COAL AVAILABILITY: ISSUES IN ASSESSING
U.S. COAL RESERVES AND RESOURCES

R.J. Newcombe

May 1981

Prepared for presentation at
CORS/TIMS/ORSA Joint National Meeting
Toronto, Canada, May 3-6, 1981

NATIONAL CENTER FOR ANALYSIS OF ENERGY SYSTEMS
DEPARTMENT OF ENERGY AND ENVIRONMENT

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INTRODUCTION

The coal resources of the United States are widely acknowledged to be enormous - some 4,000 billion tons. One might think the only exhaustion issue which would be relevant in assessing these resources would be that experienced by those responsible for locating and evaluating the resource. However, the abundance of the resource does not eliminate the need for constant reappraisal of the coal resource base. Accurate estimates of U.S. coal resources and reserves are needed for several purposes:

- to define coal supply curves in models which allocate future coal demand among competing coalfields; and which seek to predict future coal prices;

- to evaluate the structure of coal reserve ownership and control; and

- to aid coal consumers and new producers in locating coal suited to their needs and budgets.

There are a number of important uncertainties about the economic significance of U.S. coal resources. These uncertainties can be categorized as affecting:

- the physical size and location of coal resources and reserves;

- the regional and local variation in coal quality;

- the legal and economic availability of coal resources.

A more precise understanding of coal availability is important. Richard Schmidt has suggested that consumer uncertainty about reserve magnitude and availability may be exploited by producers in setting contract prices, and it has been suggested that errors in assessing the geological and legal recoverability of coal resources may affect coal prices more significantly than variability in estimates of production and distribution costs. Further, misconceptions about coal availability are more likely to cause underestimates then overestimates of future prices.

The objectives of this paper are, to discuss some methods used in modeling the nation's coal reserves and to identify some of the problems involved. The issue of coal availability is addressed in an effort to suggest the need for a systematic approach to the problem.
MODELING COAL RESERVES

The DRI Zimmerman Model

Martin Zimmerman concluded that seam thickness and overburden ratio were the most powerful predictors of underground and surface mining costs for which nationwide data were available. Based on review of a study of coal reserves for underground mining in Pike County, KY, Zimmerman felt that remaining deep minable reserves would be distributed lognormally by seam thickness in each region and sulfur category depicted in his model. Further, a study of Illinois surface mineable resources, together with a study of surface minable reserves in the Montana section of the Powder River Basin led him to conclude that strippable reserves would be lognormally distributed by overburden ratio. It has since been shown that the total virgin coal resources of Pike County, KY were not lognormally distributed.

It is still too soon to render any verdict on the lognormality hypothesis, except perhaps the Scottish verdict of "not proven."

As an aid in focusing on Zimmerman's approach to reserve issues we have listed what appear to be the major assumptions used in the DRI coal model's treatment of reserves, and have suggested a verdict for each assumption:

Assumption 1: Increasing costs/ton are experienced in mining progressively thinner seams, or seams with larger overburden ratios.
Verdict: Accepted.

Assumption 2: Numerous other factors influence mining costs, but no systematic data base is available which can be applied to coal reserves nationally.
Verdict: Accepted, pro tem.

Assumption 3: Deep minable reserves are lognormally distributed by seam thickness.
Verdict: Plausible, but not demonstrated.

Assumption 4: Surface minable reserves are lognormally distributed by overburden ratio.
Verdict: Plausible, but not demonstrated.

Assumption 5: The U.S. Bureau of Mines Demonstrated Reserve Base (DRB) is a sufficiently precise description of economically important reserves to reflect Assumptions 1, 3, and 4, above.
Verdict: Probably untrue.

Assumption 6: The DRB is delineated in such a manner as to allow the direct application of intra-mine recovery factors as the only limitation upon recoverability of the reserves it describes.
Verdict: Highly unlikely.
If these seem like harsh verdicts, they are not meant as reflections on Dr. Zimmerman or the DRI model. The paucity of detailed data on coal reserves is notorious. Assumptions 1-4 above are viewed here as entirely reasonable, given available data. The lognormality hypotheses will probably provoke sufficient empirical testing to allow confirmation or modification of their scope. Assumptions 5 and 6 appear to represent rational use of available information. However, closer examination will suggest that these assumptions may introduce a profound bias into the modeling of coal reserve availability. Some recent work done to improve the reserve data base for the ICF National Coal Model will illustrate the point.

Reserve Treatment in the ICF, Inc. National Coal Model

ICF, Inc.'s National Coal Model is amongst the most detailed in its treatment of coal reserves. Thirty six coal types by sulfur and heat content are used to construct 192 coal supply curves, representing competing coal qualities and coalfields. Each of these supply curves may have 100 or more supply steps – representing the assignment of regional reserves to mine sizes and types. By contrast, the DRI coal model has 30 supply curves with 5 steps each, plus some treatment of lignite and other coals as Btu flows. For all its attention to the idiosyncratic charms of regional coalfields and coal products, however, the NCM has been bound to the DRB by a lack of ready alternatives. Recent work by ICF, Inc. for the Electric Power Research Institute has attempted a partial revision of the DRB from state and other sources. The resulting changes in reserve totals from the four coal regions examined – Illinois, Alaska, Texas lignites, and Carbon County, Wyoming are of a very substantial magnitude, often several hundred percent (Table 1).

Problems with the DRB

Even more interesting than the magnitude of these changes is their direction. There is a strong hint that where the DRB's coal tonnages represent reserves which are

- as yet, slightly exploited compared to overall resource magnitude,
- of relatively low quality in terms of historical standards,
- and/or relatively distant from historical markets, or otherwise relatively expensive to produce,

the DRB estimates may be found to significantly underestimate available reserves. By contrast, where the DRB tabulates coal which is
in areas or seams with a long history of large scale commercial exploitation, relative to overall resource magnitude,

- in areas, or seams with relatively high quality by historical standards,

- and/or close to markets, or relatively inexpensive to produce, the DRB estimates may be significant over-estimates of remaining available reserves.

In areas like the Powder River Basin, where very large underestimates have been found, the addition of even billions of tons of "new" reserves is unlikely to have great influence on the price forecasts from coal models. The supply curves for such areas are already nearly flat, the reserves immense when compared to optimistic expansions of mining activities, and constraints on future production stem from other issues - transportation, desulfurization, Federal leasing and state regulation and taxation.

Table 1
Changes in Resource Estimates for Relatively Well Known vs. Less Well Known Coal Resources (Millions of Short Tons)

<table>
<thead>
<tr>
<th>Less Well Known Resources</th>
<th>USBOM DRB</th>
<th>EPRI, 1980</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>2,386</td>
<td>5,000</td>
<td>+209.6%</td>
</tr>
<tr>
<td>Texas Lignite</td>
<td>2,282</td>
<td>8,174</td>
<td>+289.0%</td>
</tr>
<tr>
<td>Campbell City, WY</td>
<td>31,102</td>
<td>71,402</td>
<td>+229.6%</td>
</tr>
<tr>
<td>Illinois (&gt;1.67lbs sulfur/10^6Btu, deep minable)</td>
<td>25,923</td>
<td>140,541</td>
<td>+542.1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relatively Well Known Resources</th>
<th>USBOM DRB</th>
<th>EPRI, 1980</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois (&lt;1.67lbs sulfur/10^6Btu, all mining methods)</td>
<td>5,226</td>
<td>780</td>
<td>-85.1%</td>
</tr>
<tr>
<td>Illinois (all strippable coal)</td>
<td>7,729</td>
<td>1,867</td>
<td>-75.8%</td>
</tr>
</tbody>
</table>

On the other hand, if significant overestimates of the availability of higher grade, more expensive eastern coals have been incorporated into the DRB, the models which rely on this source could be forecasting unrealistically low prices for such coals, and underestimating the future degree of dependence on western and mid-western lower grade coals which will be required to meet expanding national demands. This possibility mandates closer scrutiny of what the DRB’s tabulated totals actually represent.

ICF, Inc. has recently completed an evaluative review of the more important studies of coal reserves and resources for the Electric Power Research Institute. In reviewing the four publications in which the USBOM describes the DRB, its authors note that these studies are flawed by use of criteria for reserves which exclude some coal under current development, while including much for which no development is now foreseeable. Many of the estimates of state and county tonnages are based on older, outdated studies, and no explanation is given of how such estimates were adjusted to meet the DRB criteria. Wide extrapolation from limited data on coal sulfur content has been used, but not very carefully documented. Much of the quality data represents areas of seams long since mined out - extrapolation from such points is likely to bias estimates of coal quality toward values representative of higher quality coals no longer available. Since much of the quality data represents high quality coal purchased for government boilers in past years when coal was handpicked to remove impurities, this bias is reinforced.

Many with first-hand knowledge of coal reserves in a given area have perused the DRB volumes with an awareness of a voice somewhere in their consciousness chanting “Yes, but, Yes, but...” like a Buddhist mantra. The DRB volumes represent an attempt to complete a massive task in inadequate time with incomplete and dated information; the DRB volumes do little to identify important constraints on the recoverability of higher grade eastern coals, and they do less to apply such constraints systematically.

The implication of the flaws in the DRB is that the task involved in improving the data base is an enormous one. What remains to be done, while geologists attempt this task, is to begin to learn the processes which restrict coal availability, so that their effects can be systematically and plausibly modeled.

CONSTRAINTS ON THE AVAILABILITY OF HIGH GRADE EASTERN COALS

The Nature of the Constraints

Most of the limitations on coal availability have been listed and published many times; but the economic impact of their effects has not been assessed. It is hoped that no penalties will be imposed if we begin by once again itemizing these deductions.
Frequently, lists of these constraints are categorized as either legal or geologic constraints. While useful, this typology ignores some of the most important characteristics of coal availability constraints. Examples of legal obstacles include national parks, towns, some roads and railways, perhaps alluvial valley floors. Like the law, such obstacles to mining are often flexible - I am reminded of a coal mine which recently operated in the foundation excavation for a parking garage within a literal stone's throw of the Illinois State Capitol building; and of another surface mine which leased, drained, and stripped a sizeable community's water supply reservoir.

Geological obstacles include sandstone channels, fault systems, seam splits and benches, roof rolls, clay horsebacks, pinches, slumps, gassy coal, wet seams, and the entire demonology of adverse mining conditions, including a few overburden combinations which current surface mining technology cannot handle at acceptable cost. Most of these constraints on coal recovery will prove flexible in time as mining technology evolves and real dollar coal prices rise. The contemporary spread of punch, or highwall drift mining from Appalachian hill sites to abandoned midwestern strip mine highwalls is an example of a technology currently giving access to reserve blocks previously too deep to strip, yet too small for normal underground exploitation. With the exception of sandstone channels and other coal wants, coal reserves which are bypassed today as unminable may eventually be exploited.

Another categorization of reserves of potential economic significance is the geographic shape of mining constraints. At the simplest level, both legal and geological constraints can be identified as linear or blocky shapes on a coal reserve map. Railways, fault systems, ribbon-like suburban growth, and sandstone channels replacing coal seams form linear barriers. Towns, benched seam areas, parks and mined out areas form polygonal blocks. Areas of reserves withheld from sale or lease form either polygonal or linear map features. Again, such constraints may prove temporary. One of the largest draglines in the country has padded softly across an interstate highway. Abandoned strip mines which have been exploited to a past economic limit may be remined at a later date to extract a deeper seam. Small underground mined areas have been mined through by large strip mines where the associated problems were small.

The purpose of this discussion is to suggest the degree to which coal recovery may be constrained not only by depletion, but also by dissection of the available coal. An equally important realization is that the effects of such constraints are not static - the list for a given coalfield is dynamically changing over the entire period of resource extraction as mining practice and technology engage in economic combat not merely with progressively thinner seams, but with a changing array of geologic and socio-economic constraints. In short, the problem for those who wish to mine coal is not merely one of overcoming progressive depletion. Rather it is the more challenging task of pursuing profitable extraction methods through a network of legal, geographic, and engineering obstacles. This network waves like a flag in the winds of time. Yesterday's answers may be abandoned only to be resurrected - as shown by renewed interest in conventional mining techniques as a strategy for meeting regulatory restrictions on allowable
dust at deep mine working faces. It is this dynamic struggle against recoverability constraints which has produced much of the technical heterogeneity and geographic idiosyncracy which characterize the coal industry. Comprehension of this struggle as a process instead of as a grabbag of local adjustments will aid efficient modeling of the industry. Understanding of the process will necessarily incorporate assessment of the interactions among its social, geological, geographic and economic components.

Interactions Among Recoverability Constraints

Linear and blocky barriers to mining interact to dissect contiguous coal reserves into progressively smaller blocks over time. This process seldom has sudden or drastic effects on regional production. It may be partly reversed as new technologies, new price levels, or socio-economic barriers change. However, in the long run population growth, cumulative mining and renewed popular demand for expansion of public reservations or restrictions on mining tend to eliminate large logical mine blocks. "Depletion" can be a phenomenon of social change as well as cumulative coal extraction.

Such effects are particularly important in the midwest, and in other coalfields which combine flat topography with fairly intensive surface use. Their effectiveness can be inferred from the distribution of remaining surface minable blocks in Illinois, as tabulated by the Illinois State Geological Survey (Table 2). In areas of hilly topography, where extraction emphasizes drift or contour stripping, reserves are frequently in linear blocks. Coal reserves in hills are less subject to dissection by roads, rivers, and railways - which go around the hills rather than over them. However, spatially random extraction patterns in closely spaced hillside seams rapidly interact to produce a three-dimensional swiss-cheese effect which can very rapidly restrict economically recoverable reserves to higher-grade coals which will support the costs of small scale mining.

The inevitable decline in regional average mine size due to the above effects may be significantly slowed by the common practice of withholding blocks of reserves from production. This may occur either because the owner wishes to prevent mining, or because he wishes to delay mining until a later date when substantial rents can be gained from mining the withheld property. In order to control the mining prospects of such a block, it is seldom necessary to own more than 25% of the area's mineral rights. Judicious geographic spacing of purchased blocks, and gradual acquisition to keep pace with decreasing average mine size can assure control over such reserves at moderate annual cost. Normative solutions for control of real estate purchasing in competitive situations have been known in the Orient for centuries. Again, linear barriers can be highly effective in cutting up reserves into blocks too small or qualitatively too uneven to be mined profitably. Certainly the importance of such barriers is much greater than the coal tonnages they overlie.
<table>
<thead>
<tr>
<th>Block Size (Million Tons)</th>
<th>Number of Blocks</th>
<th>Tonnage (Millions)</th>
<th>Cumulative % of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-10</td>
<td>42</td>
<td>332</td>
<td>5.45</td>
</tr>
<tr>
<td>10-20</td>
<td>66</td>
<td>913</td>
<td>20.44</td>
</tr>
<tr>
<td>20-30</td>
<td>29</td>
<td>715</td>
<td>32.19</td>
</tr>
<tr>
<td>30-40</td>
<td>16</td>
<td>580</td>
<td>41.71</td>
</tr>
<tr>
<td>40-60</td>
<td>10</td>
<td>499</td>
<td>49.90</td>
</tr>
<tr>
<td>60-80</td>
<td>4</td>
<td>284</td>
<td>54.56</td>
</tr>
<tr>
<td>80-100</td>
<td>6</td>
<td>537</td>
<td>63.37</td>
</tr>
<tr>
<td>100-140</td>
<td>4</td>
<td>490</td>
<td>41.42</td>
</tr>
<tr>
<td>140-180</td>
<td>2</td>
<td>314</td>
<td>76.56</td>
</tr>
<tr>
<td>180-220</td>
<td>2</td>
<td>401</td>
<td>83.15</td>
</tr>
<tr>
<td>220-300</td>
<td>1</td>
<td>293</td>
<td>87.96</td>
</tr>
<tr>
<td>&gt; 300</td>
<td>2</td>
<td>734</td>
<td>100.00</td>
</tr>
<tr>
<td>TOTAL</td>
<td>184</td>
<td>6092</td>
<td></td>
</tr>
</tbody>
</table>


Geologic barriers should not be taken as permanently defined, once discovered. Accurate knowledge of mining conditions is not often available in detail until the reserves in question are being mined. Thus, knowledge of such barriers is a direct function of cumulative coal production. Many large underground mines have closed prematurely or had their capacity severely reduced due to adverse mining conditions. I could name deep mines in Illinois alone which have lost over six million tons/year capacity since 1970 due to unforeseen geological problems.

Legal and social barriers accumulate over time, but the degree to which they can be bent to accommodate mining depends greatly on the attitudes of local, state, and federal officials, which are functions of local, state, and federal prosperity and the associated attitudes toward the extractive industries.

Significance of Constrained Availability

Many previous discussions have argued for conservative interpretations of coal reserve availability. Commonly suggested regional recovery percentages are on the order of 30% for deep mining and 45% for surface mining.12
Such figures do not appear to stem from systematic studies, but rather from the judgments of experienced coal geologists and mining engineers. Schmidt calculated recovery of surface minable resources and concluded that “In most major coal producing states, only about one quarter of the reserve base is estimated to be recoverable...”

The production of Pennsylvania anthracite is recorded since 1808, with cumulative production through 1980 of 5.45 billion tons. The original resource base of Pennsylvania anthracite is estimated to have been between 24 and 27 billion tons. Historical production, when graphed, fits under a normal curve, peaking at 100 million tons/year in 1918, then declining to 5.4 million tons in 1980. A moderate rejuvenation of demand is anticipated, due to regulatory exemption from utility New Source Performance Standards and expanded export demand. However, even optimists do not foresee demand growth above 17 million tons/year. It appears unlikely that cumulative production will exceed 6.2 billion tons by 2030, and, if one assumes that anthracite production will continue to follow the normal curve which has characterized its production for the last 172 years, the industry may be extinct by 2030. Cumulative production of 6.2 billion tons of Pennsylvania anthracite by 2030 would represent recovery of 23-26% of the original resource, and about 11% of the remaining recoverable reserves.

Ultimate recovery at 23-45% of the resource, or as little as 11-27% of the remaining reserves probably represents a different inter-temporal price and production path than does recovery at 50-90% of the DRB. The DRI-Zimmerman model assumes (as default values) 50% recovery for deep minable coal, and from 70% to 90% for recovery of strippable coal. Admittedly, the DRI model allows the user to replace these percentages with values of his own choosing, but given the amorphous nature of the DRB, these values may be little more than "factoids." Perhaps they would be appropriate for the reserves held by coal operators, if this reserve could be assigned to depth and thickness intervals. The National Coal Model assumes recovery of 60% for deep minable coal and 80% for surface minable coal - again, we see the use of intra-mine recovery figures. The NCM has also incorporated estimates of coal which is illegal to mine. For surface minable coal, these are 15% for eastern reserves, 25% for midwestern reserves, and 10% for western coal. The rationale given for these figures is remarkable for its candor. I quote "The percentages used are arbitrary guesses, but no more arbitrary than making no adjustment at all." Harsh criticism of the feet of fireclay supporting widely respected coal supply modeling systems is neither kind nor constructive. The low recovery figures cited above, while suggestive, are merely another set of arbitrary numbers. If recovery percentages were randomly assigned to coal supply modelers, each could no doubt locate a handful of regional reserve studies to justify extrapolation of the assigned percentages on a nationwide basis. In as much as the use of Coal Supply Models, like coal production, is likely to prove "demand constrained" in the long run, it is to be hoped that a more systematic yet flexible approach to reserve assessment will emerge.
It will of course be immensely helpful when an inclusive encyclopedia of coal resources becomes available. The U.S. Geological Survey's National Coal Resource Data System will one day provide such a source. However, this will increase, not decrease, the need for a normative understanding of the interacting web of geologic, economic, social and geographic processes which define the availability of coal reserves. Without such an approach, we are in significant danger of misinterpreting the social, regional, and economic implications of increasing dependence on our most abundant energy resource.
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