COAL PRODUCTION IN THE UNITED STATES – AN HISTORICAL OVERVIEW[a]

Coal has been an energy source for hundreds of years in the United States. It helped provide many basic needs, from energy for domestic heating and cooking, to transportation for people, products, and raw materials, to energy for industrial applications and electricity generation. America's economic progress historically is linked to the use of coal from its abundant coal resources.

MILESTONES IN U.S. COAL PRODUCTION

Coal production in the United States grew steadily from the colonial period, fed the Industrial Revolution, and supplied industrial and transportation fuel during the two World Wars (Figure 1). Around 1950, coal consumption was distributed among the consuming sectors - industrial, residential and commercial, metallurgical coke ovens, electric power, and transportation - with each sector accounting for 5 to 25 percent of total consumption. From the end of World War II to 1960, coal use for rail and water transportation and for space heating declined. Coal demand grew, however, with the post-War growth in American industry and increased electricity generation starting in the early 1960's.

In 1950, U.S. coal production was 560 million short tons (MMst). In 2003, U.S. coal production was 1.07 billion short tons, an average annual increase in coal production of 1.2 percent per year (Table 1). Of the coal ranks in Table 1, bituminous is relatively high-Btu coal mined mostly in the East and Midwest, subbituminous is medium-Btu coal mined only in the western states, lignite is low-Btu coal principally mined in the Gulf Coast and North Dakota, and anthracite is relatively high-Btu coal mined in small quantities in Pennsylvania. With the growing importance of lower-Btu coals in the production mix over time, the energy content of coal production has not grown as rapidly as its tonnage. To depict general trends yet allow space for selected details, coal statistics in Table 1 are shown for each year from 1993 through 2003, for every fifth year from 1953 through 1993, and for 1950. A large proportion of U.S. production is consumed domestically, so yearly coal consumption levels track coal production.

The 1973 Oil Embargo renewed interest in the vast U.S. coal reserves, as the nation strived to achieve energy independence. The number of coal mines and new mining capacity burgeoned. Between 1973 and 1976, coal production increased by 14.4 percent, or 86.3 MMst.[1] In 1978, the Power Plant and Industrial Fuel Use Act mandated conversion of most existing oil-burning power plants to coal or natural gas. New research on coal liquefaction and gasification technologies was aimed at replacing imported petroleum and supplementing domestic gas supplies. Those high-cost projects were put on hold when crude oil prices fell several years later, making synthesized coal liquids and gases uneconomic.

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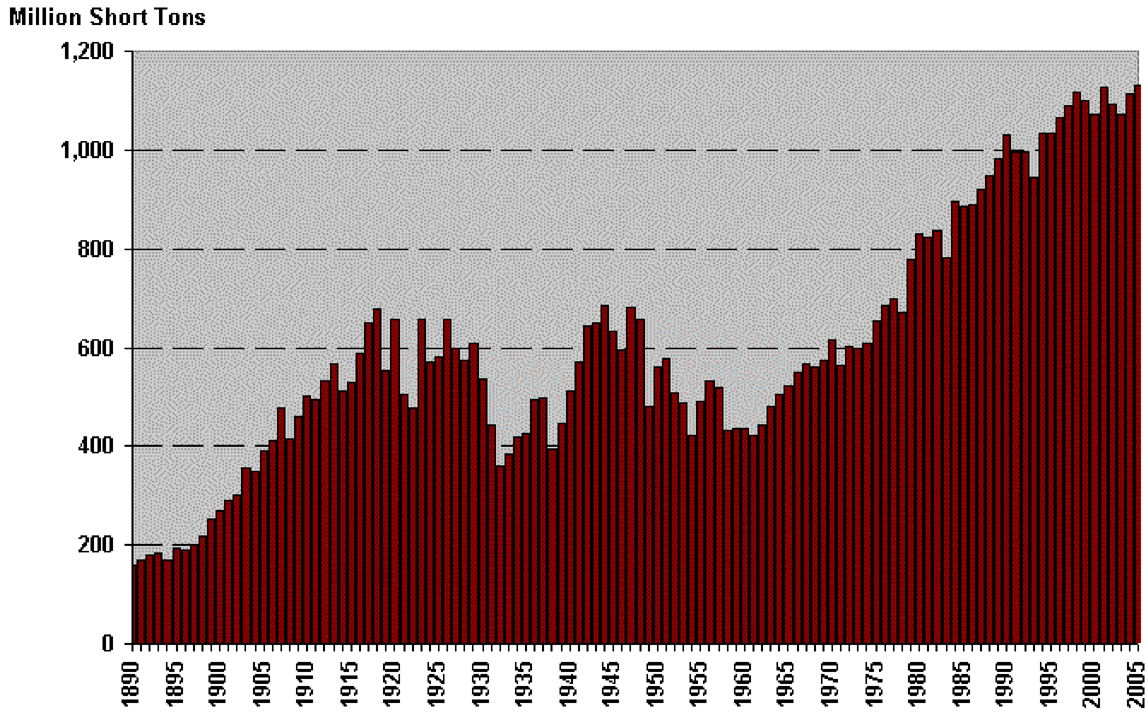
[a] This article is adapted from a reference entry for the *Encyclopedia of Energy Engineering*, Taylor & Francis Books, New York, NY (in press). Authors are Richard Bonskowski, Geologist; richard.bonskowski@eia.doe.gov, William D. Watson, Coal Team Leader, william.watson@eia.doe.gov; and Fred Freme, Coal Industry Statistician, frederick.freme@eia.doe.gov: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels

Figure 1. United States Coal Production, 1890 – 2005



Sources: Annual Coal Report, (and predecessor report titles), DOE/EIA-0584 (years 1993-2003) and DOE/EIA-0118 (years 1976-1992); Energy Information Administration: Washington, DC. In-house file data from U.S. Bureau of Mines, Annual Coal Production surveys by Bureau of Mines and by U.S. Geological Survey (years 1890-1975): Washington, DC. Link to the data.

The shift of coal production from traditional eastern coalfields to the western United States is the most important development affecting coal markets in the last 30 years. Thick beds of low-sulfur coal with low mining cost are extensive in the Northern Great Plains states of Wyoming, Montana, and North Dakota. Starting in the 1970's increasingly more stringent restrictions on atmospheric emissions of sulfur dioxide at power plants made this coal often the most cost effective choice for meeting sulfur dioxide limits without the installation of expensive equipment retrofits. In a matter of a few decades, a localized western resource grew to more than half of all U.S. production, from just over 60 MMst in 1973 to 549 MMst in 2003. This growth was accomplished through the deployment of long distance coal haulage in unit trains (of more than 100 railcars moving coal only, to a single destination) and the exploitation of scale economies in the form of immense western surface coal mines. Average U.S. mine size in 2003 at 0.814 MMst per year far exceeded mine size in 1973 of 0.126 MMst per year. The largest U.S. mine, the North Antelope Rochelle Complex in Wyoming, alone produced over 80 MMst in 2003.

In the United States today, coal demand is driven by the electric power sector, which accounts for 90 percent of consumption, compared to the 19 percent it represented in 1950. As demand for electricity grew, demand for coal to generate it rose and resulted in increasing coal production. There were years in which coal production declined from the prior year but, excluding years affected by a major unionized coal strike, annual increases in coal production between 1950 and 2003 outnumber decreases by almost two to one.

Table 1. Historical Coal Production by Type of Mining and by Coal Rank, Selected Years

(Production in millions of short tons)

Year	Type of Mining		U.S. Coal Production	Bituminous Coal Production[2]	Subbituminous Coal Production	Lignite Production	Anthracite Production
	Underground	Surface[1]					
2003	352.8	719.0	1,071.8	541.5	442.6	86.4	1.3
2002	357.4	736.9	1,094.3	572.1	438.4	82.5	1.4
2001	380.6	747.1	1,127.7	611.3	434.4	80.0	1.9
2000	373.7	700.0	1,073.6	574.3	409.2	85.6	4.6
1999	391.8	708.6	1,100.4	601.7	406.7	87.2	4.8
1998	417.7	699.8	1,117.5	640.6	385.9	85.8	5.3
1997	420.7	669.3	1,089.9	653.8	345.1	86.3	4.7
1996	409.8	654.0	1,063.9	630.7	340.3	88.1	4.8
1995	396.2	636.7	1,033.0	613.8	328.0	86.5	4.7
1994	399.1	634.4	1,033.5	640.3	300.5	88.1	4.6
1993	351.1	594.4	945.4	576.7	274.9	89.5	4.3
1988	382.2	568.1	950.3	638.1	223.5	85.1	3.6
1983	300.4	481.7	782.1	568.6	151.0	58.3	4.1
1978	242.8	427.4	670.2	534.0	96.8	34.4	5.0
1973	300.1	298.5	598.6	543.5	33.9	14.3	6.8
1968	346.6	210.1	556.7	545.2	([2])	([2])	11.5
1963	309.0	168.2	477.2	458.9	([2])	([2])	18.3
1958	297.6	134.0	431.6	410.4	([2])	([2])	21.2
1953	367.4	120.8	488.2	457.3	([2])	([2])	30.9
1950	421.0	139.4	560.4	516.3	([2])	([2])	44.1

[1] Beginning in 2001, includes a small amount of refuse coal recovery.
[2] Subbituminous coal and lignite production were treated as bituminous coal prior to 1973 and cannot be reported separately.
Sources: *Annual Energy Review 2004*, DOE/EIA-0384(2004), Energy Information Administration: Washington, DC, 2005; 207, and online data file (http://www.eia.doe.gov/emeu/aer/txt/stb0702.xls), accessed September 2005.

HOW U.S. COAL IS PRODUCED – TYPES OF MINING[2]

Growth of U.S. coal production involved expansions and adaptations in both established and evolving mining technologies. The important types of coal mining and technologies are:

Underground Mining - Extraction of coal from enclosing rock strata by tunneling below the ground surface. Also known as "deep mining," there are three types, based on mode of access. Drift mines, the easiest type to open, tunnel directly into the outcrop of horizontal or slightly sloping coal seams. Shaft mines reach the coal via a vertical shaft. In slope mines the shaft descends on a gradient to reach the coal (suitable in hilly terrain). The principal technologies used are:

Conventional Mining – traditional method, which employs the "room and pillar" mine layout leaving massive pillars of undisturbed coal in place to support the overlying rock, it includes undercutting the exposed coal (the face), drilling and blasting the coal with explosive or high-pressure air, loading the broken coal into shuttle cars, and installing supplementary roof supports as needed.

Continuous Mining – uses a mobile machine with forward, toothed cylinders that rotate and gouge coal from the face, where it falls onto a pan, is pulled onto loading belts, and fed to shuttle cars or movable conveyors.

Longwall Mining – Automated form of underground coal mining characterized by high recovery and extraction rates, feasible only in relatively flat-lying, thick, uniform coalbeds. A reserve block to be mined, the "panel," averages 1,000 feet wide and 10,000 or more feet long, and is prepared by continuous mining of coal to create access tunnels on all four sides. When the longwall machinery is in place, the entire average 1,000-foot width, the working face of coal, is progressively sheared away, ceiling to floor, in a series of advancing passes. Dislodged coal is continuously removed via a floor-level conveyor system. Mining advances beneath automated movable roof supports within the 10,000-foot or so coal panel. The roof is allowed to collapse evenly in the mined out areas behind the supports.

Surface Mining – Excavation of coal, in the most basic case, from outcroppings, or more generally, by removal of the overlying rock and soil (overburden) to expose one or more seams of coal. The principal techniques are:

Strip Mining – an early synonym for surface mining, still widely used; to some people may connote irresponsible methods, without land restoration.

Contour Mining – surface method used in sloping terrain, in which one of more coalbeds are mined at outcrop by removing overburden to expose the coal bed(s).

Area Mining – surface method used in flat terrain to expose coal for recovery by excavating long, successive "box cuts," or pits. Overburden excavated from the cut being mined is deposited in the previous, mined-out cut.

Auger and Highwall Mining – mining usually performed within a contour or area mine, in coal in-place beneath the "final highwall" (the standing exposed rock at the location where overburden becomes too thick for economical excavation). Auger mining uses a large diameter drill to excavate a succession of holes within the plane of the coal bed, recovering the drilled coal. Highwall mining uses remote-controlled cutting machines, known as highwall miners, or underground mining machines, known as thin-seam miners, to mine out successive broad channels of coal from the seam left in place at the highwall.

Mountaintop Removal (MTR) Mining – an adaptation of area mining to mountainous terrain. Often on massive scales, MTR removes all successive upper layers of rock and broad perimeters of lower rock layers. It recovers about 85 percent[3] of all upper coal beds contained within the rock layers and large portions of the lower beds. MTR operations may affect the top 250 to 600 feet of Appalachian peaks and ridges; they have recovered coal from as many as 18 coalbeds.[4] MTR mining creates huge quantities of excavated overburden that are disposed of as fill in upper portions of adjacent valleys. The fill operations are environmentally controversial but the creation of relatively flat, developable land can be economically beneficial in steep mountainous areas.

COAL MINING TECHNOLOGY TRENDS

In the period since 1973, four distinct trends dominated U.S. coal mining technology. The overall growth in surface coal mining at the expense of underground coal mining is the first. In 1973, underground and surface mines each accounted for 50 percent of total coal production. In the next 30 years, the production share from underground mines declined by a third:

Share of production from underground and surface coal mines

Year	Underground Percentage	Surface Percentage
1973	50	50
1983	38	62
1993	37	63
2003	33	67

Growth in surface coal mining was accompanied by a second trend: the accelerated application of surface mining technology in large-scale area mines in the western region, characterized in optimal locations by box cut pits a mile or greater in length and about 200 feet wide concentrated in the western states of Wyoming, Montana, North Dakota, Texas, Arizona, and New Mexico. In 1973, these six states accounted for 52 MMst out of a total of 599 MMst of U.S. coal mined, representing 9 percent of the total. By 2003, coal produced in those six western states accounted for 49 percent of all U.S. coal mined. No surface mines operating anywhere in the United States in 1973 had an annual output exceeding 5 MMst. By 2003, 64 percent of surface-mined coal was mined in the six western states in area mines exceeding 5 MMst per year of output.[5]

Surface production in western U.S. mines exceeding 5 MMst annually

Year	Percentage of U.S. total that is surface production	Million short tons
1973	0	0
1983	29	141
1993	50	299
2003	64	458

The third technological trend for the 1973-2003 period was the shift within underground mining from conventional room and pillar mining to longwall underground mining. Coal from longwall mining grew from 10 MMst in 1973 to 184 MMst in 2003, representing 52 percent of total U.S. underground production by 2003:[6]

U.S. coal production at longwall mines

Year	As a percentage of U.S. total underground production	Million short tons
1973	3	10*
1983	27	80
1993	40	139
2003	52	184

*The 10 MMst of production in 1973 is based on 9.4 MMst of reported longwall machine coal recovery and 0.6 MMst recovery by continuous mining of longwall entries.

States with substantial longwall production in 2003 included Alabama, Colorado, Pennsylvania, Utah, and West Virginia.

Due to superior productivity, large-scale surface and longwall technologies expanded faster than other mining methods. In 1983, large surface mines (greater than 5MMst per year) had productivity higher than other surface mines and in the next 20 years they experienced higher rates of productivity growth. In 1983, longwall mines had about the same productivity as other underground mines; however, their productivity growth far outpaced other underground mines in the next 20 years:

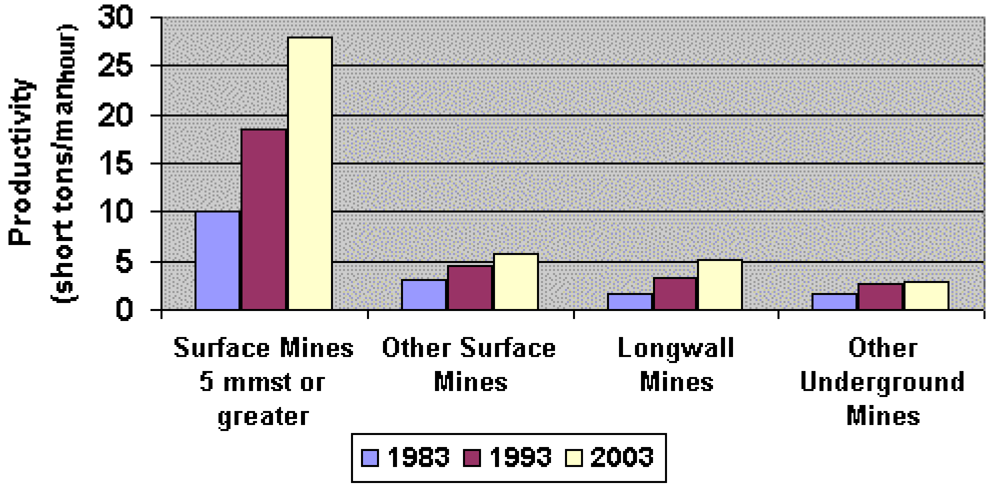
Average Productivity Growth Rates, percent per annum 1983-2003

Surface Mines of 5 MMst or greater	Other surface mines	Longwall mines	Other underground mines
5.0	3.1	5.7	2.9

In the periods 1983 to 1993 and 1993 to 2003, large-scale surface technology and longwall technology saw about equal gains in productivity, decade over decade (Figure 2). In contrast, other technologies saw decelerating gains in productivity. For a broader discussion see the Productivity section below.

The fourth important trend was improvement in mining equipment durability and capability. Improvements to equipment, like the broad technology shifts described above, continue to raise productivity and keep coal mining costs low. For more on mining equipment see Mining Innovations below.

Figure 2. U.S. Coal Mining Productivity



Sources: Annual Coal Report, (and predecessor report titles), DOE/EIA-0584 (years 1993-2003), DOE/EIA-0118 (years 1976-1992) Energy Information Administration: Washington, DC.

COAL MINING PRODUCTIVITY

General production output and trends in productivity by type of coal mining by region are shown in Table 2. Effects of external and operational changes are described below. (For detailed, annual statistics, see the Energy Information Administration website: http://www.eia.doe.gov/emeu/aer/coal.html.)

Productivity is calculated by dividing total coal production by the total direct labor hours worked by all employees engaged in production, preparation, processing, development, reclamation, repair shop, or yard work at mining operations, including office workers. In 1973, the average employee in the United States produced 2.16 short tons per hour (tph, Table 2). In 1983, productivity had increased by 16 percent, to 2.50 tph, and by 1993 another 88 percent to 4.70 tph. By 2003 average U.S. coal mining productivity was 6.95 short tph, an increase of 48 percent over 1993 and 222 percent over the 1973 level. Annual percentage increases in productivity during the 30-year span averaged 4.0 percent.

Table 2. Production and Productivity at U.S. Coal Mines, Selected Years

Item	1973	1983	1993	2003
Production (thousand short tons)				
United States	598,568	782,091[1]	945,424	1,071,753
underground	300,080	300,379[1]	351,053	352,785
surface	298,491	481,713[1]	594,371	718,968
Appalachian Region	381,629	377,952	409,718	376,775
underground	239,636	230,191	257,433	244,468
surface	141,993	147,761	152,285	132,307
Interior Region	156,412	173,407	167,174	146,276
underground	56,060	49,437	56,065	52,173
surface	100,352	123,970	111,109	94,103
Western Region	60,530	225,276	368,532	548,701
underground	10,036	18,691	37,555	56,144
surface	50,494	206,584	330,977	492,557
Number of Employees				
United States	152,204	175,642	101,322	71,023
underground	111,799	111,888	64,604	40,123
surface	40,405	63,754	36,718	30,900
Appalachian	124,000	126,111	71,321	46,507
underground	96,302	90,360	50,956	30,744
surface	27,698	35,751	20,365	15,763
Interior	22,343	34,590	18,555	11,638
underground	12,243	16,889	10,246	6,076
surface	10,100	17,701	8,309	5,562
Western	5,861	14,941	11,446	12,878
underground	3,254	4,639	3,402	3,303
surface	2,607	10,302	8,044	9,575
Number of Mines				
United States	4,744	3,405	2,475	1,316
underground	1,737	1,638	1,196	580
surface	3,007	1,767	1,279	736
Appalachian Region	4,423	2,971	2,163	1,143
underground	1,637	1,526	1,108	521
surface	2,786	1,445	1,055	622
Interior Region	226	311	219	109
underground	55	64	54	36
surface	171	247	165	73
Western Region	95	123	93	64
underground	45	48	34	23
surface	50	75	59	41

Table 2. Production and Productivity at U.S. Coal Mines, Selected Years (concluded)

Item	1973	1983	1993	2003
Productivity (short tons per miner-hour)				
United States	2.16	2.50	4.70	6.95
underground	1.45	1.61	2.95	4.04
surface	4.56	3.81	7.23	10.76
Appalachian Region	1.74	1.75	3.00	3.71
underground	1.33	1.53	2.75	3.64
surface	3.79	2.23	3.55	3.82
Interior Region	3.43	2.69	4.43	5.56
underground	2.27	1.87	3.06	3.83
surface	4.80	3.26	5.71	7.43
Western Region	6.64	7.60	13.53	20.82
underground	2.59	2.28	5.23	8.42
surface	9.64	9.63	16.49	25.01

[1] Production by regions does not total production for United States, underground, and surface (first three rows). The U.S. production for 1983, by surface and underground, represent all mines. Details such as regional production, employment, mine count, and productivity statistics were collected that year only from mines that produced 10,000 short tons or more. The small, excluded mines represented 5.5 mmst of coal, or only 0.7 percent of total U.S. production in 1983.
Notes: Coal-Producing Regions: Appalachian includes Alabama, eastern Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia; Interior includes Arkansas, Illinois, Indiana, Iowa, Kansas, western Kentucky, Louisiana, Mississippi, Missouri, Oklahoma, and Texas; Western includes Alaska, Arizona, Colorado, Montana, New Mexico, North Dakota, Utah, Washington, and Wyoming. • All statistics incorporate data for Pennsylvania anthracite coal, except for number of mines in 1973, which was not reported. Anthracite statistics were collected and published separately from other U.S. coal in 1973.
Source: *Annual Coal Report* (and predecessor report titles), DOE/EIA-0584, Energy Information Administration: Washington, DC.

In 1973 productivity was in decline. It had fallen 10 percent since 1969, when the Coal Mine Safety and Health Act initiated or strengthened nationwide mine safety standards and their enforcement. This Act increased mine permitting and design requirements, added new safety and health standards in existing mines, and imposed new permitting and Black Lung fees on existing operations. The Mine Safety and Health Act of 1977 added additional safety, dust-control, and mine ventilation requirements. Further, the federal government imposed strict new regulations on pollution and disruptions from mining through the Federal Water Pollution Control Act of 1972 and the Surface Mining Control and Reclamation Act of 1977. It can be argued that eventually these regulations improved productivity through safer, better-planned mines. The increasingly stringent controls of sulfur dioxide emissions under the Clean Air Act of 1970, and its amendments in 1977 and 1990, stimulated mining in low-sulfur coal regions, with resulting changes in mining techniques.

Underground coal mine productivity continued to decline through 1978, before starting a slow recovery. Underground productivity in 1973 was 1.45 tph. It fell to 1.04 tph in 1978 and then recovered to 1.61 tph by 1983. Productivity increased another 83 percent by 1993. By 2003, underground productivity had increased another 37 percent, to 4.04 tph. The annual average percentage increase in underground mining productivity for the last 30 years is nearly 4 percent.

Surface coal mining is less labor-intensive and its productivity is inherently higher than underground mining. Surface productivity in 1973 was 4.56 tph. It decreased in 1983 by 16 percent to a level of 3.81 tph – a temporary result of the Federal Surface Mining Control and Reclamation Act of 1977 which required restoration of mined land, diverting some employees and equipment and increasing non-production labor hours per ton of mined coal. By 1993, surface productivity had recouped the earlier loss, increasing by 90 percent, to 7.23 tph. By 2003, surface productivity had increased another 49 percent, to 10.76 tph. The average annual percentage increase in surface mining productivity for the last 30 years is 3 percent.

REGIONAL PRODUCTIVITY

Regional geology, together with type of mining, influences productivity. The States in each coal-producing region are listed in the Notes in Table 2. Appalachia has the highest number of mines, while the West has the least. As discussed earlier, coal production and mine size grew in tandem with shifts to more surface mining and toward the West. Keen price competition motivated productivity improvements accomplished through increased mine size and production.

Appalachian productivity (Table 2) did not increase between 1973 and 1983, primarily because of productivity declines in surface mining. Between 1983 and 2003, both surface and underground mining in Appalachia improved. The annual average percentage increase in productivity in Appalachia over those 30 years was 2.6 percent. The backsliding in surface productivity from 1973 to 1983 corresponds with closure of more than a thousand small contour mines (many were inefficient or seasonal operations), tightening of surface mine permitting and reclamation requirements, and greater public resistance to surface mining. Some production shifted to larger surface mines and MTR operations, but their costs and workforce requirements have been relatively high in Appalachia.

Productivity in the Interior region also declined between 1973 and 1983, before picking up over the next 20 years (Table 2). Most surface mines in the Interior are medium or large box cut area mines. Underground mines tend to be either shaft mines or drift mines entering the coal seam beneath the final highwall. The Interior region has never supported thousands of small surface mines as had Appalachian topography. In 1983, 247 Interior region surface mines produced almost as much coal (84 percent) as was mined in Appalachia's 1,445 mostly contour mines. From 1973 to 2003, the annual average percentage increase in surface productivity was 1.6 percent and in underground productivity it was 1.8 percent.

The increased productivity in the West between 1973 and 1983 can all be attributed to increased surface mining. Surface productivity from 1973 to 1983 did not in itself improve, but new mines opened and the tonnage mined from the surface quadrupled (Table 2). Those gains in surface mining production share boosted overall productivity. During that time western underground mining, working in reserves that tended to be thick-bedded, was slightly more efficient than in thinner-bedded eastern coal. In all regions, limited longwall experience and early mine development were insufficient to significantly boost productivity or increase average mine size until after 1983. Overall, productivity of the huge surface mines, principally in Wyoming and Montana, led the productivity growth between 1983 and 2003. The average annual increase in western mine productivity from 1973 to 2003 was 3.9 percent. Underground productivity gains averaged 4.0 percent annually. Little changed in surface productivity during the 1980's and early 1990's, but by 2003 ten mines were producing more than 15 million tons per year, with great economies of scale.[7] Productivity of western surface mining improved from 9.64 short tons per hour in 1973 to 25.01 short tons per hour in 2003, an average annual increase of 3.2 percent.

CHANGES IN REGIONAL COAL PRODUCTION

The relative importance of coal production regionally has changed over the past 30 years, primarily because of the increased size and productivity of western surface mines. Production in the western region increased by more than 800 percent from 1973 to 2003, dominated by surface production. In 1973 western surface production was 50.5 MMst. It rose to 206.6 MMst by 1983, to 331.0 MMst by 1993, and to 492.6 MMst by 2003.

Appalachian coal production varied little during the same period. Without new growth, the Appalachian region dropped from the top U.S. coal-producing region to second place, as western coal filled rising coal demand. In 1973, Appalachian production was 381.6 MMst. Production was 378.0 MMst in 1983, 409.7 MMst in 1993, and only 376.8 MMst by 2003. The split between surface and underground mining in the Appalachian region also has been relatively stable.

Coal production in the Interior region also has changed little over the course of 30 years. Interior production was 156.4 MMst in 1973; 173.4 MMst in 1983; 167.2 MMst in 1993; and 146.3 MMst in 2003. The production split between surface and underground mines was also stable.

COAL MINING EMPLOYMENT

Employment in the coal industry from 1973 through 2003 ties in with the factors discussed above: regional coal production levels, shifts in type of mining, and changes in productivity within regions and by mining technology. Coal mining employment includes workers at preparation plants that process the mined coal prior to sale. They are allocated to underground or surface mining proportionately based on how the coal was extracted. The average number of mine employees working daily in the United States in 1973 was 152,204 (Table 2). By 1983, daily employment had increased to a total of 175,642 (although 1983 data on employment, number of mines, and productivity covered only mines producing 10,000 short tons or more during the year). The increase resulted from surface mines hiring workers to handle reclamation and from an increase in the number of small, less efficient mines. The average number of daily employees declined to 101,322 by 1993 and to 71,023 by 2003.

Daily underground employment in 1973 averaged 111,799. That figure increased slightly by 1983, to 111,888 employees working daily. In 1993 underground employment was down to 64,604 and to 40,123 by 2003. The trend reflects the fact that by 1983 a significant number of low productivity mines were in operation – slightly fewer underground mines produced slightly less coal using slightly more employees. Over the next 20 years, declining coal prices and increasing competition forced many of those mines out of business.

Daily surface mine employment in 1973 was 40,405. In 1983 surface employment increased to 63,754 employees, reflecting increased reclamation requirements. By 1993 surface employment was down to 36,718 employees and by 2003 down to 30,900.

Regional mining employment reflects the trends in production and productivity discussed above and is outlined in Table 2.

MINING INNOVATIONS

The notable improvements in mining equipment from 1983 through 2003 include:

- Bigger and stronger longwall face coal belt conveyors
- Conversion to belt conveyors to move coal out of underground mines
- Better roof bolting equipment[b] including combination continuous-miner/bolters
- More powerful and durable longwall cutting bits
- Better sensors for and automation of longwall roof shields
- More powerful and more durable electric drive motors used in many applications
- Continuous scale-up of haul trucks, loaders, and excavators for surface mining

A feature of the improvements listed above is that significant benefits resulted from advances in materials and technology applied to existing mining techniques, not from pioneering entirely new mining machinery. That process continues. Roof bolting was a seminal change in underground coal mining. It allowed passageways to be secured with substantially fewer timbers and "cribs" (the pillars constructed of stacked short beams used to shore up million-pound roof loads). Roof bolting – a safety standard, mandated in the 1969 Coal Mine Safety and Health Act – resulted in safer, more open mine passages and led to single-operator roof-bolting machinery far more productive than the previous, labor-intensive manual timbering and cribbing.[8] For areas subject to tangential forces, steel cable roof bolts, with higher tensile strength and resistance to shear failure, give superior results. Those same qualities, along with new flexible, sprayed rock coatings, are expected to attract more proponents as mines go deeper. Though cable bolts and coatings add cost, some mines have found that fewer are needed per unit area.[9]

Examples of other recent improvements in longwall mining include variable-slip clutches in the power drives for coal face belt conveyors, to accommodate surges in power demand due to irregular loading and to drag from oversized coal. Ceramic facings on belt drums now give better traction and wear. Stronger materials are being marketed in roof shields, to extend usable life and reduce maintenance costs. With automated operation of longwall face-shearing drums and roof-shield positioning, operators can now monitor/control mining remotely from "outby" passages at the ends of panel cuts and away from some of the noise and moving machinery. New roof bolters are highly automated and shield the operator. Advances since the 1980's in distancing the operator from the working coal face also came with the accelerated use of highwall miners, which employ video or sensor-aided monitors to give the operator effective remote control of mining for distances approaching 1,000 feet. Robotic mining is expected to grow. Scaled-down longwall machines are now being tested to mine four-foot and thinner beds and robotic cutting tools have been bench tested that can extract coal as thin as six inches.

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[b] Roof bolting is a technique to secure underground mine roof and avoid rock falls by drilling 4 to 12 feet up into the overlying rock layers and inserting high tensile-strength bolts and support plates to bind together weak layers with strong layers. Bolts hold via mechanical anchors, epoxy resin, or grout.

Computerized control systems now monitor and coordinate belt speeds in some mines from the longwall face through the face belt conveyors and all downstream belt systems, out the portal and to storage piles. Mine operators are adopting new machinery to reduce the downtime when a longwall system is moved to a new panel. With specially designed trailers that can haul several roof shields at 13-15 mph versus the 2-3 mph for single shields on the common fork-lift type shield mover, one operator recently cut 2 days out of a 14-day move.[10]

Underground mines of all kinds can now take advantage of manufactured crib materials that are stronger under load than timber and more impervious to water and oil, which interlock for greater solidity, and can be assembled quickly by machine, reducing the injury potential of personnel handling heavy materials underground. Similarly, corrugated and "pumpable" supports save time and are safer to use. Portable roof shields are now available to improve safety and coal extraction in room and pillar "retreat mining," when piers of coal that supported the roof are removed in final mining stages.

In surface mining, new improvements include innovative use of computerized process control, which are currently being used at progressive operations, along with global positioning systems, to schedule and dispatch haul trucks and to control positioning and depths of cuts by bulldozers and scrapers preparing pits and exposing the coal seam. Sensors on dozer or loader blades are guiding operators in distinguishing and recovering coal versus black shales at a growing number of mines.

The opportunities for larger surface mining equipment do have physical and practical limitations, including wheel size and tire construction, but new configurations for haul trucks are on the drawing boards that may produce a 1,000-ton haul truck by 2020. At the same time, in-pit excavators will be increasing bucket size from 50 to 150 cubic yards.[11]

COAL PREPARATION

Coal preparation is processing of run-of-mine coal – the raw coal coming out of the mine – in order to enhance its characteristics for shipping and ultimate utilization. Benefits of coal preparation may include: removal of non-combustible material, whose weight raises shipping costs and which can increase wear in coal grinding equipment and boilers; enhancement of deliverable heat content; removal of unwanted minerals that can foul boilers or damage the environment if entrained in boiler emissions or ash; suppression of dust and improvement of handling and shipping qualities. These processes are carried out at preparation plants – also known as "prep" plants or wash plants – which may be located either at coal mines or at separate facilities serving numerous associated or independent mines in a mining region.

Preparation begins with crushing and screening of freshly mined coal, which normally results in removal of some of the non-coal material. Some coal, especially coal from thick-bedded surface mines, is merely crushed and screened before shipping. Additional cleaning, known as mechanical cleaning, may entail separating out non-coal material in a liquid medium, which led to the widely used term "washing." The washing medium is an aqueous chemical solution prepared to enhance wettability and dissociation of the coal and non-coal materials or to produce specific gravities calibrated higher than water alone. The liquid medium may be combined with finely ground heavier minerals, such as magnetite, in a dense medium fluid, better to effect separation of unwanted rock and mineral matter from coal particles. Wet or "hydraulic" cleaning techniques may also include particle agitation by aeration of the coal-liquid feed, materials sorting via relative density in hydro-cyclonic chambers, and froth flotation to capture fine coal particles. To meet environmental regulations, technically advanced wash plants can remove as much as 40 percent of the inorganic sulfur in coal. Dry techniques, rarely used alone, include pre-wash segregation by vigorous shaking and pneumatic air-flow separation for crushed feed coal.

Prepared coal is commonly dewatered to some degree because excess moisture degrades deliverable heat content in the coal and the added weight increases handling and shipping costs. Dewatering techniques range from vibrating screens, filters, or centrifuges to the more costly use of heated rotary kilns or dryer units. Before burning, almost all coal for electric power and industrial boilers is either pulverized or crushed and sized. Pre-combustion coal washing is usually less costly than downstream options for removing ash and sulfur.

Two trends affect the amount of coal washed in the United States. First, production of western U.S. coal has outpaced the production of eastern U.S. coal. Most western coal is crushed and sized for market but rarely washed. Second, to meet environmental regulations greater percentages of eastern coal are washed. In 1973, 28 and 69 percent of surface- and underground-mined coal, respectively, was washed. In addition, washed anthracite production, for which type of mining was not identified, equated to 1 percent of U.S. production.[12] By 1983, the shares were at least 21 percent and 63 percent.[13,14] The term "at least" acknowledges that the 1973 statistics covered all mines with at least 1,000 short tons of annual coal production whereas the 1983 survey "supplement," covering prep plants, was limited to larger mines, with at least 100,000 short tons production.

Coal washing can produce large volumes of waste. In 2002, about 25 percent of the raw coal processed through preparation plants was discharged to waste ponds as "refuse," mixtures composed of shale, clay, coal, low-grade shaley coal, and preparation chemicals.[15] Like mining, coal washing operations have undergone consolidation. Over the period 1983 to 2003, the number of U.S. wash plants fell from 362 to 132 and employment dropped from 7,300 to about 2,500 employees.

COAL PRICES

Except for price inflation generated following the energy crisis of 1973, U.S. coal prices were relatively stable from 1973 through 2003. When coal prices did rise, external factors like the 1973 oil embargo or burgeoning demand for coal and oil in China in 2003-2004 have been largely responsible. When real coal prices declined, however, as they did from 1975 through 2000, it was largely owing to improved labor productivity. That trend reflects the effects of "marked shifts in coal production to regions with high levels of productivity, the exit of less productive mines, and productivity improvements in each region resulting from improved technology, better planning and management, and improved labor relations."[16]

Adjusted for inflation, coal prices in year 2000 dollars decreased from $31.40 to $16.84 per short ton between 1950 and 2003 (see Table 3). The average price in nominal dollars went from $5.19 per short ton in 1950 to $17.85 in 2003. In energy terms - dollars per million Btu - coal has long been the least-cost fossil fuel. Petroleum products became more expensive than coal around the 1890's, when the first practical diesel and gasoline internal combustion engines were used in vehicles. Natural gas prices surpassed coal in 1979, in the first phase of natural gas price deregulation under the Natural Gas Policy Act of 1978. In 2003, one million Btu of coal sold for $0.87 on average, compared to $4.41 for natural gas and $4.75 for crude oil.[17]

Table 3. Historical U.S. Coal Prices at the Mine or Source, by Coal Rank, Selected Years

(Prices in dollars per short ton, expressed in nominal dollars and in inflation-adjusted year-2000 dollars)

	Average Price U.S. Coal Sales		**Average Price of Bituminous Coal[1]**		**Average Price of Subbituminous Coal**		**Average Price of Lignite**		**Average Price of Anthracite**	
Year	**Nominal**	**Real**	**Nominal**	**Real**	**Nominal**	**Real**	**Nominal**	**Real**	**Nominal**	**Real**
2003	$17.85	$16.84	$26.73	$25.22	$7.73	$7.29	$11.20	$10.57	$49.55	$46.75
2002	$17.98	$17.27	$26.57	$25.53	$7.34	$7.05	$11.07	$10.63	$47.78	$45.90
2001	$17.38	$16.97	$25.36	$24.77	$6.67	$6.51	$11.52	$11.25	$47.67	$46.55
2000	$16.78	$16.78	$24.15	$24.15	$7.12	$7.12	$11.41	$11.41	$40.90	$40.90
1999	$16.63	$16.99	$23.92	$24.44	$6.87	$7.02	$11.04	$11.28	$35.13	$35.90
1998	$17.67	$18.32	$24.87	$25.78	$6.96	$7.21	$11.08	$11.49	$42.91	$44.48
1997	$18.14	$19.01	$24.64	$25.82	$7.42	$7.78	$10.91	$11.43	$35.12	$36.81
1996	$18.50	$19.71	$25.17	$26.82	$7.87	$8.39	$10.92	$11.64	$36.78	$39.19
1995	$18.83	$20.44	$25.56	$27.75	$8.10	$8.79	$10.83	$11.76	$39.78	$43.19
1994	$19.41	$21.50	$25.68	$28.45	$8.37	$9.27	$10.77	$11.93	$36.07	$39.96
1993	$19.85	$22.46	$26.15	$29.59	$9.33	$10.56	$11.11	$12.57	$32.94	$37.27
1988	$22.07	$29.16	$27.66	$36.54	$10.45	$13.81	$10.06	$13.29	$44.16	$58.34
1983	$25.98	$39.84	$31.11	$47.71	$13.03	$19.98	$9.91	$15.20	$52.29	$80.19
1978	$21.86	$47.77	$22.64	$49.48	(1)	(1)	$5.68	$12.41	$35.25	$77.04
1973	$8.59	$26.97	$8.71	$27.35	(1)	(1)	$2.09	$6.56	$13.65	$42.86
1968	$4.75	$19.07	$4.70	$18.87	(1)	(1)	$1.79	$7.19	$8.78	$35.24
1963	$4.55	$20.87	$4.40	$20.19	(1)	(1)	$2.17	$9.96	$8.64	$39.64
1958	$5.07	$24.73	$4.87	$23.76	(1)	(1)	$2.35	$11.46	$9.14	$44.59
1953	$5.23	$28.67	$4.94	$27.08	(1)	(1)	$2.38	$13.05	$9.87	$54.10
1950	$5.19	$31.40	$4.86	$29.40	(1)	(1)	$2.41	$14.58	$9.34	$56.50

[1] Through 1978, subbituminous coal is included in "Bituminous Coal."
Source: *Annual Coal Report* (and predecessor report titles), DOE/EIA-0584, Energy Information Administration: Washington, DC.

The 1973 Oil Embargo spurred immediate and dramatic increases in coal prices, but in the long term it may have depressed prices through the long-lived excess productive capacity it generated. Between 1980 and 2000, coal prices remained under the overhang of excess capacity. Other suppliers often underbid contract coal prices considered reasonable, or even low, by mine operators.

Coal prices in Table 3 illustrate the changes that began in 1973. The average price in 1973 for U.S. coal was $8.59 per short ton, priced at the mine or original loading point. That price was unaffected by the oil embargo because in 1973 the federal government had not yet initiated policies to steer electricity producers away from petroleum as a fuel and to promote increased use of coal. Already, between 1968 and 1973, nominal coal prices had increased from $4.75 to $8.59 per short ton because coal producers passed through some of the increased costs of Black Lung taxes and new mine safety regulations of the 1969 Coal Mine Safety and Health Act. Building on that beginning, historic real coal prices peaked in 1975, at $50.92 per short ton ($19.35 nominal).[18]

Coal prices are also commonly influenced by the coal end use. In the United States the principal end uses are steam coal, metallurgical coal, and industrial coal. Steam coal, also known as "thermal" coal in international markets, is used to raise steam or heat to power industrial processes. It is priced primarily on its deliverable heat content and, since environmental regulations started in the1970's, its value may be rated down for high sulfur content. Any rank of coal may be used as a steam coal. The average nominal price at the mine or origin of all U.S. coal produced in 2003 was $17.85 per short ton. By comparison, the average price of all coal delivered to electric power plants - which generally accounts for 90 percent of U.S. production - was $25.91. The $8.06 difference is roughly the average costs of handling and transporting the coal to the final consumers. Examples of real delivered prices of steam coal for electricity production[19] appear below:

Steam Coal at Electric Power Plants

Year	Delivered Real Price per Short Ton (In Year 2000 Dollars)
1973	$28.29
1983	$53.66
1993	$32.34
2003	$24.44

Metallurgical or coking coal is used to produce metallurgical coke. The coke is produced in sealed, oxygen-free ovens and used in blast furnaces in standard iron smelting for steel production. Coke is made from bituminous coal (sometimes blended with up to 1 percent anthracite). It must be low in sulfur and must "agglomerate," or fuse, incorporating ash-forming minerals in the coal, to produce a strong, porous, and carbon-rich fuel that can support the load of iron ore in a blast furnace. Coal for metallurgical use requires more thorough cleaning than for steam uses and is priced higher:[20]

Coal at Metallurgical Coke Plants

Year	Delivered Real Price per Short Ton (In Year 2000 Dollars)
1973	$62.07
1983	$90.94
1993	$53.68
2003	$47.77

Industrial coal can be of any rank. It is coal used to produce heat for steam or industrial processes. Typical industrial coal consumers include manufacturing plants, paper mills, food processors, and cement and limestone products. Prices[21] tend to be higher than for coal received at electricity producers primarily because average tonnages purchased by industrial consumers are smaller and, in some cases, because the plant processes require specific or less common coal characteristics:

Coal at Other Industrial Facilities

Year	Delivered Real Price per Short Ton (In Year 2000 Dollars)
1973	n.a.
1983	$60.30
1993	$36.47
2003	$32.74

CONCLUSION

In recent years about 90 percent of coal production in the United States has been consumed at domestic electric power plants. Coal use grew because of secure, abundant domestic reserves and relatively low prices. Demand has been maintained through increasing mine productivity, which in turn has been supported by operation of larger and larger mines, using larger, more efficient mining machinery, advances in technology and control systems, and fewer mine personnel.

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