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Coal resources, reserves and peak coal production in the United States ☆

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ABSTRACT

In spite of its large endowment of coal resources, recent studies have indicated that United States coal production is destined to reach a maximum and begin an irreversible decline sometime during the middle of the current century. However, studies and assessments illustrating coal reserve data essential for making accurate forecasts of United States coal production have not been compiled on a national basis. As a result, there is a great deal of uncertainty in the accuracy of the production forecasts. A very large percentage of the coal mined in the United States comes from a few large-scale mines (mega-mines) in the Powder River Basin of Wyoming and Montana. Reported reserves at these mines do not account for future potential reserves or for future development of technology that may make coal classified currently as resources into reserves in the future. In order to maintain United States coal production at or near current levels for an extended period of time, existing mines will eventually have to increase their recoverable reserves and/or new large-scale mines will have to be opened elsewhere. Accordingly, in order to facilitate energy planning for the United States, this paper suggests that probabilistic assessments of the remaining coal reserves in the country would improve long range forecasts of coal production. As it is in United States coal assessment projects currently being conducted, a major priority of probabilistic assessments would be to identify the numbers and sizes of remaining large blocks of coal capable of supporting large-scale mining operations for extended periods of time and to conduct economic evaluations of those resources.

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1. Introduction

Coal, oil, and natural gas have been the principal commodities in meeting the industrialized world's demands for energy during the past several centuries. In the United States, coal was discovered in 1699 in the Triassic basin near Richmond, Virginia, and mined commercially by Huguenot settlers in about 1709 (Hibbard, 1990; Robinson, undated). Additional development of coal resources in the Appalachian region continued throughout the 1700s into the early to mid-1800s and during the Civil War, when Mississippian-age coal beds were mined in southwestern Virginia, to fuel the ironclad Merrimac in its battles with the Monitor in Virginia coastal waters (LaLone, 2000; New River heritage association of Montgomery County, undated). Following the Civil War the use of coal became widespread throughout the Appalachian region as a source of energy for industry and households in the industrialized northeastern part of the country. Today, coal is distributed widely across the United States (Fig. 1), and is used primarily as a fuel for coal-fired electric power plants as well as for industrial purposes. In addition, in 2009 nearly 60 million tons of United States coal were shipped to international markets in Canada, South America, Japan, and China (EIA, 2010c).

In general, estimations of the amounts of mineral and energy deposits fall into three broad categories: (1) studies designed to quantify the amount of the resource, (2) studies designed to estimate the amount of the economically producible resource (the reserves), and (3) studies designed to predict future rates of production and depletion of the resource. For many years, the coal resource classification system used by the U.S. Geological Survey (USGS) was designed to quantify the total amount of coal in the ground (in-place resources) (Wood et al., 1983). The system classified the coal into categories of "measured," "indicated," "inferred," and "hypothetical" based on distances from points of thickness measurements. For example, using this methodology, Ruppert et al. (2002) summarized the results of the United States Geological Survey's assessment of selected coal

☆ "*Recoverable coal reserves at producing mines* represent the quantity of coal that can be recovered (i.e. mined) from existing coal reserves at reporting mines. These reserves essentially reflect the working inventory at producing mines. In 2009, the recoverable coal reserves in the United States totaled 17,468 million short tons at producing (active) mines (EIA, 2011a)" (~18,000 including Alaska). The *estimated recoverable reserves* include the coal in the demonstrated reserve base (see below) considered recoverable after excluding coal estimated to be unavailable due to land use restrictions or currently economically unattractive for mining, and after applying assumed mining recovery rates. See the EIA Glossary for criteria. In 2009, the estimated recoverable reserves totaled 260,551 million short tons (EIA, 2011a). The demonstrated reserve base includes publicly-available data on coal that has been mapped and verified to be technologically minable. See the EIA Glossary (EIA, undated) for criteria. For 2009, the demonstrated reserve base was estimated to contain 486,102 million short tons (EIA, 2011a) ftp://ftp.eia.doe.gov/coal/052992.pdf.

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Fig. 1. Coal fields of the United States.
Modified from Tully, 1996

beds and zones in the major coal-producing regions in the United States They concluded that there are over 1.6 trillion short tons of coal resources remaining in all categories in the 60 coal beds and zones assessed (Ruppert et al., 2002, p. 247). They also suggested that only about one-tenth of the original resource would be economically recoverable. Olea et al. (2011) have suggested that assessments of coal beds would be improved if geostatistical methods that quantify uncertainty were used rather than a method that depends entirely on distances between coal thickness data points to calculate potential reserves.

Luppens et al. (2008, 2009) have assessed the economically producible coal reserves and resource potential of the Gillette coalfield in the Powder River Basin, Wyoming, first by estimating the amount of recoverable coal available for different mining scenarios at a stripping ratio of 10:1 or less and then by producing cost curves that illustrate the amount of the recoverable coal that is economic at different sales prices. They concluded that, depending upon the sale price at the time of the assessment, the coal reserves for the Gillette coalfield would range from about 10.1 billion (at $10.47 per ton) to 18.5 billion (at $14.00 per ton) short tons out of a recoverable resource of about 77 billion tons (Luppens et al., 2008). Furthermore, they concluded that subsequent increases in sale prices and improvements in mining technology might convert additional coal resources into economically producible coal reserves in the future.

In the past several years, there has been a substantial interest in predicting the future availability and production of United States and world coal as a long-term source for electrical power generation, conversion of coal-to-liquids, and for other industrial uses, as well as in the environmental problems that may be associated with continued large-scale use of coal (Croft and Patzek, 2009; Höök and Aleklett, 2009, 2010; Milici, 2009; Milici et al., 2009; Patzek and Croft, 2009; Rutledge, 2011).

Recently, there have been several different estimates for the amount of recoverable coal in the U.S., and the outlook for future coal production. Höök and Aleklett (2009, 2010) have described in detail the historical trends and future production outlook for United States recoverable coal supplies. Depending on the models used, Höök and Aleklett (2009, 2010) estimate that United States coal production would reach a maximum sometime between 2030 and 2100 before it eventually begins an irreversible decline (Table 1). In any case, reasonable forecasts of future coal production are dependent upon accurate estimates of the amounts of economically producible coal and potential supply rates. Some researchers have suggested that such estimates should consider limitations that may be imposed upon coal usage for environmental as well as for economic reasons (Höök and Aleklett, 2009, 2010).

Mohr and Evans (2009) have developed a predictive model for forecasting future coal production that is based upon supply and demand interactions and includes historical numbers of producing mines, historical mine production, and mine life data. In addition, estimates of ultimately recoverable resources (URR), supply rates, and historical growth rates are important parts of their model. Based on this model, they concluded that United States coal production would peak in 2049 at a production rate of 1.8 billion tons per year. Croft and Patzek (2009), however, have suggested that United States

Table 1
Peak coal production estimates (Bt = billion tons = 109 tons).

Reference	Data or method	Year of peak production	Production in peak year
Höök and Aleklett (2009)	EIA recoverable reserves (ERR)	2030–2100+	1.4 Bt
Höök and Aleklett (2009)	EIA demonstated reserve base (DRB)	2100+	2.5 Bt
Höök and Aleklett (2010)	Gompertz curve	2060	1.5 Bt
Höök and Aleklett (2010)	Logistic curve	2100+	1.4 Bt
Mohr and Evans (2009)	Production model	2049	1.825
Milici et al. (2009)	Calculated decline rates	2067–2088	1.4–1.6 Bt
Croft and Patzek (2009)	Multiple Hubbert curve analysis	~2010	~1.1 Bt

coal production passed its peak in 2008 and is already in decline. However, based on studies of the effects of environmental regulations and electricity demand, EIA (2012) predicts a general decline in coal production from the present until 2015 followed by an average annual growth rate of 1.0% per year through 2035.

This range in estimates for the time of peak coal production and decline reflects both the methodologies used by the different researchers in making their forecasts, and the lack of economically based coal reserve estimates for the whole of the United States. This paper suggests that the range of uncertainty in the amount of economically producible coal (coal reserves), as well as the uncertainty in predicting future coal production rates because of environmental constraints and competition from other methods of generating electricity (Milici, 2002, 2004), can best be captured by utilizing a probabilistic assessment methodology that calculates minimum, maximum, and mean values for coal reserves and production rates.

2. Current coal production and mine size distribution

In 2009, the United States produced 1,084,368,148 short tons of coal from 1285 mines (Table 2, 2009 data) and from an estimated recoverable reserve of about 260.6 billion tons (EIA, 2010a, Table 2). Of this amount, the top 47 mines, those that produced more than 4 million tons per annum, produced 673,672,015 tons of coal in 2009, which is about 62% of the coal produced in the United States for that year (Figs. 2 and 3). The top 11 mines, each of which produced more than 12 million tons per annum, produced about 440,565,767 tons of subbituminous coal, about 41% of the 2010 United States annual coal production. Nine of these mines are within the Gillette coalfield of Wyoming (Table 3). In comparison, the 14 largest mines in the Appalachian region produced 90,738,740 tons of bituminous coal in 2010, a little more than 8% of United States coal production for that year (EIA, 2010a). From these data, it is clear that most of the coal currently produced in the United States comes from very few large mines in the western coalfields. Fig. 3 shows the distribution of the most productive mines in the United States by region (2009 data). In order for U.S. coal production to be maintained at or above current levels, future production from these very large mines would have to be sustained from adjacent lease tracts or replaced by new large-scale mines opened elsewhere. Production and reserve data for the 11 largest coal mines in the United States are shown in Table 3.

The overall variability of coals produced from several of the major coal basins in the United States is shown in Table 4. The table illustrates their coal rank, heat content, and sulfur dioxide content, as well as spot prices (October–December 2010) per ton and per million Btu. In general, the Appalachian bituminous coals that contain the highest heat content and lowest amount of SO_2 command the highest prices. The low sulfur subbituminous coal from the Powder River Basin costs the least because of the very large scale of these mining operations, as well as the significantly lower heating value of this coal compared to the Appalachian Basin coals, and their much higher moisture content which needs to be managed before utilization. The costs of transporting these western coals to markets in the eastern and southern parts of the United States, however, allow coals mined in the Interior and Appalachian Regions to remain competitive in nearby markets. Also, their significantly higher heat content allows these coals to be competitive.

Table 2
United States Coal Production and Mine-size Distribution: Energy Information Administration (EIA, 2010a) Annual Coal Report: Report No. DOE/EIA 0584 (2009):http://www.eia.doe.gov/cneaf/coal/page/acr/table9.xls.

Mines	Percent of total mines	Coal production (short tons)	Percent of total United States production
Top 11 mines in United States	0.85%	440,565,767	40.6%
Top 48 mines in United States	3.74%	673,672,015	62.1%
Top 14 mines in Appalachia	1.09%	90,738,740	8.4%
United States total (1285 coal mines)	100.00%	1,084,368,148	100%

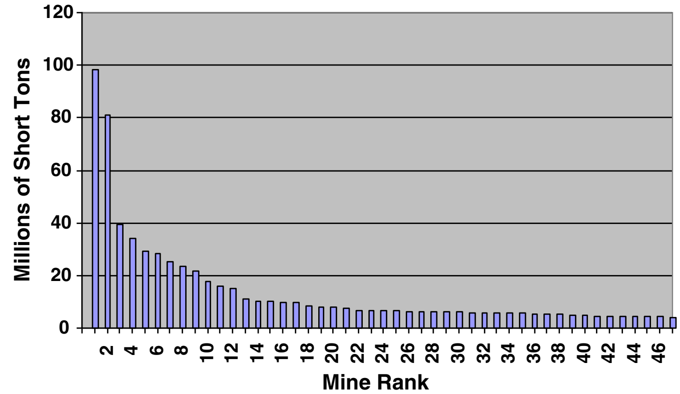

Fig. 2. Coal production from the 47 mines that mined the most coal in 2009 (EIA, 2010a, Table 9).

3. Coal resources and recoverable coal reserves

At present, EIA uses three categories of coal reserves in their annual compilations: (1) recoverable reserves at producing mines, (2) estimated recoverable reserves (ERR), and (3) the demonstrated reserve base (DRB) (EIA, 2010d, 2011a,b,c). Of these three categories, only the first is based on annual reports of producing mining companies and may be considered to be a current statement of economically producible coal reserves. The recoverable reserves at producing mines category, however, does not include all of the coal reserves controlled by the mining companies. Instead, this reserve category reflects only those coal reserves that are contained in current leases and does not include the potential reserves that may be recoverable in the future from additional leases (National Academy of Sciences, 2007a). Furthermore, EIA ERR are not reserves in the strictest sense according to SEC (United States Securities and Exchange Commission) standards.

As of 2009, EIA's total estimate for recoverable reserves (ERR) in the United States was about 260.6 Bst (billion short tons), of which 151.4 Bst are in three states, Illinois, Montana, and Wyoming (EIA,

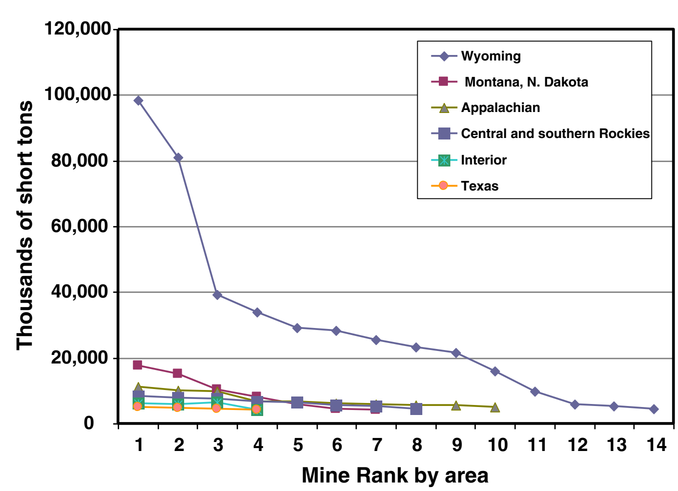

Fig. 3. Mine rank of the 47 most productive mines in the United States by states and areas (EIA, 2010a, 2009 data). Wyoming coal is subbituminous; North Dakota is lignite, Montana is subbituminous and lignite, Appalachian is bituminous and anthracite, the Rockies are bituminous and subbituminous, Interior is bituminous and lignite, and Texas is lignite (EIA, 2011e).

Table 3
Major coal-producing surface mines in the United States: Energy Information Administration (EIA, 2010a), Annual Coal Report: Report No.: DOE/EIA 0584 (2009): http://www.eia.doe.gov/cneaf/coal/page/acr/table9.xls. Reserve data from Cloud Peak Energy (2010), and BNSF Railway (2010). Black Thunder mine consolidation and reserves from Bleizeffer (2009) and Cochran (2010). Rank based on 2009 annual production. Wyoming mines are in the Gillette coal field.

Rank	Mine names/company	Mine type	State	Annual production	Annual production	Reserves (approximate)[a]
				(short tons)	MMST	MMST
1	Black Thunder/Jacobs Ranch/Thunder Basin Coal Company LLC	Surface	Wyoming	116,225,527	116.2	1370
2	North Antelope Rochelle Mine/Powder River Coal LLC	Surface	Wyoming	98,279,377	98.3	1200
3	Cordero Mine/Cordero Mining LLC	Surface	Wyoming	39,380,964	39.4	300
4	Antelope Coal Mine/Antelope Coal LLC	Surface	Wyoming	33,975,524	33.9	252
5	Belle Ayr Mine/Alpha Coal West, Inc.	Surface	Wyoming	28,395,952	28.4	406
6	Buckskin Mine/Kiewit Mining Group	Surface	Wyoming	25,411,798	25.4	450
7	Caballo Mine/Caballo Coal Company	Surface	Wyoming	23,252,475	23.3	867
8	Eagle Butte Mine/Alpha Coal West. Inc.	Surface	Wyoming	21,479,183	21.5	471
9	Spring Creek Coal Company/Spring Creek Coal LLC	Surface	Montana	17,608,969	17.6	258
10	Rawhide Mine/Caballo Coal Company	Surface	Wyoming	15,842,274	15.8	388
11	Freedom Mine/The Coteau Properties Company	Surface	North Dakota	15,046,737	15	550
	Total			434,898,780	434.8	6512

MMST — millions of short tons; R/P — reserve to production ratio.
[a] Reserve data refers to coal currently under the direct control of the mining operation and does not include potential reserves located in adjacent areas.

2009). Although Montana has the largest estimated coal resource, 60% of the resource is under more than 500 ft of overburden and at present cannot be mined economically by large-scale surface mining methods (Montana Bureau of Mines and Geology, 2011). Much of that coal is either of subbituminous or lignite grade and is currently being considered as in-place feedstock for underground coal gasification (Montana Bureau of Mines and Geology, 2011).

Original Recoverable Reserves (ORR) (Table 6) are calculated to be the sum of cumulative production (EIA, 1993; EIA, 1994-2008; Milici, 1997) plus the estimated recoverable reserves (ERR) (Fig. 4) in the ground as defined by EIA (2011a) (Tables 5 and 6). The term "estimated recoverable reserves" as used by EIA "includes the coal in the demonstrated reserve base considered recoverable after excluding coal estimated to be unavailable due to land use restrictions or currently economically unattractive for mining, and after applying assumed mining recovery rates". It is not the same as the more rigid definition of coal reserves used by the United States Securities and Exchange Commission (2001), which limits the terms used by companies in reporting coal reserves in their annual reports to "reserves," "proven reserves," and "probable reserves" and specifically excludes such terms as "demonstrated reserves" or "reserve base."

The ERR of EIA (2011a) is subject to considerable uncertainty because the amount of coal in the ground that is available for mining, the effects of evolving mining technology, and the impact of future environmental and economic constraints on coal usage are not well known. The projected growth of electricity demand resulting from the impact of population growth and increased usage of electronic products (EIA, 2012; Koonce, 2011) may be satisfied somewhat by increased use of natural gas, nuclear power, and renewable energy technologies, rather than by increased utilization of coal for electric power generation. If projections of increased coal use are correct and more is needed in the future (EIA, 2012), very large areas of coal reserves may soon be depleted by mega-mining operations in Wyoming. Replacement of this production from more numerous small mines may become increasingly difficult as thinner and deeper deposits are mined (compare Appalachian production with Powder River basin production) and coal production in the United States may eventually enter a period of irreversible decline within this century (Croft and Patzek, 2009; Höök and Aleklett, 2009, 2010; Patzek and Croft, 2009; Rutledge, 2011).

In order to predict the future of coal production and decline more accurately, we need comprehensive reports that contain economically recoverable coal reserve data. Those data are available for the Powder River Basin in Wyoming (Luppens et al., 2008, 2009) but not for all other major coal-producing basins of the United States.

The data for the demonstrated reserve base and estimated recoverable reserves of EIA were developed prior to the application of

Table 4
Average coal commodity spot prices, October/December 2010, Energy Information Administration (EIA, 2010b), average weekly coal commodity spot prices, http://www.eia.gov/coal/news_markets/. Last accessed 11/03/2011. Shaded areas indicate compliance coal, which emits less than 1.2 lbs of SO_2 per million BTU when burned.

Date	Central Appalachia	Northern Appalachia	Illinois Basin	Powder River Basin	Uinta Basin
Coal Rank	Bituminous	Bituminous	Bituminous	Subbituminous	Bituminous
Heat Content (Btu/lb)	12,500 Btu,	13,000 Btu,	11,800 Btu,	8,800 Btu,	11,700 Btu,
Heat Content (Btu/ton)	25,000,000	26,000,000	23,600,000	17,600,000	23,400,000
Lbs. SO_2 /MM Btu	1.2	<3.0	5.0	0.8	0.8
(Dollars per Short Ton)	$71.25	$69.50	$47.25	$13.25	$41.00
(Dollars per MM Btu)	$2.85	$2.67	$2.00	$0.81	$1.75

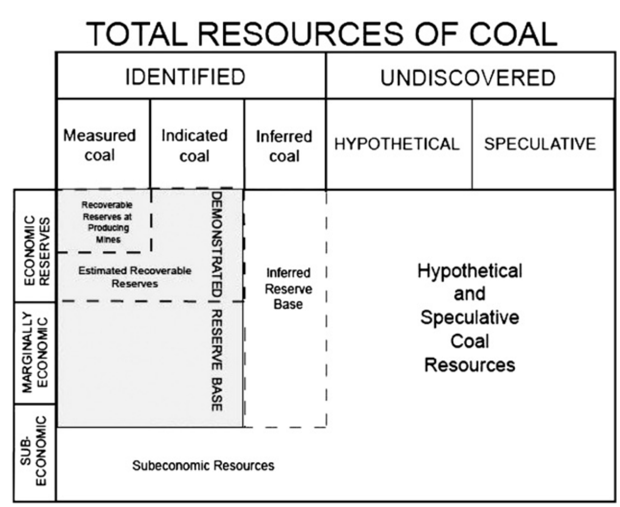

Fig. 4. Classification of coal resources and reserves. Modified from Wood et al. (1983, Fig. 2) to reflect EIA's terminology for classification of coal reserves and resources (EIA, 2011a,b,c).

Table 5
Recoverable coal reserves at producing mines, estimated recoverable reserves (ERR), and demonstrated reserve base (millions of short tons): (EIA, 2010a, Table 15, data for 2009). Numbers may not add correctly because of rounding.

Coal resource region	Recoverable reserves at producing mines	Estimated recoverable reserves (ERR)	Demonstrated reserve base
Appalachian	3949	50,094	99,022
Interior	3060	67,192	156,598
Western	9875	140,438	224,378
Alaska	W	2828	6102
Total	17,468	260,551	486,102

W proprietary data withheld because of small number of mines.

modern digital data compilations and the use of geographic information system technology in coal resource studies, and much of these basic data are outdated. For many of these reasons, the National Academy of Sciences (2007b) concluded that existing coal reserve data are insufficient for long range planning.

The relationship of coal resource terminology to reserve categories is shown in Fig. 4. Although almost all of the historical coal reserve data for the United States were obtained based on the methodology of Wood et al. (1983), their methodology for calculating coal resources and reserves is currently being reviewed by Olea et al. (2011) and may be supplemented by geostatistical methods that better reflect the uncertainty in coal resource appraisal. Olea et al. (2011) have developed methods to estimate the uncertainty in well spacings used in deterministic coal resource assessments. These methods, however, are not a complete probabilistic-based methodology for resource assessment, such as the one currently used in all USGS oil and gas assessments (Charpentier and Cook, 2011).

4. Probabilistic coal assessments

How much coal is likely to be produced from each of the major coal-producing basins in the United States and from the entire United States during the next 100 years (maximum, minimum, and mean tonnages)? When will peak coal production occur in each of these basins and in the United States, and how much coal will be produced during the year of peak production (maximum, minimum, and mean tonnages)? What is the quality of the coal remaining to be produced from these basins? All of these questions except the last require a numerical answer, and this paper suggests that the answer should be couched in probabilistic terms, with numbers that provide a 95% certainty, a 5% certainty, a median and a mean (Milici, 2002, 2004). As in the Powder River basin, it is likely that the larger mines, a relatively small percentage of the mines in each of the major coal basins, will produce most of the coal mined annually. Similar to the definition of size of an oil and gas field (Charpentier and Klett, 2005), the size of a coal mine may be calculated as the sum of its cumulative production and the reported remaining recoverable reserves at the mine. If additional coal resources are available for leasing at an existing operation, the estimated size of the mine may grow as these additional resources are explored, evaluated, and leased for mining. Mine-size distribution is an important factor to consider in estimates of future coal production because most of the coal currently produced in the United States comes from a small number of large-scale mining operations. In general, current coal production in the United States may decline if newly developed mines decline in size as the larger, more productive mines are depleted and as thinner and deeper coal beds are accessed.

Table 6
Estimation of original recoverable reserves (ORR), 2009 data.

	Short tons
Cumulative production	76,355,000,000
EIA ERR	260,551,000,000
ORR	336,906,000,000

An estimate of the remaining amount of economically producible coal in the United States would consist of evaluations of the coal reserves at producing mines plus an estimate of the potential coal reserves expected to be produced from the new mines anticipated to be developed within each of the major coal-producing regions of the United States, with an emphasis on the potential mine-size distributions of the surface and underground coal mines in each of the coal-producing regions. Additional detailed GIS-based coal resource studies, such as those summarized by Ruppert et al. (2002) and Luppens et al. (2008), would be required in order to support a comprehensive national assessment effort of this nature. The results, the remaining production anticipated from existing mines and the numbers and sizes of the new mines, would be reported in maximum, minimum, median, and mean categories. Depending upon the data available, a time frame for the assessment of the remaining amount of economically producible coal might be set, perhaps for 30 to 50 years, and in order to simplify the assessment process a minimum mine size would be established in order to exclude small operations from the assessment.

5. Peak Coal

In addition to the methods described by Croft and Patzek (2009), Höök and Aleklett (2009, 2010), Patzek and Croft (2009), and Rutledge (2011) peak coal, the time when national coal production is expected to peak, may be calculated simply by estimating the original recoverable reserves (ORR) and, assuming a normal distribution for the coal production curve, projecting historical production data into the future until half of the ORR has been produced. A factor should be applied to the ORR estimate that considers the uncertainty in both the cumulative production data and in the ERR data.

In comparison, Rutledge (2011) provides data that indicate historical coal reserve estimates have been too high. Using curve fits to production history to arrive at long-term production estimates, he concludes that only 28% of the estimated original recoverable reserves in the western United States and 60% of the estimated original recoverable reserves in the eastern United States will be produced. As a result, he estimates that 90% exhaustion of western United States coal in would occur in 2054 and 90% exhaustion of eastern United States coal in 2084 (Rutledge, 2011, Table 3). This scenario could occur unless additional very large blocks of mineable coal are identified that can replace those currently being produced by the mega-mines in the Gillette coal field of Wyoming and by the large-scale long wall operations in the northern Appalachian coalfield.

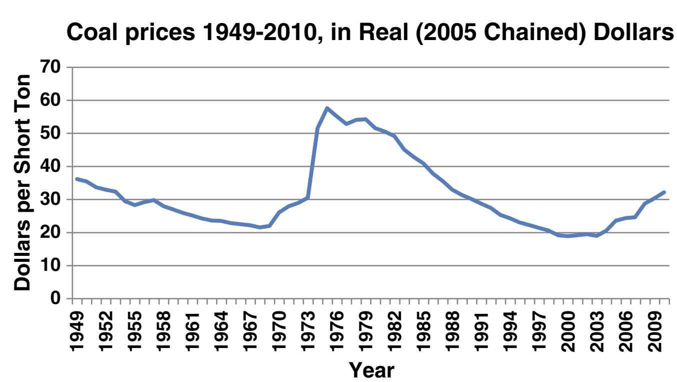

Fig. 5. Average coal prices 1949–2010, in real (2005 chained) dollars (EIA, 2010e).

6. Comparative costs of electricity production

It is most likely that the costs of producing electricity in the United States from coal-fired power plants will increase gradually as the thicker, higher grade and more accessible coal deposits are mined, as competing new uses for coal, such as coal-to-liquids (Milici, 2009), are developed, and as the demand for United States coal on international markets increases over the next several decades. As a result, effective competition from other methods of electric power generation, both non-renewable and renewable, may increase if utilities invest in the infrastructure required to produce electricity by facilities other than coal burning power plants.

The comparative levelized cost in 2009 $/MW hour for power plants entering service in 2016 is provided by EIA (2010f). As defined by EIA (2010f), levelized costs include capital, fuel, operation and maintenance, and financing costs, and an assumed utilization rate for each plant type. Selected average estimated costs (2009 $/MW hour) in 2016 are: conventional coal, 94.8; natural gas advanced combined cycle, 63.1; advanced nuclear, 113.9; wind, 97.0; solar photovoltaic, 210.7; geothermal, 101.7; biomass, 112.5; and hydroelectric, 86.4. In comparison, advanced coal with carbon capture and storage would cost 136.2 and natural gas with advanced combined cycle and carbon capture and storage would cost 89.3 in 2009 $/MW hour.

In comparison, costs of electricity production by coal, natural gas, nuclear, and petroleum presented by the Nuclear Energy Institute (2010), in 2010 cents per KWH , are 3.06 for coal, 4.86 for natural gas, 2.14 for nuclear, and 15.18 for oil. These prices include operation and maintenance and fuel costs. The sharp drop in natural gas prices between 2008 and 2010 apparently reflects the increase in abundance of natural gas resulting from the development of United States shale gas resources.

Coal prices in chained dollars: Average coal prices from 1949 to 2010, in chained dollars (Pairs of constant dollars; EIA, undated), are shown in Fig. 5. In general, coal prices declined from about 36 dollars per ton in 1949 to a low 22 dollars per ton in 1968 (EIA, 2010e). The sharp increase in 1973 is the result of oil shortages in the United States that resulted from the Arab oil embargo of the early 1970s. The long price decline thereafter is a result of the development of the large western coal deposits that dominate United States coal production to this day. More recently, coal prices have begun to rise again, from about 19 dollars per ton in 2003 to 32 dollars per ton in 2010. In its Reference Case (EIA, 2011d) EIA predicts coal prices will rise only slightly by 2035 because of competition from natural gas and renewable energy sources for electric power generation. However, in its Reference Case EIA predicts that coal production will increase by 21% from 2009 to 2035. In contrast, proposed greenhouse gas legislation is anticipated to have a considerable negative impact on coal usage both for electricity generation and for coal-to-liquids production (EIA, 2011d).

7. Conclusions

Although very detailed analyses and descriptions of potential coal production in the United States have been made recently by Höök and Aleklett (2009, 2010) and by Mohr and Evans (2009), the fundamental economically based coal reserve data for most of the United States deposits are not yet available to support important studies of this nature. Nevertheless, Croft and Patzek (2009), and Rutledge (2011) have concluded that coal production in the United States could begin an irreversible decline sometime within this century, perhaps within a few decades. It is clear, however, that the timing of peak coal production and decline within the United States will depend greatly on energy economics, including competition from alternate energy sources for electric power generation, and policy decisions regarding carbon capture and storage. In their study of United States coal resources the National Academy of Science (2007a,b, p. 44) concluded that because of the lack of use of statistical measures to calculate the uncertainty of the nation's estimated recoverable coal reserves, future policy will continue to be developed with insufficient data until more detailed reserve studies are completed.

Accordingly, this paper concludes that, in addition to current studies of the Powder River basin coal reserves (Luppens et al., 2008, 2009) and of a revised coal assessment methodology (Olea et al., 2011), fundamental economic studies of coal resources and reserves for all of the coal producing regions of the United States would provide basic data to energy policy planners in the United States, especially if the results of these studies are couched in probabilistic terms, with numbers that provide a 95% certainty, a 5% certainty, and median and mean values for economically producible coal tonnages in the United States Furthermore, these coal reserve studies would benefit from focusing, identifying and evaluating large blocks of un-mined coal that could support relatively low cost, large scale surface and underground mining operations into the foreseeable future as existing deposits are depleted. In addition, comparative cost estimates for the generation of electricity (per KWH) by coal vs. natural gas and renewable energy resources may impact estimates of the economic depletion of our coal deposits. This report concurs with the recommendation of the National Academy of Sciences that "A coordinated federal-state-industry initiative to determine the magnitude and characteristics of the nation's recoverable coal reserves, using modern mapping, coal characterization, and database technologies, should be instituted with the goal of providing policy makers with a comprehensive accounting of national coal reserves …." (National Academy of Sciences, 2007b, p. 117).

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