Innovative Energy Opportunities In West Virginia

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FINAL REPORT

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DISCLAIMER

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1. Introduction

This report assesses the availability of alternative and renewable energy resources in the state of West Virginia. Like many states in the U.S., West Virginia has multiple non-traditional energy resources that are largely untapped. These resources include wind, waste coal, coal-bed methane, wood residue, landfill gas and other types of biomass waste such as chicken litter. Many of these resources are underutilized. Use of waste and renewable resources contributes to several positive events: environmental clean up, energy independence, reducing reliance on fossil fuels and economic development.

Wind is the most truly renewable resource available in West Virginia and is presently highly underexploited. Several large projects are expected to be developed by the end of 2007 which will increase installed capacity to almost 15 percent of its estimated capability on private lands. Of all the resources reviewed in this report, wind has the greatest potential for power generation.

Coal-bed methane production is growing rapidly in the state and is likely to continue to do so. Its production is motivated by the pre-existing need to extract methane prior to and during mining for safety reasons. In addition, technology has improved making capture and transfer to a natural gas pipeline more feasible. Natural gas price volatility also has certainly contributed to motivating additional supply.

Waste coal use has a long and varied history in West Virginia that has been directly related to overall coal markets, recovery economics and environmental concerns. The availability of this resource grows annually as more waste is added to existing piles after coal washing. However, modern preparation processes are much more efficient than in previous decades and thus recently discarded coal is often of a lower energy value than older refuse. Nonetheless, recent coal separation technology developments combined with higher coal prices have induced some innovative recovery projects that have potential for duplication and expansion. These projects help reduce the large portfolio of impoundments and legacy waste piles around the state, including acid mine drainage sites, reducing the need for costly treatment systems and new impoundments.

Biomass is available in various forms, including wood residue, landfill gas and chicken litter. Waste from primary and secondary wood products facilities comprises the largest category of potential biomass. This type of wood waste is found throughout the state but is concentrated in the wood products producing central counties. While the wood products industry uses a portion of the waste it generates internally, because of low grid prices for wholesale electricity West Virginia does not have a wood residue-fueled power generation facility. Allegheny Power has invested in and retains the capability to co-fire wood and coal at their Willow Island and Albright power stations.

Landfill gas is evaluated separately in this report due to its uniqueness. West Virginia has not had a landfill gas to energy project since 1995, but has several landfills that are mature enough to produce modest amounts of methane that could be converted to electricity or used directly.

Chicken litter is another type of biomass waste that has special significance in West Virginia. The state has a unique demonstration project (Bioplex) that transforms litter into a benign fertilizer using anaerobic digestion. For this process methane is a small but useful byproduct which is well-suited to supplement on-site energy demand. A recently announced gasification project in Hardy County will demonstrate direct energy production from gasified litter to supplement on-site demand.

Small and low impact hydroelectric power has been estimated to have considerable physical potential in the state. However, because this resource is relatively more expensive per unit of energy it may be difficult to develop the entire estimated capability. This difficulty may also be compounded due to riparian rights issues and proximity of resources to end users or the electricity grid.

Enhanced oil recovery (EOR), although not a renewable resource, is also reviewed here because it is an unconventional method of extracting petroleum. There is still potential to further refine and expand both secondary and tertiary recovery methods and to extract even more from wells that are already tapped.

For most of theses resources a major hindrance to their development is the low cost of the current electricity generation mix in the region. In addition, the lack of a close market for green power may make it difficult to get a purchase power agreement for higher price power.

The estimated underlying value of the resources evaluated, if near fully exploited, is just over $1 billion. The actual values of individual resources will be reliant on the price prevalent in the market in which they are sold, which are estimated conservatively in Table 1.1. As discussed in this report, the value of these resources is already being realized. This is especially true for coal-bed methane, enhanced oil recovery and circulating fluidized bed (CFB) power plants that run on waste coal.

Table 1.1: Estimated Potential Availability and Energy Market Value by Resource

	Potential Quantity /Year	**Unit**	**Est. Price**	**Estimated Annual Value**
Wind	9,986,400 MWh	$/mwh	$ 36	$ 360,000,000
Coal-bed Methane	34 Bcf	$/mcf	$ 6.5	$ 221,000,000
Waste Coal CFB	4,200,000 MWh	$/mwh	$ 36	$ 151,000,000
Low Impact Hydro	2,823,733 MWh	$/mwh	$ 36	$ 102,000,000
Coal Fines	3 million tons	$/ton	$ 25	$ 75,000,000
Enhanced Oil Recovery	960,000 bbls	$/bbl	$ 50	$ 48,000,000
Wood Residue	2,088,372 tons	$/ton	$ 20	$ 42,000,000
Landfill Gas	4 Bcf	$/mcf	$ 3.3	$ 13,000,000
Chicken Litter	1.3 Bcf	$/mcf	$ 4.2	$ 5,000,000
			TOTAL	**$ 1,016,000,000**

More information on value assumptions is provided in the Appendix.

Costs comparison

The estimated costs of generating electricity with the resources evaluated in this report are shown below. For this analysis, the cost of electricity (COE) is the cost per megawatt-hour (MWh) to produce electricity and includes the cost of capital, construction and variable and fixed operation and maintenance (O&M) costs. This measure allows comparison of the per unit production costs across the various generating resources. These variances are indicative of the decisions that must be made when choosing a generating resource. Most of these resources cannot produce electricity at the prevailing wholesale price of $36 to $42/MWh. Thus, to promote development costs would have to decline, a subsidy would have to be in place or customers must be found that are willing to pay more than the prevailing retail price.

These costs show that even without the production tax credit, wind generation can be quite competitive with a waste coal-fired circulating fluidized bed (CFB) facility if it achieves a favorable capacity factor (utilization) and capital costs do not run on the high side of the spectrum. The production tax credit allows wind facilities to be competitive with all resources except conventional coal and landfill gas (LFG). LFG facilities have very favorable unit costs but generate relatively small quantities of electricity.

Table 1.2: Electricity Generating Costs for Selected Resources

	MW	Capacity Factor	MWh	Capital Costs	$/MW	O&M $/MWh	COE $/MWh
Coal CFB	100	80-90%	700,000 –800,000	$ 260 - 275 million	$ 2.6-2.75 million	$ 19-23	$ 52-63
Wind[1]	100	27-32%	240,000 –265,000	$ 120 - 160 million	$ 1.2–1.6 million	$ 10-12	$ 53-81
LFG	3	85-95%	22,000- 25,000	$ 4 - 4.5 million	$ 1.3-1.5 million	$ 13-14	$ 29-34
Wood Waste	50	50-70%	220,000- 310,000	$ 84 million	$ 1.7 million	$ 20	$ 48-59
Unconv. Hydro	0.5	40%	1,750	$ 1.25-1.5 million	$ 2.5-3 million	$ 6	$ 78-93
Conv. Hydro	25	50%	110,000	$ 36 million	$ 1.25 million	$ 6	$ 40
Conv. Coal[2]	600	70-80%	3.7 - 4.5 million	$750 million	$ 1.25 million	$ 8	$ 26-29
Conv. Gas	160	5-17%	70,000- 240,000	$ 64 million	$400,000	$ 11-28	$ 38-121

[1] Wind O&M costs do not account for the federal production tax credit.
[2] U.S. DOE/ EIA (2006). Annual Energy Outlook, "Cost and Performance Characteristics of New Central Station Electricity Generating Technologies."

For all these resources, COE is heavily dependent on the utilization rate of the installed capacity (MW). Wind facilities generally do not generate electricity much more than 30 percent of the time, due to the intermittency of the wind. Coal-fired facilities can generate up to 90 percent of the time, requiring outages only for maintenance. Gas facilities are commonly designed to be fired up only for peak power generation and are thus only run an average of five to 17 percent of the time.

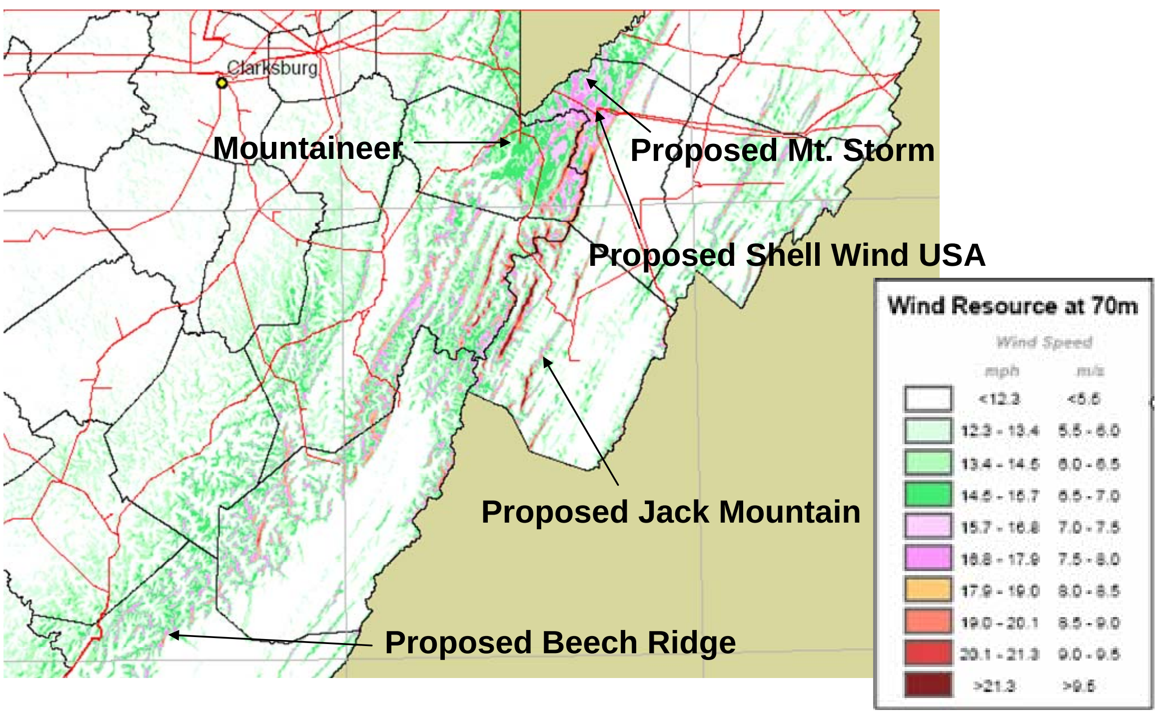
More information on COE, including the assumptions used for each resource, is presented in the Appendix.

2. Wind

Wind resources are considerably underdeveloped in West Virginia. The state presently exploits only a little more than 66 megawatts (MW) of the estimated 3,800 MW available on private land and 10,780 MW available on both public and private lands. When including all land, West Virginia may have the greatest inland wind potential of any eastern state. Wind resources are calculated at a rate of 30 MW per square mile.

Figure 2.1 shows West Virginia wind resources as calculated by TrueWind Solutions. The vast majority of wind capability is located in the Potomac Highlands region of the state, which is largely what is shown here, although additional lower speed wind capability may be found in adjacent regions. This map represents a wind speed at 70 meters above ground cover, a height which is generally considered only for commercial-scale development. Wind speeds of greater than seven meters per second are typical of sites considered attractive for commercial development and correspond with wind classes 4 and higher. The map also shows the locations of the existing Mountaineer Wind Energy Center in Tucker County and the four currently proposed facilities.

Figure 2.1: Existing and Proposed Commercial Wind Operations in West Virginia[3]



At 100 meters above ground cover wind resources are even greater, as shown in Figure 2.2. Again, this height primarily represents commercial scale development opportunities that would utilize turbines of the size installed at the Mountaineer Wind Energy Center for example.

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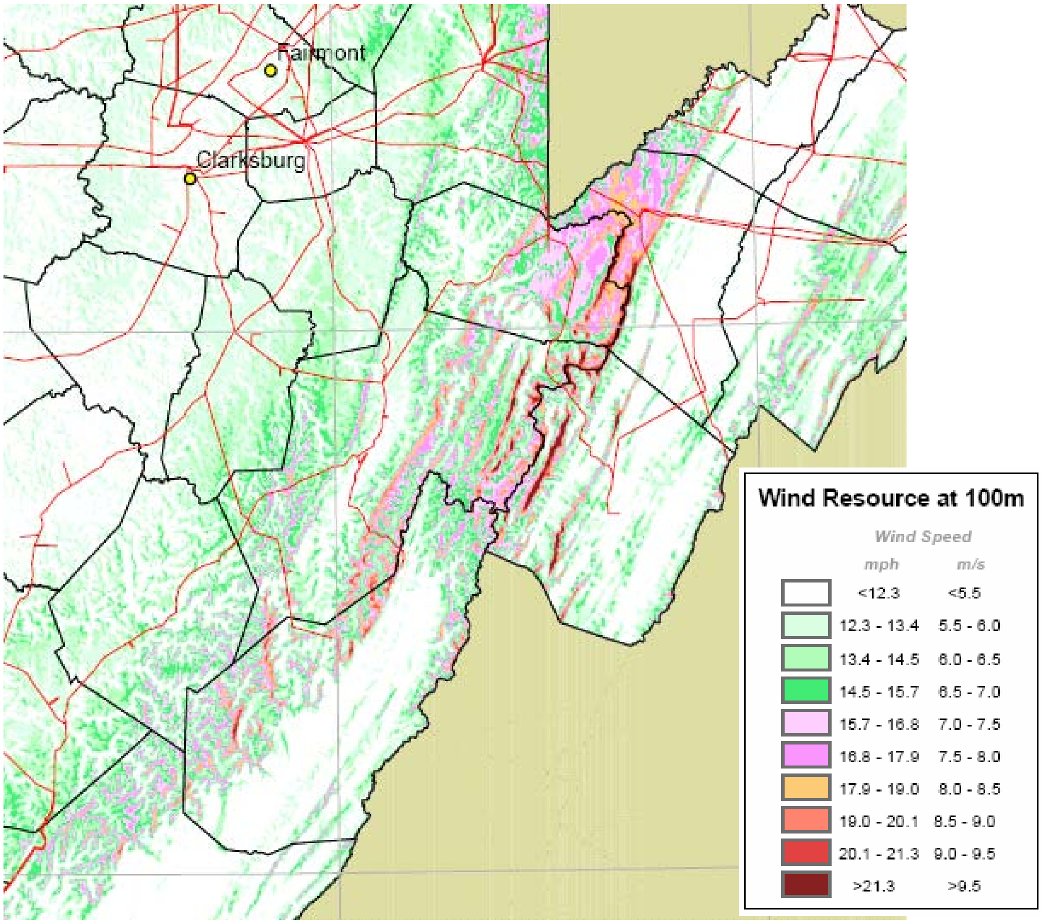
[3] TrueWind Solutions, 2002.

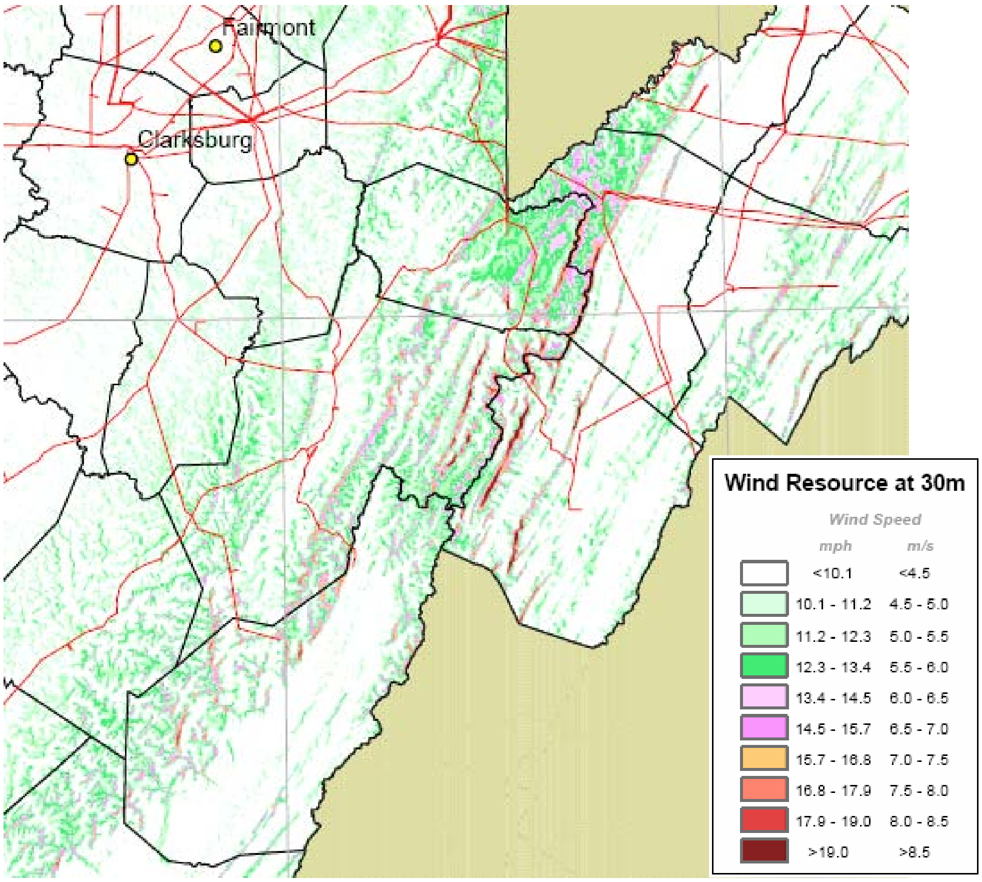
Figure 2.2: West Virginia Wind Resources at 100 Meters (meters per second)



By contrast, wind resources at 30 meters above ground cover show lower wind speeds. This height represents opportunities for smaller size turbines of the type that might be installed for residential use. Stand-alone systems for residential use may be able to utilize winds at speeds as low as four meters per second, which would make all the green areas on shown in Figure 2.3 feasible.[4] At 30 meters (98 feet) above ground cover, smaller and shorter turbines can be utilized that are more affordable for residences and small businesses. As with all wind installations, actual wind speed varies depending on the height of the turbine. This makes site specific evaluation essential to a development decision.

[4] http://www1.eere.energy.gov/windandhydro/wind_consumer_faqs.html

Figure 2.3: West Virginia Wind Resources at 30 Meters (meters per second)



Costs

In terms of capital costs per MW, wind power is competitive with many types of power generation including conventional coal-fired and landfill gas generation. However, because of the intermittent nature of wind, the capacity of wind facilities cannot be as fully utilized as other types of facilities such as coal or landfill gas. This causes the cost of wind-generated electricity to be higher than conventional resources per unit of output (KWh or MWh). Wind facilities typically operate at an average of 30 percent of their capacity while coal facilities operate at closer to 80 percent and landfill gas facilities at close to 100 percent of their capacity.

The total cost of electricity, inclusive of capital costs, for wind facilities is in the range of 5.3 to 8.1 cents per KWh ($53 to $81 per MWh). A recent increase in capital costs has contributed to somewhat higher costs at the same time that generation continues to increase relative to turbine size. Average natural gas-fired generation costs range from 3.8 to 12.1 cents per KWh[5] although the actual plant range is larger (1.5 cents per KWh

[5] For the U.S. as a whole and the East Central Area Reliability (ECAR) electricity coordinating region respectively in 2003. SOURCE: U.S. Department of Energy, Energy Information Administration (2005). 2003 EIA-906/920 Monthly Time Series File.

for plants with high utilization to over 30 cents per KWh for plants with very low levels of utilization). The federal Production Tax Credit of 1.8 cents per KWh was adopted to reduce the difference between renewable and conventional fuels and stimulate the development of renewable energy resources including wind and biomass. Exclusive of the capital investment, wind facility operating costs can be as low as one cent per KWh, which is more competitive with conventional generation than any other renewable technology with the possible exception of hydro.

Demand

Commercial development of West Virginia wind power is the result of demand for renewable energy from outside the state. Renewable Portfolio Standards (RPS) have much influence on this demand. States such as Maryland, Pennsylvania, New Jersey and The District of Columbia have enacted these standards, which require that a certain percentage of generation and/or purchases will be made from renewable sources of energy, with full implementation typically by 2020.

Developers also sell or have contracts to sell facility output to “green power” marketing firms that service customers in Pennsylvania, Maryland, Washington, DC and New Jersey. Customers include individual residences, non-profits, universities and the U.S. Army. These customers are willing to pay a premium to purchase electricity from marketing firms that buy the output of facilities that generate power from renewable sources such as wind, landfill gas and sometimes hydro.

While some residential wind systems are already installed in West Virginia, and have potential to expand, the number of residences in the windy areas of the state is small compared to the population that lives in non-windy areas. Thus, the ability to most fully and immediately take advantage of wind resources lies in commercial-scale development.

3. Waste Coal

Energy recovery from coal waste disposal sites is not an untapped energy resource in West Virginia. Many successful and unsuccessful efforts have been made over the last twenty to fifty years to re-mine the numerous waste sites that exist in the state. The high cost of processing fine coal has deterred extensive development of this resource but fine coal is currently being used along with coarser "garbage of bituminous" or gob.

There are at least 864 disposal sites in WV including both reclaimed and unreclaimed slurry impoundments in addition to abandoned dry waste piles. As of 2005, waste piles of these types are comprised of 52 sites that fall under the state Special Reclamation Fund (SRF), 700 sites that fall under the federal Abandoned Mine Lands (AML) program and 112 active impoundments that currently accept coal slurry or are already being re-mined. Almost 350 coal waste disposal sites have been reclaimed through the AML program and another 40 or so through the SRF. There are thus about 360 abandoned sites that have yet to be reclaimed. Additional dry waste coal is also found on open mining permits.

The energy value and usability of gob varies considerably from site to site and must be sampled extensively to identify a good match with a potential end user. Some of the highest btu coal is held in reclaimed sites such as the now reclaimed Antaeus Gary impoundment that had been operated by U.S. Steel. To re-mine this particular site would require removal of considerable amounts of topsoil and grass to access the now stabilized former impoundment below. Attempts to re-mine the fines were canceled due to financial concerns, and the safety of the impoundment required that reclamation be immediate and complete. The SRF thus reclaimed the site to conform to federal Surface Mining Control and Reclamation Act (SMCRA) guidelines. Other re-mining projects have met similar fates although none required such extensive and costly reclamation.

Quantity Available

For many if not most refuse sites, little is known about the energy content of the pile.[6] To accurately assess the potential recoverability of any site core drillings must be taken to assess pile depth and energy content. Clues about the site provide information upon which to make a decision to sample a pile for its recoverability. These clues are:

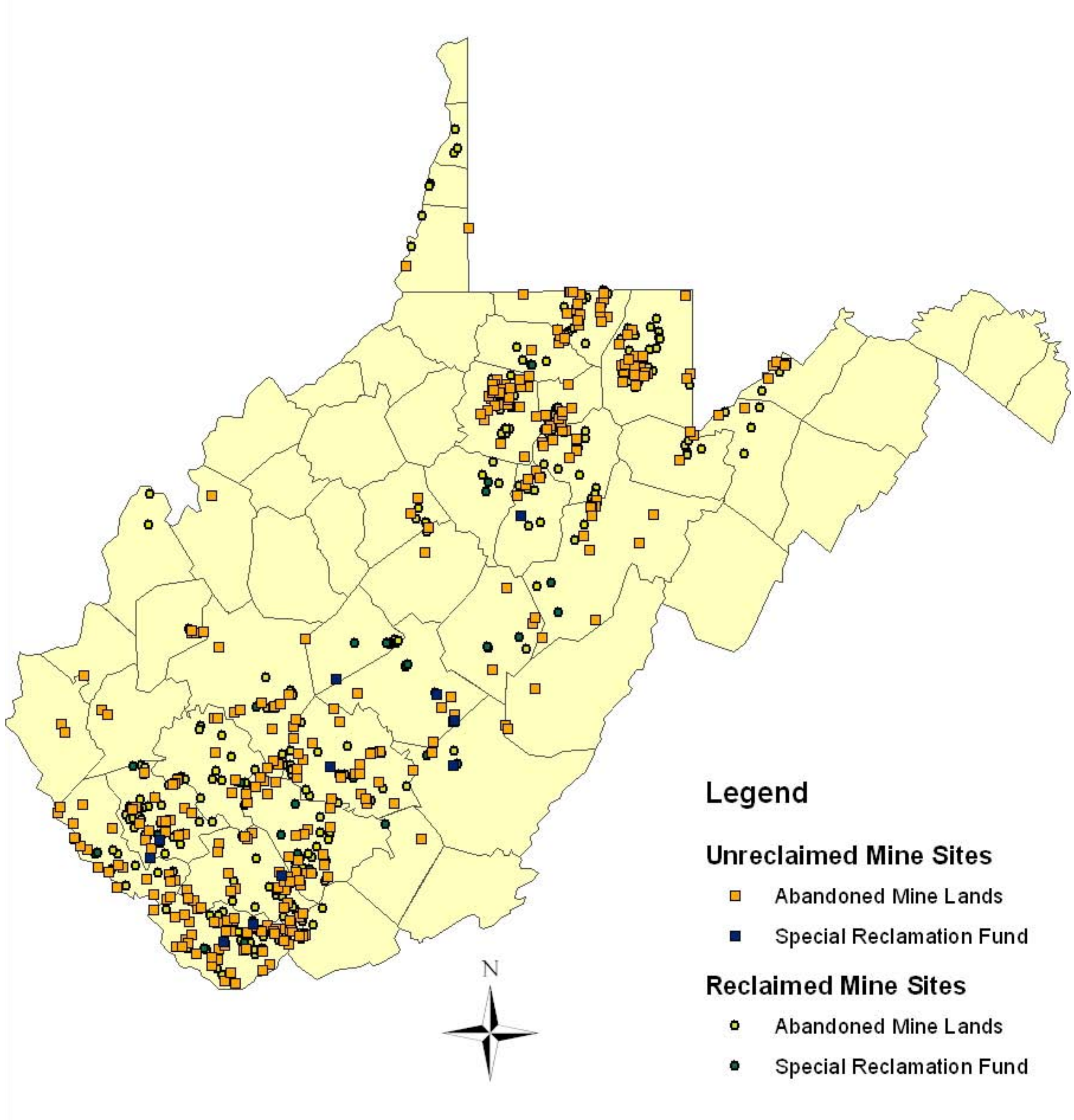
- Site vintage (years it was mined)
- Seam from which the coal was mined
- Method of mining and preparation used at the time the pile was active, and
- Acreage of the pile (from aerial photography).

Much of this information is available from mining records and permits, which can help justify whether further site evaluation and sampling would be profitable.

[6] From this point forward "pile" refers to both wet and dry impoundments and dry waste piles.

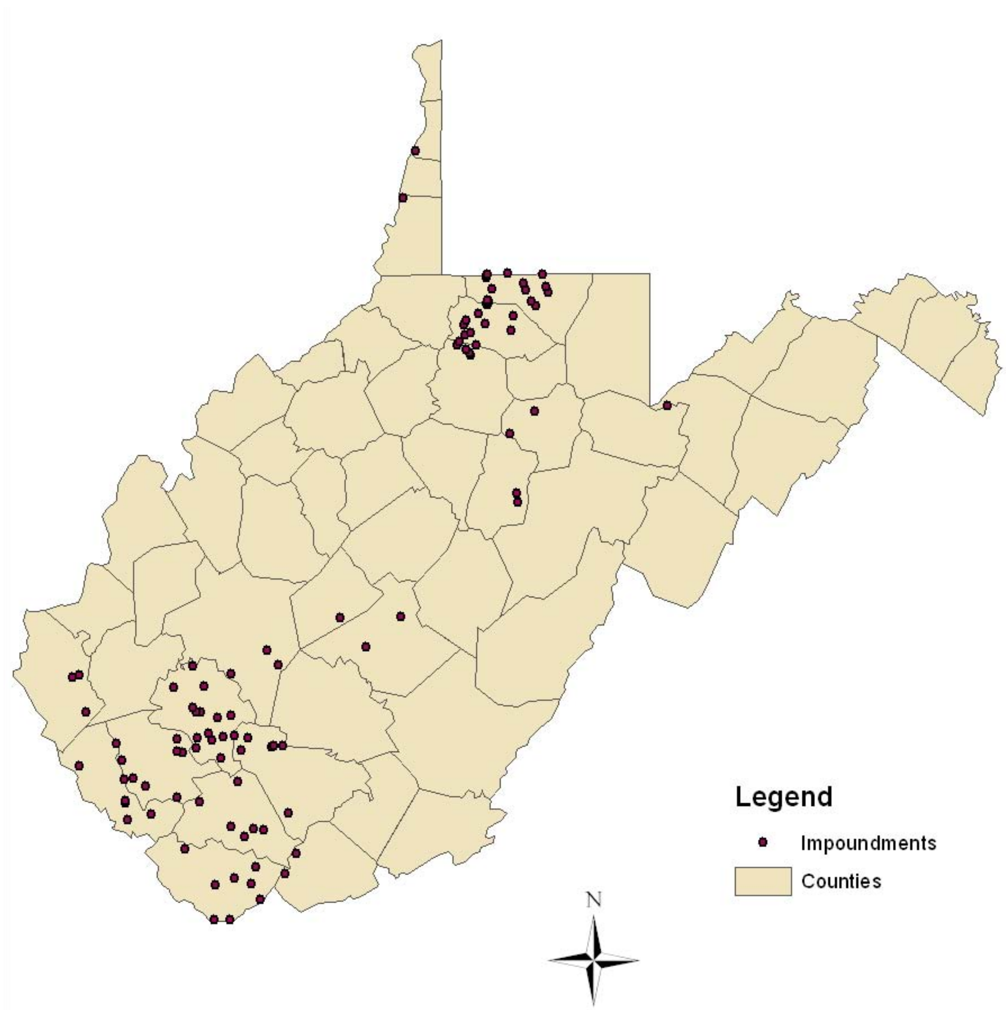
Newer waste piles are often less conducive to re-use because coal preparation technology has evolved so that less coal is placed in waste piles. Older sites that began operations prior to institution of SMCRA tend to have greater ratios of coal to waste and thus greater energy content. Date of operation is not always enough information as an impoundment could have been permitted prior to coal preparation advancements but could have implemented more modern techniques. It is also worth nothing that many piles are more than 50 years old and are still accepting waste. Such conditions necessitate site-specific sampling to accurately assess recoverability. A map of abandoned waste sites is shown in Figure 3.1 along with the status of reclamation. A map of active coal waste impoundments is shown in Figure 3.2.

Figure 3.1: Abandoned Coal Waste Sites in West Virginia



Sites that fall under the AML program may be more viable as those sites are pre-SMCRA and represent the less efficient mining and preparation practices that were practiced prior to the 1970s and 1980s. Many impoundments that fall under AML are now dry piles and some have been at least partially re-mined for use in three circulating fluidized bed (CFB) power plants[7] in Monongalia, Marion and Grant Counties.

Figure 3.2: Active Coal Waste Impoundments in West Virginia



Overall, up to 30% of an impoundment is coal fines. The remainder is rock, clay, silica, various trace metals and other chemical residue from the preparation process. The quality of the raw coal slurry varies over the length and depth of the impoundment relative to the point of discharge of the waste into the pond.

In 1991, it was estimated that 38 million tons of coal fines were discarded annually into impoundments. At the time it was also estimated that two billion tons of coal were already contained in 700 impoundments, many of which are located in central

[7] CFB plants are modern coal-fired power generation systems that have very low emissions, competitive efficiency levels and can operate on lower btu and waste coal.

Appalachia.[8] West Virginia has 112 active impoundments plus at least 94 abandoned impoundments within the AML inventory for a total of 206 impoundments.[9] This means that the state has at least 29 percent of the 700 impoundments that were tallied in 1991. Applying this percentage to the two billion estimated tonnage equals 589 million tons available in 1991. An annual addition of 11 million tons (38 million tons X 29 percent) minus estimated annual use of 1.2-2 million tons leaves current resources at 715-730 million tons 15 years later from impoundments alone. Because many of the AML impoundments are likely to be smaller than open impoundments, it may be more appropriate to exclude those from an estimate representing a minimum quantity of gob. The 112 open impoundments are 16 percent of the total 700 estimated in 1991 and available gob from those is estimated at 415 million tons. It is reasonable to use this figure as a minimum quantity of available gob fines, given that additional tonnage may exist in abandoned impoundments within the AML program. This figure also does not include dry waste piles that exist within both the AML and SRF programs and on open mining sites.

More may be known about the energy recoverability of open sites because current operators are familiar with the contents of their disposal sites. There are still operators who maintain sites on which mining commenced in the 1950s or 1960s that are likely to contain high ratios of coal in their piles and/or that use somewhat outdated preparation processes that dispose of economically recoverable coal.

Use

The primary use of waste coal is currently in circulating fluidized bed (CFB) power plants. Some synfuel operations also use fines to produce synthetic coal products that are burned along with new cleaned coal in conventional power plants. Both practices reduce the quantity of coal fines in a refuse area or an impoundment. Coal fines are sometimes pelletized using a binder and sold to power plants as coal briquettes, as was done until recently at several West Virginia locations through the Covol process. Often, this type of project works best with the fines found in older, dry impoundments.

In West Virginia, three existing and one planned CFB power plants are designed to use waste coal as their primary fuel source. Fluidized-bed combustion has fuel flexibility and can meet emissions standards while burning lower, non-utility grade coal. All three of the existing plants use a combination of waste coal and unwashed new coal.[10] The Western Greenbrier co-generation plant is scheduled to begin operating in 2007 and will use 100 percent waste coal. The four facilities' waste coal use is summarized as follows:

- Morgantown Energy Facility – Uses about 250,000 tons of waste coal per year and also uses unwashed low-btu, non-utility grade coal.

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[8] CQ, Inc. for Electric Power Research Institute (1994). "Premium Fuels from Coal Refuse."

[9] Dick Darnell of WV DEP (2006). The AML inventory includes 94 "dangerous impoundments" of varying sizes. This number excludes impoundments potentially located in refuse complexes.

[10] The Federal Electricity Regulatory Commission classification of these plants allows some of them to use up to 25% new unwashed coal.

- Grant Town – Uses about 600,000 tons of waste coal per year.[11] About 35 percent of this amount is from slurry impoundments, both wet and dry.
- North Branch – Uses about 300,000 tons of waste coal per year, much from an unreclaimed AML site at Bayard, WV.
- Western Greenbrier – Will use waste from an acid mine drainage site at Anjean, WV. The corporation has several prospecting permits to sample other nearby piles and has already confirmed about 20 million tons is available at four sites. The plant will use just over 1,000,000 tons of waste coal per year.

Currently, the existing three CFB plants consume nearly 1.2 million tons of waste coal per year. Ash from the facilities is returned to mine sites for use in reclamation.

Fines Recovery Projects in West Virginia

The products of fines recovery projects are primarily burned in conventional power plants or coke plants. The following are examples of fines recovery projects that have taken place in WV in the last two decades:

- The Covol Fuels (now Headwaters Energy Services) process has been used in conjunction with synfuel production at several sites in West Virginia including McDowell, Raleigh and Upshur Counties. This process uses a reagent as a binder to transform coal fines into a pelletized and easily handled product that can be burned in conventional power plants. Most of these sites were tied closely to federal tax incentives that expire in 2007 and become obsolete with high oil prices and are thus now closed or have substantially shrunk operations.
- Beard Technologies in Wyoming County has a permit to recover former U.S. Steel waste slurry from the Smith Branch Coal Slurry Impoundment near the Pinnacle mine complex. The site is estimated to have over 2 million tons of recoverable coal, or more if a by-zero feed system (100 percent coal recovery) is implemented. The project will begin processing fines in summer of 2006 and will be the first pond recovery project to use a paste thickener method to stabilize waste returned to the pond. [12] The output will be sold along with metallurgical coal from the Pinnacle mine.
- Deepgreen West Virginia (a subsidiary of Deepgreen Minerals of Australia, now partially owned by King Coal Corp. Ltd of the U.K.) operates a dredging operation in the impoundment at the former Pageton Preparation plant in McDowell County. The site was actively mined beginning in the 1890s, was then operated by CONSOL until 1984 and then Addington Resources. The pond had reserves of about 1.2 million tonnes (1.3 million tons) of usable coal in 2003. The product of this project is high btu metallurgical waste that is blended with regular coal and burned in conventional power plants.

[11] U.S. Department of Energy, Energy Information Administration (2004). Forms EIA-906 and EIA-860.
[12] http://www.beardtechnologies.com/pinnacle.htm

- Targe Energy/ Coal Valley, LLC operates a fines recovery project at CONSOL's Turkey Gap impoundment in Mercer County. The impoundment is no longer receiving waste.
- United Coal Company may have one of the longest histories of evaluating cost-competitive recovery of slurry as it has been involved in a Department of Energy demonstration project in Logan County since at least 1989. The project plans were to produce dry low-ash, low-sulfur coal from dredged fines.[13] No information on project production is publicly available.
- Antaeus Gary – This now reclaimed site contains one of the largest reserves of recoverable waste coal in the state. A former U.S. Steel impoundment, the refuse has a very high btu content as it is from metallurgical coal and operated beginning in the early 1900s. Recent attempts to re-mine the site were interrupted due to cost issues, although some of its smaller ponds were re-mined. Re-mining would now require removal of vegetation, in addition to re-reclaiming the site after re-mining.

Additional impoundments have been at least partially re-mined although several of those permits were abandoned or revoked prior to project completion.

A major environmental benefit of re-mining projects is the reduction in the quantity of coal waste that must be stored, thus reducing the need to build new waste facilities. Another benefit is a possible simultaneous reduction in reclamation costs. However, overall few reprocessing projects have finished a project complete with full site area reclamation. This is made difficult due to the waste nature of the process, i.e. not all the slurry in a pond can be used and thus waste disposal is also a significant aspect of re-mining. Fine recovery projects themselves can require a permit to maintain an impoundment. With many mining and re-mining projects, financial resources were not adequately allocated to reclamation and permits have often been revoked or forfeited.

Methods of Recovery

There are three major categories of separation in recovery of coal waste: 1) separation by size, 2) separation by type of solid material, and 3) separation of solids from liquids. These methods are usually used in combination. The Virginia Tech and West Virginia University Center for Advanced Separation Technologies (CAST) conducts extensive research on these processes.[14]

Size separation has many processing steps. The frequent need to reject the smallest fines and utilize only the larger pieces for the final product creates inefficiencies. Standard measurement quantifies coal fines by the screen mesh size the fines will not pass through. Screen fragility and durability are challenges, as are systems needed to reduce clogging and maintain throughput. Fines can also be sized through a process whereby materials are separated according to their velocities in a fluid. This method can

[13] National Energy Technology Laboratory (1989). Annual Report to Congress on Clean Coal Technology Demonstration Program, February 1989. U.S. DOE, Assistant Secretary for Fossil Energy.
[14] http://www.castconsort.org

generally process larger quantities of fines than can screening but is less efficient, especially in regards to smaller sizes of particulate material.

Many projects process fines larger than 28 mesh, or about 600 to 800 micrometers. The ability to process a by-zero (zero coal reject) feed directly to a final product removes the need for size separation. The Pinnacle Project described above will process fines larger than 325 mesh, or about 45 micrometers[15], and eventually plans to operate so that it processes at by-zero.

Solid material separation uses differences in specific gravity, magnetic properties, electrical conductivity, surface properties, and dielectric property to separate materials. Methods used include flotation, selective flocculation (clumping), gravity separation, magnetic /electrostatic separation and optical sorting. A major concern for solid separations is in automation and controls.

Separation of solids and liquids is a central challenge to fines recovery. These processes include thickening, centrifugation, filtration and drying. Thickening increases the percent of solids in slurry so that it can be stacked instead of having to be disposed of in impoundments. Centrifugation uses high-gravity forces to increase fine settling and to decrease the percentage of water content. Filtration is a process that selectively retains the solid on a porous medium, and may use vacuum filters or pressure filters depending on the size of the particles. Drying refers to the process of dewatering materials by thermal evaporation. Due to their fuel flexibility, CFB facilities can often utilize fines directly from an impoundment with only air-drying.

Costs

Coal waste recovery costs differ based on whether the pile is wet or dry. A fines recovery project can cost $10 to $12 million for equipment required at the site of the pile to separate and dewater the sludge. Operating costs are in the range of $8 to $12 per ton, which for high btu fines results in a favorable overall cost relative to current coal prices. Operating costs for dry waste piles are about half the costs of fines processing. However, because recovered coal from dry piles generally has a lower energy content it can only be used in specialized CFB power plants, which increases the total costs of using dry gob. CFB plants also produce large amounts of ash which must be hauled away and disposed.

Because waste goal generally contains no more than half the btu value of regular bituminous coal, the price relative to heat value must be discounted. On an energy-to-energy basis the value of dry gob is commonly equivalent to between one half (6,000 btu per pound or 12 mmbtu per ton) of new bituminous (24 mmbtu per ton) although quite a few impoundments contain waste that is equal in energy value to new coal. Gob with higher energy content is often found in impoundments containing metallurgical waste and may have an energy value of 12,000 btu per pound or more. Theoretically, gob with an energy content of 12,000 btu per pound could demand the price of new bituminous,

[15] For reference, the average width of a human hair ranges from 18 to 180 micrometers.

although it is likely to sell for somewhat less than that. Conversely, some gob has considerably lower energy content, perhaps as low as 3,000 btu per pound.

As shown earlier in Table 1.2 electricity capacity costs from CFB facilities are higher per MW compared to renewable energy sources with the exception of many low flow hydro installations. In terms of the total cost of electricity, CFB plants compare favorably to wind projects in the absence of the Federal production tax credit, but are more costly than landfill gas and generally more costly than plants that operate on wood residue.

Summary

A primary benefit to using waste coal is the recovery of energy that was discarded from less efficient mining operations. This recovery also reduces the size of the more than 800 hazardous and unattractive waste coal piles in West Virginia and the associated environmental impacts. The technology used to produce power from this resource is often cleaner and sometimes more efficient than traditional power generation methods. Second generation fluidized-bed combustion plants have near zero particulate emissions. The reduced emissions increase waste production at the plant, but the ash can be used to help mine sites with fill and waste stabilization. When burned in conventional power plants or coking plants gob displaces new coal, thus reducing the amount of coal that must be mined.

High coal prices improve the overall economics of waste coal recovery. Under any pricing regime, when the gob is to be burned in conventional coal plants the highest btu piles will be mined first. Recovery of fines that equal the energy content of new bituminous can be economical with coal prices as low $32 to $48 per ton. Fines with lower energy content would only be competitive with higher priced coal.

The distribution of recoverable West Virginia gob based on energy content has not yet been determined. Most sites must still be evaluated on a case by case basis using core sampling to match piles with potential end users. For fines recovery the metallurgical waste impoundments will provide the biggest return and can succeed without subsidies. Lower btu gob piles and fines projects have historically operated only under Federal tax credits and cost-shared programs.

4. Wood Residue and Other Biomass

Within the category of biomass energy resources, wood residue holds the most potential in West Virginia. The state has a sizeable logging and wood products industry that generates more volume than other potential biomass to energy sources.

Use of wood residue for steam production in industrial wood products manufacturing is quite common. Most wood dry kilns in the state are wood-fired, although a few are natural gas or propane-fired. There are no in-state examples of this usage outside of the wood products industry, although some industrial gas users are considering switching to wood-fired boilers.

About 2.1 million tons of wood waste not used for internal thermal needs is generated in the state each year. Of this amount, as little as 147,000 tons (seven percent) is presently matched with a re-user.[16] Re-users are largely mulch suppliers or pellet manufactures such as Hamer Pellet Fuel. The Albright power plant in Monongalia County has co-fired sawdust in its generator although it is currently not doing so. Clearly, the supply of wood waste could support additional demand.

Table 4.1 shows estimated biomass resources available by category as estimated by the National Renewable Energy Laboratory, except for mill waste which was estimated by the Appalachian Hardwood Center. A description of the categories of biomass and their significance in the state follows.

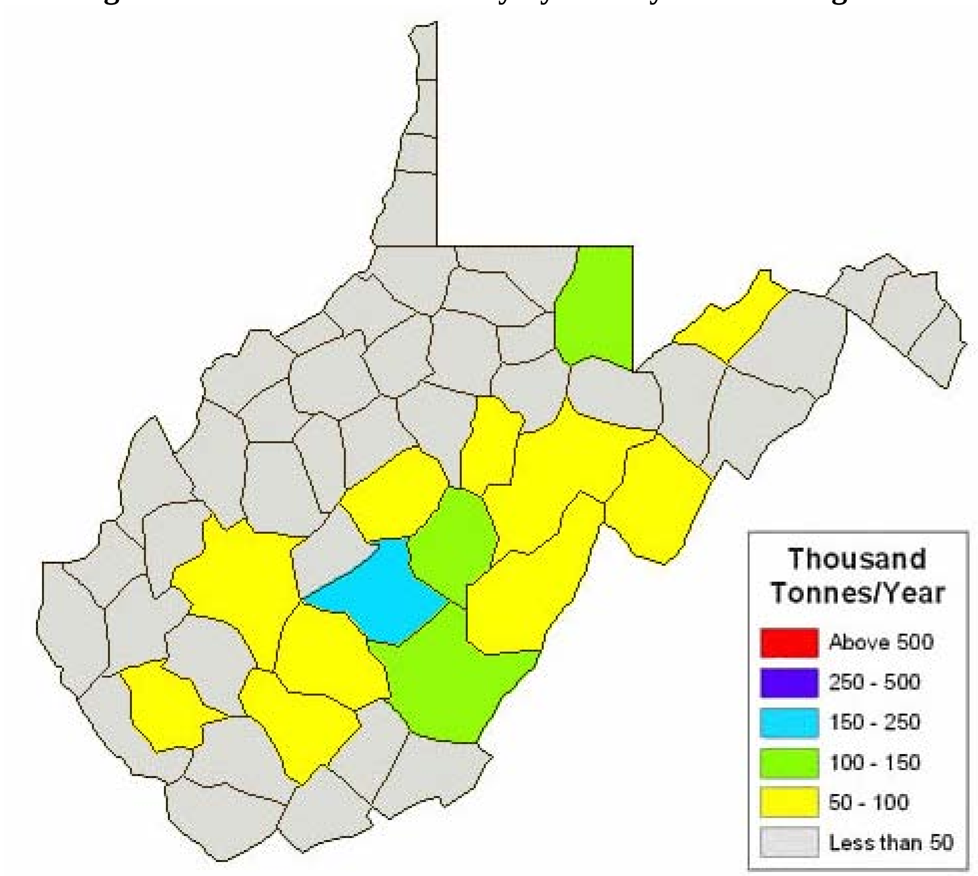
Table 4.1: Biomass Resources Available in West Virginia[17]

	Thousand tonnes/year
Crop Residue	32
Switchgrass on CRP Lands	9
Forest Residues	1,347
Primary Mill Waste	1,555[18]
Secondary Mill Waste	344[19]
Urban Wood	184
Methane from Manure Management	16[20]
Methane Emissions from Landfills	47
Methane from Domestic Wastewater	3
TOTAL	3,537

[16] West Virginia University, Appalachian Hardwood Center (2005). “West Virginia Wood Byproducts Available and Needed.”
[17] U.S. Department of Energy, National Renewable Energy Laboratory (2005). “A Geographic Perspective on the Current Biomass Resource Availability in the United States.”
[18] West Virginia University, Appalachian Hardwood Center (2005).
[19] Ibid.
[20] The study team estimates that this amount of methane is equivalent to what could be captured from all 89 million broiler chickens produced in WV in 2002.

Figure 4.1 shows combined biomass availability for the resources described above. This availability is represented largely by the presence of waste wood products in West Virginia's central and eastern counties.

Figure 4.1: Biomass Availability by County in West Virginia[21]



- Crop Residues – Include corn, wheat, barley, soybeans, cotton, sorghum, oats, rice, rye, canola, beans, peas, peanuts, potatoes, safflower, sunflower, sugarcane and flaxseed. It is assumed that about 35 percent of crop yield is available to be collected as biomass. Much of the State of West Virginia was not estimated for this analysis, most likely due to minor agricultural activity, resulting in a low level of availability. Less than six West Virginia counties, including Hardy and Pendleton Counties, were evaluated for this estimate.

- Switchgrass - The Conservation Reserve Program (CRP) is a voluntary program through the USDA that promotes growth of hearty crops such as switchgrass on land not suited for conventional farming. There is little activity related to this program in

[21] National Renewable Energy Laboratory (2005).

West Virginia. The calculation for West Virginia focuses on the potential yield on abandoned mine lands.

- Forest Residues – Includes logging residues, pre-commercial thinning and clearings not associated with round wood, or whole tree, products harvests. There is considerable availability of this type of resource in the state, primarily in the central counties which have a substantial logging industry presence.

- Primary Mills – Course and fine byproducts of mills that produce primary wood products (slabs, edgings, trimmings, sawdust, veneer clippings, pulp screenings). West Virginia has more than 350 primary and secondary wood products firms, of which primary mills generate the larger quantities of available waste. These mills are largely found throughout the state but are concentrated in the central counties.

- Secondary Mills – Wood scraps and sawdust from woodworking shops. These mills are less ubiquitous than primary mills but are also found largely in West Virginia's central counties.

- Urban Wood – Includes municipal solid waste, tree trimming, and construction demolition waste. As expected, this type of waste is generated in West Virginia's larger cities and is thus quite distributed.

- Methane Emissions from Landfills – From the EPA's Landfill Methane Outreach Program. The estimate above corresponds with the EPA's list of "candidate" landfills for energy recovery. If all West Virginia landfills were included the amount could be doubled.

- Methane from Manure Management – Includes methane produced from liquid manure management systems that collect waste from dairy cows, beef cows, hogs and pigs, sheep, chickens (layers and broilers) and turkey. West Virginia's livestock population is scattered throughout the state. The largest cattle raising counties are Greenbrier and Monroe followed by Hardy, Pendleton and Preston, with a total of about 404,000 statewide in 2002. Hogs and pigs are raised in relatively small numbers – about 13,000 animals statewide in 2002. Sheep and lambs are raised in somewhat larger numbers – nearly 39,000 animals in 2002. Because of their physical concentration it may be easier to collect manure from broiler chickens, of which the largest portion are in Hardy County. The State produced 89 million broilers in 2002, the latest year that data is available.[22]

- Methane from Domestic Wastewater – This figure is based on the EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks. Like urban wood residue, this resource is generated in the larger cities of the state. Municipalities that already have anaerobic digesters may have a head start on developing this resource for energy recovery because the gas is already being captured. These municipalities and their wastewater

[22] U.S. Department of Agriculture (2005). 2002 Census of Agriculture.

handling design capacity are: Charleston - 14 million gallons per day (mgd), Martinsburg - 3 mgd, Morgantown - 10.06 mgd, Parkersburg - 9.66 mgd and Wheeling - 10 mgd. Some of these facilities were designed with the intent of recovering the methane for internal energy needs although none are currently doing so due to issues of inadequate gas quality or quantity.[23]

Chicken litter as a source of energy is worthy of mention on its own due to the attention received regarding land application of raw litter. The pathogens and high phosphorous content of the litter are believed to be harmful to rivers and streams that receive the runoff from fields on which the litter is applied. The Bioplex project at West Virginia State University demonstrates a unique process of transforming litter to a benign and valuable fertilizer using thermophilic anaerobic digestion. This process produces modest amounts of methane gas that could also be captured for direct use. As an energy source this resource is most likely to be economical when utilized on-site.

Costs

Electricity generation capability depends on the energy content of the wood. Wood burning power plants in the region (Kentucky, Ohio, Pennsylvania and Virginia) average three tons per MWh produced,[24] with an average million BTUs (mmbtu) per ton of wood of 10.6 mmbtu per ton. At a rate of three tons per MWh, the 2.1 million tons of wood waste currently generated in the state per year could produce 696,000 MWh of electricity per year.

The value of wood waste thus depends on whether it is wet or dry. Most is somewhat wet, including the chips supplied by primary logging mills. Pelletized chips are drier but are less widely available. Use of wood pellets, which have been compressed and dried prior to combustion, nearly doubles the amount of btus per ton compared to raw wood waste. The cost to produce electricity from wood waste is a function of the price of the wood and the cost of transporting it, plus the generating equipment and associated maintenance costs.

Construction costs to build a wood waste-fired generating facility are about $1.4 million per megawatt (MW) plus about 20 percent of those costs for additional site preparation and acquisition costs. Total operating costs range from about 4.8 to 5.9 cents per kwh on average, including the cost of capital, and corresponds with a plant capacity factor of 50 to 70 percent. With higher utilization these average costs would be even lower. The wood itself costs $18-20 per ton green, or $2/mmbtu. Pelletized wood is reported to sell for $130 a ton in some markets.[25] Relative to other types of non-

[23] Information provided by the WV Department of Environmental Protection via correspondence on May 15-16, 2006.
[24] U.S. Department of Energy, Energy Information Administration (2004). 2003 EIA-906/920 Monthly Time Series File from "Electric Power Monthly."
[25] Almost all the cost information reported here was obtained from an interview with Ed Bramer of Multitrade Group, Inc. on June 9, 2006.

traditional generation, these costs make wood plants more expensive per kilowatt-hour than conventional coal and hydro facilities but often less expensive than wind or waste coal generation from circulating fluidized bed technology.

Markets for Wood Residue

For power generation wood waste holds the most promise relative to the other types of biomass available in West Virginia due to the large quantities available. Other types of biomass are generated in smaller quantities and are more dispersed, which increases the cost of collecting those resources in adequate quantities.

Each of the states that borders West Virginia has a power plant that generates wood waste-fired electricity. About seven facilities have generating units dedicated to wood waste[26] although current demand for waste wood originating in the state is not impacted by these plants. Several new wood-fired plants have been proposed for West Virginia or its border areas in the last few years although none have yet come to fruition. Plants that have been proposed at industrial sites are generally proposed to replace natural gas, which has experienced considerable price volatility throughout 2005 and much of 2006.

A factor with growing urgency that could impact regional demand for wood waste is the approaching deadline for the European Union to meet the conditions of the Kyoto Protocol. This factor could create increased European demand for high-btu wood waste products such as chips and pellets to comply with the Protocol and could substantially increase demand for regional wood. Pellets are already shipped from Virginia to Italy and it is expected that Holland, Turkey and Scotland will soon demand additional product from the U.S. Many European countries subsidize these plants, which makes them competitive with many types of conventional generation.[27]

[26] U.S. Department of Energy, Energy Information Administration (2004). 2003 EIA-906/920 Monthly Time Series File from "Electric Power Monthly."
[27] Conversation with Ed Bramer of Multitrade, Inc. on June 9, 2006.

5. Landfill Gas to Energy

Landfills with energy recovery systems are typically either located in a state with green power customers or located near industrial consumers of natural gas. There are currently landfill gas (LFG) utilization projects in 40 states, and West Virginia has not had such a project since 1996.

West Virginia was one of the earlier developers of a landfill gas to energy project. In 1985, the Berkley County Solid Waste Authority installed a direct use energy recovery system on their landfill that fed the nearby Veterans Administration hospital heating system. That landfill was shut down in 1991, following a legal dispute with a private landfill, and the energy recovery project was forced to terminate in 1996. The Berkley County landfill was one of about 23 landfill gas to energy projects built around the U.S. between 1981 and 1985, when this resource first became developed.

In the last year, two West Virginia landfills were added to the Environmental Protection Agency's Landfill Methane Outreach Program (LMOP) list of candidate landfills for energy recovery: the Short Creek Sanitary Landfill in Ohio County and the Tucker County Solid Waste Authority's landfill in Thomas, WV. This brings the total to seven LMOP candidate landfills in the state, although it is likely that more will become candidates in the future and other smaller fills may also be viable.

Installation of energy recovery systems often occurs when gas build-up gets to the point that a system to relieve pressure is needed, or when gas destruction is required due to NSPS standards regarding methane emissions. Currently, six open WV landfills have flaring systems. Three of these, the LCS Landfill in Berkeley County, the Short Creek Landfill in Ohio County and the Wetzel County Landfill flare 24 hours a day. The Short Creek fill will be adding additional capture and flare capacity in the near future. The Meadowfill Landfill in Harrison County, Sycamore Landfill in Putnam County and the City of Charleston Landfill flaring systems were put in place to reduce odor and to control gas bubbling and are used intermittently. One additional landfill, the Brooke County Landfill, has a collection system for a closed and capped section of its fill.[28]

Landfill gas potential is a function of several attributes: 1) landfill age, 2) waste in place and waste acceptance rate: 3) projected lifespan, and ultimately 4) type of waste. These characteristics determine methane production from the fill in standard cubic feet per minute (scfm). Most landfill developers require a minimum of 1000 scfm for a fill to be a viable candidate for development. This also generally means that a fill has more than one million tons of waste in place. However, in the U.S. about 34 landfills that had less than one million tons of waste were developed over the past two decades and have been designed for both electricity production and direct gas use.[29]

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[28] West Virginia Department of Environmental Protection, Division of Waste Management.
[29] Downstream Strategies (2006). "The Prospects for Landfill Gas-To-Energy Projects in West Virginia: A Report to The Mountain Institute"

Total potential gas production from the "Candidate" landfills is estimated at between 2.2 and 3.8 billion scf per year.[30] This is equivalent to one or two percent of the approximately 190 billion scf of natural gas produced in West Virginia in 2003 and nearly two percent of gas consumed (about 122 billion scf was consumed in West Virginia). However, because LFG has only half the energy content of natural gas - about 520 btu/scf compared to 1,030 btu/scf for gas - one to one substitution may not possible. LFG can be converted to a higher btu gas but this adds to the cost of a system. The list of LMOP Candidate landfills is shown in Table 5.1, with potential methane production beginning in 2012.

Table 5.1: Candidate Landfills and Estimated Annual Gas Production

Landfill Name	City	County	Waste In Place (tons)	Year Landfill Opened	Landfill Closure Year	Annual Production[31] (mmscf)	Production Rate (scfm)	Currently Flaring Methane?
Brooke County Landfill	Colliers	Brooke	1,325,118	1975	2045	173	329	Yes, for closed section
Meadowfill Landfill	Bridgeport	Harrison	2,250,000	1970	2050	260	495	Yes
Northwestern Company Landfill	Parkersburg	Wood	4,100,000	1975	2060	526	1001	No
Raleigh County SWA[32]	Beckley	Raleigh	1,600,000	1964	2075	383	450	No
Short Creek Sanitary Landfill	Short Creek	Ohio	2,985,349	1987	2058	529	1006	Yes
Tucker County SWA Landfill	Thomas	Tucker	2,000,000	1985	2013	201	383	No
Wetzel County Landfill	New Martinsville	Wetzel	1,000,000	1970	2250	116	220	Yes

When including methane production estimates for the 11 additional open landfills in the state the quantity of potential gas rises to the range of 3.5 to 5.3 billion scf. These quantities of gas are equivalent to 15 to 25 MW of power generation. Potential electricity production from candidate landfills is about 0.1% of total state production.

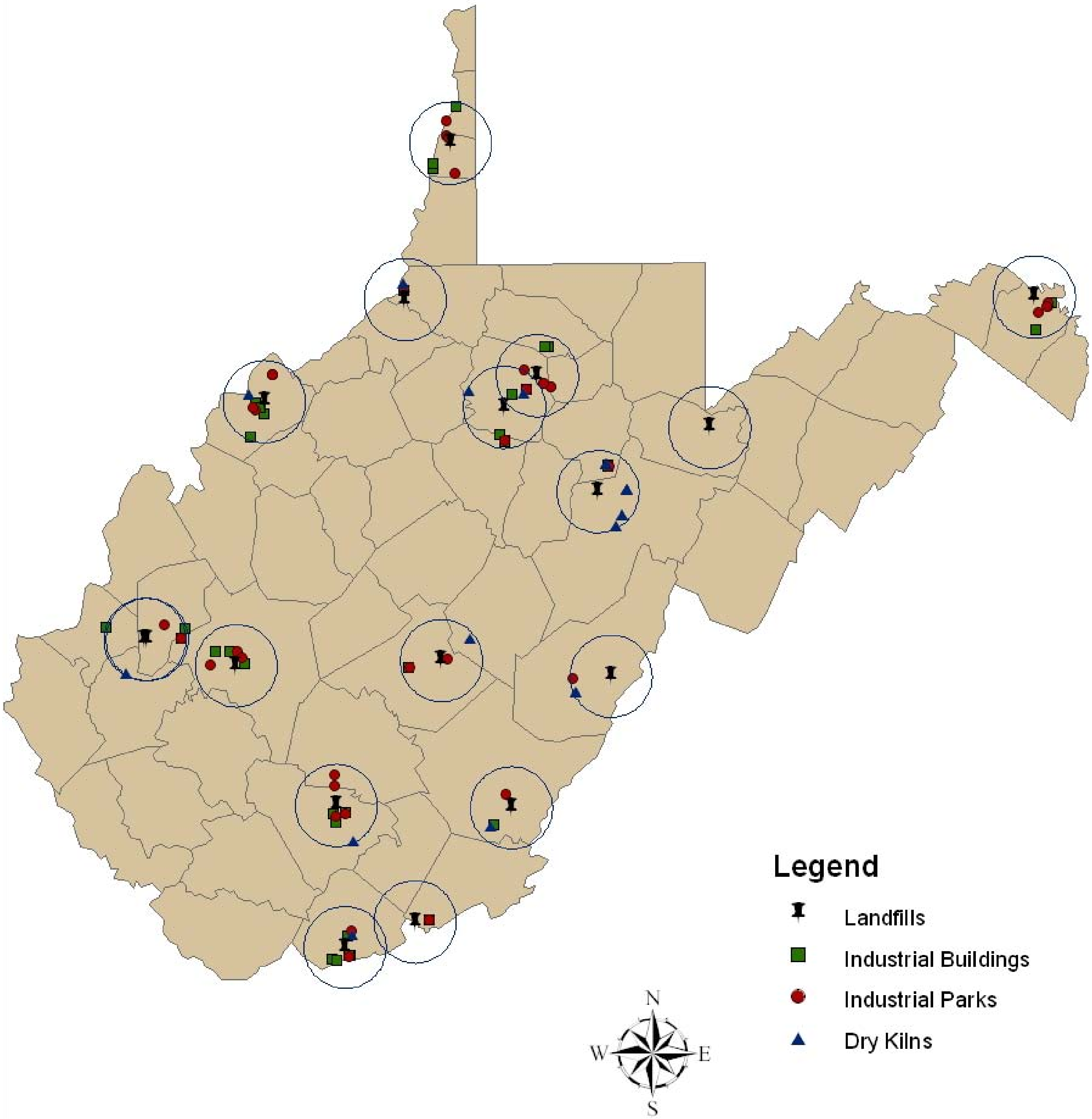
[30] These estimates are based on the EPA's Landfill Methane Outreach Program's LFGcost-Web Model (Version 1.3) calculations that consider the age of the landfill, its expected life and quantity of waste-in-place or annual waste acceptance rates.

[31] These rates were calculated based on reported waste acceptance rates between 1999 and 2005 or a calculation of that rate based on estimated waste in place.

[32] The Raleigh County SWA is considering installing a bioreactor that would accelerate methane production, potentially triple expected methane production and decrease lifecycle costs.

A map of open West Virginia landfills is shown in Figure 5.1 below, along with their proximity to industrial parks and buildings and wood dry kilns. Several of the dry kilns currently use natural gas to dry wood products and are thus ideal candidates to utilize the LFG as part of their energy supply. Gas burning kilns are located near the landfills in Wood, Mercer, Randolph (two kilns) and Pocahontas counties.[33]

Figure 5.1: Open Landfills and Selected Industrial Sites within a 10-Mile Radius



[33] Appalachian Hardwood Center (2006).

LFG Users and Systems

A wide range of industrial manufacturers use LFG directly. Such facilities are commonly located five miles or more from the landfill and generally a facility if not economical if it is located more than 10 miles from the landfill. Currently, direct users include:

- Food processing facilities (Pennsylvania) - 4,000 scfm
- Fueling of lime kilns for cement manufacturing (Oregon) - 3,500 scfm
- Steel reclamation (New Jersey) - 970 scfm. Uses a LFG/natural gas blending station to fire a furnace. This system uses the LFG first, up to the current supply of 970 scfm, and adds natural gas as needed to match production requirements.

Of the approximately 458 LFG projects around the country, 120 are direct use and 338 generate electricity.[34]

- Electricity – the dominant method of converting the gas to electricity is via a reciprocating engine. Gas and steam turbines are also used. The average annual gas volume produced by the landfills used to generate electricity is 1387 scfm.[35] Generally, if the gas is used for generating electricity the power is sold to distribution utilities.
- Direct Use – the most common direct uses are in industrial boilers and for direct thermal use. Several landfills also use the gas directly themselves to assist in leachate evaporation. The average mmscf per year is about 1108 scfm.

Overall, direct use is a more efficient method of landfill gas utilization relative to electricity generation as is direct use of natural gas compared to electricity. The size of the landfill is the primary issue. Although most developers require that gas production be at least 1000 scfm, a smaller project at a growing landfill is sometimes worthwhile. The nature of the potential industrial customers is also important. Direct use projects must be matched with existing natural gas users that operate all year around.

Costs

There are several steps required in order to develop a landfill for utilization of its methane. Each of these steps has its own cost.

- Capture – this requires installation of a piping system to collect the gas
- Clean – a system to remove impurities that includes a flaring system to get rid of excess gas
- Compress – the gas must be compressed prior to placement in a combustion engine or a pipeline

The costs of developing a landfill gas system for electricity are in the range of $1.3 to $1.5 million per megawatt (MW). These costs are about the same as for wind power for

[34] EPA LMOP Landfill Database.
[35] This rate is distorted upward due to one very large landfill in Los Angeles, CA that produces 22,222 scfm and has over 100 million tons of waste-in-place. This landfill produces more than twice the quantity of gas as the next largest landfill. Without this project the average rate is 1275 scfm.

example, but operate at a much higher capacity factor, so installed costs per unit of electricity generated are lower. Operating costs are slightly higher than for wind facilities, about $13 to $14 per MWh. If a sub-station must also be installed costs rise significantly, by approximately $8 million. This additional cost would apply to all resources that are not located near a substation.

For direct use systems, capital costs are about $260,000 per mile up to 5 miles for the pipeline plus $1 million per mile for each additional mile if the end user is more than five miles from landfill. The compressor and conditioning units for systems up to 1000 scfm costs about $1 million and the collection and flaring system adds about $1.5 million.[36]

Benefits of Using

Much of the development of LFG has been spurred by realization that methane, the primary compound in LFG, is more powerful than carbon in contributing to climate change. It is for this reason that the Environmental Protection Agency requires flaring of the gas at certain rates of production and actively promotes capture of the methane as an alternative to flaring through its LMOP program. When faced with this requirement it is often in the landfill operator's best interest to simultaneously develop a secondary income stream from its operation. Variable gas prices also make LFG attractive to industrial gas users who benefit from the stable prices allowed by supply from a landfill.

[36] April 11, 2006. Conversation with Joel Zyllstra of Granger Energy.

6. Small and Low-Head Hydroelectric

Small and low-flow hydropower is another underdeveloped energy resource in West Virginia and in the U.S. In terms of the density of available hydropower this state is one of the wettest in the nation. West Virginia has the fourth highest potential KWh per square mile of the 50 states, after Hawaii, Washington and Idaho. When just evaluating low head/low power resources, West Virginia has the sixth highest availability per square mile.[37]

West Virginia is estimated to have 484 megawatts of undeveloped hydropower within this category that could be feasibly constructed. This number represents estimated average power generation potential and excludes streams excluded from development by federal statutes. The estimates are also based on geographic and environmental feasibility. Without these exclusions and when including high power resources available undeveloped hydropower potential is about 2,500 MW.[38]

An earlier report published in 1998 identified 1,149 MW of undeveloped dammed hydropower in West Virginia. This estimate was divided into 1,002 MW of potential at 27 existing dams without hydroelectric power and 147 MW at 10 undeveloped sites.[39] Fifty-five percent of the undeveloped power was identified as being within the Kanawha River Basin. The size of these projects would average 31 MW.

The definition of "small hydro" extends up to 30 MW, although in West Virginia only five sites with development potential of more than ten MW have been identified. Much of the data reported here emphasizes low hydro power resources with low hydraulic head, which describes the change in elevation from where the water is initially collected to where the generating equipment is located. Types of this resource are:

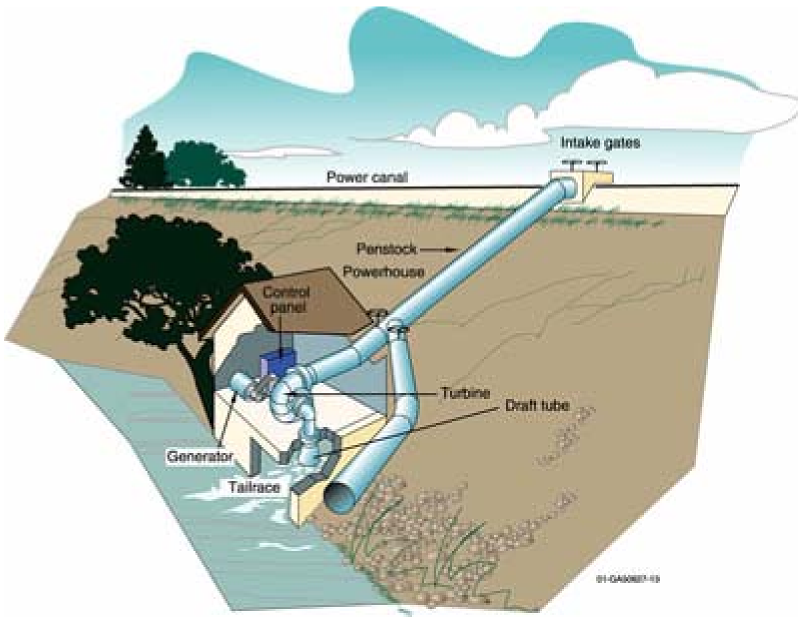
- Small hydro: < 30 megawatts and hydraulic head > 30 ft.
- Low head/low power hydro:
    - Conventional Turbine: >= 100 KW and < 1 MW and hydraulic head >= 8 ft but < 30 ft
    - Unconventional Systems: >= 100 KW and < 1 MW and hydraulic head less than 8 ft
    - Microhydro - power less than 100 KW (typically for residential use)

Any of these systems can be what is termed "run-of-river" systems that do not utilize a dam. Instead of damming a river, this type of hydro system diverts a portion of a river into a channel, or penstock, which may flow from a holding pond used for sediment control. The penstock then feeds a generator and turbine set that produces power. The

[37] Idaho National Laboratory, April 2004. "Water Energy Resources of the United States with Emphasis on Low Head/ Low Power Resources."
[38] Idaho National Laboratory, January 2006. "Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants."
[39] Idaho National Laboratory, February 1998. "U.S. Hydropower Resource Assessment for West Virginia."

diverted water is returned to the river after leaving the penstock. A diagram of such a system is shown in Figure 6.1.

Figure 6.1: Diagram of Low Power Hydroelectric Installation[40]



About 97 percent of existing hydroelectric generators in the U.S. are high-head systems. It is widely believed that such systems are largely developed and have little room for expansion and that expansion of hydropower in general lies primarily with low power and low-head systems.[41] Dammed systems have more consistent output than do undammed systems, however. Use of unimpounded hydropower appears to be more common in the Western U.S. but there is ample opportunity for development in the Eastern U.S., including West Virginia.

Technology

There are several types of turbine systems that could be used with these resources. Commonly used types include the Pelton, Francis, Kaplan and Cross-Flow or Banki turbines. Pelton turbines are typically used for high head resources while Francis turbines are more optimally suited for lower flow resources and can take advantage of waters with varying flow. The Kaplan turbine is used for resources with low head and high flow rates. Cross-Flow turbines can also accommodate low head resources and varying levels of flow and could be used in conventional or unconventional systems.

[40] U.S. Department of Energy, Idaho National Laboratory (2005). http://hydro2.inel.gov/hydrofacts/hydropower_facilities.shtml
[41] http://natelenergy.com/overview.htm

Microhydro systems are generally designed to charge battery-powered electric systems which are the primary source of electricity for a building instead of providing electricity for immediate use.

Many of the older hydro installations in West Virginia are small; 12 of 33 commercial hydro generating units in the state are less than one MW. These 12 units were installed between 1909 and 1913 and were the original generating units of what are now larger facilities.

Table 6.1 describes the availability of small and low-power hydro resources that could be feasibly developed, as estimated by Idaho National Laboratory. Because these estimates represent average available power (MWa) instead of installed capability (MW), the capacity factor corresponding with this power level is 100 percent.

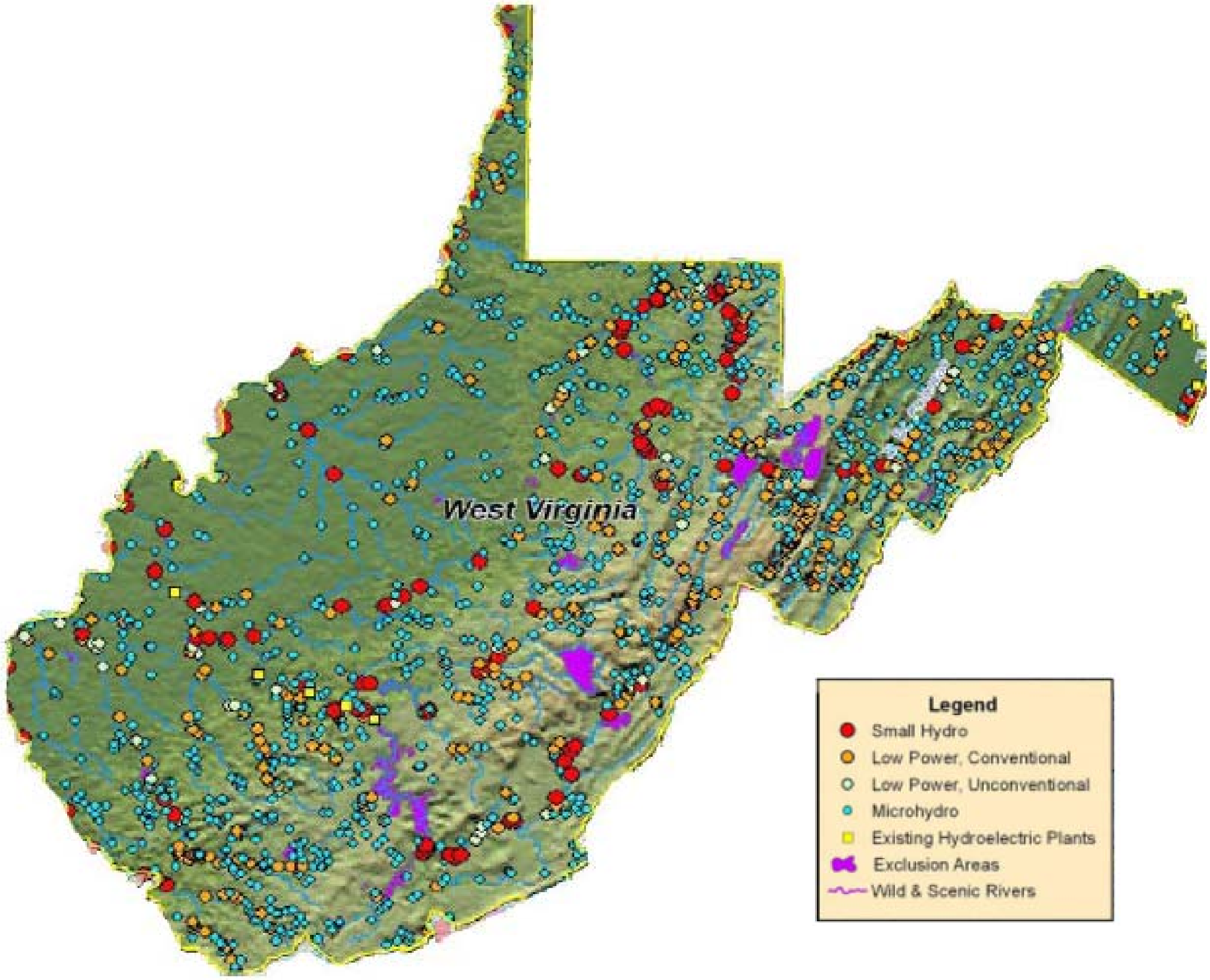
Table 6.1: Feasible Small and Low-Power Hydro Potential in West Virginia (MWa)[42]

	Total MWa	Number of Sites	Average MWa
Small Hydro	339	113	3
Low Head/ Low Power			
Conventional Turbines	90	296	.3
Unconventional Systems	17	58	.3
Microhydro	39	1,234	.03
Total	**484**	**1,701**	**.3**

These 1,701 sites determined to be feasibly developed are located throughout the state along all the major and minor rivers including the Ohio, Big Sandy, Kanawha, Guyandotte, Monongahela, Potomac, Elk, Greenbrier and their tributaries. These estimates do not include streams excluded from development by federal statutes: national parks and monuments, wildlife management areas and designated wild and scenic rivers. The estimates are also based on feasibility as determined by proximity to population centers, industry, and existing infrastructure and location inside or outside non-Federal exclusion areas as well as environmental, legal and institutional constraints on development. Figure 6.2 illustrates these sites.

[42] Idaho National Laboratory, January 2006. "Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants" Appendix B.

Figure 6.2: Feasible Low Power and Small Hydro Projects in West



The designated status of a conventional versus an unconventional system refers to the nature of the water resource rather than the underlying technology. A low-power resource that is also low-head is what makes a system unconventional. Resources that allow use of conventional turbines have higher - but not high - hydraulic head (8 to 30 feet) and are more likely to have the capability to be uniformly designed to suit the capabilities of common turbines. Unconventional and microhydro systems might require special system configuration due to the low hydraulic head of the water resource or their small-scale. Low-head, high-volume systems have unique challenges related to passing large volumes of water, dealing with sediment load and possibly related higher equipment costs related to custom engineering and design.[43]

[43] http://natelenergy.com/overview.htm

Costs

The cost of installing and operating undammed hydro systems varies considerably. Up to 75% of costs are site specific.[44] Per unit of energy produced, costs are inversely related to the head of the resource. Higher hydraulic head gives lower per unit energy costs with lower head resources being more costly to develop. Costs range from $1800 to $8800 per KW for low head resources and $1000 to $3000 per kW for higher head resources. These figures include construction costs, generator equipment and engineering costs. Microhydro systems often have additional costs for piping, controls, batteries and wiring that may add $1000 to $5000 to a project.[45] For comparison, costs to build conventional dammed hydro systems range from about $1.2 million per MW for expansion of existing hydroelectric installations to $3.6 million per MW for undeveloped sites.[46]

Costs also vary widely as a function of electricity generation. Capacity factors for hydroelectric systems are generally higher for impounded systems that have some control over the amount of water flowing to the turbines.[47] Capacity use of around 40 percent may be more realistic for in-stream systems.[48]

Summary

This evaluation excludes potential hydro development using traditional damming technology. West Virginia's hydroelectric generation potential would be higher than these estimates if that potential was included. Focusing only on small and low-flow hydropower avoids the question of whether or not to include traditional hydropower as a category of renewable energy. However, most states and nations do consider traditional hydropower to be an important component of their renewable energy portfolios.

There is certainly undeveloped hydroelectricity capability at current dams in the state. The recently announced plan to develop a new 30 MW hydroelectric power plant on the Tygart River Dam is an example of efforts to utilize these dams.[49] The approved Bluestone Dam project and the existing New Martinsville Hydroelectric Power Plant are others. Development of hydropower at existing dams minimizes potential environmental impact as the impact of the dam is already in place.

Small and low-power hydro is somewhat more expensive to develop than other types of renewable and alternative energy. Within this category, the least expensive opportunities lie in high head resources, most of which are located in the more

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[44] http://ns379.ovh.net/~testmypn/documents/NGuessan-Vienna-microhydro-technicalfeasibility.ppt
[45] http://www.geocities.com/dieret/re/Hydro/hydro.html - citing World Bank figures.
[46] Idaho National Laboratory, 2003. "Estimation of Economic Parameters of U.S. Hydropower Resources"
[47] EIA uses 64 percent for their renewables module (based on NWPP rates) for impounded hydro http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/renewable.pdf
[48] The average 2003 capacity factor for utility hydroelectric systems operating in the ECAR region was 46 percent. The average for plants in West Virginia was 72 percent.
[49] June 7, 2006, *Huntingtonnews.net*. "Grafton Hydro Plant Clears Major Hurdle with New Legislation."

mountainous regions of the state. Low head resources are more expensive and are located in the flatter areas. In addition to its renewable nature, the benefits of hydroelectric power generation are the longevity and the low maintenance costs of the installations.

7. Coal-Bed Methane

Production of coal-bed methane (CBM) is increasing rapidly in West Virginia. While most CBM was in the past simply vented from the mines, today more and more of the gas is being captured and sent to join the natural gas supply system. Between 2003 and 2005, CBM production in West Virginia more than doubled. In 2005 CBM production in the state was approximately 17.6 billion cubic feet (bcf), rising from just over eight bcf in 2003. Production has in fact been rising quickly since the mid-1990s. 1997 production was about one bcf.[50] At the 2005 levels, CBM accounts for about eight percent of total gas production in the State.

Nationwide CBM also accounts for a substantial portion of gas reserves. In 2002, CBM was estimated to account for 9.5 percent of total proven U.S. gas reserves.[51] In Northern Appalachia, recoverable reserves have been estimated at 11.5 trillion cubic feet.[52]

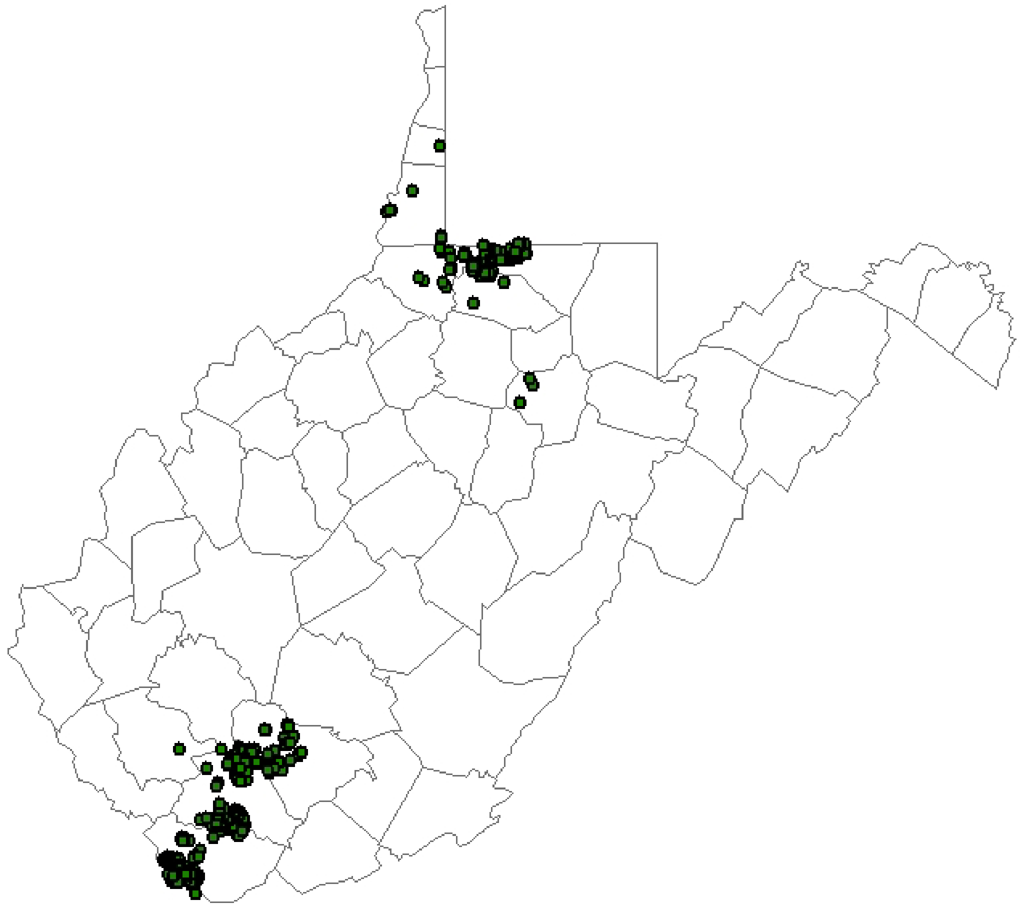
There are a number of reasons why coal-bed methane is removed from coal seams and why its production is increasing. In Appalachia, CBM has commonly been extracted for safety reasons prior to underground mining. For production purposes it is also extracted and captured during and after mining from coal waste and from unmineable coal seams. Although CBM production in West Virginia existed as early as 1905, relative to Southern Appalachia, CBM production in Central and Northern Appalachia is considered less mature, with additional room to expand.[53] Much of the commercial CBM production in southern West Virginia and southwestern Virginia did not begin until the late 1980s. This fact is favorable to West Virginia in terms of development potential.

The following map shows the location of the approximately 690 CBM wells that presently exist in West Virginia. Most CBM wells are located in the southeastern and northern counties. Recently however, new wells have also been drilled in some of the central counties.

Figure 7.1 below shows the location of CBM wells in the state as of 2005. In the north, wells are concentrated in Monongalia County, with the Pittsburgh coal seam being the most productive source of CBM. In the south, wells are concentrated in Wyoming and McDowell Counties, with the Pocahontas seams being the most productive. Prior to 2005 there were no wells in the central part of the state. The wells in Barbour County are initial developments for that area.

[50] West Virginia Geological and Economic Survey.
[51] Oil and Gas Investor (December 2002). "CBM: Coming to a Basin Near You."
[52] Petroleum Technology Transfer Council (2005), "Innovative Technology for Coalbed Methane in the Appalachian Basin" - citing the U.S. Geological Survey.
[53] U.S. Geological Survey (2002). "Coalbed Methane Production in the Appalachian Basin."

Figure 7.1: Location of Coal-Bed Methane Wells in 2005[54]



The larger CBM sites in the state include production at the Pinnacle Mine in Wyoming County (CDX Gas), the Blacksville (CONSOL) and Federal (Peabody) mines in Monongalia County. CDX Gas developed its unique multi-lateral horizontal drilling systems, the Z-Pinnate drilling method, in southern West Virginia. One of the Marshall County CBM wells is the site of a carbon dioxide sequestration project being undertaken by CONSOL. This project extracts CBM from unmineable coal seams using a slant-hole drilling technique and then injects carbon dioxide into those seams for sequestration.

Potential and Process

Coal-bed methane production is advantageous for a number of reasons. Because some methane must be removed prior to mining anyway for safety reasons, mine operators already have experience capturing the gas. CBM also provides an income stream post mining when extracted from pillars and other unmineable coal left behind. In terms of production for use, integration with the existing natural gas infrastructure is generally not difficult due to widespread availability of gas pipelines. CBM can also be a

[54] West Virginia Geologic and Economic Survey (2006).

source of on-site power to supplement electricity used to power mine machinery. In southwestern Virginia, CBM is used to power an 88 megawatt electricity generation facility that produces power for the grid.

Overall, CBM development is often seen to carry less geologic risk than conventional natural gas development because coal formations have less variation than gas deposits.[55] Issues that make CBM development somewhat difficult include the need to dispose of water that is generally not potable or suited for irrigation. The quality of the water often necessitates that holding ponds be constructed to contain the water when it cannot be returned underground.

The process of producing pipeline quality CBM involves compression prior to putting into gas pipeline, and clean up to meet criteria of transmission operator, depending on moisture content and chemical makeup. The typical required makeup is that inert gases (nitrogen, oxygen, carbon dioxide) are no more than four percent of gas content. Specifically, carbon dioxide levels must be less than or equal to 1.25 percent, oxygen levels must be less than or equal to 0.2 percent, and hydrogen sulfide levels must be less than or equal to 0.25 grains per 100 cubic feet (or about four parts per million by volume) to avoid being sour. In addition, the energy content of the gas must be greater than or equal to 967 btu per cubic foot.[56]

Even though CBM production is increasing rapidly, it is still estimated that there is considerable room to increase production at existing mines that release methane. The EPA estimated potential CBM production, in terms of avoided methane emissions, from a subset of 12 of West Virginia's methane liberating deep mines to be 7.1 billion cubic feet per year at a 60 percent rate of recovery.[57] This represents an increase of three and half times 2003 production for those 12 mines.

Coal-bed methane is also believed to have additional potential to be produced from unmineable coal seams that are used for CO2-sequestration. CONSOL's project in Marshall County will demonstrate this capability. The coal seams would absorb the CO2 and release methane. The process is essentially enhanced CBM recovery.[58]

CBM production provides income and reduces the contribution of coal mines to greenhouse gas production. Overall, further development of CBM in West Virginia appears likely given the recent trends and the potential exists for both existing methane-emitting mines and untapped reserves. Estimates of the full extent of this potential are not readily available due to the unique situations surrounding each potential well. CBM development is faced with geological challenges such as water management and in many cases legal issues regarding ownership of development rights.

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[55] Oil and Gas Investor (December 2002), Supplement. "Opportunities in Coalbed Methane."
[56] Presentation by Curt Tipton of Equitable Gas on October 29, 2003.
http://www.wvenergyroadmapworkshops.org/presentations/03Oct_Tipton.pdf
[57] U.S. Environmental Protection Agency (2005). "Identifying Opportunities for Methane Recovery at U.S. Coal Mines: Profiles of Selected Gassy Underground Coal Mines 1999-2003."
[58] Ibid.

8. Enhanced Oil Recovery

Conventional oil production is only capable of recovering up to 20 to 30 percent of a reservoir's original oil in place. However, there are methods available that can improve or enhance the recovery ratio. These methods are generally referred to as enhanced oil recovery (EOR).

EOR frequently refers to both secondary and tertiary oil production that occurs after primary production, which relies mostly on the natural pressure of the well to expel the oil. Secondary production uses water flooding to extract petroleum that was not able to be produced in primary production, often moving the oil to other nearby producing wells. Secondary recovery results in recovery of 20 to 40 percent of original oil in place. Tertiary recovery follows secondary recovery, with the most common methods involving steam or gas injection including carbon dioxide. Other more experimental forms of tertiary recovery include chemical injection and microbial EOR. Tertiary recovery allows recovery of 30 to 60 percent of original oil in place.[59] Many in the petroleum industry however do not consider water flooding to be enhanced recovery and reserve that descriptor for tertiary recovery.

CO_2 recovery is especially promising for enhanced oil recovery and is often considered to be a 'game changer" in terms of its potential impact on recovering petroleum reserves. CO_2 helps to improve the flow of oil by reducing its viscosity and is used along with water to push residual oil to the surface. The oil and water are separated at the surface and the oil is transported to market while the water can be reused in the well. This method of EOR is increasing potential reserves tremendously. The U.S. Department of Energy estimated that EOR could increase discovered U.S. crude oil resources by 100 billion barrels.[60] Additional resources could be developed through "game changer" EOR technology and processes that utilize higher volumes of CO_2, more innovative flood and well design combined with greater control of the mobility of CO_2 relative to water. It has been estimated that this sort of "next generation" CO_2 EOR could allow 81 percent recovery of original oil in place.[61]

In West Virginia all post-primary oil production is presently secondary production. The existing water flood wells in the state were drilled in the 1970s by Pennzoil in response to the high world oil prices experienced throughout much of that decade. Of total 2005 oil production of 1.6 million barrels, about 800,000 barrels were produced using secondary recovery.[62] Some tertiary production is in the planning stages, motivated by high petroleum prices. Pennzoil also engaged in some tertiary recovery pilot projects using CO_2 methods, and although technically feasible these efforts were not

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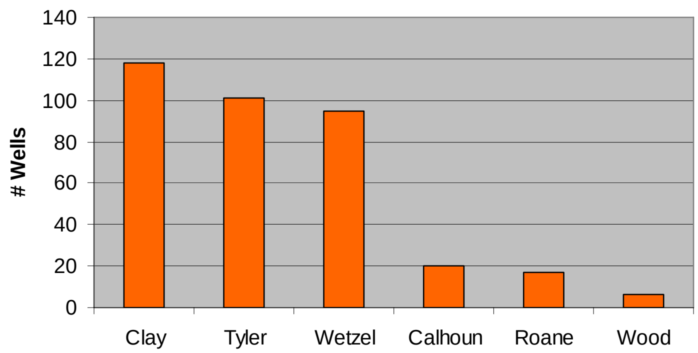
[59] U.S. Department of Energy, Fossil Energy Program. http://www.fe.doe.gov/programs/oilgas/eor
[60] DOE Fact Sheet (2006). "Recovery of Undeveloped Domestic Oil Resources Can Provide the Foundation for Increasing U.S. Oil Production."
[61] Advanced Resources International (February 2006). "Evaluating the Potential for "Game Changer" Improvements in Oil Recovery Efficiency from CO_2 Enhanced Oil Recovery."
[62] West Virginia Department of Environmental Protection, Oil and Gas Division.

shown to be economically viable.[63] Overall, the ability to expand oil production using either secondary or tertiary methods will be determined by future world petroleum prices.

Secondary production is concentrated in the eastern part of West Virginia, mostly in Clay, Wetzel and Tyler Counties. In 2005, there were 689 secondary injection wells in the state. The county location of these injection wells is shown in the following figure.

Figure 8.1: Secondary Oil Recovery - Injection Wells by County in 2005[64]



Overall, in the form of water flooding or secondary recovery, EOR is a fairly well established method of extracting petroleum from wells that have already been produced using conventional pressure and pumping. Estimates of production capability using these methods are not publicly available although it is likely that sustained high oil prices could induce additional production. Water flooding has been the primary reason for most oil production increases in West Virginia since the 1907s.[65] Although many expect overall petroleum production in West Virginia to decline in coming years, production using secondary recovery could increase at the same time that overall production declines.

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[63] Conversation with Paul Dudenas of East Resources on 10/5/06.
[64] West Virginia Department of Environmental Protection, Oil and Gas Division.
[65] Paul Dudenas.

Appendix: Economic Value and Costs

i. Value

The annual value of the alternative and renewable resources evaluated in this report is conservatively estimated at about $1.1 billion. As much as $280 million of this amount is being realized today, largely from coal-bed methane production, waste coal power plants and secondary oil recovery. For this analysis electricity generating resources are evaluated at a wholesale electricity price of 3.6 cents per KWh ($36 per MWh), which is a conservative price relative to recent wholesale prices seen in the region.[66] Assuming the full retail price of electricity would obviously increase the generation value of these resources.

Wind. Potential wind resources are estimated to have an annual value of $330 million if the wind power capability of 3,800 MW on private lands is fully utilized. This amount is based on a 30 percent utilization rate. If wind were also developed on federal and State lands the potential value would be nearly triple this amount.

Coal-Bed Methane. Of the resources evaluated, coal-bed methane leads the way in realized value. Potential is quite conservatively estimated at 34 billion cubic feet per year, a doubling over 2005 production, which was a doubling over 2003 production. This estimate is a somewhat arbitrary figure and is certainly conservative as the largest producer in the state (CDX Gas) has stated they intend to triple production by 2008. At a well-head natural gas price of $6.5 per mcf the 34 bcf would be worth $221 million.

Coal Fines. As much as 415 million tons of coal fines remains in coal waste impoundments throughout the state. The recovery rate of 3 million tons per year is not constrained by physical recovery efforts or by an estimate of what is economically recoverable. This amount merely represents a quantity of some magnitude greater than the 500,000 or so tons that is currently recovered and that could be sustained for a couple decades or more. At an average price of $25 per ton the 3 million tons would be worth $75 million per year. It is likely that of much of the recovered metallurgical coal could command a higher price due to its high energy content, which is often on par with new coal.

Gob to Power. The number of CFB power plants that could potentially be supported by the supply of waste coal in the state is evaluated at six. Three plants currently exist and are located in the northern part of the state. Competition for waste coal supplies in that area suggests that no additional plants could be supported in that area. A fourth plant is planned in the southern part of the state, where the presence of waste coal sites is no less pronounced than in the north. However, the availability of gob best suited for CBF use is uncertain. Plant operators generally prefer not to transport fuel more than 35 miles from

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[66] The Pennsylvania, Jersey and Maryland (PJM) off-peak price averaged $41/MWh from September 21, 2005 to September 21, 2006. IntercontinentalExchange – Accessed September 22, 2006. https://www.theice.com/marketdata/naPower/naPowerHistory.jsp.

the waste pile to the plant. Given the dispersion of waste piles in Central and Southern West Virginia, this distance would not restrict the region to one plant. With six plants utilizing the waste the estimated value of wholesale power sold would amount to $139 million per year.

Wood Waste. Relative to available waste, very little wood residue in West Virginia is sold. At a price of $20 per ton for green wood, the 2.1 million tons produced every year from primary and secondary mills would be worth $42 million. If slash from forest residue were also to be included this figure would be higher.

Landfill Gas. The methane production potential from landfills in West Virginia is estimated at 4 billion cubic feet. Assuming that this gas could be sold for half the value of natural gas, due to its lower energy content, the gas would be worth $13 million per year. None of this value is being realized today although several landfills are flaring methane or are preparing to install gas capture systems.

Chicken Litter. Relative to the other resources evaluated, chicken litter has lower potential energy value when converted to electricity or methane. This resource may obtain a greater value when sold as fertilizer. However, when methane from the litter is used as a substitute for natural gas, cost savings will occur. This savings potential is estimated at $5 million per year based on calculated potential methane production of 1.2 billion cubic feet per year from the 89 million broilers produced in West Virginia each year. Each chicken is assumed to annually produce 0.6 pounds of volatile waste per pound and the average chicken is assumed to weigh five pounds.[67] Methane is produced at a rate of 4.8 pounds per pound of volatile waste and is assumed to be worth about 65 percent of natural gas in terms of energy value.[68] If gasified litter were to be substituted for propane, the higher per unit price relative to natural gas would make avoided costs even more substantial.

Low Impact Hydro. As stated earlier, of all the resources surveyed here low impact hydro may be the most difficult to realize its value. This resource is more disperse and more expensive per unit of energy than other resources and may encounter legal restraints that are more prohibitive than those faced elsewhere. If the full potential estimated for this resource were to be realized, and produced 4.2 million MWh of electricity, it would be worth $153 million in the wholesale electricity market. At two-thirds of this potential, the market value would be $102 million per year. The latter amount is used in this report.

Enhanced Oil Recovery. Secondary oil recovery utilizing water flooding is a well established process of producing petroleum in West Virginia. As much as half of all oil produced in the state is via this process. In spite of its maturity and a projection of slow and steady declines in overall oil production in the state, it is likely that secondary recovery has some growth potential. Tertiary recovery has considerable technical potential but requires higher petroleum prices to compete. For the purposes of this report, it is assumed that secondary recovery in West Virginia could see a sustained increase of

[67] http://bioplexproject.wvstateu.edu/poultrylitter.html
[68] Energy content information provided David Stafford of Enviro Control, Ltd.

160,000 barrels per year. At $50 per barrel, the approximately 800,000 barrels of oil that are produced annually via secondary recovery in the state are valued at $40 million. Adding 160,000 barrels to this amount brings the total value to $48 million.

ii. Cost of Electricity

The cost of generating electricity with the resources evaluated here varies with the cost of capital, the cost of fuel and the cost of maintaining the facility. Cost of electricity (COE) is a standard industry measure used to evaluate the ultimate per unit cost of producing energy (KWh or MWh). Although petroleum and coal-bed methane could be used to generate electricity, COE is not calculated for these resources due to their more common non-electricity uses. A range of figures was calculated to represent uncertainties regarding actual capital outlays and generating performance. For this analysis, COE refers to the cost of capital and construction plus operating and maintenance (O&M) costs. For consistency, COE is calculated under the following assumptions:

1. Capital Costs per Megawatt ($/MW) - Where possible, costs were based on conversations or reports from industry. Industry numbers were used for the waste coal CFB, wind and small hydro facility costs. Other costs are based on the U.S. Department of Energy data used in their National Energy Modeling System.[69] The cost of obtaining capital is assumed to be eight percent and the full amount of capital is assumed to be paid back in 20 years.

2. Capacity Factor (%) and generation (MWh) – The capacity factor, or plant utilization rate, for each generating resource is based largely on plant level data published by the U.S. DOE.[70] When possible, West Virginia-specific or region-specific capacity factors were used. Industry figures were used for coal CFB, landfill gas and low impact hydro facilities.

   For example, dedicated wood waste facilities in the U.S. averaged about 57 percent utilization in 2003. For the wood waste analysis, national figures were used as there is no such plant in West Virginia and the number of regional plants is small. To calculate a range of COE costs, capacity factors of 50 and 70 percent were used.

3. O&M $/MWh - This figure includes both fixed and variable O&M. Where possible, costs were based on conversations or reports from industry. Industry numbers were used for the waste coal CFB, wind and small hydro facility costs. Other costs are based on the DOE NEMS model previously referenced.

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[69] U.S. DOE/ EIA (2006). Annual Energy Outlook, "Cost and Performance Characteristics of New Central Station Electricity Generating Technologies."

[70] U.S. Department of Energy, Energy Information Administration (2005). 2003 EIA-906/920 Monthly Time Series File.

References

Advanced Resources International (February 2006). "Evaluating the Potential for "Game Changer" Improvements in Oil Recovery Efficiency from CO_2 Enhanced Oil Recovery."

Beard Technologies. http://www.beardtechnologies.com/pinnacle.htm. Accessed March 2006.

Center for Advanced Separation Technologies. http://www.castconsort.org Accessed March 2006.

CQ, Inc. - for Electric Power Research Institute (1994). "Premium Fuels from Coal Refuse."

Downstream Strategies (2006). "The Prospects for Landfill Gas-To-Energy Projects in West Virginia: A Report to The Mountain Institute"

Equitable Gas Presentation on October 29, 2003. By Curt Tipton, http://www.wvenergyroadmapworkshops.org/presentations/03Oct_Tipton.pdf

Huntingtonnews.net, June 7, 2006. "Grafton Hydro Plant Clears Major Hurdle with New Legislation."

IntercontinentalExchange – Accessed September 22, 2006. https://www.theice.com/marketdata/naPower/naPowerHistory.jsp.

NatEl America. http://natelenergy.com/ - Accessed June 2006.

Oil and Gas Investor (December 2002). "CBM: Coming to a Basin Near You."

Oil and Gas Investor (December 2002), Supplement. "Opportunities in Coalbed Methane."

Petroleum Technology Transfer Council (2005), "Innovative Technology for Coalbed Methane in the Appalachian Basin".

The World of Renewable Energy – Hydro Power. http://www.geocities.com/dieret/re/Hydro/hydro.html - Accessed June 2006.

TrueWind Solutions (2002). West Virginia Wind Maps.

U.S. Department of Agriculture (2005). 2002 Census of Agriculture.

U.S. Department of Energy, Fossil Energy Program. http://www.fe.doe.gov/programs/oilgas/eor

U.S. Department of Energy Fact Sheet (2006). "Recovery of Undeveloped Domestic Oil Resources Can Provide the Foundation for Increasing U.S. Oil Production."

U.S. Department of Energy, Energy Information Administration (2006). Annual Energy Outlook, "Cost and Performance Characteristics of New Central Station Electricity Generating Technologies."

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (2006). http://www1.eere.energy.gov/windandhydro/wind_consumer_faqs.html

U.S. Department of Energy, Energy Information Administration (2004). 2003 EIA-906/920 Monthly Time Series File from "Electric Power Monthly."

U.S. Department of Energy, Idaho National Laboratory (2005). http://hydro2.inel.gov/hydrofacts/hydropower_facilities.shtml

U.S. Department of Energy, Idaho National Laboratory, April 2004. “Water Energy Resources of the United States with Emphasis on Low Head/ Low Power Resources.”

U.S. Department of Energy, Idaho National Laboratory, January 2006. “Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants.”

U.S. Department of Energy, Idaho National Laboratory, February 1998. “U.S. Hydropower Resource Assessment for West Virginia.”

U.S. Department of Energy, Idaho National Laboratory, 2003. “Estimation of Economic Parameters of U.S. Hydropower Resources”

U.S. Department of Energy, National Renewable Energy Laboratory (2005). “A Geographic Perspective on the Current Biomass Resource Availability in the United States.”

U.S. Department of Energy, National Energy Technology Laboratory (1989). Annual Report to Congress on Clean Coal Technology Demonstration Program, February 1989. U.S. DOE, Assistant Secretary for Fossil Energy.

U.S. Environmental Protection Agency, Landfill Methane Outreach Program (2005). “Identifying Opportunities for Methane Recovery at U.S. Coal Mines: Profiles of Selected Gassy Underground Coal Mines 1999-2003.”

U.S. Geological Survey (2002). “Coalbed Methane Production in the Appalachian Basin.”

West Virginia Department of Environmental Protection, Oil and Gas Division.

West Virginia Department of Environmental Protection, Division of Waste Management.

West Virginia University, Appalachian Hardwood Center (2005). “West Virginia Wood Byproducts Available and Needed.”

West Virginia Geologic and Economic Survey (2006).

West Virginia State University (2006). http://bioplexproject.wvstateu.edu/poultrylitter.html, Accessed September 19, 2006.