances conserved women's strength. Even the strip-mining of coal, which saved resources, labor, and lives, was seen as a form of conservation.[2]

While American strip mining of coal employing power equipment dated from the 1870s, it first became important at about the time of World War I, when it began to grow rapidly. By 1945, 18 percent of both anthracite ("hard") coal and bituminous ("soft") coal came from stripping (Figure 1).

Historians of the Progressive Era's conservation movement have largely ignored the coal industry. Nor has there been much historical writing on strip mining.[3] Yet worries over the wastes and long-term availability of coal and other fuels were central to conservation concerns during these years, and strip mining needs to be understood in this context, for it provided a market response to these worries.

Modern writers emphasize the environmental damages of present-day stripping, yet Progressive environmentalists were not blind to its harm. Rather, they saw stripping as a conservation measure and viewed it as an acceptable tradeoff between different resources. In addition, historians sometime contrast "preservation" and "wise use" as alternative environmental visions. Yet strip-mining coal, as will be seen, blurs this distinction. Finally, the rise of strip mining is important because it emerged just as the great energy transition from coal to oil and gas began to gather speed. One of its results—like fracking today—was to retard that transition a bit. Writers on energy transitions have observed that it is often difficult to dislodge an existing system, and the strip mining of coal provides an historically important case study.[4]

This paper begins with a brief review of Progressive Era worries over the wastes associated



U. S. Bureau of Mines, Mineral Resources of the United States *and* Mineral Yearbook*, various years.*

with coal production and consumption. It distinguishes between popular and engineering definitions of waste and points out that the wastes contemporaries emphasized included not only coal but also the loss of life in mining. The next section explains the sense in which stripping conserved natural resources, and also briefly reviews early efforts to reduce its environmental damages. The following section discusses the technology and economics of early strip mining. Section four discusses the evolution of stripping technology and traces the expansion of stripping from World War I through World War II, one result of which was surely to slow the transition to liquid fuels. The final section demonstrates that achieving safer working conditions that would conserve human life was also an important concern of early environmentalists. It compares labor in strip mining to that in underground work and demonstrates that strip mining conserved lives as well as coal.

Conserving Coal, Reducing Waste

In 1909 the National Conservation Commission published estimates of American coal reserves and discussed the many ways in which coal was wasted.[5] Its findings and conclusions were widely and respectfully discussed in both popular and technical publications.[6] Joseph A. Holmes gave its summary of mineral resources. He had been head of the North Carolina Geological Survey and in 1905 moved to the United States Geological Survey, where he led the Technological Branch. There he supervised its studies of fuel research, and in about 1907 began investigations into the wastes involved in coal mining.[7]

Relying on data in a subsequent volume provided by two other U.S.G.S. scientists, Homes informed readers that in bituminous coal mining, about one ton of coal was irretrievably lost for each ton actually mined. In anthracite the wastes had once been even worse, but by then were somewhat less, with only about .4 tons lost for each ton produced. The nation's *available* soft coal supply could be exhausted by the year 2050, he informed readers, while, as Pinchot had warned earlier, the situation for anthracite might be even worse.[8]

It is important to emphasize that Holmes, Pinchot, and others differentiated between coal reserves and *available* coal reserves, for while they realized that reserves might be vast, easily available reserves were not. Thus, in his public pronouncements Pinchot had simply warned that we would run out of anthracite coal, but in the commission's overall summary, to which his name was attached, he qualified this claim. The "*available and easily accessible* [emphasis added] supplies of coal... [will,] at the present increasing rate of production,... be so depleted as to approach exhaustion before the middle of the next century." Similarly, Charles Van Hise, the distinguished geologist and president of the University of Wisconsin, cited commission statistics suggesting that "available and accessible" coal would be gone by 2027.[9]

These concerns with coal also reflected the belief that it had no good substitutes, for available natural gas and oil reserves were, everyone imagined, even more limited in supply, making coal conservation all the more important. Relying on the work of David Day of the U.S.G.S. that formed part of the commission's report, Pinchot concluded that oil "can not be expected to last beyond the middle of the present century." Natural gas was equally limited, and again relying on Day's work, Holmes claimed that supplies from existing fields might last no more than another twenty-five years. Throughout the interwar years, these worries that oil and gas reserves were extremely limited reinforced the continuing need for coal conservation.[10]

While the wastes associated with burning coal were equally vast, "even more serious than the question of waste of materials," Holmes claimed, "is the excessive loss of life in our mining and metallurgical operations." Holmes knew that he did not have to spell out the details of this "excessive loss of life." Two years earlier, just three explosions in December 1907 had made national headlines, killing 635 men, while altogether 2,534 men died mining bituminous coal that year. These failures of mining to conserve either coal or men provided yet another example to Progressives of the dangers of unfettered laissez faire.[11]

Accordingly, Congress established the U.S. Bureau of Mines in 1910; its purposes were to "make mining in the United States less wasteful of life and resources." For Holmes, and doubtless for other scientists like him, these wastes were matters of ethics as well as efficiency. There was "no right to waste that which is not needed for present use," he thought. "In a higher way, our mineral resources should be regarded as property to be used and to be held in trust with regard to both the present and future needs of the country." Holmes went on become the bureau's first director where he would devote the remainder of his life to the reduction of these wastes.[12]

Waste, however, was not easy to define. To the public, perhaps, and to politicians, waste was as simple as coal left in the ground, or unrecovered byproducts, but to engineers, waste was synonymous with inefficiency—unscientific mining practice—and so some of what the public termed "waste" often reflected economic decisions based on costs, prices, and technology. Holmes had made this distinction earlier, in his presentation to the Conference of Governors in 1908. "Unnecessary waste" meant coal lost from inefficiencies, and this clearly should be prevented. "Necessary waste," however, was coal lost because it was uneconomic to mine under current conditions. The editor of *Engineering and Mining Journal* made the same point at about the same time, observing that "much apparent waste ... is not waste at all." Yet, over time, even "necessary" waste might be reduced due to improvements in technology or changes in prices.[13]

Geologists and mining engineers had long made this distinction, for the Conservation Commission's data were the outcome of decades of research on coal mining. In the late 1870s, the Pennsylvania legislature had directed the state's geological survey to report on the wastes of anthracite mining, which it did in 1881 and again in 1883. A subsequent report appeared about a decade later.

Franklin Platt wrote the 1881 report on anthracite mining practices. In it he noted that while then-current practice left thin seams of coal, "without doubt [seams] as small as 15 inches will be worked here to a profit ... after the larger ones have been exhausted as to make coal higher in price." He went on to note as well that while more coal might be mined if European methods (longwall mining) were employed, the combination of cheap coal and expensive labor precluded such changes. Similarly, in 1883, H. Martyn Chance of the Pennsylvania Survey, observed that "only a few years since, coal[s] of the size now marketed as pea and even chestnut were discarded as refuse." [14]

Marius Campbell and Edward Parker, who assembled the Conservation Commission's coal report, also acknowledged that much of the coal that had been "wasted" reflected "low selling prices" that made its mining uneconomic. At about the same time, Israel C. White, West Virginia's state geologist, made the same point, noting that thin coal seams and dirty coal were "wasted" because they were too expensive to mine or lacked a ready market. In 1911 the editors of *Mines and Minerals* assured readers that larger, better capitalized mines conducted with better "engineering ability" were already increasing the percent of coal recovered. A decade later, the United States Coal Commission also noted that much of what was termed "waste" was a matter of economics. Whether waste was avoidable or unavoidable was "largely a question of cost ...[and] granted a sufficiently high price ... there are very few ... losses ... that could not be overcome." Thus, as coal became increasingly scarce and valuable and mining technology improved, market forces would ensure that such waste would begin to disappear. In fact, conservation did not have to wait for increasing scarcity, for at about this time strip mining ap-

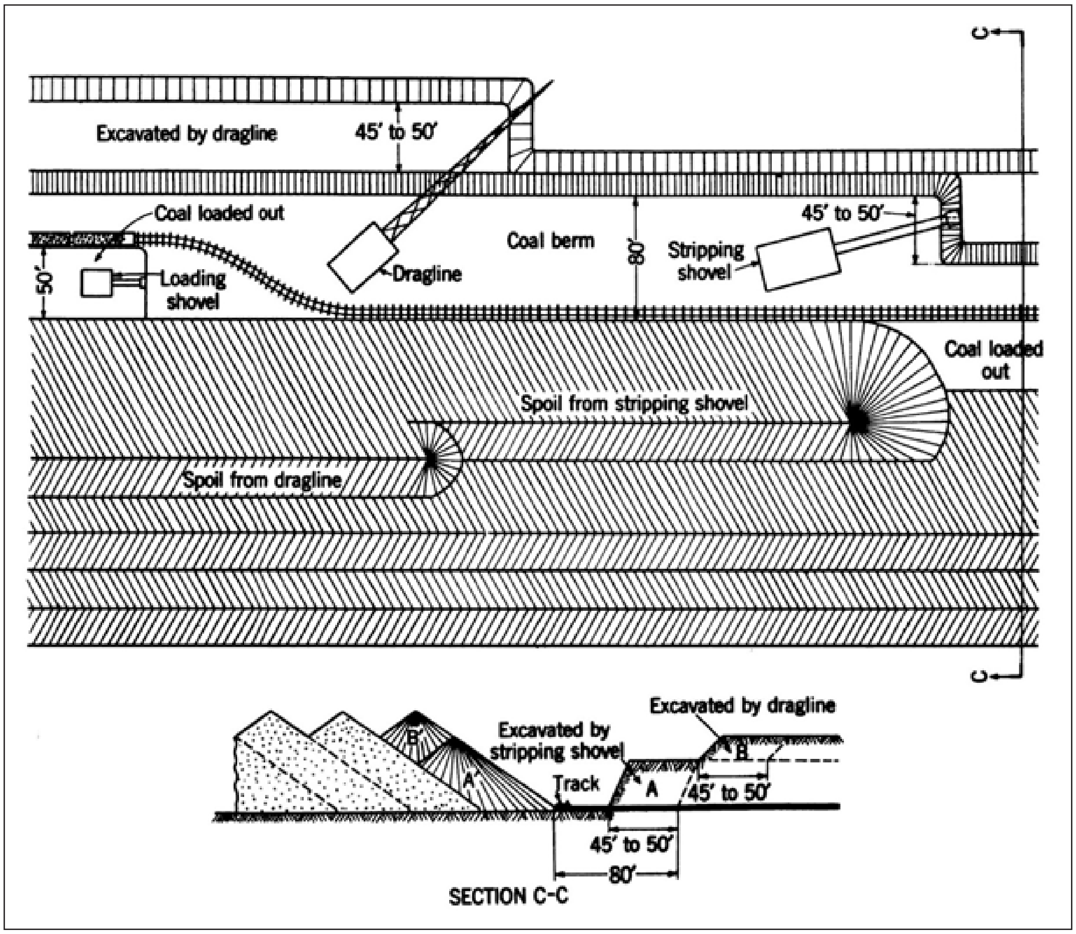


Figure 2. Vertical view of a strip mine layout with work progressing from left to right; the dragline removes the top cover that it casts farther than the stripping shovel could. Combined they can work deeper seams than could the shovel alone. Both shovels and dragline are working on previously exposed coal. (From USBM Information Circular 6957 *(1937).)*

peared.[15]

Strip Mining as Resource Conservation

There were and are several common types of strip mining. The most widely employed during those years was area mining, which worked well in comparatively flat parts of the Middle West. In this approach, the overburden might be blasted—with either dynamite or black powder—if necessary. Typically, a large power shovel or dragline (or both) would then proceed across the coal, stripping the overburden and dumping it in a ridge in a previously worked area—either directly or employing a conveyer to do so (Figure 2). Workers would then blast the exposed coal and hand load it directly into railroad cars headed to market without cleaning or sizing, although by World War I small steam shovels were replacing hand loading. At the end of the seam or property, the process worked backwards, depositing the spoil in the previously mined area.[16]

Adam Smith reminds us that "it is not from the benevolence of the butcher … or the baker that we expect our dinner but from ... their self-interest." Accordingly, for entrepreneurs, the great attraction of strip mining was its profitability. But for others with broader interests, what made it a conservation measure was its ability to extract coal that underground methods could not mine and might irretrievably destroy. Eli Conner was a mining engineer who claimed that his father had introduced steam shovel mining for anthracite in 1881. In 1911, the son rehearsed the by-then standard indictment of America's wasteful mining techniques, but pointed out that "stripping methods furnish complete conservation."[17]

Stripping conserved coal in three ways. One was that the steam shovel allowed mining of coal too shallow for underground methods. On the eve of World War I, *Coal Age* reported on stripping operations in Pennsylvania, Ohio, and Kansas where "the extraction of coal ... could not be secured by any other means." A writer in 1920 reported stripping where "the cover is so shallow and the roof 'so rotten'" that underground mining was impossible.[18]

A second conservation advantage was that strippers could re-work fields previously mined via underground methods that had left coal either because it was too shallow or was needed for pillars or roof. In 1916, *Coal Age* reported on a large underground mine near Hazleton, Pennsylvania, that had been abandoned as worked-out, but which when re-worked by strippers was expected to yield "many thousands of tons of coal." In the 1920s some anthracite strippers were mining the same bed for the third time; there had been an underground working and then a previous stripping, but with better equipment a second striping extracted even more coal. "Stripping Completes Recovery of Deep and Already-Mined Beds," ran a 1929 headline in *Coal Age*. In the late 1930s, Illinois stripping companies reported working much land in the southern part of the state, where underground mining had long since been abandoned as unsafe and unprofitable. "As a natural resource conservation measure," the strippers crowed, "coal stripping is the ideal." A variation on this theme was that because stripping cost less than underground work, strippers might re-work an old bed where underground mining had become uneconomical.[19]

The third way that stripping conserved resources was by recovering a larger fraction of the coal than was achievable by underground working because it did away with the need for roof support. In Illinois, in the late 1920s, underground mining got out almost precisely half of the coal; by contrast, stripping in that state at about the same time recovered 90 to 98 percent. Such conservation concerns shaped views on stripping throughout these years. As late as 1947 the Bureau of Mines was claiming that "strip mining ... recovers more coal ... than underground mining and therefore is an important factor in the conservation of this valuable natural resource." Stripping, in sum, "created" more available coal.[20]

Yet if stripping created more available coal, in the process it "absolutely destroys the land for farming purposes," a writer bluntly asserted in *Coal Age* in 1916. Occasional dissenters, such as E. C. Drum, informed *Coal Age*'s readers in 1917 that, "disturbance of the surface improves the land for agricultural purposes." A later writer noted that when stripping turned over the soil near Frontenac, Kansas, it replaced clay with shale thereby improving its fertility.[21]

If such improvements were probably rare, neither was there much criticism of the effects of stripping on the landscape during these years. A 1916 story in the *Kansas City Star* did report on the destruction of farmland occasioned by stripping in that state, noting that "twelve hundred acres of prairie and farm land [*sic*] has been turned upside down." Criticism of stripping, the paper pointed out, came from unions worried about job loss from more productive, lower-cost competitors, and from real estate dealers, bankers, merchants, and others who worried about property values. Thus, the critique was not environmental but economic. The paper also observed that the farmers in question had sold the land that was otherwise worth $20 an acre for $500 to $1,200 an acre. A search of Illinois and Indiana farm papers yields almost no criticism of stripping before World War II. In the 1920s and 1930s, with much of agriculture in depression and farmland depreciating, farmers with coal underlying their lands could not afford the broader concerns that motivated more well-to-do, urban environmentalists in the post-war years.[22]

For many, then, strip mining offered an acceptable trade off. Mining engineers pointed out that most stripping worked low-value land, and that the coal recovered was of far greater value than the farm production lost. Market forces were, as they saw matters, generating an efficient result. As one writer put it, this too was "real conservation," for "the world needs to be warmed as well as fed."[23]

All the same, many contemporaries wished to minimize the environmental costs of stripping. To mining companies, leveling the land was unthinkable as that would have essentially doubled excavation costs, but, as the *Kansas City Star* noted, some other form of economic reclamation was even then being talked about. In the 1920s and 1930s a number of states saw efforts to regulate stripping and legislate reclamation, but little seems to have come of them.[24]

Beginning in the late 1920s, however, coal companies worried about such potential legislation began reforestation and other efforts to make strip-mined land again economically productive. By 1942, Illinois strippers had formed an association to take care of reclamation, and, working with state agencies, had reforested 7,250 of the roughly 16,000 acres that had been stripped, planting about seven million trees. In Indiana, a strippers' association planted about 3.4 million trees on reclaimed land from 1934 through 1938, and a similar efforts were underway in Ohio. In Pennsylvania, market forces were moving *underground* coal companies to begin reforestation because they had stripped local forests bare, using the wood for roof support.[25]

In the late 1930s, the Bureau of Mines studied reclamation in Illinois, Indiana, Kansas, and Missouri and was cautiously optimistic. It found stripped land that had lain idle for several decades where natural vegetation had come back strongly, and in one instance was growing trees twelve to twenty-four inches in diameter. Some of the land was being leased for hunting and—because the last cut of a strip usually filled with water—fishing. Some land had become a state park. The bureau was skeptical that reclamation for farming would pay, but it reported successful reforestation efforts in all of the states that it studied. The early post-war years generated much research into these early efforts that found considerable success in reclamation for ranching as well as forestry.[26]

Beginnings: Technology and Economics

Stripping possessed certain inherent advantages over underground work. Most obviously, there was no need to support a roof, and thus no need for the vast amounts of timber consumed by underground operations. Strip mining, that is, conserved forests. In stripping there was also no need for ventilation. Machinery, including mine cars and locomotives, could be much larger as well. Companies could open a strip mine comparatively quickly, and, because much of the capital investment was in equipment and therefore mobile, the mine had a higher salvage value than investment in an underground mine, much of which consisted of tunnels and timbering. Finally, stripping saved labor and was much less dangerous than underground work.[27]

While power strip-mining for coal dated from as early as the 1870s, it seems to have been unimportant until the first decade of the twentieth century. The keys to its expansion lay in the interaction of geology, technology, and economics. Given technology and the price of coal, there is some maximum amount of overburden that can be removed per foot of coal seam that will allow a company to turn a profit. The size of this maximum overburden will, in turn, increase with the price of coal and the productivity of stripping equipment.

For example, using the formula below, suppose that coal is selling for $2.00 per ton. Mining costs are $0.75 per ton, the target profit is $0.25 per ton, and the cost of removing a yard of overburden is $0.20. The maximum ratio of overbur-

$$\frac{\textit{Overburden (ft.)}}{\textit{Coal (ft.)}} = \frac{\frac{\textit{Price}}{\textit{ton}} - \frac{\textit{Profit}}{\textit{ton}} - \frac{\textit{Mining cost}}{\textit{ton}}}{\frac{\textit{Excacation cost}}{\textit{yd.}}}$$

den per yard of coal that it will pay to remove is five, or, for a five-foot bed of coal, twenty-five feet of overburden.[28]

Nineteenth century stripping equipment was simply not sufficiently large and efficient to make very much stripping economical. That is, with excavation costs per yard high (and coal cheap), the ratio of overburden to coal was necessarily low. When stripping began in the 1880s the economic ratio of overburden to coal was about 1:1, hence little coal could be stripped.

Early power equipment included dredges, drags, and most often, shovels. These latter were small by later standards: the first employed in anthracite stripping had a 1.75-cubic-yard bucket. They were made at least partly of wood and were often not sturdy enough for stripping (Figure 3). All early equipment was steam powered, which required a coal and water supply and a fireman. Early railroad shovels ran on tracks and could not revolve a full 360°, both of which slowed production and raised costs (Figure 4). Such equipment could only mine shallow coal, and beds close to the surface are likely to be of poorer quality, weathered and with reduced energy content. Heavier equipment could extract deeper coal and deeper coal meant better coal.[29]

In the early twentieth century, stripping technology improved rapidly and dramatically. In 1914, the Bureau of Mines reported that the average ratio of overburden to coal was about 6. In 1930 it had risen to 7.6, and more in some states where coal prices were higher. At about that time one writer in *Coal Age* thought the bureau's estimates were conservative, claiming that even with average prices, better technology had raised the economical stripping ratio to 15:1.[30]

The first really successful stripping shovel did not arrive until 1911, when a mining operation approached the Marion Steam Shovel Company with a proposal for a heavier, self-propelled, revolving shovel with longer range. Marion responded with the Model 250 with a 65-foot boom, a 40-foot dipper stick, and a 3.5 cubic yard bucket (Figures 5). It was fully revolving and had a hydraulic leveling system. Bucyrus followed the next year with similar equipment, and their rivalry and close association with buyers would spur rapid technological change in stripping equipment from then on. A Marion catalog explained how closely that company worked with buyers. "The builder is seldom called upon to exactly duplicate a former machine," it noted, and stressed that "our engineering department is at all times available for the adaptation of our machinery to special requirements." This close association resulted in intimate knowledge of buyers' needs and, combined with competitive rivalry, it resulted in rapid technological advance.[31]

The first electric shovels appeared in 1915, and they grew rapidly in size; the largest at that time sported eighty-foot booms and eight-cubic-yard buckets. The bureau first took official note of what it termed "steam shovel mining" in 1914, doing a partial survey. A more complete survey in 1915 found such operations digging soft coal in Alabama, Illinois, Indiana, Kansas, Missouri, Ohio, and Oklahoma, with a collective total of eighty-seven shovels and 2,300 workers producing 2.8 million tons of coal—about 0.6 percent of that year's total.[32]

Like most new technologies, early stripping had a number of teething problems. Some strip mines had no tipple and so uncleaned coal was simply loaded into freight cars to be sold. Not

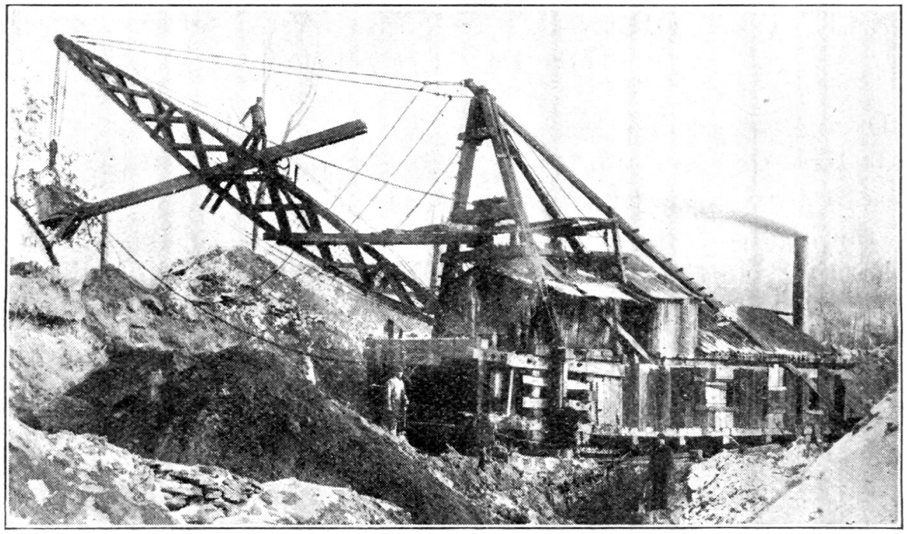


Figure 3. This homemade stripper of 1886 was made mostly of wood and was a converted dredge mounted on wheels that required a block and tackle to move. It stripped ten to fifteen feet of cover to expose a six-foot seam of coal. (From USBM Bulletin *289 (1929).)*

Figure 4. A steam-powered railroad shovel demonstrating almost its maximum ability to rotate. By the 1920s, these were fast being replaced by fully rotating, electric, and later diesel-powered, shovels operating on caterpillar tread. (From The Bucyrus Company *(1910).)*

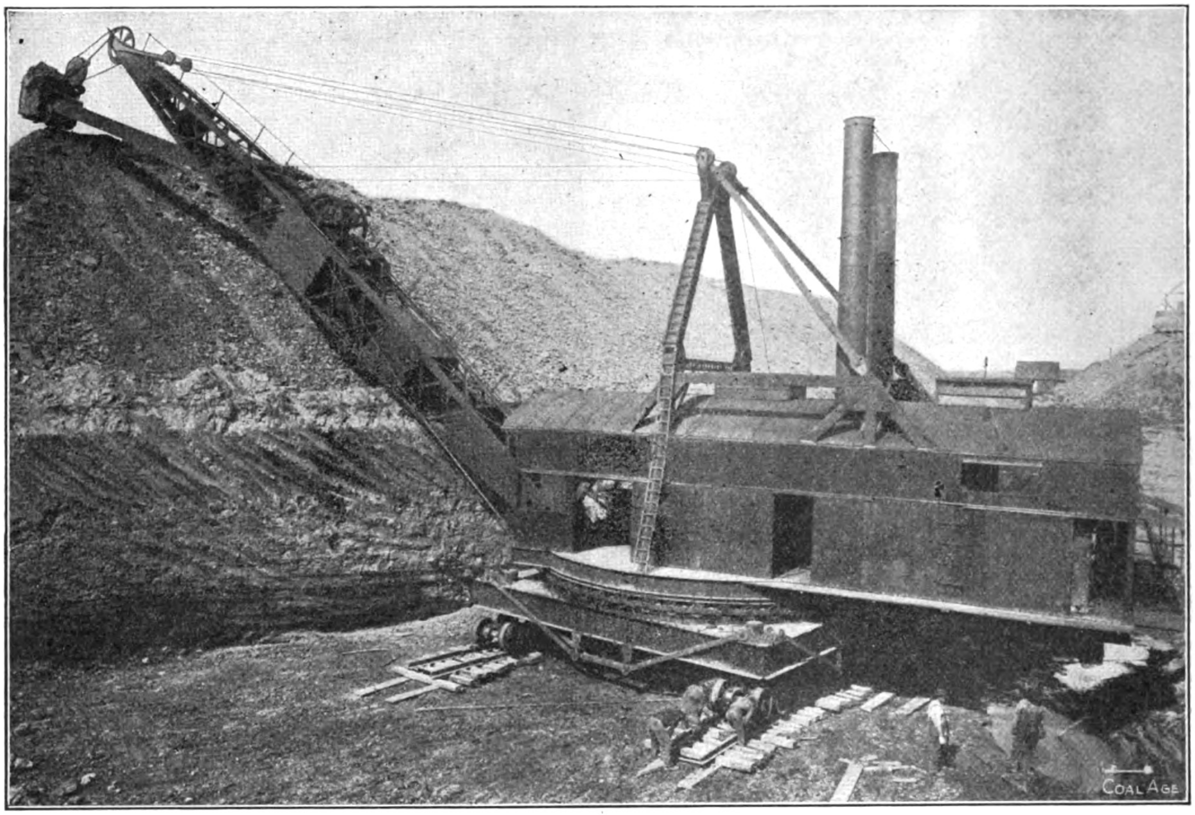


Figure 5. The world's largest steam shovel in 1913. The Marion Model 250 was fully rotating, weighed 525,000 pounds, had a ninety-foot boom and a five-cubic-yard bucket. For scale, compare the men to the side of it. Note that it travels on track. Within a decade, the next generations of shovels would make it seem tiny. (From Coal Age, *4 Jan. 1913.)*

surprisingly, in the early years stripped coal often sold at a discount from that mined underground. In 1920 *Coal Age* noted that poor quality was giving stripping a bad name. The bureau also pointed out another difficulty plaguing early stripping: whereas underground mines operated an average of 238 days in 1914, the strippers averaged only 187 days—a result of equipment failures and bad weather, for strip pits had a propensity to flood.[33]

Despite such problems, stripping retained an enormous productivity advantage compared to its underground rivals. For soft coal, output per worker-day in 1915, was 3.9 tons in underground work versus 5.9 tons in stripping, a 50 percent advantage. Stripping, that is, saved labor as well as coal—an edge that the labor shortages of World War I would soon emphasize. As the bureau put it: "a smaller number of men is required for a given output in this method of mining."[34]

From War through War: Stripping Spreads

Figure 1 (p. 52) and Table 1 help provide an overview of the rapid expansion of bituminous stripping during the years including the world wars. From beginnings in six midwestern states with 87 shovels at work in 1915, coal stripping had spread to twenty-five states and used over 2,400 shovels by 1945. During these years, production spread from the Middle West east into Pennsylvania, Kentucky, and West Virginia and

Table 1 Bituminous Coal Stripping 1915-1945	1915	1925	1935	1945
No. of States	6	18	19	25
Pits	NA	227	368	1,370
Shovels	87	144	497	3,439
Coal (Tons)	2,831,619	19,870,909	23,647,292	109,986,865
Percent of US Total	0.6	3.2	6.4	18.9
Employment	NA	8,609	10,484	33,569
Productivity*	6	11.2	18.07	15.48

Source: U.S. Bureau of Mines, Mineral Resources and Minerals Yearbook, various years and author's calculations.
*Tons per employee-day

west to Montana, South Dakota, and other states. Productivity rose from not quite six tons per worker-day in 1915 to over fifteen by 1945. Output over that period rose twenty-seven times, an annual rate of not quite 16 percent per year.

Stripping thus evolved from a technique that might mine coal unavailable with underground methods to an approach that was economically preferable under an ever-widening range of circumstances. Accordingly, the market share of stripping for both hard and soft coal reached 18 percent by the end of World War II and continued to expand, reaching 41 percent for anthracite and 55 percent for bituminous mining by 1975. By 2020 stripping's market share had risen to 62 percent.

World War I kicked off this expansion by generating an immense demand for coal. The mine price of bituminous coal, which had been $1.13 per ton in 1915, hit $3.75 per ton in 1920, while anthracite prices went from $2.07 to $4.05 over the same period, with widespread shortages of both coals as well. As the Bureau of Mines observed, the spread of stripping reflected "the dispatch with which a property suitable for this method of mining can be opened up and equipped for large scale production." At a time of severe labor shortage, stripping's conservation of labor also made it attractive. Accordingly, stripping's output share of both hard and soft coal roughly doubled during World War I.[35]

Some contemporaries thought that the wartime growth of stripping was an aberration that would quickly die in more normal times. Indeed, production of both underground and strip-mined coal fell sharply in 1921. Thereafter however, they parted company. Alternative sources of energy and power—oil, gas, hydroelectricity—began to chip away at the markets for both hard and soft coal, while major customers such as railroads, coke producers, and electric utilities also sharply increased their energy efficiency. As a result, aggregate sales of anthracite fell steadily after 1917, while bituminous coal production peaked in 1918 and stagnated thereafter.

Of course, the new competition came at the expense of high-cost coal producers, which were the underground workings. The number of underground soft coal mines declined by nearly 2,500 between 1919 and 1939. Strip mine production, by contrast, recovered quickly, as companies made investments and rapidly improved technologies and operating methods that steadily enhanced stripping's competitive position.[36]

The trend toward giantism in shovels and draglines continued. Stripping shovel capacity and efficiency grew steadily; by the early 1920s, five- to eight-cubic-yard buckets with 85- to 90-foot booms were common. By the end of the decade buckets that held twelve to fifteen cubic yards on 120-foot booms had appeared (Figure 6). By 1940 there were 35-cubic-yard stripping shovels, and some mines employed seven- to ten-cubic-yard loading shovels. Very large drag lines also appeared. By World War II some had 215-foot booms and fourteen-cubic-yard buckets, sometimes employed in concert with power shovels (Figure 7), and sometimes as substitutes. Drag lines could move spoil longer distances and thus allow economical mining of deeper coal. By 1945, draglines were mining deeply pitching seams of anthracite down to four hundred feet.[37]

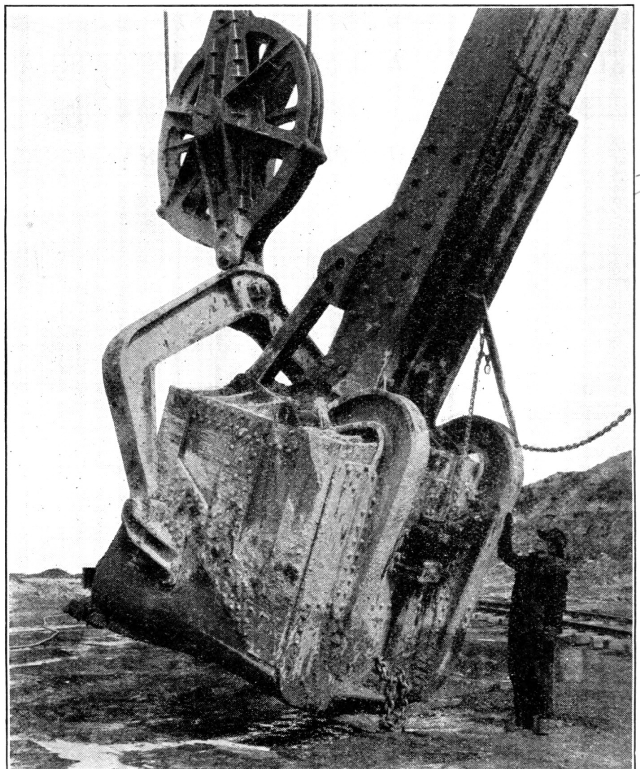


Figure 6. A twelve-cubic-yard bucket circa 1929. It dwarfed the shovels of a decade earlier and would in turn be dwarfed by the thirty-five-cubic-yard buckets of 1940. (From USBM Bulletin *289 (1929).)*

Figure 7: A dragline with a fourteen-foot bucket stripping overburden at Maumee collieries in Indiana in 1941. By World War II such equipment came with 215-foot booms allowing the mining of thin coal under heavy cover. (From William Rittase, courtesy of PDNB Gallery.)

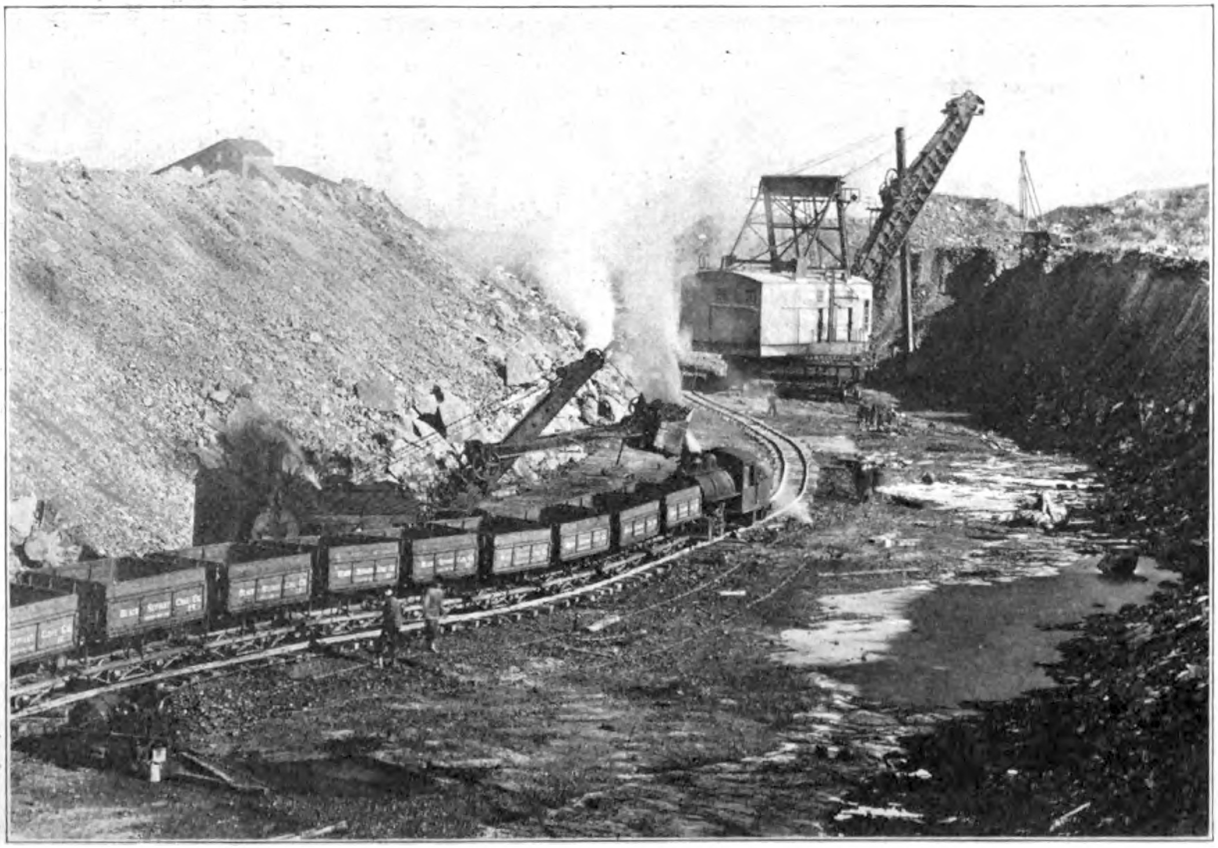


Figure 8. An electric-powered stripping shovel on caterpillar tread with a six- or eight-cubic-yard bucket and a loading shovel in Illinois about 1925. The shift from steam to electricity sharply increased productivity. Both shovels are operating on the exposed coal; the spoil bank is to the left and stripping is proceeding right to left. (From Illinois Geological Survey Cooperative Mining Series Bulletin *28 (1925).)*

Digging equipment became more sophisticated as well. In the 1920s revolving shovels supplanted older types. Caterpillar traction first appeared on smaller coal loaders in the early 1920s, and by the end of the decade it had become common on the largest stripping shovels. As commercial electric power spread in the 1920s, electric operation gradually replaced steam, accounting for 35 percent of all shovels by 1931 (Figure 8). Electric shovels could swing faster than steam and experienced far less expensive downtime; one company kept them operational 90 percent of the time versus 68 percent for steam. In addition, electric operation required three operators while steam required five. Use of aluminum and alloy steel in buckets and booms arrived in the mid-1930s and since their lighter weight allowed bigger loads, companies switched out ten-yard for twelve- to fifteen-yard buckets. Walking draglines that generated less over pressure than caterpillar tread appeared in the 1930s. These had "feet" that could be pulled up to slide back and forth on the dragline frame. To "walk" the machine backwards, the operator moved the feet backwards, extended them to bear the weight, and then slid the machine back on the feet. In the 1940s, bucket-wheel excavators appeared that could rapidly remove cover that was not too compacted. About 1940, shovels with knee action booms that increased range also appeared. Photoelectric leveling of equipment arrived in the 1940s, as did more sophisticated controls that speeded up movement.[38]

The late 1920s saw the beginning of a revolution in haulage as well, as trucks began to supplant railroads. Rail haulage was especially expensive where coal beds were thin, for track needed to be moved often (one company designed steel ties with ski-tip ends for ease of dragging). Companies switching to truck haulage reported cutting costs as much as 50 percent. In 1938 one Indiana mine reported trucking reduced its costs of hauling coal from sixteen to seven cents a ton. Trucks were more flexible as well; they could climb steeper grades and navigate sharper curves. Initially they burned gasoline or butane, but by the 1940s diesel engines that burned cheaper fuel and required less maintenance were in the ascendance. In haulage as in digging, equipment size steadily rose. In 1932 one company began haulage with trucks of six-ton capacity; by 1939 their capacity had risen to eighty tons.[39]

The speed of technical change in stripping encouraged companies to bet on it as well. In 1938, *Coal Age* reported on an Indiana mine that designed a shovel with a reinforced structure to accept a longer boom that would later be needed to mine deeper coal. Anthracite strippers also planned for stripping operations deeper than was then economical on the assumption that they soon would be.[40]

The increasing size of equipment also reshaped stripping in complex ways. By the 1930s, stripping was far more capital intensive than underground work, requiring $380 of machinery and equipment and 26 horsepower per worker versus $63 and 8.5 horsepower per worker for deep mining. This equipment allowed economical stripping of increasingly heavy cover, and by the late 1930s some pits removed seventeen to twenty yards of spoil per yard of coal. Companies learned to combine use of draglines and strippers in ways that minimized the costs of cover removal; some of them also employed double stripping of two separate seams, thereby increasing recovery. The expense of the giant shovels also led to their operation two or even three shifts a day. Mines employed time and motion studies to calculate stresses on shovel components and ways to increase swing efficiency. One company estimated that, with coal selling for $2.50 per ton, every swing the shovel failed to make cost the company $2.50 in lost revenue.[41]

Economic and technical pressures reinforced the need for improved drainage and led to other changes that reduced the impact of bad weather on operations. By the late 1920s, strip pits operated about as many days as did underground mines. Strippers also improved product quality. After removing top cover, companies began to use tractors and power sweeps to remove dirt that remained, and by the late 1920s most companies shipped stripped coal to a tipple to be cleaned of debris and sized. Here again, large shovels shaped incentives. By increasing the amount of coal that could be economically mined from a pit, and thereby extending the life of the mine, they reduced the annual fixed costs of a tipple, thus making cleaning and sizing more economical. By the late 1920s, coal washing was beginning to spread and the ability to clean small coal increased its value, thereby widening its market and encouraging its conservation.[42]

New methods also appeared for drilling and blasting. Liquid oxygen (LOX) could not be used in underground work because, as a long-flame explosive, it might ignite dust or gas, but in the 1920s, strippers began to substitute it for dynamite for blasting overburden, as it was safer to use and cheaper as well. One mine reported that shifting from dynamite to LOX cut blasting costs from thirty to fifteen cents per ton of coal. In the 1930s rotary drills—a technology borrowed from oil fields—appeared, and these were faster and thus cheaper than older, churn-style drills. Companies increased hole size from four to as much as nine inches in diameter, using more explosive but less labor, and they learned to "deck load" charges, placing differing quantities of explosives at different spots depending on the nature of the overburden.[43] Horizontal drilling also appeared in the 1930s and, where applicable, it proved superior to vertical drilling.[44]

Some small coal beds could not be economically mined with large, specialized equipment, and in the late 1930s construction companies with equipment idled by the Depression moved into stripping. They employed smaller shovels and draglines, as well as off-the-shelf bulldozers, tractors, and scrapers on such beds in both hard and soft coal fields. While these operations might be comparatively high cost, lighter cover, better coal, or market access might provide an offset. The wartime boom after 1940 resulted in an explosion of small operations as it shut off civilian construction and idled many contractors. These small strips did little prospecting, as they often mined outcrop coal too close to the surface for underground work, and many sub-contracted haulage, blasting, or coal preparation. As a result, they could open rapidly—one company began operation in three months. These developments also moved stripping into eastern Ohio, western Pennsylvania, Kentucky, and West Virginia. Between 1940 and 1945, the number of strip pits in Pennsylvania rose from 107 to 542.[45]

The expansion and evolution of stripping during these decades had several important consequences. While it maintained a wide productivity advantage over underground work, labor productivity in stripping stagnated in the 1930s (Table 1) and then fell as the new technology mined deeper seams and as smaller contactors entered the field. Still, stripping retained a cost advantage, and in a stagnant coal market its gains came partly at the expense of the underground industry. In 1930 the Washburn lignite mine in North Dakota that had been worked underground for decades converted to stripping, probably because it was able to cut the workforce from over 270 to 70 employees. And as noted, many underground mines simply closed.[46]

Yet in bituminous mining, at least, stripping also helped protect coal markets that might otherwise have been lost to oil, thereby delaying that energy transition. For example, when stripping of Texas lignite began in the mid-1920s, local coal prices collapsed, and power plants that had previously switched from coal to oil promptly switched back to lignite. And when the Northern Pacific Railroad discovered vast amounts of lignite on its North Dakota properties in 1923, it immediately began stripping and converted its locomotives from oil to coal.[47]

Stripping also continued to make available coal that would otherwise have been lost. Writing in 1930, the Bureau of Mines observed that "today many million tons of coal are being recovered by open cuts from sites that an earlier generation … would have passed by as not commercially viable or if workable at all, only by underground methods." This conclusion remained valid at least through the war years. Smaller contractors stripped coal close to the surface, while reworking older beds remained common. In 1944 *Coal Age* reported on a large strip mine where 73 percent of the coal could not be recovered by underground methods. Of the coal that might have been mined with underground techniques, stripping generated a 30 percent higher yield. And as stripping won more coal, it paid with fewer lives as well.

Stripping Coal, Conserving Lives

Some modern writers have distinguished the conservation movement of the Progressive era from the broader post-World War II environmental concerns. Samuel Hays argues that conservation, to Progressives, meant wise resource use and was largely a technical and economic matter. By contrast, in Hays' evocative phrase, environmentalism concerned "beauty, health, and permanence," an evolution reflecting rising standards of living.[48]

Yet, as a number of writers have emphasized, this distinction can be overdone. There was a strong ethical component to the condemnation of waste, while conservationists were not blind to the health and safety problems of their day. The National Conservation Commission's 1909 report, for example, included a long section by economist Irving Fisher on "national vitality," that focused on life expectancy, illnesses, and public health, as well as eugenics. A related document expressed concern over diet and "poisons in ordinary use," such as alcohol and tobacco, as well as "the pollution of the air breathed by workmen." And, while modern writers have noted these early health concerns, they have mostly ignored that industrial accidents too were a focus of conservationists. Fisher's report claimed that a half million workers a year were "killed or crippled," and in 1912 he repeated these claims in a memorial presented to Congress supporting broader powers for the Bureau of Public Health.[49]

The early proceedings of the National Safety Council are full of references to work safety as an aspect of conservation. Indeed, the council's constitution originally asserted that its purpose was "to promote the conservation of human life ... in the industries of the nation." Charles Van Hise stressed "the conservation of man himself" in his authoritative *Conservation of Natural Resources*, and he too noted the toll taken by work accidents. As noted earlier, mining accidents were then of special concern and the formation of the Bureau of Mines in 1910 was intended not only to investigate ways to conserve coal but also—and perhaps especially—ways to improve mine safety.[50]

Early twentieth century mining literature contains many references to the safety of strip mining compared to its underground cousin. Contemporaries believed that stripping was inherently safer, having more in common with heavy construction than underground mining. Surface mining had no roof to collapse—a danger that typically accounted for half of all fatalities in underground mining. Surface gas and dust explosions were unheard of, and without the problems of confined spaces, electricity and haulage could be made safer, while there was less risk of silicosis and black lung disease.

These dangers were inherent to underground work, but bad technique exacerbated these problems. Thus, skimping on roof support wasted both coal and lives, while sparking electrical equipment was a prolific source of gas and dust explosions. "For speed and safety ... the stripping method is ideal," a writer in *Coal Age* informed readers in 1916. The next year H. H. Stoek, professor of mining engineering at the University of Illinois, made the same point, noting that "from the standpoint of safety ... strip mining is always to be preferred." This theme continued throughout the 1920s. In 1926 it seemed self-evident to Frank Kneeland, editor of *Coal Age*, that stripping was the "safest form" of mining, and in 1928 the

Table 2.
The Human Costs of Coal, 1930-1945

	Fatalities			
	Per Million Employee-Hours		Per Million Tons of Coal	
Year/Type of Coal	Under ground	Strip mining	Under ground	Strip mining
1930				
Bituminous	1.89	0.98	4.15	0.50
Anthracite	1.76	1.66	6.52	3.15
1935				
Bituminous	1.43	1.22	2.74	0.59
Anthracite	1.79	1.60	5.58	1.42
1940				
Bituminous	1.65	0.99	2.82	0.52
Anthracite	1.54	0.82	3.97	0.81
1945				
Bituminous	1.16	0.58	1.90	0.35
Anthracite	1.08	0.11	3.16	0.10
Average 1930-45				
Bituminous	1.45	0.84	2.63	0.44
Anthracite	1.64	0.92	4.92	0.92

U. S. Bureau of Mines, Coal Mine Accidents in the United States, *various years and titles.*

Bureau of Mines simply observed that "accidents and fatalities are low."[51]

The U.S. Bureau of Mines first collected data on strip mining fatalities in 1930, and it confirmed what contemporaries had long asserted: stripping was a far safer way to mine both bituminous coal and anthracite (Table 2). Stripping bituminous coal was hardly risk-free—its 1930 fatality rate exceeded that of railroading or steel manufacturing. Still, the dangers of stripping paled compared to those of underground mining. Over the period from 1930 to 1945, workers' risks in bituminous coal mining averaged 0.84 fatalities per million employee hours in stripping versus 1.45 in underground work, making the latter about 73 percent more dangerous. Similarly, underground work in hard coal mining was about 78 percent more dangerous than work in stripping.[52]

While fatalities per worker-hour measures the risk of death to employees, fatalities relative to coal production captures some of the human costs of producing this form of energy. Using this measure, as Table 2 also reveals, stripping's advantage in mining bituminous coal was even more impressive. Again, over the whole period, 2.63 fatalities occurred per million tons of soft coal mined underground, while in stripping the rate was 0.44, about one-sixth as high. Anthracite stripping was about one-fifth as expensive of life as was underground work. Two reasons existed for such striking disparities in fatalities per ton: not only were risks per worker lower in stripping, that method also required far fewer workers to mine a given quantity of coal.

Detailed figures on injuries begin in 1936. These included those that were temporary, as well as permanent partial injuries that reflected the loss of a finger or a leg or an eye, and permanent total injuries, such as double amputations or total blindness. For both forms of permanent injuries, the relative risks of stripping and underground work from 1936-1945 are similar to those for fatalities. The average rate for all permanent disabilities in underground mining was twice as high as in stripping: 2.13 versus 1.04 per million employee hours. Relative to coal production, underground mining was nearly seven times more productive of permanent injuries: 3.76 versus 0.55 per million tons.[53]

We can illustrate the safety payoff from stripping by constructing the following counterfactual: Suppose that the coal stripped each year had instead come from underground mines with their associated higher fatality rates per ton. This increase—presented for bituminous coal in Table 3—represents the fatalities *avoided* because the coal instead came from stripping. As can be seen, had stripped coal instead come from underground mines at existing fatality rates per ton, about 1,400 more miners would have been killed from 1930 to 1945. Such calculations for anthracite (not shown) indicate that, had it all come from underground work, an additional 370 miners would have died over the same period. Similar reasoning indicates that many more permanent injuries would have occurred had all coal come from underground work—1,630 more in soft coal and 113 more in anthracite mining from 1936 to 1945. Stripping, in short, traded land for lives.

Progressive Conservation

An underappreciated concern of the Progressive conservation movement was the need to husband coal. Running out, experts worried, might occur within a century, while oil and gas reserves had an even shorter life expectancy. Conservation of human life, including the prevention of what appeared to be needless work injuries and fatalities, was also a serious public concern. Progressives such as Gifford Pinchot, Joseph Holmes, and Charles Van Hise publicized what they saw as the profligacy with which Americans wasted coal and lives. A new branch of the national government—the U.S. Bureau of Mines—was created to help prevent the waste of both resources.

What most Progressives and subsequent historians have overlooked, however, is the ways that

Year	Strip Mined Coal (000) tons	Strip Mining Fatalities	Under-Ground Fatality Rate*	Hypothetical Estimated Fatalities	Hypothetical Decrease in Fatalities
1930	19,842	10	4.15	82	72
1931	18,932	2	2.97	56	54
1932	19,641	11	3.26	64	53
1933	18,270	6	2.61	48	42
1934	20,790	8	2.81	58	50
1935	23,647	14	2.74	65	51
1936	28,126	15	2.65	74	59
1937	31,750	8	2.86	91	83
1938	30,407	18	2.70	82	64
1939	37,260	9	2.39	89	80
1940	42,167	22	2.82	119	97
1941	55,478	34	2.26	125	91
1942	67,203	31	2.35	158	127
1943	79,821	33	2.32	185	152
1944	100,898	30	2.07	209	179
1945	109,987	24	1.90	209	185
Total		275		1,715	1,440

Table 3. Conservation of Life from Strip Mining Bituminous Coal, 1930-1945

* Per million tons of coal

U. S. Bureau of Mines, Mineral Resources, Minerals Yearbook *and* Coal Mine Accidents in the United States*, various years and author's calculations.*

market forces supported these conservation measures by propelling the rise of strip mining. On the eve of World War I, the arrival of large-scale excavation equipment made stripping coal relatively profitable for an increasing range of deposits. As contemporaries stressed, stripping extracted coal that would otherwise be lost or obtained only by far more expensive methods. At a time when the availability and expense of coal was of national concern, this was a powerful advantage, and if such benefits came at the cost of stripped land, that seemed an acceptable exchange. Because of its low costs, stripping also protected some coal markets from the incursions of oil and gas. Stripping's other great benefit—that it saved lives—was less well understood, both because it was a comparatively new technology, and because of the absence of data until the 1930s. Yet stripping surely constituted a major and largely overlooked innovation in the technology of mine safety that probably saved thousands of lives.

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Notes:

1. Gifford Pinchot, "The Conservation of Natural Resources," *Outlook* 8 (12 Oct. 1907): 291-4 (quotation on 291); Gifford Pinchot, "The Foundations of Prosperity," *North American Review* 188 (Nov. 1908): 740-52.
2. See "The Prodigal Waste of Natural Resources," *New York Times* (10 Nov 1907); "A National Campaign for the Conservation of Vision," *Illuminating Engineer* 5 (Jan. 1911): 558-61; Ralph Richards, "The Conservation of Men," *Railway World* 56 (12 July 1912): 616-18; Ralph Richards, *What the Safety Committees of the Chicago and North Western Railway Have Done for The Conservation of Men* (Chicago, 1912); "President's Address," American Wood Preservers' Association *Proceedings* 9 (1913): 30-3; Marcus Dow, "A Nation's Neglect," *Outlook* 105 (27 Sep. 1913): 190-8; Frank and Lillian Gilbreth, *Fatigue Study: The Elimination of Humanity's Greatest Waste* (New York: Sturgis and Walton Co., 1916), 16.
3. Samuel Hays (*Conservation and the Gospel of Efficiency: The Progressive Conservation Movement, 1890-1920* (Cambridge, MA: Harvard Univ. Pr., 1959)) discusses federal policies toward coal lands, but says little about mining or other non-renewables and nothing at all about stripping. Robert Gottleib (*Forcing the Spring: The Transformation of the American Environmental Movement* (Washington, D.C.: Island Press, 1993)) and Benjamin Johnson (*Escaping the Dark, Gray City: Fear and Hope in Progressive Era Conservation* (New Haven, CT: Yale Univ. Pr., 2017)) are also largely silent on these topics. Thomas Wellock (*Preserving the Nation: The Conservation and Environmental Movements, 1870-2000* (Wheeling, IL: Harlan Davidson, 2007)) mentions coal as a source of smoke pollution. On the history of strip mining see: Robert Munn, "The Development of Strip Mining in Southern Appalachia," *Appalachian Journal* 3 (Aug. 1975): 87-95; James Branscome, "Paradise Lost," *Southern Exposure* 1 (1973): 29-41. The best discussion of opposition is: Chad Montrie, *To Save the Land and People: A History of Opposition to Surface Coal Mining in Appalachia* (Chapel Hill: Univ. of North Carolina Pr., 2003), but it focuses on post-World War II developments. See also: Chad Montrie, "Agriculture, Christian Stewardship, and Aesthetics: Ohio Farmers' Opposition to Coal Surface Mining in the 1940s," *Ohio History* 111 (Win.-Spr., 2002): 44-63.
4. For a sampling of writing on energy transitions see: Vlacov Smil, *Energy Transitions: History, Requirements, Prospects* (Santa Barbara: Praeger, 2010); Arnuf Grubler, "Energy Transitions Research: Insights and Cautionary Tales," *Energy Policy* 50 (2012): 8-18; Benjamin Sovacool, "How Long Will It Take? Conceptualizing the Temporal Dynamics of Energy Transitions," *Energy Research and Social Science* 13 (2016): 202-15; Peter O'Connor, *Energy Transitions* [Pardee Papers No. 12] (Boston: Boston Univ. Pardee Center, 2010).
5. Johnson (*Escaping the Dark,* 256) argues that conservationists exhibited a "deep interest in economic development." The emphasis on waste of non-renewable resources clearly reflects such a concern, as advocates assumed that shortages of these resource might ultimately constrain economic growth. Hays (*Conservation)* emphasizes the scientific and technical side of the conservation movement, as does this paper. Other writers emphasize aesthetic and ethical motivations. Mark Stoll, in *Inherit the Holy Mountain: Religion and the Rise of American Environmentalism* (New York: Oxford Univ. Pr., 2015), and *Protestantism, Capitalism and Nature in America* (Albuquerque: Univ. of New Mexico Pr., 1997), stresses its religious roots. In the latter work (1997, 151) he notes that early environmentalists such as Pinchot blended efficiency and aesthetics through "evangelical science". Richard Judd, *Common Lands, Common People: The Origins of Conservation in Northern New England* (Cambridge, MA: Harvard Univ. Pr., 1997), Ch. 8, argues that New England farmers also blended these positions. Similarly, the mining engineers discussed in this paper thought that the "unnecessary" waste of coal that future generations might need was immoral as well as inefficient.
6. "The Conservation Commission," *Engineering and Mining Journal* [hereafter *E&MJ*] 87 (2 Jan. 1909): 33, is one of many such articles in that publication. A search of the Proquest database "American Periodicals" under the term "Conservation Commission" for 1908 to 1910 yielded 138 articles in publications such as *Chautauquan*, *Outlook*, *Outing Magazine*, *The Independent*, and *Field and Stream*, as well as many trade journals. A similar search of the *New York Times* over the same period yielded 43 items.
7. Joseph Holmes, "Mineral Resources," in: Henry Gannett (ed.), *Report of the National Conservation Commission* [hereafter *Commission Report*] v. 1 (Washington, D.C.: USGPO, 1909), 95-111. For Holmes' life see: "Joseph A. Holmes," in *Dictionary of North Carolina Biography*, William Powell, ed. (Chapel Hill: Univ. of North Carolina Pr., 1979-1996).
8. The Commission's findings on the wastes from coal mining are in: Marius Campbell and Edward Parker, "Coal Fields of the United States," in *Commission Report* v. 3, 426-42.
9. Modern writers distinguish between resources, a geological construct, and reserves, which reflect technological and economic constraints. Gifford Pinchot, et al., "Progress Bulletin No. 4," in *Commission Re-*

port 1, 5-21 (quotation on 8); Charles Van Hise, *The Conservation of Natural Resources* (New York: MacMillan, 1910), 25.

10. Pinchot, "Progress Bulletin," 8; Joseph A Holmes, "Mineral Resources Summary," *Commission Report* 1, 95-111 (quotation on 101). For a modern discussion of the varying estimates of coal resources and reserves throughout these years see: Sam Schurr, et al, *Energy in the American Economy, 1850-1975* (Baltimore: Johns Hopkins Univ. Pr., 1960), Ch. 8.
11. Holmes quotations from: Charles L. Parsons, "Notes on Mineral Wastes," USBM *Bulletin 47* (Washington, D.C.: USGPO, 1912), 6.
12. The bureau's purposes are from: U.S. 61st Cong., 2nd Sess., *Bureau of Mines* [Senate Report No. 353 to accompany H.R. 13915] (Washington, D.C.: USGPO, 1910), 3; Parsons, "Notes on Mineral Wastes," 6. The best discussion of its founding is in: William Graebner, *Coal Mining Safety in the Progressive Period: The Political Economy of Reform* (Lexington: Univ. Pr. of Kentucky, 1976), Ch. 1.
13. Joseph A. Holmes, "How Conservation of Mineral Resources May Be Accomplished," in: Newton Blanchard (ed.), *Proceedings of a Conference of Governors in the White House, Washington, D.C.: May 13-15, 1908* (Washington, D.C.: USGPO, 1909), 439-45; "The Conservation of Resources," *E&MJ* 86 (19 Sep. 1908): 583-4 (quotation on 583).
14. Franklin Platt, *A Special Report to the Legislature Upon the Causes, Kinds and Amount of Waste in Mining Anthracite* (Harrisburg: Pennsylvania Second Geological Survey, 1881), 5, 48; H. Martyn Chance, *Report on the Mining Methods and Appliances Used in the Anthracite Coal Fields* (Harrisburg: Pennsylvania Second Geological Survey, 1883), 481. For continuing concerns see also: Pennsylvania Commission to Investigate Waste of Coal Mining, *Report of the Commission Appointed to Investigate the Waste of Coal Mining with a View to the Utilizing of the Waste* (Philadelphia: Allen, Lane and Scott's Printing House, 1893). Sometimes better technology resulted in *more* waste, however. Early mechanized undercutting of coal using punch drills generated clouds of dust. See "Waste in Mining in Maryland," *Mines and Minerals* 27 (July 1907): 509.
15. Campbell and Parker "Coal Fields of the United States," 432; Israel C. White, "The Waste of Mineral Fuel Resources," *E&MJ* 85 (6 June 1908): 1139-41; "Conservation of Coal," *Mines and Minerals* 32 (Dec. 1911): 258-9; George Rice and J. W. Paul, "Amount and Nature of Losses in Mining Bituminous Coal in the Eastern United States," U.S. Coal Commission, *Report of the United States Coal Commission* v. 3 (Washington, D.C.: USGPO, 1925), 1841-76 (quotation on 1858). For an excellent survey of market incentives for waste recovery that excludes the wastes of mining see: Pierre Desrochers, "How Did the Invisible Hand Handle Industrial Waste? By-product Development Before the Modern Environmental Era," *Enterprise and Society* 8 (June 2007): 348-74.
16. In more mountainous regions miners also used contour mining, which essentially pealed the top cover off the side of a mountain and mined a "bench" of coal. Auger mining and mountaintop removal did not become common until after World War II.
17. Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776; reprint: New York: Dutton, 1910), 13; Eli Conner "Anthracite and Bituminous Mining," *Coal Age* 1 (21 Oct. 1911): 42-5 (quotation on 44).
18. C. M. Young ("Strip Pit Mining with Steam Shovels," *Coal Age* 3 (4 Jan. 1913):10-11) reported mining in Kansas "where the roof is too poor to permit underground work." Ralph Mayer, "Strip Mining Where Bad Roof Prevails," *Coal Age* 13 (20 Apr. 1918): 735-7; Frank Kneeland, "Large Stripping Operation," *Coal Age* 8 (25 Sep. 1915): 497- 501 (quotation on 497). "Coal Stripping, Rush Run, Ohio," *Coal Age* 9 (2 Jan. 1916): 161-3, reported that "there was no roof for the regular method of mining." F. H. King, "Steam Shovel Has Rendered Operable Many Properties Not Hitherto Worked," *Coal Age* 17 (6 May 1920): 434, 437-8.
19. "Hazelton, Pennsylvania," *Coal Age* 10 (29 July 1916): 204; Frank Kneeland, "Wasting Strip Pit Spoil by Means of a Cableway," *Coal Age* 27 (1 Jan. 1925): 3-5; Illinois Coal Strippers Association, *Open Cut Coal Mining Industry of Illinois* (Chicago: The Association, 1939), 15; "Stripping Completes Recovery of Deep and Already-Mined Beds," *Coal Age* 34 (Aug. 1929): 602+; R. S. Weimer, "Stripping Brings New Life to Dying Coal Fields," *Coal Age* 33 (Apr. 1928): 278-81+.
20. Harold Culver ("Preliminary Report on Coal Stripping Possibilities in Illinois," Illinois State Geological Survey, Cooperative Mining Series *Bulletin* 28 (Urbana, IL, 1925)) claims 90 percent recovery for Illinois stripping. *A Compilation of the Reports of the Mining Industry of Illinois from the Earliest Records to the Close of the Year 1930* (Springfield: Illinois Department of Mines and Minerals, 1931) claims 95 to 98 percent recovery for stripping. C. A. Allen ("Coal Losses in Illinois," Illinois Geological Survey Cooperative Mining Series *Bulletin 30* (Urbana, 1925)) claims traditional mining losses amounted to 49.7 percent of coal in place. Scott Turner, et al., "Mining Bituminous Coal by Stripping Methods," USBM *Information Circular 6383* (Washington, D.C.: USGPO, 1930), 1; Louis Turnbull, et al., "Use of Scrapers and Other Light Earth-Moving Equipment in Bituminous Coal Strip Mining," USBM *Report of Investigation 4033* (Washington, D.C.: USGPO, 1947), 37.
21. "Coal Stripping, Rush Run," 162; E. C. Drum, "Econ-

omy of Mining Coal by Stripping," *Coal Age* 12 (22 Dec. 1917): 1055-6; "Kansas Fields Use largest of Shovels to Strip Thinnest of Seams," *Coal Age* 43 (Aug. 1938): 41-3.

22. "Turns Farms Upside Down, "*Kansas City Star*, 11 May 1916. The newspaper searches were on https://newspapers.library.in.gov/ for Indiana and http://idnc.library.illinois.edu/ for Illinois.
23. King, "Steam Shovel Has Rendered," 938.
24. "Turns Farms Upside Down".
25. For cooperative efforts in Illinois see: Illinois Coal Strippers Association, *Open Cut Coal Mining*, passim. For an independent assessment see: J. P. Schavilje, "Reclaiming Illinois Strip Mined Coal Land with Trees," *Journal of Forestry* 39 (Aug. 1941): 714-19. See too: Timothy Bailey and Catherine Hooey, "'From Wasteland to Wonderland': New Uses for Mined Land in Rural Kansas," *Midwest Quarterly* 58 (Spr. 2017): 252-63. Indiana is from: Albert Toenges, "Reclamation of Stripped Coal Land," USBM *Report of Investigation 3440* (Washington, D.C.: USGPO, 1939). Walter Ludwig, "Reforestation by Coal Companies in Southwestern Pennsylvania," *Journal of Forestry* 21 (May 1923): 492-6.
26. Toenges, "Reclamation," passim. For a list of studies of reclamation down to 1960 see: G. A. Limstrom, "A Bibliography of Strip Mine Reclamation," Central States Forest Experiment Station *Miscellaneous Publication 9* (N. p.: U.S. Forest Service, 1953), and: Kenneth Bowden, *A Bibliography of Strip-Mine Reclamation, 1953-1960* (Ann Arbor, 1961). For evaluations of programs see: G. A. Limstrom, et al., "Reclaiming Illinois Strip Lands by Forest Planting," University of Illinois Agricultural Experiment Station *Bulletin 547* (Champaign-Urbana, 1951), and: A. F. Grandt and A. L. Lang, "Reclaiming Illinois Strip Coal Land with Legumes and Grasses," University of Illinois Agricultural Experiment Station *Bulletin 628* (Champaign-Urbana, 1958). See too: Raymond Finn, "Ten Years of Strip-Mine Forestation Research in Ohio," Central States Forest Experiment Station *Technical Paper 153* (N. p., 1958). The politics of modern strip mine regulations are discussed in: Richard Vietor, *Environmental Politics and the Coal Coalition* (College Station: Texas A&M Univ. Pr., 1980), chs. 3 and 4.
27. On the advantages of strip mining see: Harry H. Stoek, "Strip Pit Mining of Bituminous Coal–I," *Coal Age* 12 (29 Sep. 1917): 522-7; and "Methods, Cost, and Safety in Stripping and Mining Coal, Copper Ore, Iron Ore, Bauxite, and Pebble Phosphate," USBM *Bulletin 298* (Washington, D.C.: USGPO, 1929). Many other writers also stressed the advantages of stripping, for example: Frank Kneeland, *Practical Coal Production: Getting Out the Coal* (New York: McGraw Hill, 1926), Ch. 1.
28. This formula is from: Thomas Kennedy, "Anthracite Stripping–II," *Coal Age* 13 (5 Jan. 1918): 13-25. The economic ratio also depended upon the nature of the overburden, as top cover might be more or less expensive to remove. See: Albert Toenges and Robert Anderson, "Some Aspects of Strip Mining of Bituminous Coal in Central and South[-]Central States," USBM *Information Circular 6959* (Washington, D.C.: USGPO, 1937).
29. Histories of early strip mining are from: Harry H. Stoek, "Steam Shovel Mining of Bituminous Coal," American Institute of Mining Engineers *Transactions* 57 (1917): 514-48; Robert Marsh, *Steam Shovel Mining* (New York: McGraw Hill, 1920), Ch. 1; Grant Holmes, "Early History of Strip Mining Full of Heartbreak–I," *Coal Age* 25 (29 May 1924): 797-800; John Hollingsworth, *History of Development of Strip Mining Machines* (South Milwaukee, WI: Bucyrus-Erie, 1960), passim; Culver, "Preliminary Report," passim. That deeper coal would be better in quality, but that mining at depth likely had diminishing returns is from: Turner, "Mining Bituminous Coal."
30. The 1:1 ratio is from: Eli Conner, "Anthracite and Bituminous Mining," *Coal Age* 1 (21 Oct. 1911): 42-5; USBM, *Mineral Resources of the United States* [hereafter *Mineral Resources*] 1914, Part II, 626-7; C. M. Young, "Fifteen Feet of Cover to One Foot of Coal No Deterrent to Southwest Strippers," *Coal Age* 34 (Aug. 1929): 480-3.
31. The Model 250's origins are from: Hollingsworth, *History of Development*, passim; Marion Steam Shovel Company, *Catalog 39, Steam Shovels, Dredges and Ballast Unloaders* (Marion Ohio: The Company, 1911), 9 and 10. That this was the first successful shovel, see: King, "Steam Shovel Has Rendered."
32. Hollingsworth, *History of Development*, dates electric shovels from 1915. Stoek, "Steam Shovel Mining," has a table of shovels and their characteristics as of 1917. However, a given model of shovel tended to become larger over time. USBM, *Mineral Resources* 1914, Part II, 626-7.
33. Frank Schraeder, "A Coal Tipple for a Stripping Operation," *Coal Age* 17 (8 Apr. 1920): 698-701.
34. USBM, *Mineral Resources* 1914, II, 627. Productivity data for anthracite stripping are unavailable until 1930.
35. USBM, *Mineral Resources* 1917, II, 942.
36. Changes in the costs of labor, materials, and land, along with improvements in product quality, also aided strip mining during the 1920s. Timber costs were twice as high as in pre-war years, while miners' wages rose 260 percent between 1914 and 1920, and in the unionized fields in the Mississippi Valley they remained at that level during the 1920s. Both developments handicapped timber- and labor-intensive underground work. Meanwhile the agricultural depression that settled over the Midwest reduced the price of farmland, cheapening the cost of its ac-

quisition by coal stripping companies. See: O. E. Keissling, et al., "The Economics of Strip Coal Mining," USBM *Economic Paper 11* (Washington, D.C.: USGPO, 1931).

37. "New Shovel Operation and 14-Yd. Dragline for Rider Work Mark Advances at Maumee Mines in Indiana," *Coal Age* 47 (Mar. 1942): 40-2; "Round Table Stripping Session," *Mining Congress Journal* 26 (May 1940): 41; "Trends in Strip Coal Mining," *Mining Congress Journal* 31 (Feb. 1945): 36-9. See too: "Tecumseh Electrification Provides Flexibility and Safety," *Mining Congress Journal* 26 (Sep. 1940): 52-7. For a good discussion of the evolution of technology at one mine up to 1936, see: "United Electric Coal Companies' Fidelity Mine and Washery," *Mining and Metallurgy* 17 (Sep. 1936): 416-20.

38. A. M. Nielsen, "Electric Shovel and Improved Shooting Cut Strip Mining Costs," *Coal Age* 33 (Apr. 1928): 210-2; "Unusual Practices Adopted at Strip Mines in Illinois," *Coal Age* 34 (Nov. 1929): 681-2; E. R. Lewis, "Electric Power Essential to Modern Strip Coal Mining," *Electrical World* 106 (19 Dec. 1936): 42-4+; "One Foot of Coal No Deterrent to Southwest Strippers," Coal Age 34 (Aug. 1929): 481-3; "Stripping with Three to Nine Yard Draglines," *Mining Congress Journal* 29 (July 1943): 46-7; "Modernizing the Strip Pits," *Mining Congress Journal* 23 (July 1937): 65-7; "Shovel Leveling Done Automatically by Electronic Unit," *Coal Age* 47 (Nov. 1942): 56-8. The share of electric shovels is calculated from data in *Mineral Resources* 1931, II, 449.

39. N.A., "Unusual Practices"; "12-Yd Electric Dragline Strips 2½ to 3-Ft. Seam at Old Glory Under 40 to 58½ Ft. Cover," *Coal Age* 43 (Jan. 1938): 67-9; "Transportation at Indiana Strip Mines," *Coal Age* 43 (Dec. 1938): 83-6; "Truck Haulage Moves with Times in Serving Strip Pits," *Coal Age* 49 (July 1944): 81-3; "80 Ton Semi-Trailer Passes Tests with Butane Fuel at Sinclair Strip Mines," *Coal Age* 44 (Aug. 1939): 39-41.

40. U.S. Bureau of the Census, *Sixteenth Census of the United States: 1940: Mineral Industries: 1939*, 1 (Washington, D.C.: USGPO, 1944), tables 1 and 24 and p. 229; "Operating Practices at Indiana Strip Mines," *Coal Age* 43 (Dec. 1938): 77-81.

41. Frank Kneeland, "Triple Shifting Makes Big Stripper Profitable," *Coal Age* 28 (15 Oct. 1925): 528-31; Alphonse Brodsky, "Engineering Forethought Expedites Operation of Kansas Stripping," *Coal Age* 35 (Sep. 1930): 524-6; "Boonsville is Proving Ground for New Stripping Project," *Coal Age* 33 (July 1928): 417-21; H. C. Widmer, "Time Studies Increase Efficiency at Strip Mines," *Coal Age* 36 (Nov. 1931): 227-30. A modern study finds horsepower is the most important determinant of productivity change in hard coal; see: G. S. Maddala, "Productivity and Technological Change in Bituminous Coal Industry, 1919-54," *Journal of Political Economy* 73 (Aug. 1965): 352-65.

42. "World's Largest Strip Mine Has Expectancy of 30 Years," *Coal Age* 34 (June 1929): 335-7; "Market Handicap Lifted by Adoption of Wet Preparation for 3x0-In. Coal at Fidelity No. 11 Strip Mine," *Coal Age* 40 (May 1935): 187-200. Keissling ("Economics of Strip Coal Mining") provides a good discussion of the impact of new technologies on the economics of stripping.

43. Nielsen, "Electric Shovel and Improved Shooting," 210; "Bituminous Stripping Adopts New Methods in Active Year," *Coal Age* 42 (Feb. 1937): 75-7; "Bituminous Stripping Featured by Transportation Progress [*sic*]," *Coal Age* 43 (Feb. 1938): 58-60.

44. Suppose that a company wished to blast a forty-foot-deep section of overburden fifty feet long and sixty feet back from the face. Vertical drilling would require five sets of holes, ten feet apart along the face, with three holes in each set, twenty feet apart and forty feet deep, for a total of six hundred feet of drilling. Horizontal drilling, by contrast, would require five sixty-foot holes spaced ten feet apart along the face for a total of three hundred feet of drilling.

45. Turnbull ("Use of Scrapers") provides a brief history of the use of light equipment. *Coal Age* ("Bituminous Stripping") noted a bifurcation of stripping in 1937. See also: "Add to Working Facilities in a Year Marked by Increased Production," *Coal Age* 45 (Feb. 1940): 68-9; "Bituminous and Lignite from Strip Mining," *Mining Congress Journal* 30 (Feb. 1944): 31; "The Future of Strip Mining in the Northern Appalachian Field," *Mining Congress Journal* 30 (May 1944): 25-7. The mine that opened in three months is from "Box Cut, Yields 2,000 Tons Per Day at Pond River," *Coal Age* 50 (Mar. 1945): 74-7.

46. Frances Wold, "The Washburn Lignite Coal Company: A History of Mining at Wilton, North Dakota," *North Dakota History* 43 (Fall 1976): 4-20.

47. Turner, "Mining Bituminous Coal," 1; "Texas Lignite Field Sets Steam Shovel to Work," *Coal Age* 26 (25 Sep. 1924): 435-6; H. E. Stevens, "Railroad Opens Large Strip Mine in Rosebud Coal Field," *Railway Age* 80 (6 Feb. 1926): 370-2.

48. See the sources cited in note 3, as well as: Samuel Hays, *Beauty, Health, and Permanence: Environmental Politics in the United States, 1955-1985* (New York: Cambridge Univ. Pr., 1987).

49. *Commission Report* 3, 650, 659; Committee of One Hundred on National Health, "Report on National Vitality, its Wastes and Conservation," *Bulletin 30* (Washington, D.C.: USGPO, 1909), 41.

50. National Safety Council, *Proceedings* 2 (1913): 69; Van Hise, *Conservation of Natural Resources*, 354-72. For a broad discussion of the need to conserve human life, see: Irving Fisher, *Memorial Relating to the Conservation of Human Life*, 62nd Cong., 2nd Session, S.

D. 493 (Washington, D.C.: USGPO, 1912).

51. "Coal Stripping, Rush Run," 162; Stoek, "Steam Shovel Mining," 514; Kneeland, *Practical Coal Production*, 1; "Methods, Cost, and Safety in Stripping," 12.

52. For fatality rates in a number of concurrent industries see: U.S. Bureau of Labor Statistics, "Handbook of Labor Statistics, 1936 Edition," *Bulletin 616* (Washington, D.C.: USGPO, 1936).

53. Temporary injuries were not necessarily minor injuries. The Bureau of Mines began to collect lost workdays per temporary injury only in 1943, and in that year the number of lost days per temporary injury was twenty-two for underground mines and seventeen for stripping. See also: Seth Reese, et al., "Injury Experience in Coal Mining, 1949," USBM *Bulletin 525* (Washington, D.C.: USGPO, 1953), Table 81.