This afternoon I would like to present an overview of what I consider to be the significant developments in underground coal mining equipment technology over the past 130 years. Technology has maintained the competitiveness of the coal industry by improving both safety and productivity.

Also I will briefly discuss the changes that have occurred in the structure of the coal industry over the past thirty years and future outlook for coal.
A key development in the mechanization of mining machinery occurred in 1870 when the compressed air driven English Channel Machine (Figure 1) was built and operated to drive a tunnel under the English Channel. The machine actually penetrated at a rate of 70 feet per day and drove 1½ miles of tunnel before the project was abandoned for political reasons.

Mechanization of American coal mines did not begin until the late 1870’s. Until that time, coal was undercut with a hand pick, hand drilled for blasting and hand loaded into mule or horse drawn cars (Figures 2, 3, 3-A, 4, 5). Undercutting was necessary to
provide another free face for blasting and enhance the yield of high-priced lump coal for railroads, home heating and coke making.
In 1877 the Harrison compressed-air puncher and air motor powered Jeffrey (Lechmer) breast machines were developed (Figure 6) and the following year, Jeffrey developed an electrically powered breast machine. The puncher basically performed the same functions as the miner pick while the breast machine made a series of parallel 44-inch wide by 6 or 7 foot deep undercuts in the coal seams (Figure 7).
In 1887 the General Electric Company installed the first electric trolley locomotive to replace animal haulage (Figure 8).

In 1897 Sullivan introduced an air-operated shortwall cutter. An electric machine followed in 1898 (Figure 9). Both Jeffrey and Goodman soon brought out similar
machinery (Figure 10). In 1910, 47 shortwall machines were in service compared to 6,716 punchers and 5,973 breast machines and all coal was loaded by hand.

In 1911 Jeffrey developed the first track-mounted cutter (Figure 11).
First Continuous Miner

Alex Szakacs - 1910
Between 1911 and 1920, at least 12 types of loading machines were tried. Only two survived. One was the track mounted, gathering arm Joy loader which was tried out in the Somers Mine of Pittsburgh Coal Company in 1916 (Figure 12). The other was the McKinlay Entry Driver, a track mounted boring machine in 1918 (Figure 13). This machine had overlapping boring arms rotating in opposite directions. Coal was carried away by a conveyor in the center of the machine and the machine was advanced utilizing hydraulic jacks set between the machine and the ribs. This machine is considered the forerunner of the Marietta Boring Machine which was manufactured beginning in the early 1950’s.
Despite all this activity, the decade ending in 1920 was the last time that all coal was loaded by hand. By this time, shortwall (Figure 14) and track cutting machines had almost replaced breast and puncher machines and power drills were introduced for drilling coal (Figure 15).
In 1922, Joy had perfected the first loading machine that was not tied to track (Figures 16, 17, 18, 19). This patented gathering arm loader was mounted on Caterpillar
treads and utilized a swinging discharge conveyor for loading into mine cars. By the end of 1923, Joy had sold 123 of these machines. Other manufacturers followed Joy with loading machines, but they were mostly track mounted and were not as efficient as Joy’s machine.

In the 1920’s, shaker conveyors (Figure 20) and duckbills for mechanical loading were introduced by Goodman Manufacturing Company. The duckbill was essentially a coal-loading device with a fast forward motion and slow backward motion. The duckbill fed the shaker conveyor and was pulled into the coal by means of a hand wench and rope attached to jacks wedged between the roof and bottom.
Other conveyors popular at that time for hand loading were pan chain conveyors (Figure 21) and pit loaders (Figure 22). The pit loader simply reduced the height the hand loader raised the coal to the mine car.

**Figure 21 – Face Chain Conveyor**

**Figure 22 – Pit Loader - 1920**

By 1930, mechanically loaded coal had risen to approximately 50 million tons or 11% of that year’s underground production.
The major innovation in the 1930’s was the development of the four-wheel self-contained shuttle car by Joy Manufacturing Company (Figures 23, 24). This battery-

Figure 23 - First Joy Shuttle Car - 1938

Figure 24 – Joy 32-E Battery Shuttle Car - 1938
powered car, which evolved into today’s electric cable reel car, eliminated the necessity of installing track into each working face. Coal could then be hauled from the loading machine and dumped onto outby conveyors or into mine cars.

Up through near the end of World War II, shortwall cutting machines (Figure 25), track mounted cutting machines (Figure 26), and track mounted loading machines (Figure 26-A) continued to be widely used. The Joy crawler loading machine continued to displace track loading machines (Figure 26-B).

Figure 25 – Goodman Bottom Machine - 1937

Figure 26 – Track Mounted Cutters

Jeffrey 29-L Arcwall Cutter - 1937
Jeffrey 29-U Universal Cutter - 1937
Sullivan Sawloader Continuous Miner – 1937
Sullivan 7-AU Track Cutter - 1943
Figure 26-C shows the Konnerth Mining Machine conceived by K. L. Konnerth, Vice President, U. S. Steel Coal Division in 1941. The machine used four (4) cutting bars (two (2) vertical and two (2) horizontal) and electric hammer picks to break the coal as the cutter bar cut a 6.5 feet wide by 4.5 feet deep sump. Prior to mining, the coal face was shot loose by explosives. Jeffrey Manufacturing Company built the machine for U. S. Steel. This machine was very similar to the Jeffrey Entry Driver manufactured by Jeffrey in the 1920’s. The Entry Driver utilized air picks to fracture the coal block and was not mounted on crawlers. Neither machine enjoyed much success.
In 1945, Joy (Sullivan) introduced the first rubber-tire mounted cutting machine (10-RU) (Figure 27). Conventional mining was now completely off track.
The other manufacturers (Jeffrey and Goodman) soon followed, and by the early 1950’s, offered a complete line of off-track loading machines, cutting machines, drills and shuttle cars.

In 1945, Kennametal introduced the first tungsten carbide cutting bit (Figure 28). This bit, along with other advances in metallurgy that strengthened machine components, fostered the introduction of two (2) successful continuous miners in 1948.

1. The Jeffrey Colmol (Figure 29) was developed by and acquired from Sunnyhill Coal Company in Pennsylvania. This initial machine used twin 50 hp motors to power the cutting head. Later improved models used 100 hp cutter motors and three models were produced to mine coal seams ranging from 28 inches to 72 inches thick.
Depending on the model, cutting height could be varied by 16 to 22 inches and had a rated capacity of 3 to 5 tons per minute.
2. The Joy Ripper 3-JCM miner was introduced in 1948 (Figure 30). It utilized two (2) 65 hp cutter motors, was 34 inches high and could cut coal seams ranging from 44 to 66 inches thick. Joy produced several models and 620 were sold by 1960.

In 1946, roof bolting (Figure 31) was introduced at a Consolidated Coal Company mine in Staunton, Illinois. At that time, roof falls accounted for approximately 430 or 50% of all coal-mining fatalities (Figures 31, 31-A). The first commercial bolt was introduced in 1949 and was a 1-inch diameter slotted wedge bolt installed with an air operated stoper drill or rotary drill (Figure 32). Roof bolting, in addition to reducing roof fall injuries, substantially increased the coal reserves that could be safely mined.
In 1950 the Lee Norse Company introduced the Koal Master (Figure 33), a drum miner mounted on wheels. The cutting principle of simultaneously oscillating two cutting drums horizontally as the machine made a downward shear provided superior cutting action compared to a chain type miner. The diamond cutting pattern (Figure 34) traversed by the bits produced a higher percentage of lump coal and the Joy gathering arms provided better cleanup of loose coal. For better traction, in 1951 the machine was mounted on crawlers (Figure 35). Variations of this machine dominated the continuous miner market until the mid-1960’s (Figure 35-A).
In 1955 Wilcoxon introduced the Mark 20 auger miner and in 1960 Jeffrey the 100-L Miner (Figure 36). Both miners were pulled across the coal face, similar to a shortwall cutting machine, with ropes affixed to self-powered winches (Figure 36-A).
These machines could mine coal seams ranging from 24 to 48 inches thick and became the mainstay of thin-seam mining. Jeffrey discontinued manufacturing the 100-L in 1970 and the Wilcox has been crawler mounted (Figure 37) and marketed by Fairchild, Inc.

Figure 37 – Fairchild International F330 Auger Miner - 1970

During the 1950’s Jeffrey continued with the production of the Colmol. Marietta capitalized on its 1918 design of the McKinlay entry driver and introduced the Marietta Boring Miner (Figure 38). Both Goodman and Joy introduced similar boring machines (Figures 39, 40). These machines were highly productive, but carried a high purchase price and were costly to maintain. Since they were boring machines, they would not
adapt to changes in seam height. For these reasons, these machines never found wide acceptance. Some are still operating in Potash and Trona mines.

In 1964, to combat Lee Norse’s dominance of the continuous miner market, Joy introduced the 8-CM oscillating head miner (Figure 41).

In 1967, Jeffrey entered the market with the non-oscillating gear driven solid head continuous miner (Figure 42).

Joy followed in 1968 with a solid drum miner driven by a ripper chain and National Mine introduced their 3060 drum miner in 1970 (Figure 43).
Lee Norse preserved their oscillating head design until 1970 when they entered the market with their 265 and 245 solid head models (Figure 44).

This finally entrenched the future of the solid drum miner, which is the design of preference today.

With the enactment of the 1969 Health and Safety Act, underground productivity began to drop as coal companies were required to change their production practices and technology to comply with new Health and Safety Laws. Conventional underground mining equipment (cutting machines, loading machines and mobile coal drills) began to be replaced with continuous miners. Continuous miner sections, with two (2) less active working places and the elimination of dangerous explosives used for blasting coal, were easier to ventilate and supervise.

Other significant developments in the 1970’s included:
1. Introduction of more reliable solid-state electrical controls to replace mechanical contactors and timers on face equipment.

2. Remote controls for continuous miners that enabled the operator to be positioned at a safer distance from unsupported roof at the working face (Figure 45).

3. Positive ventilation at the working face as scrubbers were mounted on continuous miners to provide better compliance with respirable dust (Figures 46, 47, 48).
Figure 46 – Joy 14-CM Miner with Remote Control & Dust Collector (Jewell Ridge Coal Co. – 1974)

Figure 47 – Dust Collector on Joy 14-CM Miner Discharge Behind Line Curtain (Jewell Ridge Coal Co. – 1974)

Figure 48 – First Self-Contained Scrubber on Miner (Peabody Coal Company – 1977)
4. Development of the reliability of battery powered coal haulage tractor-trailer coal haulage units (Figure 49).

5. Improvements in mobile bridge (Figures 50, 51, 52) continuous haulage units to convey coal directly from the continuous miner to the underground belt haulage system. These units heretofore had been used primarily on thin seam bottom auger type miners (Jeffrey 100-L and Wilcox) to feed intermediate chain-conveyor pan line haulage dumping onto belt conveyors or mobile haulage units.
6. In 1973 a major advancement in roof support occurred when a fully grouted roof bolt using epoxy resin was developed (Figure 53). This was a $\frac{3}{4}$-inch rebar with a forged 1-1/8-inch square head using resin to anchor it in the hole. This bolt could withstand a pull of almost 30,000 pounds compared to about 10,000 pounds for a 5/8-inch mechanical bolt. In addition to reducing roof-
fall injuries, this bolt greatly expanded the coal reserves that previously could 
not be safety mined.

A unique example of the application of the resin bolt is shown in Figure 54. 
This is a mine in Logan County, West Virginia, mining two splits in the 
Coalburg seam. After the top split was mined, the bottom split was safely 
mined under an eleven-foot in-seam rock parting and successfully supported 
with resin bolts.
7. **Employment of Longwalls**

Longwalling was initiated in 1951 at Eastern Gas and Fuel’s Stokesbury Mine in the Pocahontas seam in West Virginia (Figure 55). The face was 328 feet long and used steel headers weighing 50 pounds supported on collapsible...
jacks set between wood cribs. A German plow, pulled across the face by a chain, plowed the coal onto a face conveyor. This face is reported to have averaged 560 tons per shift operating one shift per day. The face employed 31 men, most of whom spent the other two idle shifts moving the cribs and advancing the roof support jacks and headers.

Figure 55-A – Eastern Gas & Fuel Longwall - 1951

Face conveyor with compressed air rams

Mechanical jack and steel I-beam roof supports

Westfalia Plow
Between 1960 and 1962, Eastern Gas and Fuel installed two (2) 600-foot wide plow faces at their Keystone Mines in southern West Virginia. These were the first successful U.S. installations utilizing self-advancing hydraulic roof supports. Roof support yield capacity was 40 tons. These units operated two shifts per day, with a crew of seven (7) men, and averaged producing about 800 tons per shift.

In an effort to control extreme bounce conditions under 1,000 to 2,000 feet of cover being experienced at their Sunnyside, Utah mine, in 1961 Kaiser Steel installed a British manufactured self-advancing, 30-ton Dowty roof support system (Figure 55-B). The longwall face was 420 feet long and utilized a 125
hp British Jeffrey Diamond shearer. The system was considered to be successful, averaging about 500 tons per shift.

With the successes at Eastern Gas and Fuel and Kaiser Steel, eastern mining companies began to seriously look at longwalling as the solution to adverse roof control conditions.

In 1964 both Jeffrey and Long Airdox began offering British manufactured self-advancing, 3-leg, roof supports and shearing machines. Jeffrey offered the 33-ton Dowty support and Long Airdox offered almost an identical Dobson support. At least six of these installations were installed in eastern mines in the mid-1960’s at a cost of approximately $500,000 for a 500-foot face (Figures 56, 57, 58, 59). With the experience gained on these faces, it was established that higher capacity supports were required, and in order to be
productive, longwalls required the same stable firm roof conditions as successful continuous and conventional mining systems.

By 1976, in an effort to reverse the trend of declining productivity, longwalling was firmly established with over 70 installations in the United States. Most longwall systems now used four-leg chock roof support systems with capacities ranging from 500 to 700 tons. These systems, along with the conveyors, shearers and plows were manufactured mostly by German and British companies. In 1978, Joy produced the first complete American-designed longwall face. It included a 950 volt shearer, chainless haulage, armored face conveyor, roof supports, stage loader and belt tailpiece.

Also during this period, many companies, flush with high profits from the “coal boom” of the mid-70’s, experimented with longwall installations in thin seams, and shortwall mining which substituted a continuous miner for a shearer and shuttle cars in lieu of a face conveyor.
Figure 60 shows a 500-foot wide Westfalia plow face installed in 1976 in the 30-inch Jawbone seam in Virginia. Roof supports were rated at 520 tons. Total cost of the system was approximately $2.0 million. This system operated with marginal success for about two years with peak production of about 600 tons per shift. Due to frequent thinning of the coal seam and inability of the plow to penetrate in-seam rock, the system failed.

The shortwall system (Figure 61) was a 200-foot wide face utilizing 550-ton Joy Gullick supports installed in 1976 in a 5-foot coal seam in Virginia. The systems did not survive because of high capital cost of the supports ($1.3
million for the 200-foot face shown), the inability of the 10-foot cantilever of the roof canopies to provide enough tip support to prevent roof failure at the face, and the production delays resulting from having to bolt the corner at the entrance to the face after each continuous miner pass.

From the 1970’s, the basic concept of underground mining equipment has not substantially changed. The equipment today is safer, has higher horsepower and is more productive and reliable.

**Safety**

The coal industry’s commitment to safety and the development of new technologies has yielded remarkable improvements in mine safety (Figure 62). In 1907 the coal industry experienced a high of 3,242 fatalities. In 1969 the industry suffered 203 fatalities and in 2002, there were 27 fatalities. Mining has a lower rate of injuries and illnesses per 100 employees than agriculture, construction or retail trades. According to

![Coal Fatalities* for 1900 Through 2202](image)
the Department of Labor, the injury rate for miners today is comparable to that of grocery store workers.

**Productivity**

Since 1970 through 2002 (Figure 63), underground productivity has increased from 1.72 to 4.02 tons per miner hour worked. In 2002, total U.S. underground
production by all methods was approximately 370,000,000 tons (Figure 64). Approximately 51% of this total production was produced from the 49 longwall faces operating in the U.S., and 47% from continuous miners. The average productivity of these 49 longwalls was 5.37 tons per miner hour worked with the more efficient longwalls achieving production rates of 10 to 15 tons per miner hour worked. Average continuous miner productivity was approximately 3.0 tons per miner hour worked.

The progress in underground mining equipment has been evolutionary. Since the 1970’s, the basic concept of mining equipment has not changed. Equipment has become more sophisticated, reliable, powerful and productive. Longwalls are automated with computerized controls and equipment diagnostics, data logging and surface communication. Average face widths have increased to over 1,000 feet, and roof support unit capacities are approaching 1,300 tons. Equipment voltages of up to 4,160 volts have allowed horsepower on shearsers to approach 2,000 hp. It is not uncommon for longwall faces to produce 20,000 tons per day.

Depending on seam height, drum continuous miners now mine at the rate of 10 to 38 tons per minute with cutter head horsepowers up to 590 horsepower and total horsepowers approaching 1,000 hp.

The only underground equipment manufacturers to survive as independents from the 1970’s were the Joy Mining Machinery Company founded in 1919, and the Fletcher Equipment Company, a manufacturer of roof drills, founded in 1947. DBT America was formed in 1994 by consolidating the manufacturing and marketing in the U.S. of the German longwall manufacturers; i.e., Westfalia, Hemsheidt, Kloechkner and Heintzmann. DBT has since acquired Jeffrey Manufacturing Company, Long Airdox
(Anderson Mavor Shearers), and rights to the Eimco continuous miner. In the 1990’s, Oldenburg acquired the Stamler Company and began manufacturing underground battery coal haulers and continuous haulage bridge conveyed systems.

Product lines being offered by manufacturers:
Joy (continued)

Figure 69 – Joy Roof Bolters
Figure 70 - Continuous Miner

Figure 71 – Face Haulage Equipment

Figure 72 – Roof Bolters
Figure 73

Figure 74 – Longwall Support System
Figure 75 – Roof Drills

Figure 76 – Mobile Roof Support

Figure 76-A – Pillar Recovery with Mobile Roof Supports
Oldenburg Stamler

Battery Hauler

Mobile Bridge Module

Conveyor Bridge Module

Mobile Breaker for Module

Figure 77
The makeup of the major U.S. Coal producing companies has been in a constant state of flux since the 1970’s. Only three of the top ten coal companies in 1970 (Peabody, Consol and General Dynamics Group) remain in business as independent coal producers today (see Chart I).

During the energy crisis, beginning in 1974, the windfall profits being enjoyed by coal companies enticed oil companies, electric generating companies, and others to enter the coal business. It was at this time big oil companies began to heavily invest in Wyoming Powder River surface operations. Coal prices skyrocketed to $60 to $80 per ton and utilities fearing a shortage of compliance coal were paying high prices ($40 to $50/ton) for long term compliance coal supply agreements. Some export metallurgical coal was being sold for over $100 per ton.
During this period, productivity was still falling in 1978 (Figure 78) due to the effects of the 1969 Health and Safety legislation and labor strikes at UMWA mines were exacerbating the problem. With so many new coal producers entering the business, the coal industry began to experience labor shortages due to competition for existing labor. Also the labor force had aged and the industry was forced to hire and train replacement workers. It was 1978 before these problems were beginning to be solved. Productivity had dropped 26% from 1974 levels and mining costs at many companies had risen to meet the sales prices they were receiving for coal.

By 1982, underground productivity had almost climbed back to the 1974 level of 11.31 tons per man-day when the eastern metallurgical coal export market collapsed. Metallurgical coal was forced onto the domestic steam markets and oversupply began to drive prices down to unprofitable levels. At the same time, eastern coal companies increased production at lower cost surface mines.

Beginning in the mid-1990’s the utility industry began to deregulate. Since coal is approximately 60% of the cost at coal generating stations, the utilities took advantage
of the oversupply and drove coal prices down further. This forced more unprofitable operations to close and/or sell their assets.

During the last three decades, the coal industry has weathered substantial environmental restrictions, labor problems, and marginal profits. There has been considerable industry consolidation as many coal companies were sold and big oil exited the business (see Chart I).

Also during this period, the major underground equipment manufacturers were not without their problems. During the coal boom of the 1970’s, equipment manufacturers geared up to handle the huge demand for equipment. When industry prosperity came to a screeching halt in the early 1980’s, declining orders for new equipment took its toll. Equipment manufacturers were forced to downsize with the final result being a series of consolidations.

The Base Case for Coal’s Strong Competitive Position in U.S. Energy

- The fuel for 52% of U.S. electrical generation
- Growing total consumption/production (up 70% over twenty years) with nearly 1.1 billion tons produced in 2002
- Domestic electricity generation (88% of U.S. coal consumption)
- Low cost (typically 1/3 the cost of gas on a delivered cents per MMBtu basis)
- 250 years (275 billion tons) of mineable reserves
- Oil is 2% of domestic fossil fuel reserves, Gas is 3% and Coal is 95%
Projected Coal Production Growth

Source: Energy Information Administration

Projected U.S. Electricity Generation by Fuel, 1970-2020

Source: Energy Information Administration (2002 Annual Energy Outlook)
Coal clearly has a bright future. Although there will be more industry consolidations, it will be at a slower rate. Wall Street institutional investors and investment brokers see the potential of coal and want a piece of the action. Consolidation of the industry has resulted in some companies becoming public held entities and, for the first time, having to answer to shareholders.

The mining engineers of the future will be working in a more sophisticated industry. In addition to technical skills, the mining engineer will require financial and analytical skills as he or she advances in management.

I recommend that as each student chooses elective courses, consideration be given to basic accounting and financial courses.