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Reserve reporting in the United States coal industry

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ABSTRACT

United States energy policymaking can be better supported with accurate and consistent data on coal reserves, both in the public and private sectors. In particular, reserve data for coal and other energy resources should be directly comparable so that decision-makers can easily understand the relationship among available resources. Long-term policy and investment choices regarding energy security, the environment, and resource allocation depend on accurate information, but existing and easily available data on the magnitude of geologically, environmentally, economically, socially, and legally accessible coal reserves are of insufficient quality to guide such decisions. Even still, these data are often presented for use in policy and energy analysis. Currently, coal reserves are overstated relative to competitor energy resource reserves, in part because coal reporting standards have historically been more liberal and vague than standards for resources like natural gas. Overstating the marketable coal resource could lead to inefficient allocation of limited capital investment that can be difficult to reverse. US government bodies like the Energy Information Administration, United States Geological Survey, Securities and Exchange Commission, and Bureau of Land Management can help correct deficiencies by clarifying standards and collecting data that are relevant for decision-makers, such as energy-based reserve information.

1. Introduction

Coal currently fuels about half of the electricity generation in the United States (US) (EIA, 2011b), and it is often described as cheap and abundant (EIA, 2011d). Many analyses presented to the public indicate that US coal reserves are sufficient to meet domestic demand for over 200 years at current consumption rates (BP Statistical Review, 2011; Coffey, 2009; EIA, 2011d). However, a growing body of literature suggests that the amount of marketable coal in the US is overstated, largely because reported reserves do not carefully account for limitations on extracting coal. Van Rensburg (1982) warned 30 years ago that US coal reserve figures did not account for factors like coal's economic competitiveness, the need for investment in mining infrastructure, regulation, and social acceptability. This situation persists, though the USGS has recently made efforts to take such factors into account in several major basins (e.g., Luppens et al., 2008).

Correcting reporting deficiencies and filling information gaps about coal is a prerequisite for efficient US decisions about energy, as expectations about continued resource availability and pricing affect private and public decisionmaking and investment. Such decisions are particularly relevant at the current time, as growing US electricity demand coupled with new environmental regulations and aging power infrastructure suggest that major investments in long-lived assets are likely to be made in the coming years. Decisions from the national policy level to the individual power plant level frequently compare coal and natural gas as generation fuels, with particular focus on cost, domestic availability, and environmental impact. Coal's main competitive attributes are that it is inexpensive and domestically abundant, though concerns about the environmental impacts of coal mining and use have discouraged its use. Simultaneously, technological advances in the natural gas industry have made natural gas – coal's main competitor in the electricity sector – less expensive and more domestically abundant, but these same technological advances have raised new environmental concerns. Decisionmakers must increasingly compare coal with natural gas whether or not good data are available, and so it is important that data be as transparent and directly comparable as possible if efficient decisions are to be made. Use of any fuel involves uncertainties about long-term impacts on the US economy, environment, and public health, which emphasizes the importance of using high quality data when possible. US understanding of the nation's coal reserves is less advanced than for other fuels, and this deficiency should be corrected to allow actors to make information-based investment and policy decisions.

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A major driver of US overestimates of the marketable coal reserve is a failure to distinguish between physically available coal in the ground (the coal resource) and coal that can profitably and legally be produced and sold with societal acceptance (the coal reserve). Study of the size of the coal resource should not be confused with analysis of how much coal will actually enter energy markets. For example, much of the US coal resource has high sulfur content, occurs in thin seams that are complex and costly to produce, is located too far from markets to be economic (e.g., Alaskan coal), or is too close to communities, important watersheds, or other mineral and ecological resources to extract. Arguably, the size of the resource base is mostly irrelevant for policy makers, energy analysts, and planners (Gordon, 1987), as resources do not directly translate into production. Presenting resource information – even recoverable resource information – as a reserve estimate is inappropriate and misleading.

The existing data on US coal reserves are compromised by historically inconsistent standards and methods for reporting and assessing coal reserves. In addition, both vocabulary (like "resource" and "reserve") and criteria for reserve assessment (like expected date of production) are defined differently for coal than for other energy resources like oil, natural gas, and uranium, further complicating comparisons and judgments about total resource availability. Such defects in coal reserve reporting create a market failure in information. However, information gaps can probably be eliminated or narrowed with some attention to data collection and enforcing reporting standards. Two major reasons that coal data are less accurate and less available than data for other energy resources stand out. First, US coal has always been considered abundant, to the point where little exploration has been necessary (see Gordon, 1987 for a discussion on the possibility of coal underexploration in the US). Second, coal is not a global commodity, in part because coal's bulkiness means that transportation is often expensive. Contracts between specific mines and specific power plants can be made for decades' worth of deliveries, perhaps reducing buyer interest in the details of all coal available in the US. Coal's large, easily accessible deposits and limited opportunity for long-distance trade do not seem to have fostered strict reporting standards the way that competition for resource-bearing lands and international trade deals have motivated standards for oil and thus natural gas, which is frequently produced with oil and by oil companies. Concern about nuclear materials and a cradle-to-grave reporting system have contributed to detailed information about uranium. Increasing coal data quality such that reserve data for coal can be meaningfully compared with data for other energy resources is important, as different energy resources often compete for investment.

The potential impacts of coal-related decisions are large and relevant at many levels of American society, from an individual's health to macroeconomic directions. Therefore, it is appropriate to identify, define, and compare modes for government intervention in US coal reserve reporting. The private sector requires coal reserve estimates as inputs to many decisions, the most significant being long-lived and inflexible capital investments in technology, primarily for power generation. Several US government agencies also rely on coal reserve estimates for decisionmaking: the Energy Information Administration (EIA) is tasked with providing data on energy for policymakers to help guide government investment, mandates, subsidies, and other energy-related decisions; the Bureau of Land Management (BLM), which has control over substantial federal coal resources, is required to steward federal land and mineral assets; and the Securities and Exchange Commission (SEC) is required to protect investors by regulating and collecting relevant data from companies that allow investment by the public, which includes many coal companies. In addition, the Environmental Protection Agency (EPA) regulates coal mines and power plants in its mission to protect public and environmental health. Pending environmental regulations that affect coal production and use (both greenhouse gas-related and otherwise) are likely to reduce the economic availability of coal, which directly affects the size of the exploitable reserve base.

This work focuses on identifying and defining possible solutions to US coal reserve reporting problems, beginning with a discussion of the status of coal reserve reporting in the US, including terminology, unit issues, and a history of reserve reporting and major shortcomings. It next argues that reserve data are a relevant input for decisionmaking, so the government has a responsibility to improve the accuracy and availability of information. The paper concludes with policy suggestions and potential implementation routes. The Appendix presents basic information about the US coal resource for context.

2. Reserves and reporting

Coal reserve reporting is hindered by data quality problems, including incompatibility with reporting standards for other resources. Coal reserves are often overreported as a fraction of the physical resource (Hansen et al., 2009), while oil and natural gas reserves have historically been considered conservatively

Cumulative production	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability range – or	
	Measured	Indicated		Hypothetical	Speculative
Economic					
Marginally economic	Reserve base		Inferred reserve base		
Subeconomic	Subeconomic resources		Inferred subeconomic resources		

Other occurrences	Includes	nonconventional	materials

Fig. 1. McKelvey Diagram for Classification of Coal Resources and Reserves. Resources of Coal. Area: (mine, district, field, state, etc.). Units: (Short tons).
Source: NAS, 2007. Figure 3.1. "Resources of Coal." The McKelvey diagram classifies coal based on geologic certainty (horizontal axis) and economic availability (vertical axis), demonstrating the difference between the resource base and the subset of the resources comprising recoverable reserves.

underreported (Grubert and Swift, 2007). Several bodies and programs are responsible for maintaining coal reserve data, much of which is intended to support policymaking.

2.1. Terminology

Coal and other energy resources are often classified using terms like "resource" and "reserve," extending to more specific words like "proved reserve," "probable reserve," and so on. One major shortcoming of the current system is that these words are frequently used inconsistently both within and across energy resource types (Whitney et al., 2009). While the term "resource" typically refers to physical existence of a substance, "reserve" denotes a subset of the total resource that is economically and otherwise available for use. Even more complicated than the distinction between resources and reserves are the distinctions among proved, unproved, inferred, probable, possible, geological, and demonstrable reserves. The 1976 accounting system that divides coal resources among classes of resources and reserves was standardized into a McKelvey framework by USGS Circular 891 in 1983 (Fig. 1).

SEC guidelines attempt to standardize these terms for reporting, but rules have historically been vague for solid minerals (Stevens, 2004). Maintaining accurate reserve information is challenging, since nongeological factors like price, demand, environmental regulation, proximity to people or protected habitats, and other characteristics change over time. This argues for a more dynamic reserve database that includes information on geological setting, likely mode and costs of extraction, resource quality, and other possible restrictions on mining that can extend the useful lifetime of data.

2.2. Units

Reporting quantities of market-available energy resources is difficult to do consistently given wide variability among resource types. For example, the amount of coal that could be sold to power plants is limited by fundamentally different systems than the amount of solar energy that could be used for electrical generation. Adding to the complexity is the fact that reserves are likely to be reported in units that must be manipulated before use. Most coal in the US is used to generate electricity (Pierce and Dennen, 2009), so an analyst interested in the potential of US coal and natural gas reserves for electricity generation might be interested in the number of gigawatt hours that could be generated from either fuel. However, coal reserves are typically reported by weight (short tons), while natural gas reserves are typically reported by volume at standard conditions (cubic feet). Converting these units to an amount of electricity requires first determining how much energy is present, then considering how efficiently that primary energy can be converted to electricity. Natural gas is mostly methane, and a given volume of natural gas has approximately the same energy content (about 1 megajoule, or MJ) regardless of its source. On the contrary, coal is a highly heterogeneous material, and energy density varies dramatically across ranks and regions. The energy density of US coals typically ranges between 14 MJ per kilogram (MJ/kg) for lignite and about 31 MJ/kg for bituminous coals (EIA, 1995) – over a factor of two difference. This variability means that reporting US coal reserves by weight does not provide sufficient information to judge energy availability. Indeed, the energy content of delivered US coal has been declining (Fig. 2).

Moreover, given the US' increasing reliance on low energy density Western coal reserves, weight-based reserves-to-production ratios (R/P) overstate the availability of coal energy: the remaining reserve base has lower average energy density than the

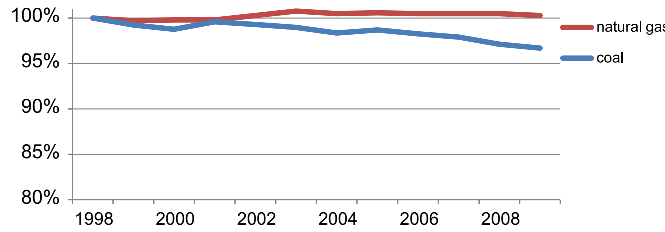


Fig. 2. Average Energy Content of Fuel Delivered for Power Generation (Normalized to 1998).
Source: EIA, 2011c. The energy density of coal delivered to US power plants is declining with time, but the energy content of natural gas per unit of volume is essentially constant. Note that the vertical axis does not start at 0.

coal being burned now. One billion short tons of Appalachian bituminous coal contains about 50 percent more energy than one billion short tons of Powder River Basin subbituminous coal (EIA, 2011a). Fig. 3 illustrates the difference between a weight-based and an energy-based R/P of 200 years. These significant differences suggest that reporting coal reserves by total energy content instead of or in addition to reporting reserves by weight could improve the usability of coal reserves data.

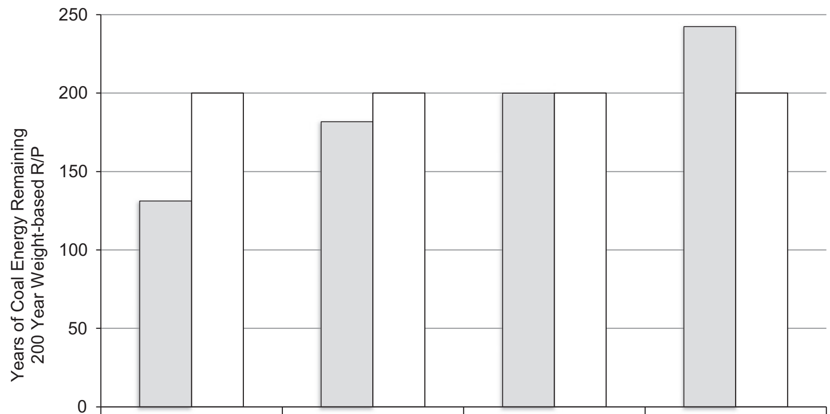
Even after the total primary energy content of a reserve is determined, the electricity generating potential of two fuels might not be directly comparable due to differences in plant efficiency. For example, combined cycle power plants – far more commonly fueled by natural gas than coal – tend to produce more electricity per unit of primary energy than a simple cycle plant. However, efficiency effects are not exclusively fuel dependent and are therefore beyond the scope of reserve reporting. Reserve reports should include primary energy content, but the amount of useful energy that is derived from a fuel is highly user dependent and should be considered separately.

2.3. Data quality

Supply curves for resources like coal can be used to illustrate availability to markets (Fig. 4).

Coal supply depends not only on coal's existence but also on its quality, location, and anticipated mode and cost of extraction (Whitney et al., 2009). The best-known deposits are usually extracted first (NAS, 2007), so the cost of supply tends to increase with time absent technological improvements or a change in demand patterns. Though coal extraction technologies have improved over time, mainly through more durable machinery that is able to move more rock quickly, major breakthroughs in extraction techniques are unlikely to substantially lower the cost of extraction in the near future. Very little research funding is dedicated to research and development for coal mining and processing: of the $538 million allocated for coal research in 2005, only about $1.3 million was devoted to mining and processing (NAS, 2007). One notable potential breakthrough is in situ gasification, where coal is partially combusted underground to produce gas. This method allows producers to extract the energy-rich gas without physically removing the coal or allowing contaminants like mercury to enter the atmosphere. However, runaway underground fires still pose a major challenge (Kavalov and Peteves, 2007).

As pointed out by Zimmerman and Adelman, estimates of economically recoverable coal are systematically and severely overstated, largely because reporting conventions do not appropriately account for exclusion criteria like quality issues or nearby towns (Gordon, 1987). For example, a high sulfur coal source located beneath a major city is highly unlikely to be exploited, but it may be considered economically recoverable using current



	lignite	subbituminous	average delivered (2009)	bituminous
Energy-based R/P	131	182	200	242
Weight-based R/P	200	200	200	200

Fig. 3. Energy- versus weight-based reserves-to-production ratios for different ranks of coal.
Sources: Average energy densities of US lignite, subbituminous, and bituminous coals: EIA, 1995. Average energy density of delivered coal to US coal-fired power plants in 2009: EIA, 2010. Reserves-to-production ratios (*R*/*P*) are typically presented in terms of weight. This figure shows that a weight-based R/P of 200 years could represent much less than 200 years' worth of primary energy from coal at current rates of consumption, depending on the average rank of coal reserves. If US coal reserves have the same average energy density as delivered coal, weight- and energy-based *R*/*P* should be the same. However, the average energy density of delivered US coal has been declining as the reserve base shifts toward lower-energy subbituminous and lignite coals. In particular, many of the higher energy density coals are also high in sulfur (EIA, 2003), which restricts their marketability.

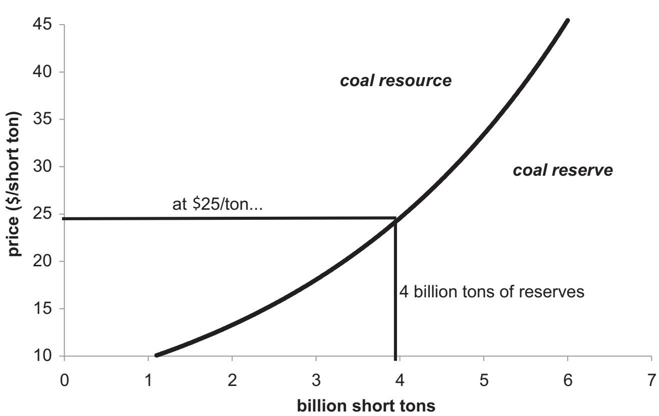


Fig. 4. Coal Supply Curve.
Source: Based on Luppens et al., 2006, Figure 13. "Coal Resource/Reserve Cost Curve." Coal reserves are a subset of coal resources that are economically extractable under given conditions. In this example, 3.9 billion tons of coal can be extracted for $25/ton or less. Social, environmental, and other effects can be incorporated by considering the cost of overcoming given restrictions.

practice. The US uses rules-based reporting standards rather than the methods-based standards used in many other countries. Methods-based approaches rely on established estimation methodologies and demonstrated positive project economics, while rules-based approaches rely on older techniques, like quantification of seam thickness, rock parting thickness, and drill hole spacing (Stevens, 2004). Methods-based approaches are often better able to account for nongeological limitations than the American rules-based approach.

Invalid comparisons of resource data for coal with reserve data for oil and natural gas leads to overconfidence regarding the availability of coal for future use (Gordon, 1987). Coal reserves reporting standards are less stringently regulated than those for oil and natural gas: oil is a much-traded global commodity, which encourages data accuracy, and natural gas has inherited oil's reporting standards. US coal has lower market exposure, which reduces the pressure to have consistent, accurate data on the amount of economically available coal worldwide. Coal's lower market exposure is largely due to transportation constraints, as coal's relatively low energy density makes transportation unwieldy and expensive. Global coal trading is less typical than global oil trading in large part for this reason, though coal trade is increasing (see, e.g., Morse and He, 2010). Even locally, coal's market exposure is often low. Domestic coal contracts can be infrequently negotiated, decades-long contracts that depend heavily on available transportation between a specific mine (the point of fuel extraction) and power plant (the point of fuel use) (see, e.g., Buchsbaum 2009), though many contracts have much shorter duration (Kozhevnikova and Lange, 2009).

As described above, coal markets may respond to supply and demand changes more slowly than markets with higher activity, like oil markets, and so inaccurate data might be more readily tolerated, whether intentionally or not. Coal owners derive several benefits from overstating reserves, while oil and natural gas owners often err on the side of understating reserves because of regulatory constraints. This differential bias increases the appearance that coal is a highly abundant resource, which might give coal a perceived advantage that could lead to inefficient resource allocation. The effect of inefficient resource allocation is exacerbated by the fact that capital-intensive investments in infrastructure, made based on assumptions about future availability and use, may artificially increase the competitiveness of the fuel for which they are built. For example, if funding is allocated to build rail lines near unexploited coal reserves but no funding is allocated for transmission lines in windy areas, a proposed coal plant that does not need to invest in new rail might provide higher returns than a proposed wind farm that needs to pay for transmission, even if the projects are otherwise equally economic.

Taxation practices provide local governments with little incentive to closely track the size of coal reserves but significant incentive to promote extraction, as coal regions benefit more from severance taxes on extraction than from low property taxes on unmined coal deposits. Taxes are often based on the value of surface improvements that owners of large tracts of coal-bearing lands are unlikely to make, and so property taxes on coal lands are typically low. In the Western coal basins, most coal is located on federal lands, which are typically exempt from property taxes (Goodstein, 1989; Fig. 5).

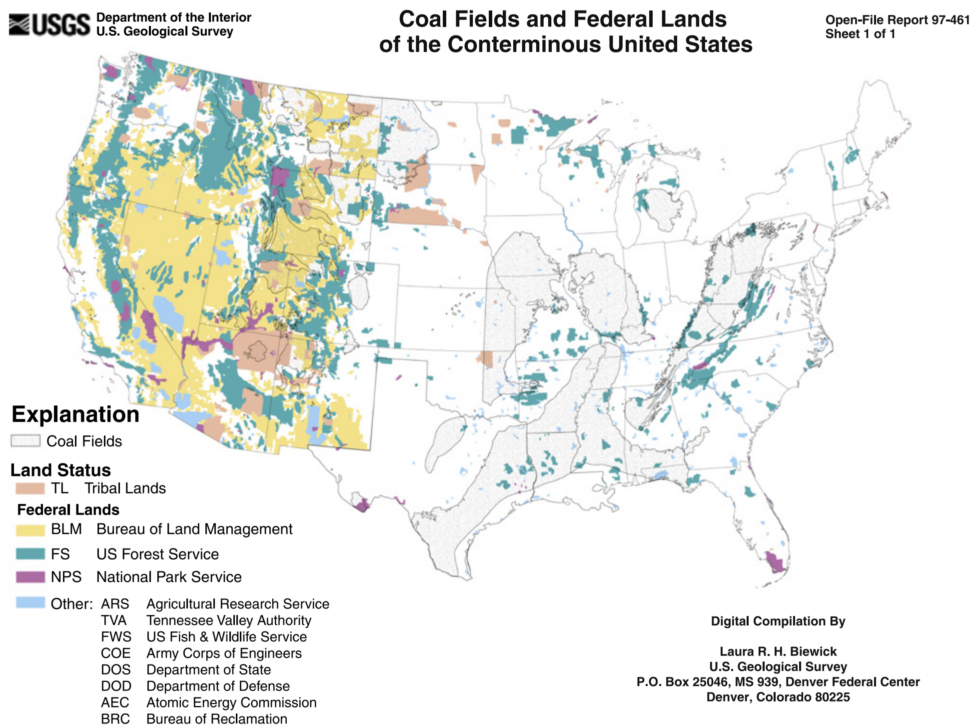


Fig. 5. Federal Land Holdings and Major Coal Basins of the United States.
Source: Biewick, L. "Coal Fields and Federal Lands of the Conterminous United States." USGS Open-File Report 97-461. Western coals are almost entirely located on federal lands, which has implications for land ownership and leasing characteristics that differ greatly from the situation in Appalachia, where most coal mineral resources are privately owned.

Given the lack of a substantial property tax on most coal lands, there is little motivation for governments to keep accurate records of the value of a coal resource. This results in land being highly undervalued with respect to the resource it hosts (Torries and Kern, 1999). Simultaneously, locally coal-rich regions have an incentive to overreport reserves to attract investment by indicating an opportunity. While the US government estimates West Virginian recoverable reserves at 18 billion short tons, with a demonstrated reserve base of 32 billion short tons, the West Virginia Coal Agency suggests 52 billion recoverable short tons, and West Virginia state agencies claims 23 billion short tons of reserves (Hansen et al., 2009).

While overreporting of coal reserves is likely widespread, SEC rules that apply to oil and natural gas reserve reporting force a systematic underreporting of economically recoverable resources. Updated SEC reserve reporting guidelines took effect in 2010 (SEC, 2009), replacing a 1978 vintage definition of proved reserves that was criticized for not keeping pace with technological developments or modern financial and economic considerations (SPE, 2006). Though companies themselves have limited incentive to understate reserves, SEC rules often made understatement difficult to avoid, particularly for natural gas: because probable and possible reserves could not be reported, future developments could be difficult to foresee (Grubert and Swift, 2007). Unlike in the case of coal, where reserve estimates are generally adjusted downward with time and closer scrutiny, oil and natural gas reserves often increase with time as new extraction technologies are developed (BP Statistical Review, 2011).

The SEC has recognized inconsistency and a tendency for the coal industry to overreport resources and reserves, issuing a letter to owners and operators of coal mines and properties required to file with the Commission. Invoking Industry Guide 7's definition of reserves as "[t]hat part of a mineral deposit which could be economically and legally extracted or produced at the time of the reserve determination," the letter references the fact that companies continue to report subeconomic, nonrecoverable, or geologically inferred deposits with reserve estimates. The SEC restricts coal reports to the terms "reserve," "proven reserve," and "probable reserve," and requires that reported reserves are drilled, sampled, and characterized consistent with industry criteria. However, these terms are often misused. In particular, coal classified as "proven reserve" in public databases is typically not confirmed with detailed drilling (AAPG, 2007). The SEC also notes problems like an industry focus on geologic coal resources without accounting for legal, economic, and technical limitations. For example, surface features like rivers, buildings, highways, power lines, and others that prevent mining are often ignored. Also, nonrecoverable coal in mine pillars, roofs, and floors is often included in estimates. Seams that are too narrow to mine economically and poor quality coals that are difficult to sell are often included in estimates, and many estimates neglect to deduct losses from coal washing at the plant (Schwall, 2009). Thus, problems with reserves reporting are widely known but difficult to correct, which perpetuates inaccurate data and inappropriate perceptions of the availability of American coal.

Compounding the problem of overstating the recoverability of US coal is that social and environmental issues related to coal extraction (or coal use) are not reflected in traditional assessments based on economic recovery alone. Some assessments deem coal economically recoverable if extraction results in a breakeven revenue stream, which does not account for a normal profit margin and thus overstates the amount of coal likely to enter markets (Pierce and Dennen, 2009). Environmental criteria can prevent coal mining, and so they are highly relevant to reserve estimates. For example, mining within 40 ft of a mined-out seam is prohibited due to safety concerns (Pierce and Dennen, 2009). Power plant-level criteria like air pollution standards might not directly prevent coal mining, but markets for coal that does not meet standards upon combustion can be limited. Also, coal resources should not be classified as reserves if there is not a reasonable expectation that permits associated with mining and transportation infrastructure could be obtained (SME, 2007b). The United States Geological Survey recognizes that these issues have not been appropriately considered in the past. A US reserve study that accounts for social, environmental, legal, and more accurate economic conditions would likely be more useful than additional US coal resource studies (Pierce and Dennen, 2009).

Though there are some obvious deficiencies within the current system for coal reserve reporting, the Society for Mining, Metallurgy, and Exploration, Inc. (SME) stresses that determining whether a coal resource can be classified as a reserve is based on different criteria than might apply for other resources like oil or natural gas. For example, coals are often geologically continuous over large areas, allowing for relatively accurate extrapolation in many cases. Controlling long-term reserves has strategic value for several reasons, including the ability to prevent surface development that could preclude the volumetric extraction required for later coal exploitation. Additionally, disclosing assumptions about price and the sensitivity of a mining operation to price fluctuations could be viewed as anticompetitive price signaling. Given that coal properties are not frequently bought and sold, the risk of anticompetitive activity could be an argument to exempt coal from price disclosure requirements applied to many other resources (SME, 2007b). However, a lack of price-related data makes accurate public assessment of the US coal reserve base more challenging.

2.4. Coal reserve reporting in the United States

Coal reserve reporting in the United States takes several forms, including the EIA's Demonstrated Reserve Base (DRB) database, the EIA's Coal Reserves Database (CRDB) program (Bonskowski, 1993), and the USGS' National Coal Resource Assessment (2000–2009) and Regional Coal Assessments (ongoing) (USGS, 2009a, b). Despite the existence of multiple programs, existing coal resource and reserve data are of insufficient quality for the needs of policymakers and energy analysts, in part because these data are both very old and based on outdated methodology. Many of the figures used in government publications on American coal availability date to the early 1970s and are derived from methods that have not been updated since the advent of reserve measurement in 1974. Widespread information problems affect both private and public resource decisions. In order to promote proper stewardship of public resources, the Energy Policy Act of 2005 required a new assessment of federal coal resources that considers environmental and other restrictions (DOE, DOI, and USDA, 2007). However, not all US coal has been carefully assessed in a systematic and consistent way.

Providing coal resource and reserve information is the responsibility of two main American agencies, the Energy Information Administration (EIA, in the Department of Energy) and the United States Geological Survey (USGS, in the Department of the Interior) (Whitney et al., 2009). The EIA is responsible for maintaining the Demonstrated Reserve Base (DRB) database, which includes only publicly available data on sulfur content, county, and coal seam for coal that has been mapped and meets EIA mineability and reliability requirements (EIA, 1998). However, the DRB does not include sophisticated data on coal quality, physical setting, engineering parameters, land ownership, other land uses, and environmental restrictions (Bonskowski, 1993). Despite infrequent updates, DRB data remain largely supported by the original 1974 study, and embedded geological and technological assumptions are those of 30 years ago. As information is republished yearly, the age of these data is not obvious (NAS, 2007). The DRB system was never intended to be used for detailed energy and policy analysis (Bonskowski, 1993), but the lack of a more policy-oriented system has made such analysis challenging. Concerns about the reliability of EIA coal reserve data set forth in a 1987 National Coal Council report led to the creation of the EIA's Coal Reserves Database (CRDB) in 1990 (Conolly and Rupp, 2001). The CRDB program allows the EIA to partner with state geological surveys and other groups to improve overall coal reserve data, with a specific goal of supporting policy analyses (Conolly and Rupp, 2001). The pace of development remains slow. In addition to the DRB database and CRDB, the EIA measures Estimated Recoverable Reserves (ERR) by applying state-specific recoverability criteria to DRB data. ERR also includes the coals' energy densities and records the mining technique used.

The US coal reserve estimate that most closely corresponds to a consistent definition of proven reserves (based on drilling and detailed information about access) is the Recoverable Reserves at Active Mines (RRAM) estimate. RRAM data is based on confidential data from mining companies that the EIA is authorized to request, and so the data are more often based on detailed drilling information than are other EIA estimates. For 2010, RRAM proven reserves suggest a US coal R/P of 17 years (EIA, 2011a), not the 241 year US coal R/P reported by BP (BP Statistical Review, 2011). Notably, this proven reserves R/P is much closer to similarly calculated US oil and natural gas R/Ps (11 and 13 years, respectively, BP Statistical Review, 2011), suggesting that coal might not have the overwhelming abundance advantage over other resources that is typically reported. Another advantage of using the RRAM as a measure of proven reserves is that, like proven oil and natural gas reserves, the RRAM self-stabilizes as investment in mines provides access to additional coal over time.

Though RRAM data are better than traditionally reported US coal reserve data, they are difficult to collect comprehensively and are not reliable enough to be useful for long range planning (NAS, 2007). Reserve data are collected annually from about 1,500 entities through EIA's mandatory Form 7A, the Coal Production and Preparation Report (EIA, 2008). Form 7A is explicitly intended to comply with the Federal Energy Administration Act of 1974 to provide Congress with information on the nation's coal supply (EIA, 2008a). The form itself requires respondents to report the amount of coal estimated to be recoverable in the future, to the level of accuracy known, assuming current prices, and justification is required only if the number changes by more than 40 percent year over year. Inspection of the form shows that there is no requirement or space to report how the estimate was made, level of confidence, or major uncertainties (EIA, 2008). Form 7A reserve reports do not appear to be audited by the EIA.

As the other major US agency responsible for tracking coal reserve data, the USGS maps American coal resources and characterizes them by quality, energy density, location, and other characteristics. Recent efforts have focused on accurately assessing economic reserves rather than the full physical resource, which should improve the accuracy of EIA reserve figures that rely on USGS data (Luppens et al., 2006). A primary goal of USGS coal research is to characterize coals by features that could be environmentally damaging, like the presence of elements that are currently regulated or are expected to be regulated in the future. However, coal quality is difficult to ascertain reliably, as spatial variability in sulfur, ash, and other contaminant content is not detectable without additional sampling (NAS, 2007). USGS research programs have suffered from limited funding and the size of the tasks involved.

One of the USGS' major coal-related efforts is to produce impartial assessments of the amount of coal that can reasonably be considered usable in the near- and mid-term future. Regional Coal Assessments and the recently completed National Coal Resource Assessment (NCRA) program (USGS, 2009a) are the US' main modern effort to quantify national coal reserves. The NCRA program created digital databases of existing coal for use by decisionmakers, with particular focus on its five priority regions: the Appalachian Basin, the Illinois Basin, the Gulf Coast, the Colorado Plateau, and the Northern Rocky Mountains and Great Plains. Informing energy, environmental, and health policymaking and strategic decisions is an explicit goal of the NCRA (USGS, 2009b).

The experience of the completed studies reaffirms that the difference between resources and reserves is substantial, and distinguishing between the concepts is vital to fact-based decisions on energy. Modern coal availability studies that consider technological and regulatory barriers before declaring a resource mineable suggest that less than 50 percent of a presumed coal resource is typically available for mining (NAS, 2007). When environmental, economic, and other considerations are included, this figure decreases. Basin-level USGS studies have suggested that US reserves account for five to 25 percent of the identified resource (NAS, 2007). In the large Gillette field in the Powder River Basin, reserves account for about 6 percent of the identified coal resource (Luppens et al., 2008).

Though public data on coal reserves have been challenged as inaccurate and methodologically outdated, more sophisticated, empirical data do exist. Companies have historically had better data than the government agencies from their own exploration efforts, which have greatly advanced with the advent of digital technologies (Upadhyay, 2000). This greater access to data reduces the chance that mining companies inefficiently allocate investment in mining infrastructure. However, those data are considered proprietary – as information may influence a company's desire to purchase certain lands – and are not available for public resource and reserve estimates. Only operating mines are required to produce reserve estimates. Older government data are often based on information from maps of abandoned mines, rock outcrops, roadcuts, and water, oil, and natural gas wells instead of the industry drilling and mining samples (NAS, 2007). The Bureau of Land Management requires that exploration data be submitted before a lease is granted, but those data usually remain confidential until a lease is issued (BLM, n.d.; 43 CFR 3590). This practice does not correct the data gap for unmined lands.

An imperfect understanding of the exploitable US coal resource suggests that coal use will be associated with increased costs in the future due to environmental, social, and other factors. Combined with an increasingly heated national debate about energy and environmental policy, known data quality issues for US coal make reserve reporting a highly germane topic. Expectations for the future are widely used as a basis for decisions. Thus, reported reserve figures and disclosure (or lack thereof) of relevant uncertainties can have powerful implications for capital allocation and policymaking.

3. Reserve estimates as input to decisionmaking

Coal reserve estimates influence decisionmaking on national and local, private and public levels. The EIA is legally required by its chartering Federal Energy Administration Act of 1974 to provide data to support public policy analyses and assess energy supply adequacy (EIA, 1996), the USGS explicitly considers policymakers an audience for its data, the BLM is required by 1976's Federal Coal Leasing Amendment Act to obtain fair market value for coal leases sold (BLM, 2010), and the SEC has mandates under the Securities Act of 1933 and the Securities Exchange Act of 1934 to require that investors receive relevant information about investments, through mandatory reporting if appropriate (SEC, 2010). The fact that multiple government agencies are tasked with obtaining and generating reliable, accurate data on reserve estimates for use in policy- and decisionmaking provides some insight as to the relevance of such information.

3.1. Private decisions

Private decisions by companies and private investors can be hindered by inaccurate data, particularly because expectations about the long-term value of an investment depend on information about resource availability. Information about coal resources and reserves, including various economic, environmental, and locational characteristics, can influence technology decisions, fuel choices, and other decisions that may be irreversible in the short to medium term. Capital assets can be stranded if conditions change, whether because of regulations (e.g., carbon limits) or supply issues (Johnston et al., 2010).

3.2. Public decisions

Public decisions by governments on all levels can also be affected by the quality of information on coal supply. Publicly available coal reserve figures are particularly relevant to popular perception of the US energy situation. In a democracy, governments respond to citizens, and citizens are unable to express true preferences for long- or short-term energy planning in the face of inaccurate information. Thus, because the government presents itself as a repository of statistics on energy through the EIA, it has a responsibility to ensure that those statistics are accurate. The government has already accepted the task of intervening in energy markets to provide information that would not otherwise be public, and it serves as a protective rulemaker and enforcer through bodies like the SEC, which is meant to protect investors, and through agencies like the EIA and the USGS, which are responsible for providing government officials with enough information to make policy that protects the public interest. Also, the Bureau of Land Management (and to some extent, the United States Forest Service) are responsible for stewarding public resources and rely on reserve estimates to plan federal land use (OTA, 1984). Without accurate information about the value of resources based on overall supply availability and relative quality, the BLM and USFS are unable to assure the public of proper management.

3.3. Reserve estimates and cost-benefit policy analysis

Policy and decisionmakers often rely on cost-benefit analyses to predict the wisdom of a potential policy or strategy. Coal reserve estimates are important for energy and environmental decisions, including land use, air emissions, and water use and contamination. Coal reserve estimates are particularly relevant to the current debate on greenhouse gas emissions. For example, carbon capture and storage (CCS) technologies could be used at coal plants to capture carbon dioxide (CO_2) emissions from the power plant's flue stream and store supercritical CO_2 underground. The technology has not yet been demonstrated at commercial scale, and both government and private entities may choose to invest significant capital in CCS commercialization and deployment.

Information about coal availability and quality are highly relevant to decisions about deploying CCS technologies, particularly because options like deploying renewable, nuclear, or natural gas-based electricity compete with CCS for investment as no- or low-carbon emission technologies. Coal-fired power plants with CCS require significantly more coal than plants without CCS because of large parasitic electrical loads. A new coal-fired power plant in 2030 using amine-based CCS could require about 65 percent more coal to provide the same amount of electricity while capturing less than 90 percent of the baseline carbon dioxide (Grubert, 2010). If decisionmakers are to make rational choices about long-lived capital like CCS that could dramatically increase rates of coal consumption, accurate information about coal availability and expected prices is a fundamental need. In addition, existing pilot carbon capture units are extremely sensitive to sulfur contamination (Pehnt and Henkel, 2009), so information about coal quality is also highly relevant. Utilizing more low sulfur Western coal could require large investments in the stressed rail system (Cambridge Systematics, 2007), while utilizing higher sulfur Eastern (including Interior) coals increases the parasitic load and operating costs at power plants. CCS and associated investments are likely to be large, justifiable only with long-term use of large volumes of coal for several decades. Thus, accurate assessment of coal availability and quality is vitally important to the choices about CCS deployment. Assuring that reserve information about coal is compatible with information about alternative investments that compete for funding is also essential to appropriate decisionmaking.

3.4. Local versus national effects

Inaccurate resource and reserve data have different impacts on localities than on the nation as a whole. Major regional differences in coal availability and use make the United States' coal reliance profile lumpy in that certain regions are not at all dependent on coal, while others are almost exclusively dependent on coal. Local economies in major coal producing regions often display high reliance on coal, notably in Wyoming and the Appalachian states. Tax revenue is one source of this reliance, but the jobs and investment associated with the coal industry also tend to be highly concentrated. Though there were only about 81,000 coal miners in the United States as of 2008 (BLS, 2011), certain counties have very few other industries providing jobs. Jobs associated with rail and coal company operations boost the total estimate of coal-mining related jobs to about 555,000, with about $8 billion in federal and state tax revenue from coal mining (Arch Coal, 2008). The timing of local economic depletion is strongly influenced by actual marketability of coal, and so inaccurate assessments can dramatically alter local planning.

Both local and national level bodies use reserve estimates for revenue forecasting, given that coal development is associated with property taxes, severance taxes, jobs, and investment. The Bureau of Land Management is required to assure that the US public receives fair market value for Federal minerals and that Maximum Economic Recovery and Diligent Development guidelines are followed. Revenue forecasting and assuring operator compliance on Federal lands are much aided by accurate data on coal reserves.

4. Reforming reserve reporting: policy proposals

Accurate estimates of marketable coal supply in the US are necessary for efficient investment decisions and policies that protect the public interest. As demonstrated in prior sections, the problem of poor quality data for coal reserves is not unknown, but there remain gaps in efforts to correct the issue. One highly relevant issue is that coal reserve reports should be made compatible with natural gas reserve reports to streamline fuel choice decisions, as coal and natural gas are major competitors for electricity generation. This section proposes specific policy actions to address these gaps, grouped by agency.

4.1. Energy Information Administration

As the main collector of coal reserve data from active mining operations, the EIA should attempt to increase the quality of the recoverable reserve data it collects annually through Form 7A. Currently, the form requires only a best-guess estimate of economically recoverable reserves at current prices. The EIA could significantly improve the quality of collected data by clarifying what is meant by "Recoverable Reserves" on the form itself, not simply online: this includes a stricter time horizon, as 7A currently asks how much coal could be mined "in the future" (EIA, 2008). The uncertainty associated with the recoverable reserve estimate should also be reported, as should the estimated energy content of the coal. Sulfur content, proximity to towns and other off-limits mining areas that could expand, and other potentially limiting factors could be requested, depending on the additional burden imposed. Most of the cost and time here accrues to entities that must submit Form 7A, though the EIA would need to incorporate additional data into its reports.

As the public face of energy statistics, the EIA should also make an effort to distribute new information on coal reserves (both from its own collections and from USGS work), updating links and posting notes on archived pages that new information addressing specific data shortcomings is available elsewhere. Presenting coal reserve information both in terms of weight and energy content would likely make information easier to understand and more useful to the public. In particular, an energy-based reserves-to-production ratio should be published. Implementing such changes would likely require the part-time work of an EIA employee for several months each year.

4.2. Securities and Exchange Commission

The SEC requires accurate data about businesses that are relevant to investors, and it is also allowed to require periodic reporting. SEC rules for coal reserve reports should be clarified, standardized, and reconciled with international reporting standards and with reporting conventions for other resources to the extent possible. The Society for Mining, Metallurgy, and Exploration, Inc. (SME) recommends that reporting rules for coal be similar to those for other minerals, and policymakers would be better able to compare US energy supply across fuel types if reserve estimates were consistent. This is particularly true for coal and natural gas. Like the EIA, the SEC should require that coal reserves be reported both by weight and by energy content, as both metrics are valuable to investors (for example, weight is more relevant from a shipping perspective, while energy content is more relevant from a power generation perspective). The SEC should aim to correct chronic overreporting of coal reserves and should perhaps model new coal reporting guidelines on its process for the reform of oil and natural gas reporting standards (SME, 2007a). One major challenge for this reconciliation will be choosing an appropriate timeline: oil and natural gas reserves are by SEC definition expected to be extracted within five years, while coal reserves are generally considered mineable within a 50 year period. These conventions are in part due to the differences in the way oil, natural gas, and coal are sold, including the more robust futures markets for oil and natural gas.

The SEC proposed revised oil and natural gas reporting requirements approximately 17 months before they were implemented (SEC, 2008). SME has submitted recommendations to the SEC for changes to coal reserve reporting requirements, but SEC rules for coal reporting are relatively vague, based on Industry Guide 7 (SME, 2007a). Given this information, reform of SEC reporting rules for coal could take perhaps three to five years. Costs of compliance to coal companies would likely be low, given that many already comply with SME guidelines or Combined Reserves International Reporting Standards (CRIRSCO) guidelines for other purposes (SME, 2007a). Streamlining SEC requirements with guidelines more widely used in industry could reduce the burden to coal mining operations.

4.3. Environmental Protection Agency

As the US' main environmental regulator, the EPA has indirect control of coal marketability through environmental restrictions. The EPA should compile standards for coal quality that affect its future marketability – its status as a reserve – to aid USGS and other studies of environmentally compliant coal reserves. EPA guidelines for emissions to air and water affect coal marketability based on sulfur levels, heavy metal content, proximity to water bodies, and other characteristics, and specific regulations on mercury and carbon are expected. Explicitly identifying the major environmental limitations that commonly affect coal and producing a guidance document (that does not necessarily need to be comprehensive) could aid efforts to consistently assess coal reserves for environmental parameters and supply the public with a direct, accessible guide to environmental restrictions on coal development. Such a project would likely require several months of work by two to five EPA employees, based on an examination of authorship on other EPA reports. Drafts would likely need to be submitted for public comment, which could extend the process by a year or more.

4.4. United States Geological Survey

The USGS is in the process of a major data gathering effort aimed at assessing US supplies of marketable coal, based on geologic, environmental, economic, and other parameters. This is an important step towards providing accurate data on US coal supply and will likely continue for several years. Basin-level studies for strategically important coal basins are underway. The Powder River Basin study required the work of two geologists for approximately one year (Luppens et al., 2006), in addition to time and effort related to writing, reviewing, and publishing reports.

Currently, reserve data are only collected at active mines, which means that reserve data in regions not being actively mined are scarce. The USGS should consider including coal-bearing regions without active mining in its basin assessment, perhaps after the high-priority active basins have been studied. Such a project would likely prove expensive, as exploration data are likely limited or nonexistent, and the USGS might need to seek funding for sampling to complete these studies. The Bureau of Land Management and United States Forest Service are logical partners in an assessment of reserves in unmined areas.

4.5. Local bodies

Landownership is often unclear in coal-bearing regions, particularly in the East, where parcels are small and numerous (Hansen et al., 2009). Local bodies could have a role to play in identifying whether landownership patterns are depressing local economies or otherwise negatively impacting conditions, particularly where coal companies are full or major owners of separate landholding companies. Theories that landownership patterns could be blocking non-coal investment and development that would otherwise generate tax and other revenue, masking important information about coal resources and reserves that are not being actively mined, or monopolizing communities are often heard but underinvestigated. Local bodies could benefit from clarifying landownership, even by digitizing deeds that are currently in the public record but only available in hard copy in county courthouses (Author Experience, West Virginia, 2009).

5. Conclusions

Coal reserve reporting can shape policy by indicating future coal availability. Indeed, the substantial move into coal in the American power sector was based on a 1970s perception that coal was cheaper and more available than oil and natural gas in the long term (Carter, 1977). The current dominance of coal as a generation fuel today reflects that perception of 40 years ago. As strikingly demonstrated in the case of natural gas, where access to unconventional shales has substantially increased the economically and technologically accessible reserve base, time and technological development can change the relative competitiveness of fuels. Coal reserve data based on old information and old methodologies are inappropriate for continued use by policymakers and investors. This is particularly true given the importance of accurate information for infrastructural development in the face of large, carbon-related changes in the American economy and energy system. When variable standards and incompatible industry cultural biases can lead directly to policy choices that would not have been made with better information, there is great risk of making poor economic, social, and environmental choices.

Government intervention to correct the market failure in information that currently exists in the US energy industry is appropriate, given that inaccurate data on coal's marketable abundance can create public and private sector harm and that multiple government agencies have mandates to provide coal reserve information. This work's main policy recommendation is that reserve reporting be made consistent across fossil energy resources, probably by reconciling coal reserve reporting with the stricter standards in place for oil and natural gas. In addition, coal quality information like heat content and any factors that could restrict marketability should be collected and reported, and uncertainty should be transparently documented.

When policymakers implement decisions based on resource data that are assumed to be accurate, capital can be locked in for decades. Infrastructural choices made based on a small difference in the anticipated future of fuels are long-lasting and often either irreversible or very expensive to reverse. Even if coal reserve data cannot feasibly be updated in a short time, statistical assessments indicating uncertainty about the figures presented to decision-makers should be made and included with traditional reserve estimates.

Coal's greatest political strengths are its domestic abundance and its low cost. Those strengths are inferred from data that is widely acknowledged to be of poor quality. The power of reserve data to influence policy choices means that this state of misinformation should be made more explicit and corrected.

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Appendix

Coal resources in the United States

The US is widely assumed to have more coal in place than any other country, but estimates of the size of the economically accessible coal reserve base are controversial. The US has three major coal-bearing regions with significant differences in coal grade, or compositional quality, and coal rank, or energy density. These are the Appalachian, Interior, and Western regions. The Eastern (Appalachian and Interior) coals are much older than the Western coals, which means that Eastern coals are characteristically more energy dense but also more contaminated by non-carbon elements than Western coals, as they have spent more time exposed to both pressure and external contamination (University of Wyoming, 2002).

Coal is formed in swampy regions where large quantities of plant biomass accumulate and are compressed over millions of years. While coal is primarily carbon, it is not a homogeneous material: coal contains both mineral (inorganic) and maceral (organic) content with characteristics related to the environment in which the coal was formed. The minerals and macerals in a given coal depend upon the chemical composition of the silt, sand, and other rock material commingled with biomass, and biomass chemistry also varies by type. Seventy-six of the 92 natural elements have been found in coals (Schweinfurth, 2003). The environmental impacts related to mining and burning this nonhomogeneous material can thus be difficult to control consistently, and the economic availability of coal seams depends strongly upon their compositional characteristics.

Appalachian coals have been most heavily mined because of their relatively high energy density, high quality (low sulfur content), and proximity to the populous East. Mining of Appalachian coals can pollute the region's extensive mountain-based water resources with heavy metals and acid mine drainage, which results from the oxidization of exposed sulfides. Many of the high quality seams have been substantially mined, and recent development has included mountaintop removal mining of thin coal seams (many less than 30 in. thick). Appalachian mining is characterized by many small mines, with over 1200 mines operating in 2009 (EIA, 2011e). Appalachian supply is estimated to be able to remain constant until about 2050, when production will decline (Höök and Aleklett, 2009).

Interior coal mining has declined since the passage of the Clean Air Act Amendments of 1990, which limited sulfur emissions to the atmosphere. Interior coals have high energy density, but their high sulfur content increases the cost of compliance with air quality laws. The Interior region holds substantial coal resources, and technological developments that reduce the sulfur challenge – including lower costs for sulfur scrubbers – could lead to increased utilization. Using Interior coal could be attractive in the face of forecasted decline in Appalachian production (Höök and Aleklett, 2009), especially as Interior coals have higher energy density and are geographically closer to large coal-utilizing power plants than Western coals.

Western coals are the youngest, and by many metrics, they are also the cleanest. Western coals' low sulfur and heavy metal content is largely due to their genesis in a swamp isolated from the ocean, where they were not exposed to as much contamination from marine sediment as Eastern coals. They have very low sulfur content and are often blended with higher sulfur coals to ensure overall compliance with sulfur regulations. Western coals are found in thick beds close to the surface, which means that inexpensive surface mining methods can be used. Lower production costs balance the high transportation costs associated with bringing low energy density Western coals to power plants in the east (Höök and Aleklett, 2009). Western surface mines are extremely large, with 17 mines producing about 40 percent of US coal supply (EIA, 2011e). Most Western mining takes place in Wyoming, though Montana has significant unexploited reserves. Competition with agriculture, opposition to mining within Montana, and lack of rail access make expansion of Montana's output unlikely in the near future. However, the West is anticipated to continue growth as a United States coal production region. Without Montana, Höök and Aleklett (2009) predict that American coal production could peak by 2030.

Further analysis of US coal production trends and production forecasting can be found in Höök and Aleklett (2010) and Mohr et al. (2011), which suggest that the logistic model can be an effective modeling tool for long-term production forecasts. Such forecasts can be useful for estimating basin-level reserves based on historical production.

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