COAL REPORT

SCHOOL OF ENERGY RESOURCES

WYOMING COAL:
INFLUENCES ON CURRENT AND FUTURE MARKETS — COMPETITION, REGULATION, AND TECHNOLOGY

November 1, 2016

UW UNIVERSITY of WYOMING

School of Energy Resources

WYOMING COAL:
INFLUENCES ON CURRENT AND FUTURE MARKETS – COMPETITION, REGULATION, AND TECHNOLOGY

NOVEMBER 1, 2016

Presented By The University of Wyoming School Of Energy Resources To:

Joint Minerals, Business and Economic Development Interim Committee,

Joint Appropriations Interim Committee

Principal Authors:

Mark A. Northam, Kipp Coddington, Robert Godby, Richard Horner, and Diana Hulme

CONTENT

Executive Summary

Coal is an important part of Wyoming's past, its economy and its future. Production of coal in the state is facing unprecedented challenges due to reducing coal-fired generation capacity in the United States (US). While the need for coal to fuel base-load capacity in the US will not disappear anytime soon, future demand for Wyoming coal will be dependent upon a complicated mix of policy, economic and technical factors. Powder River Basin (PRB) coal appears to have an advantage over coal from other regions of the US due to its low sulfur content and a low cost of production. As such, PRB coal will likely continue to gain market share against other US coals; however, the overall market volume is not expected to grow.

Three main factors exert an outsized influence on coal markets in the short-to-medium term:

1. Competition with abundant and cheap natural gas supply;
2. National and international carbon dioxide (CO_2) emissions policies; and
3. Growth of renewable energy resources – incentives and cost reduction.

All projections indicate future supplies of natural gas in the US will remain plentiful, and thus will ensure a low-price environment for the foreseeable future. Policy and regulatory pressure aimed at reducing the use of coal is likely to increase, notably through the regulation of CO_2 emissions. Construction of new renewable energy assets will continue to accelerate, especially with continuation of tax incentives and the assumption that the US Supreme Court (Court) upholds the validity of the Clean Power Plan (CPP). The development and implementation of carbon capture, utilization and storage (CCUS) technology is progressing; but, high capital and operating costs associated with the introduction of available technologies, high costs of demonstration at scale, and the lack of infrastructure and markets for CO_2 are barriers to full-scale deployment. These factors represent a significant challenge for both the existing coal-fired generation fleet—where retrofit will undoubtedly add to the cost of electricity produced—and for the construction of new coal-fired generation plants in the future.

Erosion of demand for coal is likely to abate somewhat in the near-term due to the urgency to preserve base-load generation capacity. On the other hand, reduced coal demand will likely result in response to implementation of new clean energy policy. Coal demand is likely to reach a steady, albeit reduced state over the long term, largely because of the difficulty and impracticality of retrofitting the entire coal-fired generation fleet. Access to export markets for coal would ameliorate the demand reduction in the US, and progress in identifying and developing suitable infrastructure and export facilities is important. The western Pacific Rim and India are the most promising markets for export of PRB coal.

Investment by the state and the University of Wyoming (UW) in new technology to preserve existing markets for Wyoming coal should focus on efficiency gains in coal-fired generation, CCUS, and other emission reduction technologies. UW should capitalize on its leading position in CO_2 storage and CO_2 enhanced oil recovery (CO_2-EOR) technology, and further its work to target efficient coal combustion and integrated CO_2 capture. Remaining distinguished and pioneering in approach are imperative for the state of Wyoming and UW to gain an advantage in capturing outside funding for research, demonstration, and deployment of commercial projects.

Developing new markets for coal as a feedstock to manufacture non-fuel and energy products with associated product conversion industries holds promise for developing a manufacturing sector in the state. Doing so could result in positive economic impacts, particularly in terms of job creation and other local economic benefits.

It is recognized that the magnitude of future revenue contribution to the state's economy will be dependent upon how tax considerations are handled by the Legislature. This said, UW will continue to leverage the funds provided by the state by strategically and sharply focusing research on high-impact areas. UW will aggressively pursue external funding with external agencies and develop collaboration with private industry and national laboratories to address technology needs. Supporting development of a product manufacturing base in the state—built upon the abundant and inexpensive natural mineral wealth—will be a priority. These pursuits will involve deepening the ongoing relationships with other state entities such as the Wyoming Business Council and the Wyoming Infrastructure Authority.

Introduction

The 2016 Wyoming Session Laws, Chapter 31, Section 067, footnote 6 charged that "Not later than November 1, 2016, the University of Wyoming school of energy resources shall report to the joint appropriations committee and the joint minerals, business and economic development interim committee on the research efforts and funding expended to advance powder river basin coal viability in consideration of federal regulations aimed at reducing carbon emissions. The report shall identify research and potential technologies which may maintain or increase revenues to the state from the production of coal."

The following report is submitted to both committees in fulfillment of that charge.

Brief History of Coal Mining in Wyoming

History

Coal was discovered in what is now Lincoln County, Wyoming in 1843 by the second Fremont Expedition that was guided by Kit Carson. The first report of coal in the PRB was made by the Raynolds Expedition in 1859. Geologist Ferdinand V. Hayden was a member of that expedition and reported "true lignite beds covering the region from Platte County to Pumpkin Buttes in what is now Campbell County," (Anderson, The Coal Business in Wyoming, 2016). Over time, the PRB would prove to be one of the most significant deposits of coal in North America.

Commercial mining of coal in Wyoming began in what is now Carbon County with the arrival of the Union Pacific Railroad in 1867, (Anderson, A History of Coal and Mining in Wyoming, 2016). Access to coal was an important factor in charting Union Pacific's route across what was to become Wyoming Territory. The first mines were owned by the Wyoming Coal and Mining Company on land leased from the railroad. The Wyoming Coal and Mining Company operated mines in Carbon, Rock Springs, and Almy, and sold the coal to the railroad until 1874 when the government terminated the agreement between the two companies. The Union Pacific Coal Company was then formed to continue providing coal to the railroad.

Three websites and the references therein provide much information and a colorful history of the early days of coal mining, and the relationship with the railroad in Wyoming, (Anderson, The Coal Business in Wyoming, 2016), (Wyoming Mining Association, 2016). A recent paper published by UW's Center for Energy Economics and Public Policy also provides a detailed history of coal production in Wyoming, (Godby, Coupal, Taylor & Considine, 2015).

Coal Leasing

Much of the coal in Wyoming occurs in areas where the land and mineral ownership is complex, (US Department of Interior, Bureau of Land Management, 2015). Early federal land and mineral policy was to dispose of the public domain lands fee simple. But in the 1900s and 1910s, statutes were enacted that provided for coal and other minerals to be retained by the US when the public domain was patented. In 1920, the Mineral Leasing Act was enacted such that coal became a leased commodity and development was required to be in compliance with the terms and conditions of the lease.

During the first one hundred years of coal mining in Wyoming, the volumes of coal produced were extremely modest by today's standards – peaking at just under 10 million tons per year in 1945 (Wyoming Mining Association, 2016). From 1868 until 1958, coal resources in Wyoming were primarily exploited to fuel rail transportation. From 1959 until 1969, a period of transition saw coal production for the purposes of rail transportation end and modern coal-fired electricity production begin in the state. By 1969, coal production had almost tripled its low from eleven years earlier and Wyoming's share of national production had doubled to 0.8%

From 1955 to 1970, large amounts of coal were leased even though production of coal declined by 75%. In order to manage speculation in holding coal leases, a leasing moratorium was declared in 1971. In 1974, a new lease program was introduced to link new leasing activities to need.

The 1970s and 1980s were a very active time for federal legislation and programs related to regulating, leasing, and mining coal. The basket of regulations resulted in a number of significant changes in how coal was leased and mined in Wyoming:

- The Federal Coal Leasing Amendment Act (1976) eliminated non-competitive coal leasing, and required that the Bureau of Land Management (BLM) assure maximum economic recovery;
- The Federal Land Policy and Management Act (1976) required that BLM manage all resources, assuring public participation, land use planning, and multiple use of all resources;
- The Surface Mining Control and Reclamation Act (1977) established standards for permitting surface coal mining on federal leases, and for determining lands unsuitable for mining operations;
- The Clean Air Act (CAA) was amended in 1977 and 1990, each time adding new, more stringent emissions control language, (US Environmental Protection Agency, 2016); and
- The Federal Coal Management Program (1979) provided for a process of addressing coal in land use planning, established coal regions and regional leasing, and required closing pending non-competitive leasing cases, sales procedures, diligence, maximum economic recovery, regional coal teams, and public participation.

From 1982 through 1990, a complex history of leasing occurred through regional lease sales. In 1990, the PRB Regional Coal Team recommended that the region be decertified (regional lease sales suspended, to be replaced by "leasing by application") in order to meet the needs of the industry and to maintain production. The PRB continues to operate as a decertified region today.

Coal Production

Coal production in Wyoming saw its first major increase in the 1960s as coal-fired electric generation units grew in size and number in Wyoming and the nation. In the 1970s, three additional drivers catapulted Wyoming into the lead for coal production in the US. These were:

1. *Economy of scale*. Surface coal mining - particularly in Wyoming's PRB where the coal seams are near the surface, extensive, and thick – has a much lower production cost than underground mining, (Godby et al., 2015). According to the Wyoming Geological Survey, Wyoming has more than 18 billion tons of economically mineable reserves remaining at today's prices, (Wyoming State Geological Survey, 2016).
2. *Deregulation of the rail industry*. In 1980, the Staggers Rail Act was passed which eliminated rail rate regulation and allowed for low cost rail transport between states. Coal companies in the PRB took advantage of this and began shipping most of the coal out of Wyoming for use in other states, (Godby et al., 2015).
3. *The CAA amendments of 1970 and 1990*. There was only limited market demand for PRB coal until sulfur dioxide (SO_2) and nitrogen oxide (NOx) emissions from power plants became a concern. PRB is classified as sub-bituminous and has a low sulfur content – about 0.4% compared to 4.2% for Illinois bituminous. Its lower rank and higher bound-oxygen and moisture content result in a lower heating value than bituminous and anthracite coals that were more commonly used for power generation prior to the CAA, (Clyde Bergemann Power Group, 2016). But the low sulfur content of PRB coal gave it an operating cost advantage over higher-rank coals because its use greatly reduced or eliminated the need for installation of costly scrubbing equipment required to meet new emissions standards. According to the Energy Information Administration (EIA), the cost of adding flue gas desulfurization (FGD) equipment to remove SO_2 from a plant burning bituminous coal is, in 2006 dollars, \$301/KW for a 300 MW plant, \$230/KW for a 500 MW plant, and \$190/KW for a 700 MW plant, (US Energy Information Administration, 2010). For the 500 KW plant, the cost dropped to \$137/KW if the plant was fueled with PRB coal.

In 1970, a total of 7.2 million tons of coal was produced in Wyoming, with just 600 people employed in the industry. Production of coal from the PRB represented a small fraction of the state's total production. The first mines and largest volume producers at this time were located in Carbon and Rock Springs and were owned by the Wyoming Coal and Mining Company. Volumes produced and numbers of employees increased annually at an average rate of more than 12% per year, with production peaking at 466 million tons in 2008 (Figure 1), and employment peaking at nearly 7,000 employees in 2011, (Wyoming Mining Association, 2016).

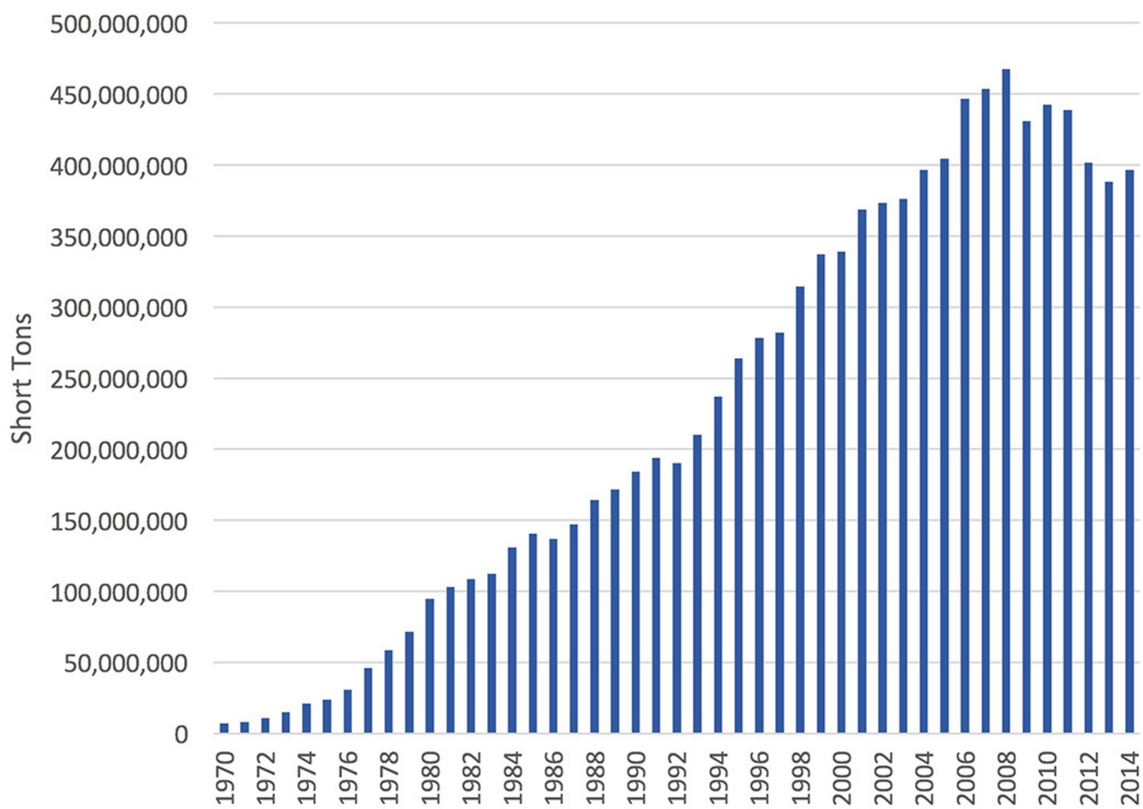

Figure 1. Wyoming Coal Production: 1970-2014, (Godby et al., 2015).

In 2008, production from PRB mines represented 96% of the state's total production, and approximately 40% of the total coal produced in the USA. Since 2009, economic and regulatory factors have resulted in decreased production (down 19%) and employment (down 7%). Latest figures for Wyoming coal production indicate that 377 million tons were mined in 2015 (363 million tons from the PRB), and employment was down to 6,500, (Dorgan, 2016).

Impact of Coal Mining on the Economy of Wyoming

Four UW faculty members who also contribute to the School of Energy Resources' Center for Energy Economics and Public Policy—Drs. Robert Godby, Roger Coupal, David Taylor, and Timothy Considine—wrote a report for the Wyoming Infrastructure Authority entitled "The Impact of the Coal Economy on Wyoming," (Godby et al., 2015). That report is a comprehensive accounting of the impact that coal mining has had and continues to have on the state's economy. It presents results of forward-looking models for various production scenarios.

Since the original report was published, the US Environmental Protection Agency (EPA) introduced the final CPP, and parties to the United Nations Framework Convention on Climate Change (UNFCCC) reached consensus on the Paris Agreement, which will enter into force on November 6, 2016. Both of these developments have potential impacts on the future of coal production and, thereby, the economy of Wyoming. The authors continue to update their foundational work on how the CPP and Paris Agreement might impact the economy of the state. The entire body of work referenced herein can be found at http://www.uwyo.edu/cee/working-papers.html. The reader is directed to these reports for the desired level of information on the topic.

Coal production has been a cornerstone of the modern Wyoming economy since the 1970's, and has served as Wyoming's most stable source of tax revenue over the past four decades. Revenue to state and local governments from coal mining has grown steadily during that time, peaking in 2012 at $1.3 billion.

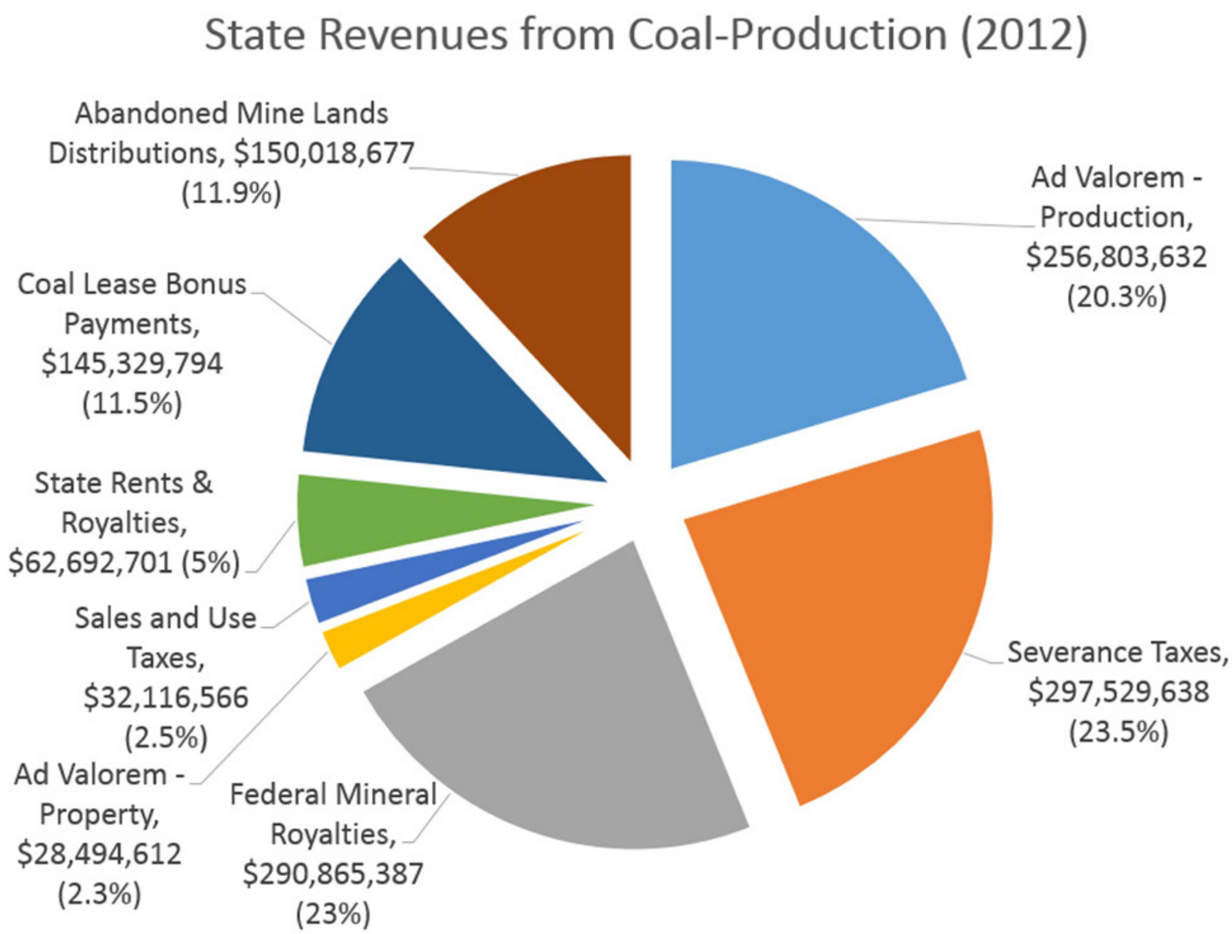

Figure 2. State revenue from Coal Production in 2012, (Godby et al., 2015).

The largest sources of revenue in 2012 were Severance Taxes (23.5%), Federal Mineral Royalties (23.0%), and Ad Valorem Taxes on Production (20.3%), (Figure 2). Combined, these three revenue sources represented two-thirds of total state and local tax revenue from coal. Following these three revenue sources, Abandoned Mine Lands (AML) distributions and Coal Lease Bonus Payments each accounted for more than 11% of total coal revenue. The remainder of the $1.3 billion represented State Rents & Royalties from coal production on state lands (5.0%), Sales & Use Taxes associated with coal production (2.5%), and Ad Valorem Taxes on Property associated with coal mine facilities (2.3%). Overall, the $1.26 billion in revenues collected from coal production represented 11.2% of the state's total revenues collected in 2012, (Godby et al., 2015).

Additionally, coal mining employment has provided a substantial number of jobs for which wages and salaries are significantly above the state average. The Bureau of Labor Statistics estimates that in 2013 total wages and salaries for Wyoming coal mining employment were $550 million (excluding benefits). This represents average annual earnings per job of $82,654 for coal mining, more than twice the average state wage, (Godby et al., 2015).

It is an important fact that Wyoming ships the majority (93%) of its produced coal to 33 other states (Figure 3), (US Energy Information Administration, 2015, December). Internal consumption is dominated by 12 coal-fired power stations and three industrial electricity generation facilities – two in support of soda ash mines and one in support of a sugar refinery. The reliance on export of Wyoming coal to 33 other states reduces market influence for the state, especially in the era of increasing federal and state regulation.

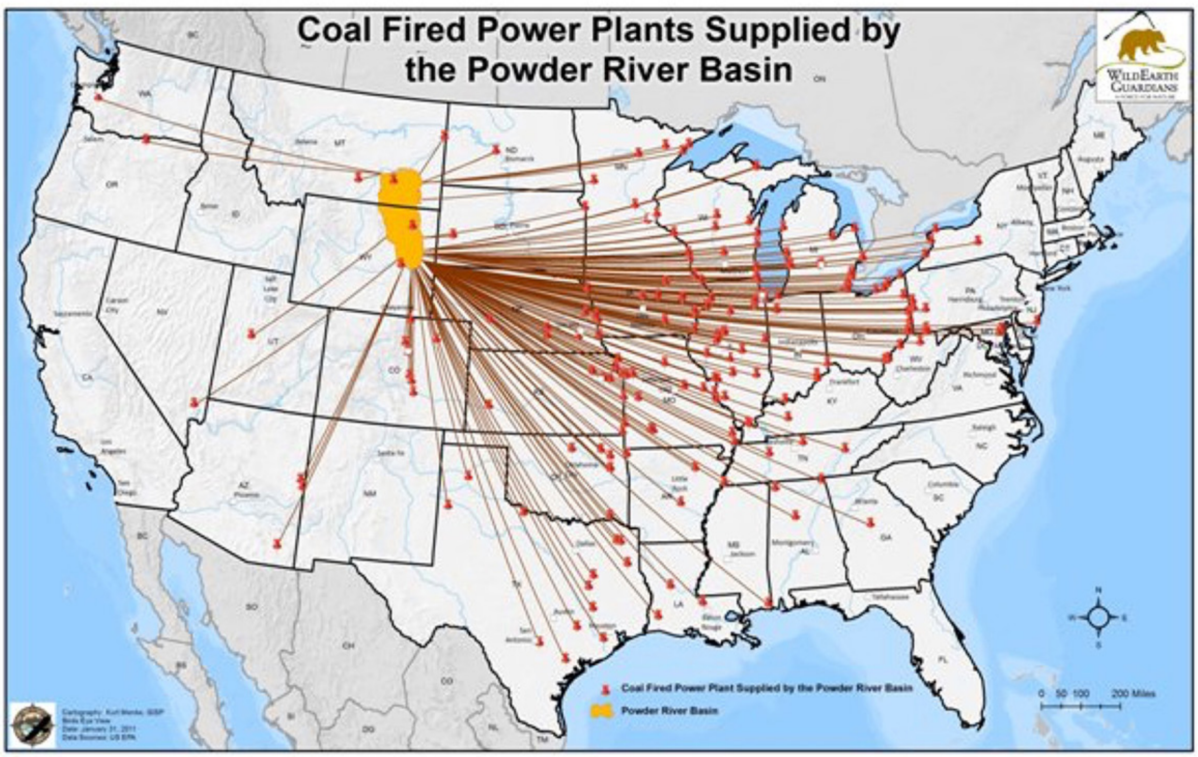

Figure 3. Coal Fired Power Plants Supplied by the Powder River Basin, (WildEarth Guardians, 2011).

As previously stated, Wyoming coal production peaked in 2008 at 466 million tons and has since declined by about 19%. In addition to reduced production, the price per ton of coal has also declined from $14.60 per ton in 2011 to $11.55 per ton in 2014 to around $9.00 per ton in October 2016 (US Energy Information Administration, 2016, October 26). Recent data indicate that while coal production volumes have stabilized for the time being, the demand outlook for Wyoming coal will continue to face downward pressure.

Exporting coal to new international markets could well be a valuable addition to PRB coal producers' bottom line. However, export requires access to railroad trade routes and export terminals, both of which have been extremely challenging for Wyoming producers. Recently newly-proposed coal export terminal projects in Oregon and Washington have been cancelled. Alternatives are still being sought.

Eleven major companies are actively mining coal in Wyoming. Of these, Arch Coal, Peabody Energy, Cloud Peak Energy and Alpha Natural Resources are the largest. Most recently (in 2015-16) three of the leading coal miners in Wyoming (Alpha Natural Resources, Arch Coal and Peabody Energy) were forced to enter bankruptcy proceedings due to changes in international market conditions. Alpha Natural Resources and Arch Coal have just emerged from bankruptcy as smaller, healthier companies. Peabody Energy is expected to announce exit from bankruptcy proceedings soon. Significant uncertainty remains as to how these businesses will reinvent themselves to assure viability.

Factors Currently Influencing Coal Markets

Three main factors continue to exert an outsized influence on the recent decline in demand for Wyoming coal in the short-to-medium term:

1. Competition with abundant and cheap natural gas supply;
2. International and national CO_2 emissions policies; and
3. Growth of renewable energy resources – incentives and cost reduction.

Two additional factors have the potential to impact demand for coal – the pace of the US economy, and opening of export routes to meet growing demand for and consumption of coal in developing economies including, but not limited to, China, India, and Japan. As the pace of the economy is largely outside the control of the state, it will not be addressed here.

1. Competition with abundant and cheap natural gas supply

Production of dry natural gas in the US has grown over the past decade. Production grew by approximately 50% over that time period due to increased production of natural gas from the development of unconventional oil and gas reservoirs, (Figure 4).

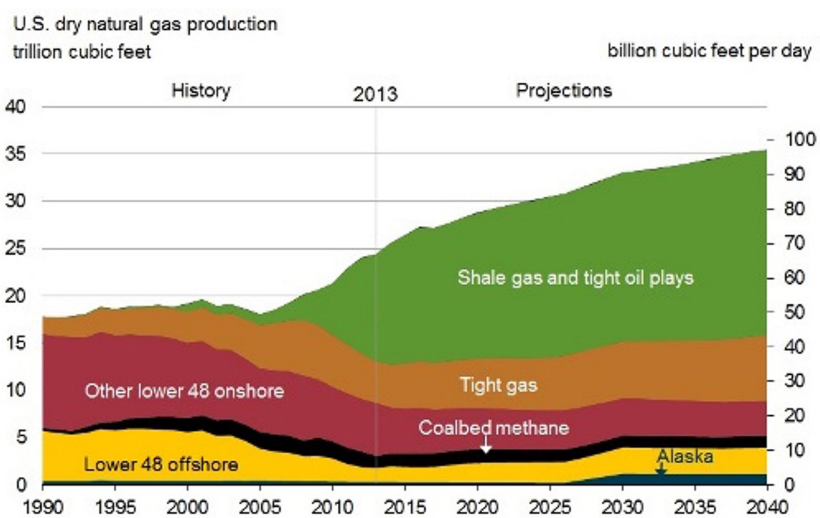

Figure 4. US Dry Natural Gas Production (1990-2040), (Green, 2015).

Projections by the EIA show that supply of natural gas from domestic production will continue to grow for the next 20 years as a result of exploitation of this resource. Furthermore, the growth in production was accomplished from a large variety of shale plays that are widely distributed geographically (Figure 5). The wide geographic distribution of the supply facilitates delivery of natural gas to many of the locations where PRB coal is currently supplied for coal-fired electric power generation.

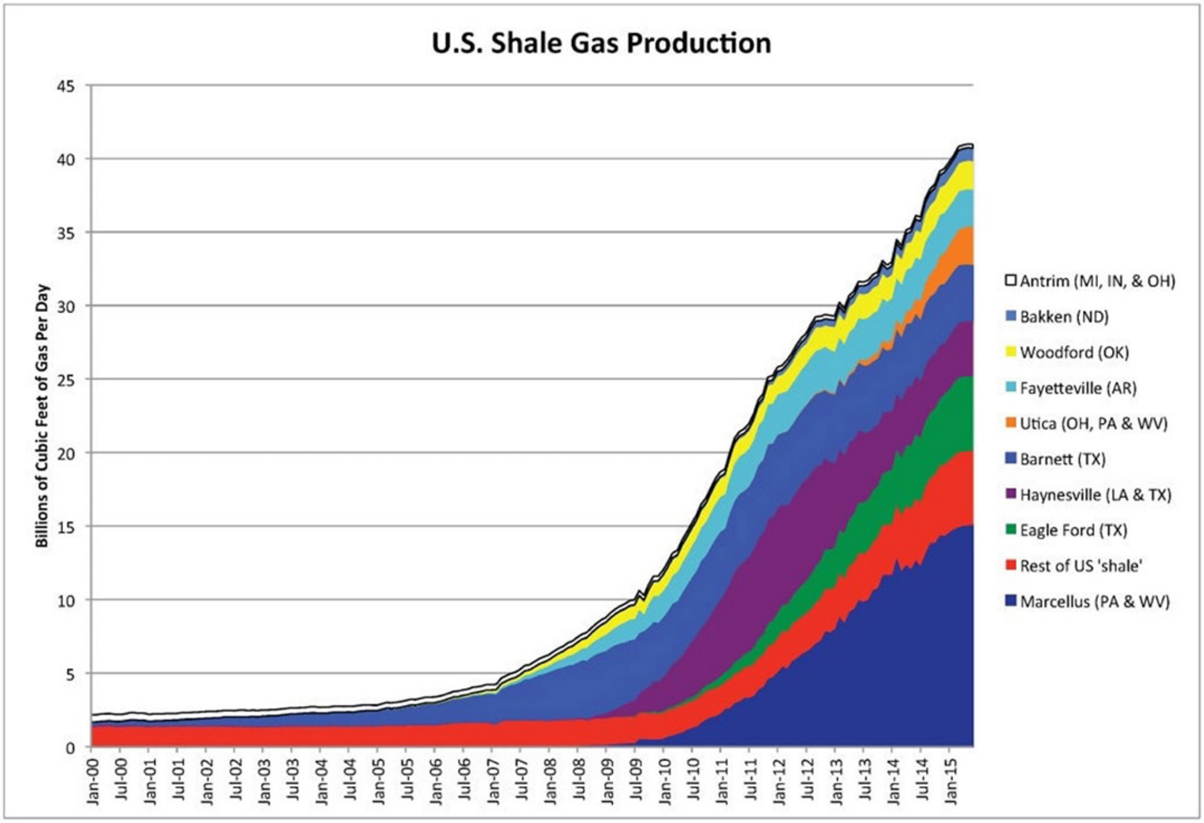

Figure 5. Growth in US Shale Gas Production by Play, (US Energy Information Administration, 2016).

The start of growth in natural gas production from shale plays correlates roughly with the timing of the 2009 global economic recession that saw a decline in demand for natural gas, (Figure 6). The result of increasing supply and decreased demand was a dramatic decline in the price of natural gas. Natural gas spot prices at Henry Hub fell rather precipitously from a peak of just over $12/MMBtu in 2008 to $2/MMBtu in 2009 over a period of 18 months. For the past 6 years, natural gas has traded in a narrow range of prices between $2 and $5/MMBtu.

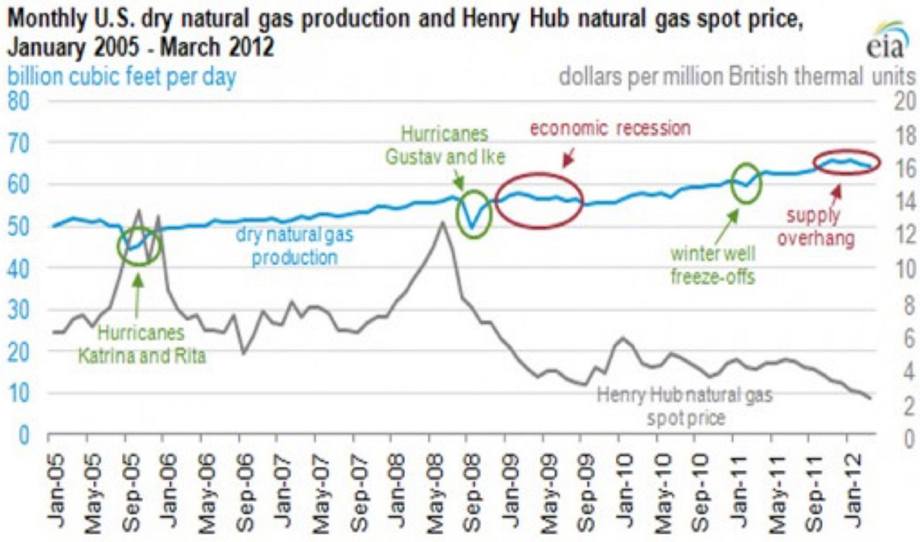

Figure 6. Monthly Natural Gas Production and Henry Hub Spot Price, (LNG World News, 2012).

The EIA has modeled prices for natural gas out through 2035 in a range of scenarios representing various supply cases with expected demand to determine the impact on future prices (Figure 7). All four of their cases show modest price growth for the next two decades. The current NYMEX natural gas price ($3.18/MMBtu) coincides well with the "high resources" case in Figure 7.

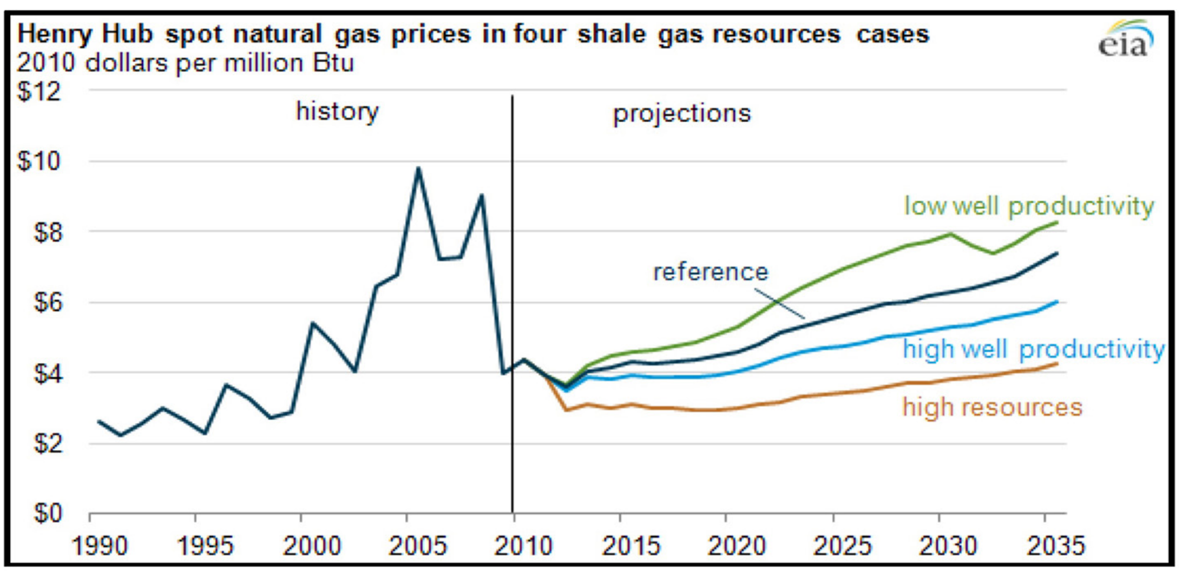

Figure 7. EIA Projection of Natural Gas Prices, (US Energy Information Administration, 2012).

Considering that the projections demonstrated in the above graphics are consistent with dozens of similar studies conducted by others, one is led to conclude that the US supply of natural gas will be sufficient to meet demand at prices not expected to rise above $6/MMBtu over the next 10 years. While the price of fuel alone is not sufficient to justify the cost of fuel-switching at existing coal-fired power plants, it is a contributing factor; and it is an important factor when planning for construction of a new power plant.

2. International and national carbon dioxide emissions policies

For the foreseeable future, all fossil fuels are expected to face policy pressure to reduce their emissions of greenhouse gases (GHG). To date this policy pressure has focused on emissions of CO_2 from the combustion of fossil fuels. This development has disadvantaged coal in comparison to natural gas because stack emissions from coal are approximately twice that of natural gas per unit of energy produced. In the years ahead, however, it is expected that this regulatory advantage for natural gas will deteriorate. Policymakers appear poised to require reductions in fugitive methane emissions from the production, transportation and usage of natural gas. It is likely that EPA will require further reductions in CO_2 emissions from power plants below that which can be achieved by switching to natural gas alone. In other words, both coal- and natural gas-fired power plants will likely require CCUS technology to meet more aggressive emissions limits.

2.1 International

Concerns that the continued addition of man-made GHG to the atmosphere would accelerate global climate change began to shape international policy, and also became the subject of heated scientific and political debate 25 years ago. In 1992, the UNFCCC committed the parties to stabilize "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The convention set no binding limits on GHG emissions for individual countries and contained no enforcement mechanisms, (United Nations Framework Convention on Climate Change, 1992). The parties to the convention have met annually since 1995 in Conferences of the Parties (COP) to assess progress in dealing with climate change. In 1997, the COP negotiated the Kyoto Protocol that established the first legally binding obligations for developed countries to reduce their GHG emissions in two commitment periods – first from 2008-2012 and then from 2013- 2020. The 2009 Copenhagen Accord states that the maximum global average temperature increase should not exceed 2.0 °C (3.6 °F) relative to preindustrial levels. The US never ratified the Kyoto Protocol on the grounds that it unduly burdened developed countries.

In 2015 the COP adopted the Paris Agreement which governs emission reductions after the Kyoto Protocol ends in 2020. The US signed the Paris Agreement on April 22, 2016, and officially accepted it on September 3, 2016. The agreement enters into force on November 6, 2016. Countries, including the US, made commitments to reduce GHG emissions in filings known as Intended Nationally Determined Contributions, (United Nations Framework Convention on Climate Change, 2016).

The Paris Agreement sets climate policy through 2050. Under the Paris Agreement, the US pledged to reduce its GHG emissions by 26% to 28% by 2025, based on 2005 levels. More broadly, the Paris Agreement envisions an approximate 80% reduction by 2050 – an aspirational goal that almost certainly may only be met by the decarbonization of all major fossil fuel-fired energy systems through the use of technologies such as CCUS, bioenergy with CCUS, and massive implementation of renewable energy generation.

In late 2014, the United States and China separately entered into a bilateral climate agreement under which:

1. The Unites States will endeavor to reduce its GHG emissions 26-28% below 2005 levels by 2025; and
2. China will attempt to achieve peak CO_2 emissions by 2030, with the intention to try to peak prior to that date, and to increase the non-fossil fuel share of all energy to around 20% by 2030.

Although these and related international climate agreements are not binding per se under US law, they are influential in maintaining low-carbon policy pressure on fossil fuels.

2.2 National

Domestically at the US federal level, the Court has largely upheld the authority of the EPA to regulate GHG emissions under the federal CAA. Since 2009, EPA has moved aggressively to implement that authority by, for example, issuing climate regulations that require:

- ✓ Major new stationary sources of CO_2 and existing stationary sources of CO_2 undergoing major modifications to reduce their CO_2 emissions through implementation of Best Available Control Technologies (BACT) such as CCUS, and CO_2-EOR. By and large these regulations have been separately upheld by the Court.

- ✓ New coal-fired power plants to meet an emission limit of 1400 lbs of CO_2/MWh which – according to EPA – may be met through application of CCS, CCUS, and CO_2-EOR technologies. Co-firing coal with natural gas is an additional option. Issued under section 111(b) of the CAA, these regulations are subject to ongoing litigation.

- ✓ Existing coal-fired power plants to meet statewide CO_2 emission targets set by EPA under the CPP. Issued under section 111(d) of the CAA, these regulations also are subject to ongoing litigation.

In February 2016, the Court granted a stay, halting implementation of the CPP pending resolution of legal challenges to the program. Although the section 111(b) and 111(d) regulatory programs remain subject to litigation, the decades'-long history of CAA implementation suggests that even if the Court ultimately strikes them down, in whole or in part, EPA is likely to re-propose them in the future in modified form to satisfy judicial scrutiny. Stated another way, under all scenarios, it is likely that in the coming years the CAA will continue to be implemented in a way that compels reductions in GHG emissions from fossil fuels.

The CPP, if upheld by the Court, creates a particularly onerous burden for Wyoming as it will limit emissions of CO_2 for coal-fired power plants that operate in the state and it will exert additional downward pressure on markets for PRB coal outside of the state. Godby and Coupal (2015) present the results of analyses to determine the potential impact that the CPP could have on Wyoming coal production. In all scenarios that they examined, there is significant reduction in consumption of PRB coal for power generation compared to 2015 production (18% to 45%). However, all scenarios show that demand stabilizes in 5 to 10 years at those reduced levels.

US federal climate-based policy pressure on coal is not limited to the CAA. The BLM's current moratorium on new coal leases is premised in part on "how best to assess the climate impacts of continued Federal coal production and combustion and how to address those impacts in the management of the [coal leasing] programs to meet both the Nation's energy needs and its climate goals ….," (US Department of Interior, 2016). In August of 2016, the White House finalized guidance under the National Environmental Policy Act (NEPA) that explains how federal agencies such as BLM should assess the climate impacts of activities on federal lands, such as mining coal, (Goldfuss, 2016). The guidance references the Social Cost of Carbon (SCC) as one metric to assess climate impacts. The net effect of the guidance is that future coal leases on federal lands will have to take into account the climate impacts that the produced coal presumably will cause. The guidance notes that agencies should take into account technologies such as CCUS.

The main impact on coal has been growing difficulty and reluctance to plan, finance, and construct new coal-fired power plants. Regulations in the US—specifically the sections 111(b) and (d) programs under the CAA—have created a significant disadvantage for new coal-fired plants as compared to new natural gas-fired plants. This is so because new coal-fired plants must likely implement costly CCUS technology to meet the 1400 lbs of CO_2/MWh limit on emissions, whereas modern combined cycle natural gas fired plants can do so without implementing CCUS. As a result, capital investment costs are lower for new natural gas-fired plants than for new coal-fired plants.

Although not a policy to reduce GHG, a set of regulations known as the Mercury and Air Toxics Standards (MATS) also continues to have an impact on coal-fired plants and should be discussed here. The EPA finalized MATS to limit emissions of mercury, acid gases and other HAPs to the atmosphere from coal- and oil-fired power plants in December 2011. Shortly thereafter, EPA modified the standards with respect to new power plants and startup/shutdown procedures. By EPA's estimate, MATS annual compliance costs are $9.6 billion compared with $4 to $6 million in quantifiable benefits.

Following litigation before the US Court of Appeals for the D.C. Circuit, in mid-2015 the Court struck down MATS on the grounds that EPA unlawfully failed to consider MATS compliance costs before finalizing the regulations. The Court remanded the matter back to the D.C. Circuit for further proceedings, where miscellaneous aspects of the litigation continue. In response to the Court's mandate, EPA subsequently took costs into account and determined earlier this year that it was still appropriate and necessary to implement MATS.

MATS is in effect and utilities are complying with it. MATS impacts approximately 1,100 existing coal-fired units and 300 oil-fired units at about 600 power plants (Figure 8).

SNL—the highly regarded energy analytics company – estimates that approximately 4,600 MW of coal-fired power was shuttered by mid-2015 in response to MATS, with further retirements expected, (Walton, 2015). SNL separately estimates that MATS could lead to up to 46,000 MW of coal-generation retirement by 2022. Technologies are available to enable PRB coals to comply with MATS but utilities must weigh a variety of factors, including costs, in deciding how to proceed.

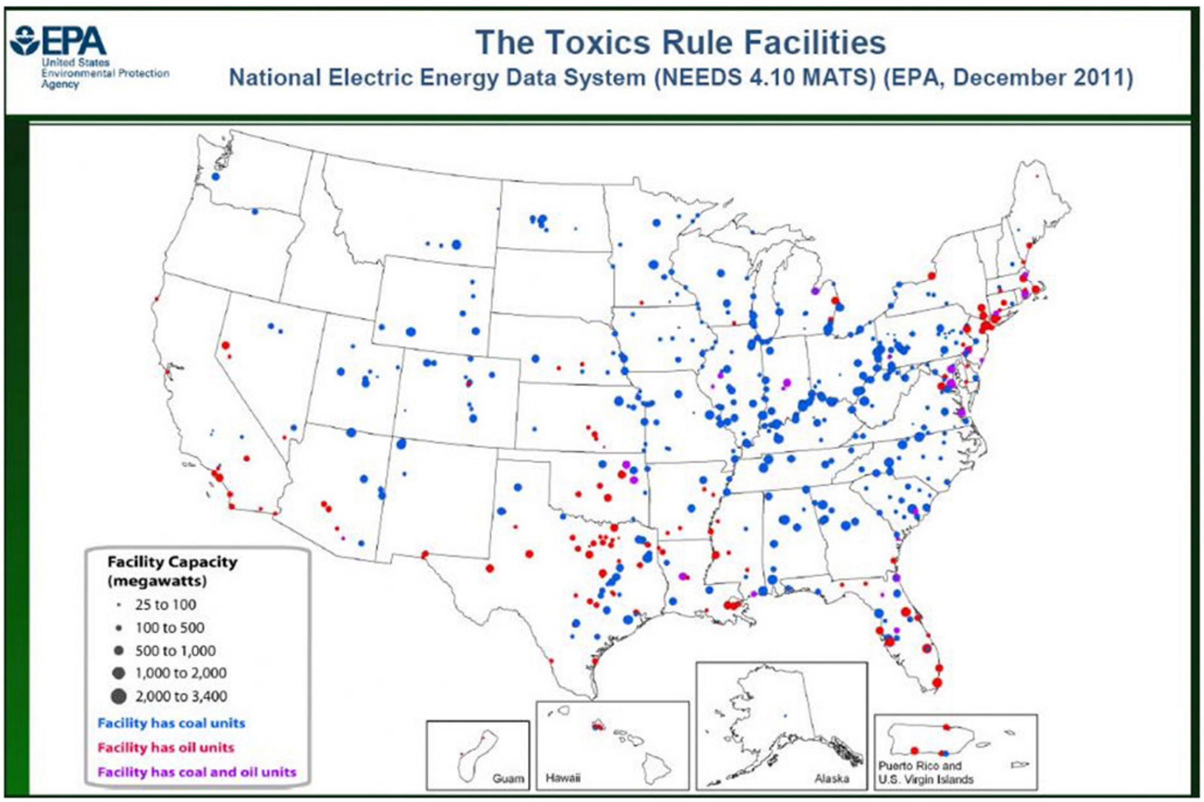

Figure 8. Power Plants Likely Subject to MATS, (US Environmental Protection Agency, 2011).

There is a plethora of other regulations that impact the ability to permit, finance and mine coal in Wyoming. The number and severity of the regulations have accelerated over time. All add to the cost of producing coal which negatively impacts the companies involved in mining. These will not be addressed in this paper as they are not major factors that influence markets for coal even though they represent increasing challenges for an industry that is already struggling.

Twenty-five years of growing public and policy pressure aimed at reducing GHG emissions (though it has had little impact on the use of fossil fuels in the US until recently) have increased uncertainty over the ability of society to rely upon the use of fossil energy resources in the future. At the same time, in recognition of the urgency for reducing GHG emissions, governments around the globe have dedicated substantial amounts of funding for research, development and implementation of a broad scope of new technologies for improving energy efficiencies and reducing or eliminating fossil fuel generated GHG emissions to the atmosphere. Much has been accomplished, but there is still work to be done for these technologies to be economically deployable.

As 2016 is an election year, it may be if interest to the readers to compare the general Democratic and Republican platforms as they address coal and climate regulation and policy. The Democratic platform supports reduction of GHG emissions through implementation of the CPP, use of CCUS technologies for fossil-fuel fired units and an overall reduction in fossil fuel use. The Republican platform supports continued use of fossil fuels and urges the private sector to focus on continued development of CCUS technology. The Republicans also tend to reject the Paris Agreement and calls for defunding of the UNFCCC.

3. Growth of renewable energy resources – incentives and cost reduction

Renewable energy resources—wind, solar (photovoltaic and thermal), geothermal, hydroelectric, and biomass—are being considered more and more as appropriate alternatives to fossil energy-fired electric power generation. The advantages of renewable energy assets are near zero CO_2 emissions and an inexhaustible supply of the resources. However, with today's grid configuration and technology state, distance of most renewables from demand centers, inherent intermittency of the resource, and lack of energy storage capacity, it is challenging for these forms of alternative energy to be complete substitutes for fossil energy-fired power generation. More detail on the various renewable energy sources is provided below.

Hydroelectric power generation has been employed in the US since the 1880's and by the early 1900's supplied 40% of all electric power in the US, (US Department of Interior, Bureau of Reclamation, 2016). In the 1940's hydropower provided about 75% of all the electricity consumed in the West and Pacific Northwest and about one third of the total for the US. Today, hydroelectric power provides about 6% of the total electricity in the US. Almost all existing hydroelectric capacity in the US was built before the mid-1970s. New hydroelectric potential is extremely limited in the US.

Geothermal power is a relatively small player in the US with 3.5 GW of installed nameplate capacity and 2.7 GW of net capacity, (Matek, 2015). Since 2005, 38 new geothermal power projects added nearly 700 MW to the US electricity capacity. Although geothermal power may grow more rapidly in the future, there is only a total of 1,250 MW of geothermal power under development in the US.

Biomass is a renewable fuel that can be consumed in a wide variety of ways to generate electricity, the most common of which is combustion in the same way that coal is used, (International Energy Agency, 2007). Although considered a renewable fuel, combustion of biomass results in the emission of CO_2 to the atmosphere unless coupled with CCS technology. In the CPP final rule, the EPA specifies that "qualified biomass" may be included in a state plan given certain conditions. EPA defines qualified biomass as "biomass that can be considered as an approach for controlling increases of CO_2 levels in the atmosphere." The EPA appears to have opened the door for coal facilities to co-fire with biomass, but only fuel from approved feedstocks, (Cleaves, 2015). However, there remains uncertainty about which forms of biomass EPA will deem acceptable. Further, there are various stipulations associated with the use of biomass to generate electricity for the CPP. Thus, it is not clear what role biopower will play in the implementation of the CPP.

Solar power generation exists in two forms: solar photovoltaic (PV) in which solar cells convert photons into electrons, and concentrated solar power (CSP) which concentrates heat from solar energy to generate steam. PV is deployed at the residential, industrial, and utility scales. CSP is only deployed at the utility scale. The main concern for both PV and CSP has been the price to install capacity as compared to other sources. However, the blended average PV price has fallen from about $7.50/watt installed to $2/watt from 2009 to present, (Solar Energy Industries Association, 2016). That reduction in the price coupled with the solar Investment Tax Credit (ITC) have stimulated growth in new solar capacity (Figure 9). Total US solar capacity now stands at 32 GW.

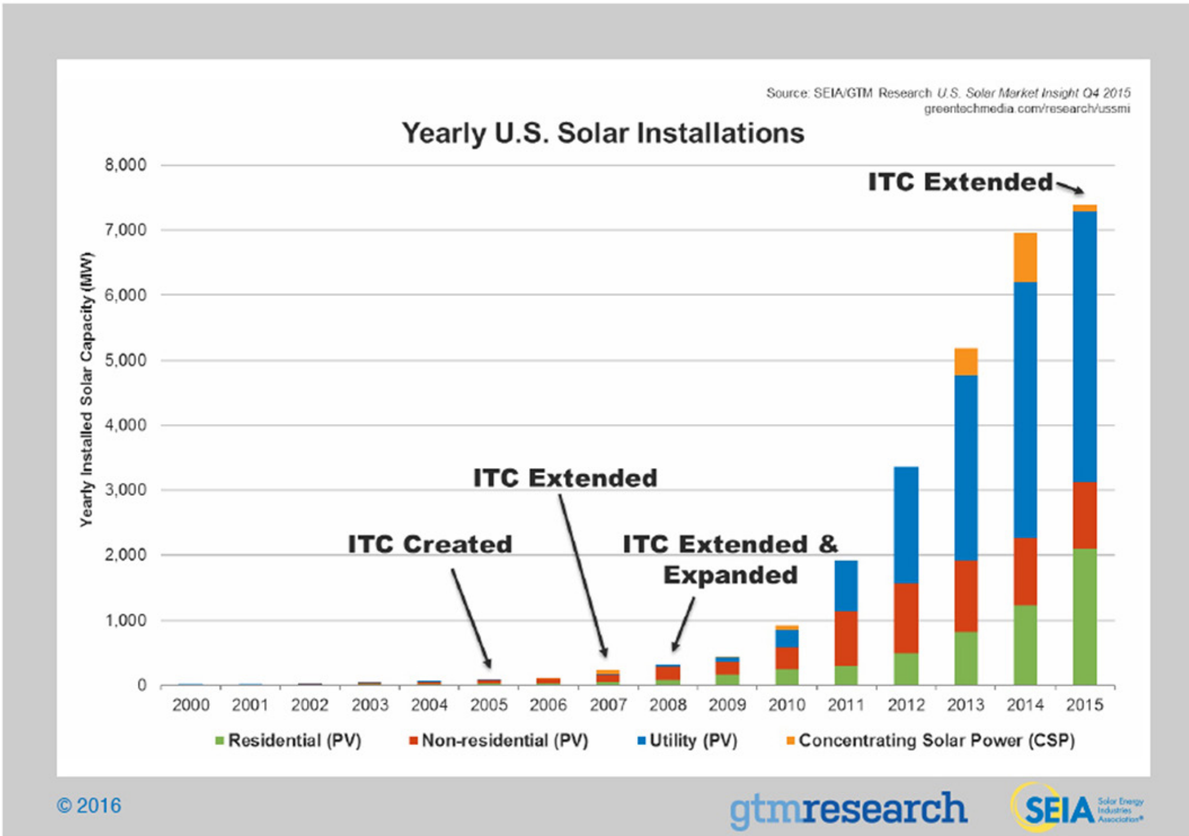

Figure 9. Yearly US Solar Installations (2006 – 2016), (Solar Energy Industries Association, 2016).

Wind power is the renewable energy resource that has experienced the greatest growth over the past two decades, both in the US and globally. As of 2013, wind supplied 4.5% of the nation's electricity demand with 61 GW of installed capacity from installations in 39 states. Installations of new capacity have grown from 2 GW/yr in 2006 to 13 GW/yr in 2012. Like solar power, wind power installation has been incentivized by various tax credit programs, most notably the Production Tax Credit (PTC) and the Investment Tax Credit (ITC), (US Department of Energy, 2015, March). Figure 10 illustrates the annual capacity additions for wind power and also the strong correlation between new capacity additions and the availability of PTC. Wind power has the greatest potential for broad geographic deployment of any of the renewable energy resources. Wind power is able to compete on price with natural gas-fired conventional combined-cycle electricity generation ($50.9/MWh vs. $56.4/MWh Total Levelized Cost of Electricity, respectively) and is more favorable than the cost of advanced coal-fired generation with CCS ($139.5/MWh), (US Energy Information Administration, 2016, August).

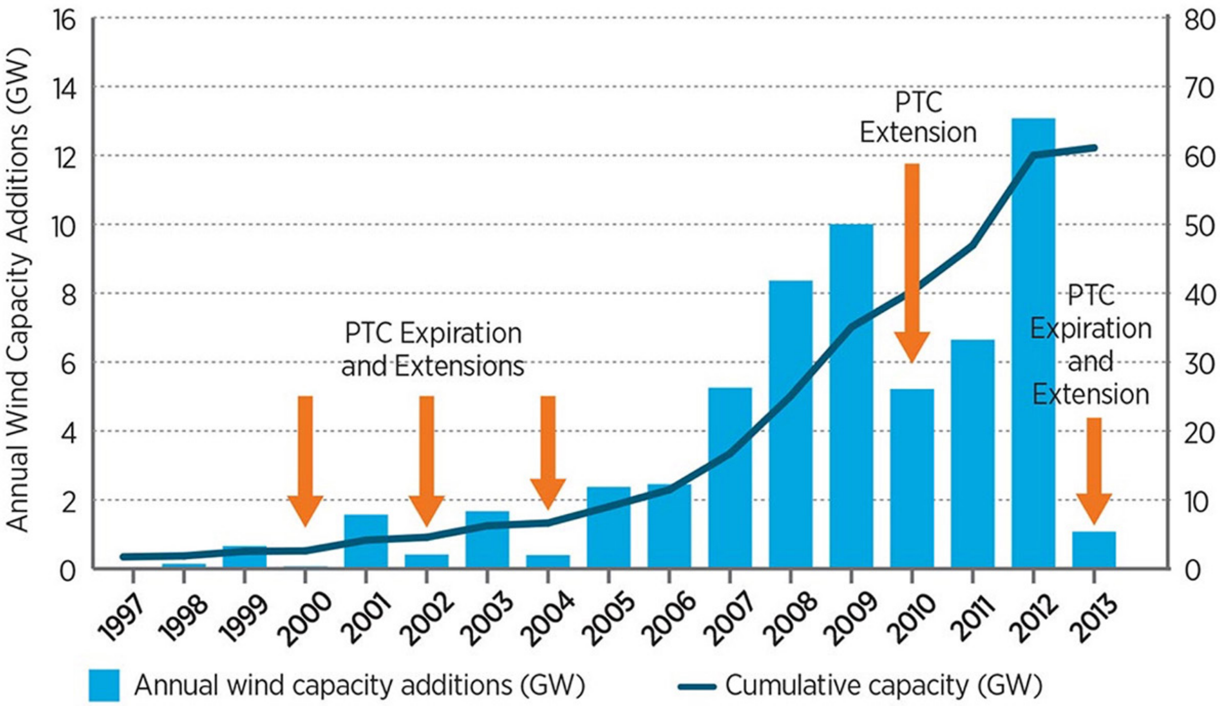

Figure 10. Annual US Wind Capacity Installations and Capacity, (US Department of Energy, 2015, March).

Figure 11 illustrates how dramatically the cost of electricity from wind installations has declined since the earliest days of utility-scale installation.

Figure 11. Wind Energy Cost and the Growth of Capacity (1980-2014), (US Department of Energy, 2015).

These comparisons of renewable energy installation to coal-fired plant construction are not, perhaps, fair because they compare fully dispatchable technologies (i.e., baseload) with a non-dispatchable technology (i.e., intermittent). If and when energy storage technologies are deployable, the cost of wind or solar plus storage will be the correct comparator.

Total renewable electricity generation from utility-scale plants in 2015 was about 1,450 GWh/day. Hydro power was about 45% of that total, and wind power was 35%. In its 2015 Annual Energy Outlook, the EIA projects in its reference case that renewable generation capacity will roughly double by 2040 with the greatest portion of the increase from wind (Figure 12), (US Energy Information Administration, 2015, May). The reference case takes into account new legislation and regulations enacted in 2015, model changes, and data updates.

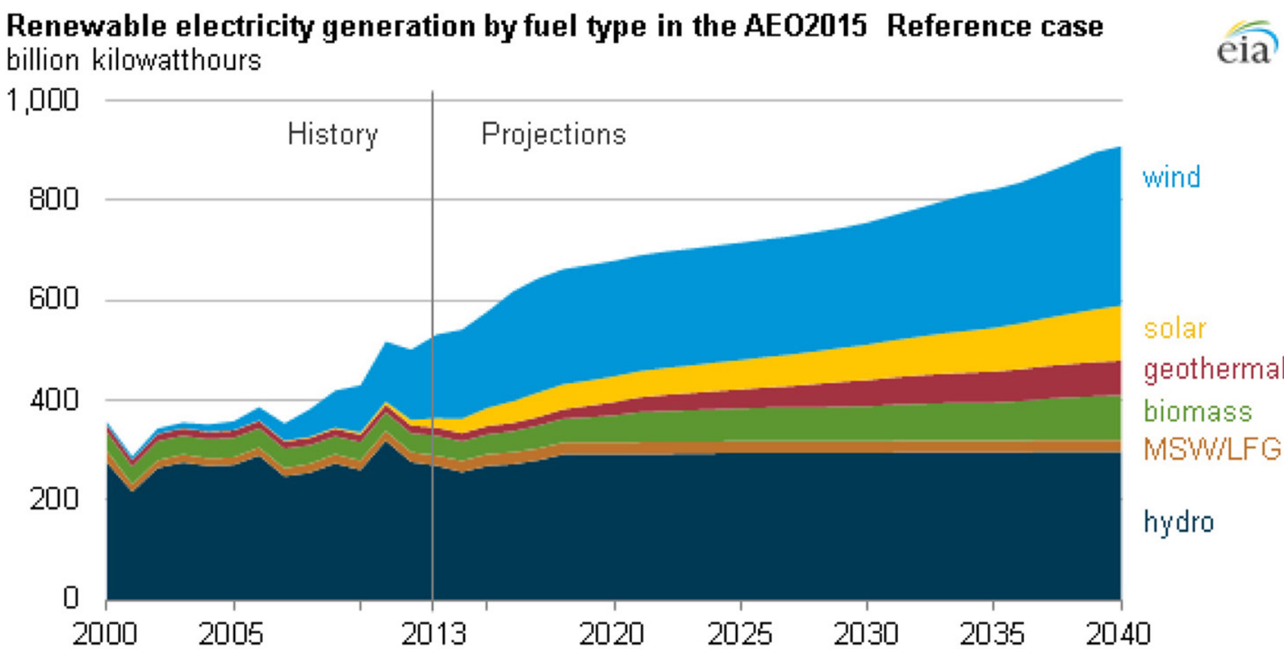

Figure 12. Renewable electricity generation by fuel type, (US Energy Information Administration, 2015, May).

Coal Market Overview

The complex interplay among natural gas prices, emission regulations and the growth of renewable energy is resulting in unprecedented downward pressure on US coal markets. Natural gas and renewables are dominating the market for new capacity based on price, low or zero emissions, and tax incentives (for wind and solar). Natural gas has recently, for the first time, overtaken coal as the dominant fuel source for electric power generation (Figure 13).

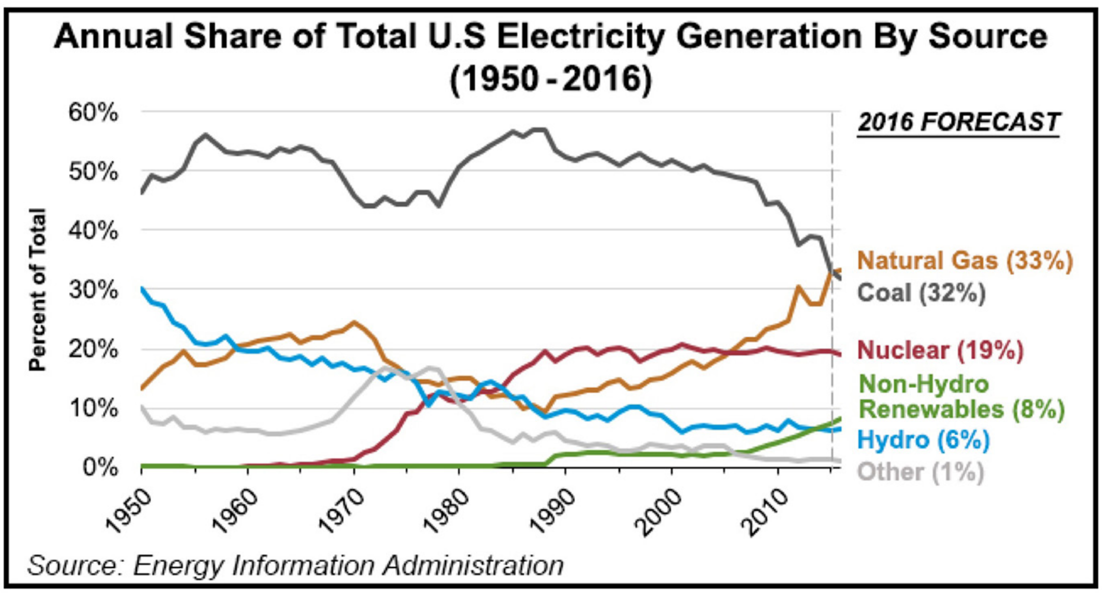

Figure 13. Annual Share of Total US Electricity Generation by Source, (Bradley, 2016).

Wind and solar are still a small fraction of the total, but wind is expected to continue to grow significantly, especially if tax incentives remain in place. Still, all projections indicate that fossil fuel fired generation will continue to dominate the sector for the foreseeable future largely because of the absolute necessity to ensure baseload capacity is sufficient to reliably support demand.

It is of interest that natural gas is likely to overtake coal as a source of energy-related CO_2 emissions (Figure 14), (Feldscher, 2016). However, growing concerns over fugitive emissions of methane—a more potent GHG than CO_2—from natural gas production causes significant speculation that climate regulations regarding the use of natural gas are likely to increase. When that occurs, it will decrease the regulatory advantage that natural gas now has over coal.

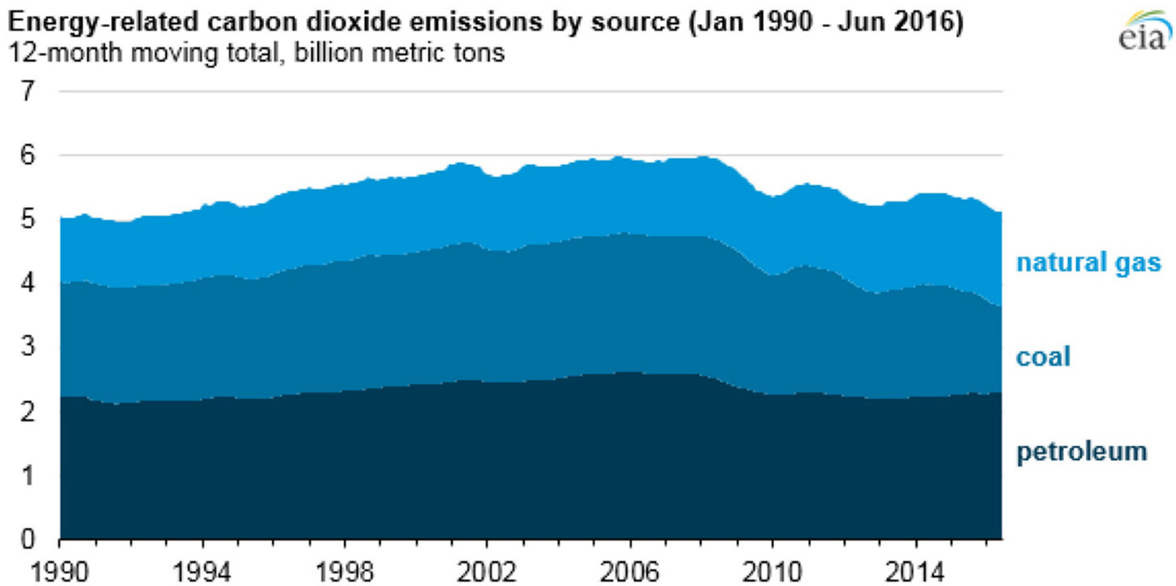

Figure 14. Energy-related carbon dioxide emissions by source, (US Energy Information Administration, 2016, October 12).

Low natural gas prices are the main factor decreasing the likelihood of further coal-fired generation capacity being built. In fact, sustained low natural gas prices will promote early removal of aging coal-fired generation capacity and replacement with natural gas-fueled alternatives. Increasing the competitiveness and profitability of coal-based electricty generation through implentation of new, economic technology is crucial to curtail further coal market erosion. It is almost a certainty that some sort of government incentives will be required for this to happen in the near term.

The EIA's "Annual Energy Outlook 2016" compares coal plant retirements (Figure 15) and coal production (Figure 16) in two scenarios – with and without the CPP, (US Energy Information Administration, 2016, September). Figure 15 illustrates that coal plant retirements have been relatively high in recent years because of competition from units burning low-priced natural gas and implementation of environmental regulations – mainly MATS. Nearly 14,000 MW of capacity was actually retired in 2015. About three times the amount of coal retirements in 2015 are expected to occur in 2016 as the final deadline for MATS occurred in April, (Hislop, 2016). The EIA projects that if the CPP is upheld by the Court, the amount of additional coal capacity that will be retired by 2040 in the US will be more than double that of the case where CPP is not implemented (55 GW vs. 20 GW). In both cases, natural gas is expected to continue to gain market share at the expense of coal.

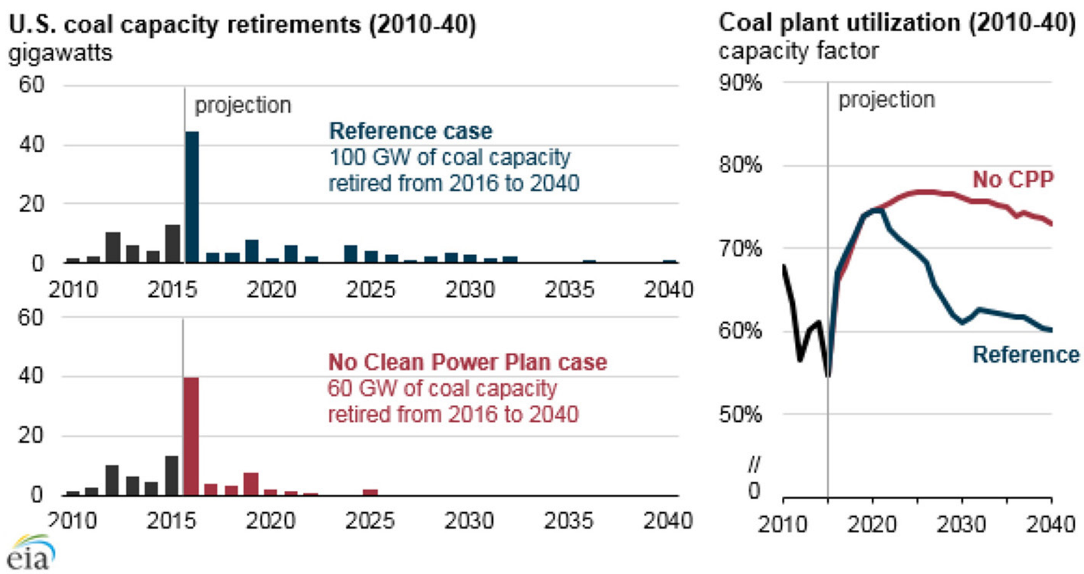

Figure 15. US Coal Capacity Retirements (2010-2040), (US Energy Information Administration, 2016, September).

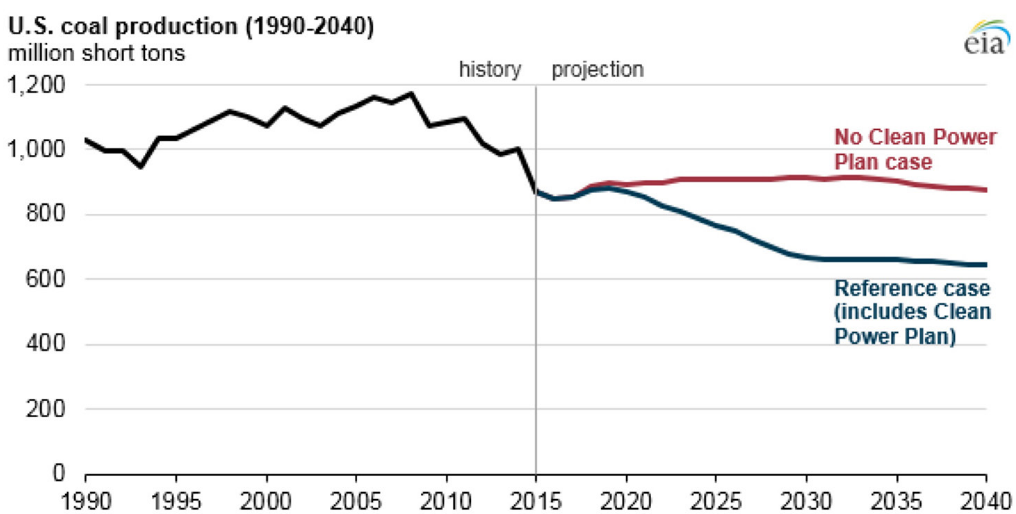

Figure 16. US Coal Production with and without CPP (1990-2040), (US Energy Information Administration, 2016, September).

In the "Annual Energy Outlook," coal demand is projected to remain flat from 2016 levels through 2040 in the absence of the CPP. If the CPP is implemented, coal demand is projected to steadily decline by an additional 25% through 2030, and then reach an almost steady state. There is uncertainty in the models that have led to these projections, but it is hard to envision a case where coal demand is not significantly driven down by implementation of the CPP. There is a small, optimistic aspect in the projected coal market erosion. Western region coals (dominated by PRB) have fared better than eastern region coals over the past 20 years based on low production cost, availability, and low sulfur content. Although future declines in overall demand for coal seem probable, PRB coal is likely to continue to gain market share versus those from other regions of the country (Figure 17).

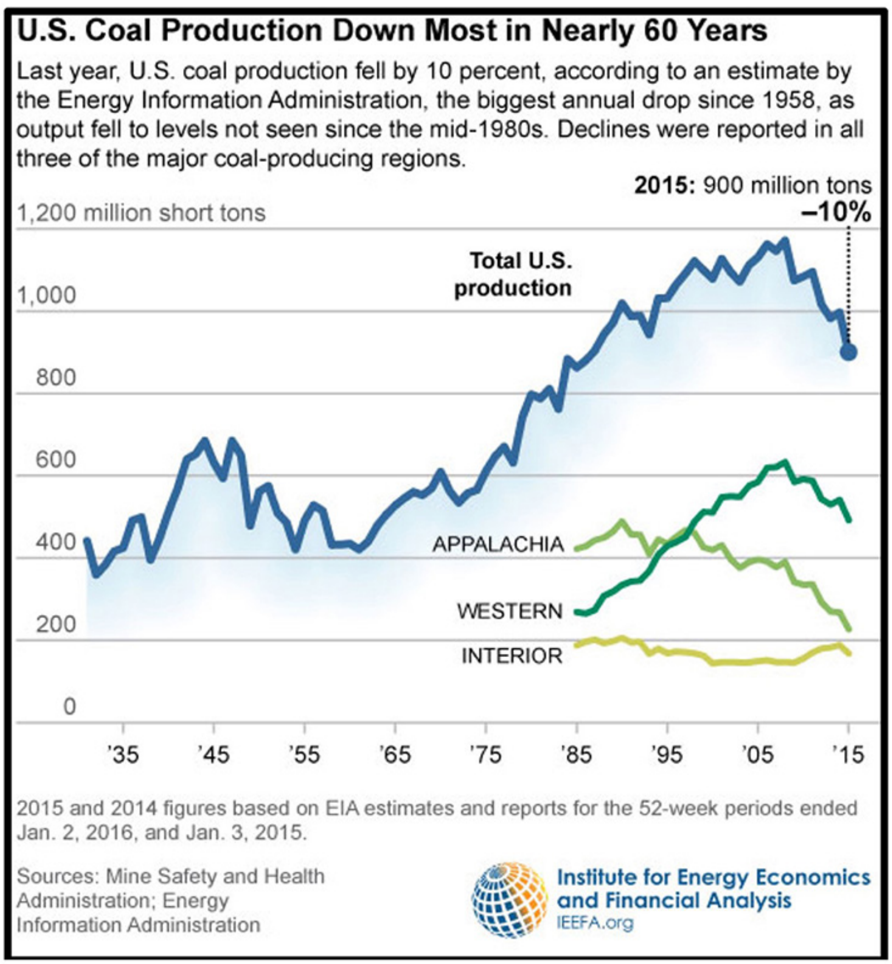

Figure 17. US Coal Production (1930-2015), (Feaster, 2016).

The situation for coal in the US is not representative of global markets. Demand for coal in developing economies, especially in China, India and Japan is projected to continue to be strong and substantially greater than in the US as access to cheap natural gas in those regions is not an option (Figure 18), (US Energy Information Administration, 2016, May). Although China is largely self-sufficient in thermal coal supply, India and Japan will rely heavily on imports. Access to these and other foreign markets would provide a boost to PRB coal production as it will enjoy the same advantage in those markets as it does in the US.

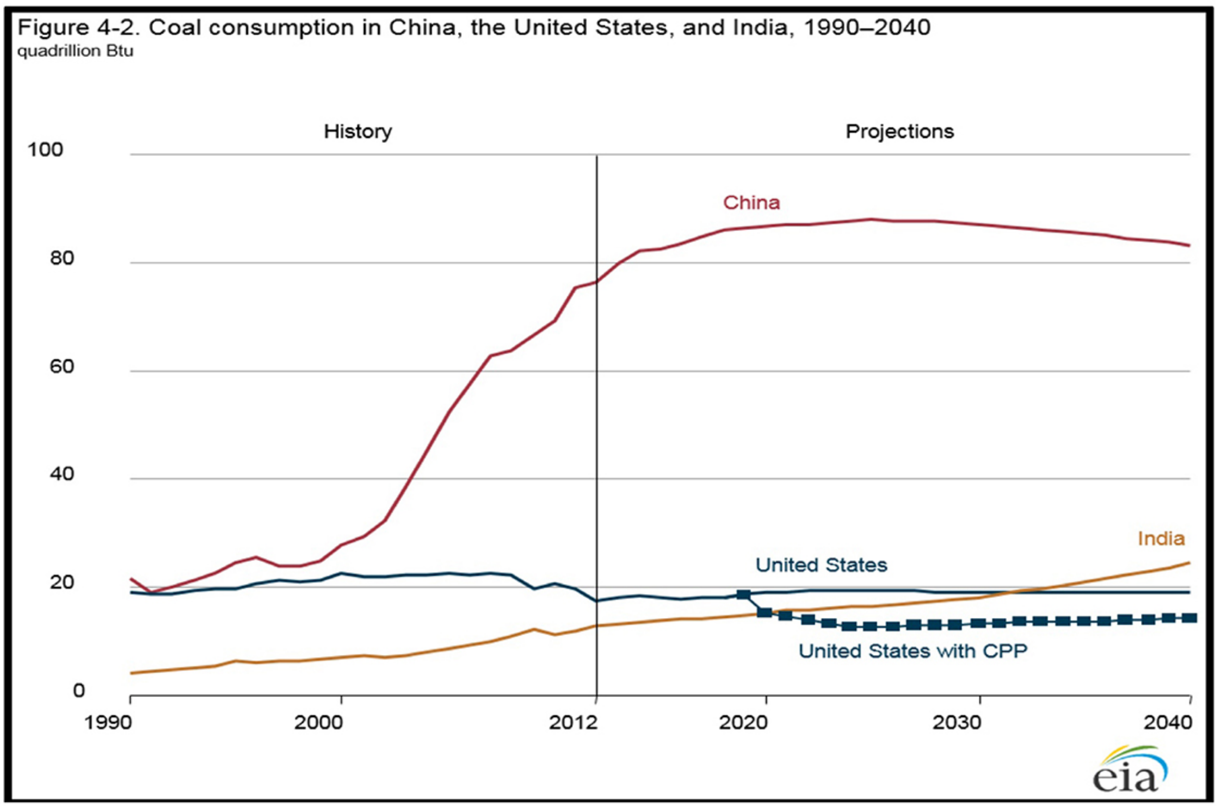

Figure 18. Coal consumption in China, US, and India (1990-2040), (US Energy Information Administration, 2016, May).

While there are a large number of international coal exporting terminals on the West and East Coasts of the US, and to the north through Canada, Wyoming is rather remote from all of these locations (Figure 19). Producers are beholden to cooperation from neighboring states to allow PRB coal to cross their land. In addition, availability of suitable railroad capabilities may be problematic.

Figure 19. US and Canadian Coal Export Terminals, (Platts, 2016).

At this time, low ocean freight rates are helping US coal compete in the international market, and they are likely to remain low for another three to five years. The primary challenge is getting the needed additional export terminals built. Presently, there are significant concerns that new terminals will expose local residents to coal dust, diesel fumes and noise pollution.

In April 2012 the EPA stated that it desired a thorough review of the consequences of coal export through northwest ports, staying the first project in the pipeline—the Port of Morrow—on the basis that there are sufficient potential negative human health and environmental factors that needed to be quantified. EPA cited potential problems including health impacts from coal dust and diesel emissions from train and barge trips through the Columbia River Gorge. They also cited problems from the effects of ozone, particulates and mercury returning on trade winds after coal is burned in Asia.

Advanced Technologies – Key to the Future of Coal Utilization

Consuming coal in combustion processes to generate electricity and power gives rise to a variety of undesirable waste products that must be managed. Clean coal technologies have evolved for decades to successfully manage a cascading set of environmental concerns that have become problems as the demand for electricity generation and other uses for coal have grown. It is crucial that research and technology development investments continue to be made in this direction if coal is to continue as a valuable primary resource for energy production.

Concern for reducing CO_2 emissions to the atmosphere are the latest in a long list of issues that have been the subject of government regulation. As such, various clean coal technologies have been applied for years, (World Nuclear Association, 2016). Some prominent examples are listed below:

- Coal cleaning by "washing" to reduce emissions of ash and SO_2 when the coal is burned.
- Electrostatic precipitators and fabric filters to remove fly ash from the flue gases.
- Flue gas desulfurization to reduce the output of SO_2 to the atmosphere. The requirement is determined by level of sulfur in the coal.
- Low-NOx burners to reduce NOx emissions by up to 40%. Coupled with re-burning techniques, NOx can be reduced 70% and selective catalytic reduction can clean up 90% of NOx emissions.
- Increased efficiency of plant—up to 46% thermal efficiency now (and 50% expected in future)—means that newer plants create less emissions per kWh than older ones.
- Advanced combustion technologies such as Integrated Gasification Combined Cycle (IGCC) and Pressurized Fluidized Bed Combustion (PFBC) enable higher thermal efficiencies.
- CSS to remove CO_2 from the flue gas and dispose of highly compressed liquid or supercritical carbon dioxide into deep geological strata.

The well-being of the coal industry has, for many years, been highly correlated with the development and successful implementation of economical coal-fired generation technologies. Many of these advances impose capital and operating cost increases together with energy consumptive penalties without benefit to the operator. It is sometimes difficult in a highly regulated industry to absorb higher costs of operation—and often necessary—to pass the increased cost on to customers.

Reducing emissions of CO_2 is the main focus of current research, development, and demonstration of future clean coal technologies. The overarching goals can be categorized into four main areas:

- Improved efficiency in the generation of coal-fired electricity – advanced energy systems;
- Reduced emissions of CO_2 per unit of energy produced from coal-fired plants – advanced energy systems and carbon capture;
- Utilization of CO_2 captured from flue gas – CO_2-EOR and conversions; and
- Safe, economical, and permanent geological storage of CO_2 – carbon storage.

Activities to achieve these goals are largely funded from government sources, and the research, development, and demonstration of advanced technologies has become a significant global enterprise, but relatively few deployments of the technologies have been achieved.

One of the biggest challenges is moving novel clean-coal technologies out of the research stage. While some of these advanced solutions have approached pilot-scale, fewer still are being demonstrated. At each stage, the cost of projects goes up and access to funding beyond the research stage into pre-commercial demonstration is problematic resulting in what is euphemistically called the "valley of death" for promising new technologies. In fact, adequate funding to field test and evaluate individual technologies, and then scale up to provide confidence in their performance is the biggest obstacle to implementing successful CO_2 reduction technologies.

Current challenges for technologies to achieve required (i.e., by the CPP) reductions in CO_2 emissions for coal-fired power plants are:

- Technology readiness – many of the technologies have not been sufficiently demonstrated at scale;
- High capital cost;
- High operating cost;

- Parasitic energy load; and
- What to do with the massive volumes of CO_2 captured at the point of combustion, including development of pipeline infrastructure for acceptable permanent disposition or utilization.

Global efforts to address all of these challenges are continuing and progress is being made. A number of projects in the US and Canada are underway to demonstrate the efficacy of low or zero emissions coal-fired generation, and to gain experience to decrease capital and operating costs to acceptable limits. Three notable projects are:

- Kemper County – Southern Company's Mississippi lignite-fueled IGCC plant with CO_2 capture and CO_2-EOR; US Department of Energy (DOE)-financed; under construction. Full operation expected October 31, 2016, (MIT, 2016).
- Petra Nova W.A. Parish – NRG's PRB coal-fired unit with retrofit post-combustion CO_2 capture and CO_2-EOR; DOE support; under construction. Full operation expected 4th Q 2016, (Global CCS Institute, 2016, Petra Nova).
- Boundary Dam – SaskPower's Saskatchewan lignite-fueled unit with retrofit post-combustion CO_2 capture and CO_2-EOR; Canadian government support; operational for two years, (Global CCS Institute, 2016, Boundry Dam).

Globally, there are 15 large-scale CCS projects in operation with an additional seven under construction. For these projects, the experience and knowledge gained are crucial to the ultimate commerciality of CCS technologies. A large body of information for all of these projects is available at the Global CCS Institute website.

As these large CCS projects have progressed, global awareness of the need to find many suitable utilization (thus CCUS) options for the massive quantities of CO_2 that will result from wide implementation has grown. The favorite options to date have been a relatively narrow range of geologic storage processes – from the well-developed CO_2-EOR which can be a profitable enterprise, to storage of CO_2 in a variety of subsurface geologic settings without much hope for revenue generation. All of these methods hold promise for permanently storing CO_2 below the Earth's surface, but there are geographic (e.g., lack of developed infrastructure for the transport of CO_2 from capture facility to storage facility) and volumetric (e.g., insufficient proof that reservoir capacity exists to store the quantities of CO_2 that need to be captured) limitations that preclude them from being universal solutions.

A publication commissioned by the National Coal Council entitled, "CO_2 Building Blocks: Assessing CO_2 Utilization Options," was recently published, (Coddington et al., 2016). The lead author on this white paper was Kipp Coddingtion, Director of Energy Policy and Economics at the UW School of Energy Resources, and a National Coal Council Coal Policy Committee member.

The referenced report points out that "CO_2-EOR represents the most immediate, highest-value opportunity to utilize the greatest volumes of anthropogenic CO_2." It further states that "the economic value is sensitive to the price of oil, and will vary in response to oil market conditions," and recommends continued government investment and incentives to spur further development of CO_2-EOR projects. Wyoming has the advantage of having the Enhanced Oil Recovery Institute to work with industry in developing and implementing CO_2-EOR technologies in Wyoming.

The report also recognizes the urgent need for research aimed at developing non-geologic CO_2 utilization pathways, specifically chemistry solutions that break apart the CO_2 molecule, or convert it to other valuable products. Both of these processes are far from reality and represent significant thermodynamic and kinetic challenges.

Wyoming Integrated Test Center (WYITC)

Utilization pathways are the main purpose for Wyoming's Integrated Test Center (WYITC) that has teamed with the XPRIZE Foundation to develop a research facility at Basin Electric's Dry Fork Station near Gillette.

In 2014, the Wyoming State Legislature appropriated $15 million for the design, construction and operation of an integrated test center to study the capture, sequestration and management of carbon emissions from a Wyoming coal fired power plant. Basin Electric will host the facility and will provide in-kind support. Additionally $5 million will be provided by Tri-State Generation and Transmission Association and a further $1 million has been pledged from the National Rural Electric Cooperative Association.

The focus of the WYITC is to provide space for researchers to test CCUS technologies using actual coal-based flue gas derived from the utility plant. The WYITC is pioneering, in that it is one of only a few facilities around the world and only the second one in the US capable of validating CCUS technologies outside of the laboratory.

Engineering, site preparation and other construction began in the spring of 2016 (Figure 20). The WYITC is scheduled to be completed in the summer of 2017.

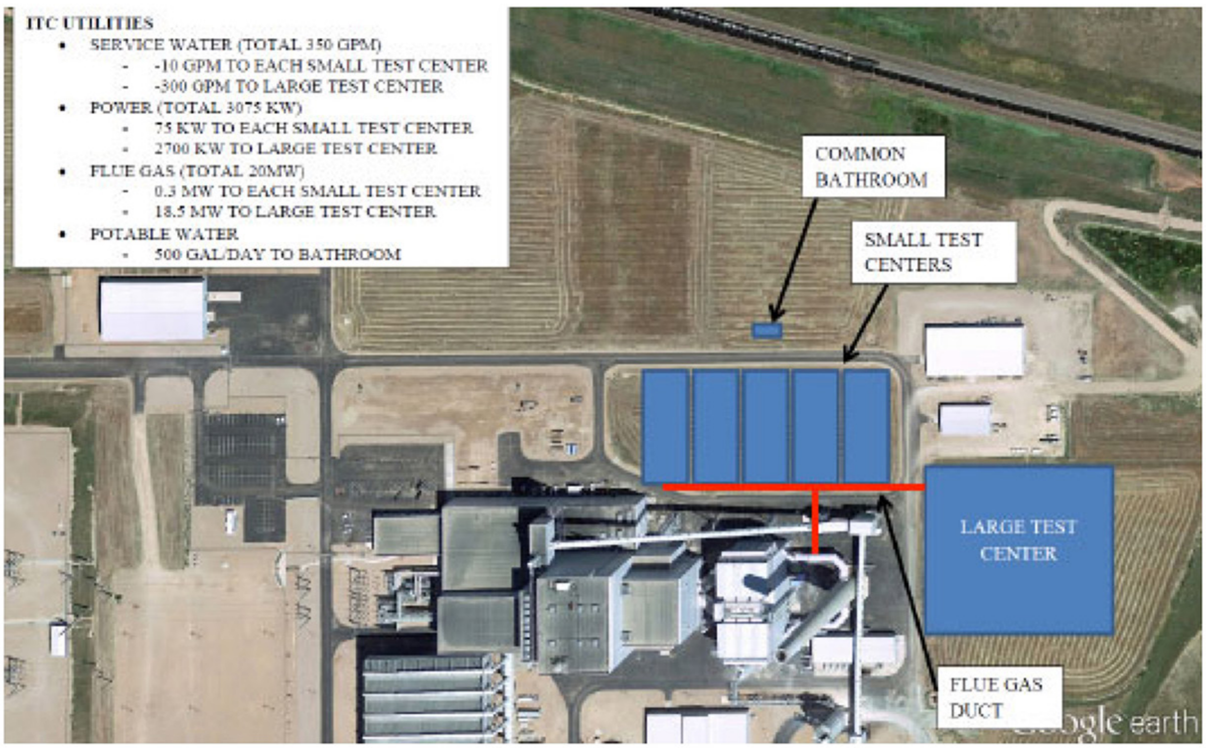

Figure 20. Layout of the ITC at Dry Fork Station operated by Basin Electric near Gillette, (Source: Wyoming Infrastructure Authority, 2015).

Wyoming and UW Investments and Achievements in Clean Coal Technologies

Since 2006, the State of Wyoming has invested significant state and AML funds through UW to support research to advance clean coal technologies. UW has also been the recipient of funding from the DOE for research in advanced coal technologies in partnership with China. These funds have been highly leveraged with federal grants, private sector funding, and collaboration with numerous research groups that provided their own funding. Primary among these programs has been:

- Wyoming Clean Coal Technology Fund (CCTF);
- Wyoming Carbon Underground Storage Project (WY-CUSP);
- Joint US/China Clean Energy Research Consortium – Advanced Coal Technology Center (CERC); and
- Carbon Engineering Initiative.

These are by no means the entirety of the research accomplished in the field of clean coal technologies at UW; many faculty have received other grant money to conduct individual research that falls into this category.

Wyoming Clean Coal Technology Fund (CCTF)

In 2007, House Bill 301 created the Clean Coal Task Force (Task Force) consisting of the current voting members of the UW Energy Resources Council (ERC). That legislation appropriated $2.5 million from the general fund to the CCTF which could only be expended upon appropriation by the Legislature. The legislation also directed the Task Force to solicit proposals for research in clean coal technologies and required that the appropriation could not be disbursed unless the projects demonstrated a dollar-for-dollar match from non-state funds.

The CCTF was created to stimulate research and development in the area of low-emissions and advanced conversion technologies. The objectives of the program were to:

- Enable and accelerate demonstration and early commercial deployment of conversion technologies that have the potential to enhance and improve the use of sub-bituminous coal at high altitudes, specifically in Wyoming;
- Generate and test new ideas for significant improvement and cost reductions in next-generation, low-emissions, and advanced conversion technologies; and
- Support collaborative research and development in accomplishing the above objectives.

The CCTF supported proposals addressing the following:

- Research and development of new or improved conversion technologies that reduce emissions;
- Pilot-scale demonstration of emerging technologies;
- Engineering scale-up of demonstrated technologies; and
- Integration and operation of CO_2 capture technologies.

In subsequent years, various additional changes occurred, but the mission of the CCTF remained the same. Additional funds were appropriated to the CCTF in 2008, 2009, 2010, and 2012 – all from AML funds (Table 1).

Appropriation	Amount	Reversion Date
2007 Appropriation	$2,500,000	No reversion date
2008 Appropriation	$3,800,000	June 30, 2012
2009 Appropriation	$10,613,047	June 30, 2012
2010 Appropriation	$14,000,000	June 30, 2014
2012 Appropriation	$10,000,000	June 30, 2016
Total	**$40,913,047**	---

Table 1: Funds Appropriated for Clean Coal Technology Research, (University of Wyoming, School of Energy Resources, 2016).

SER issued a request for proposal (RFP) each year from 2007 to 2012 to solicit proposals to conduct research in the following technology areas:

- Pre-combustion/pre-gasification technologies
- Combustion and gasification design technologies
- Post-combustion/post-gasification gas clean-up technologies
- Advanced cycle technologies
- Air separation technologies
- Carbon capture and sequestration technologies
- In situ gasification technologies
- Coal to liquids/coal to hydrogen technologies
- Economic analysis

Each proposal that was submitted had to demonstrate that it had secured non-Wyoming state funds in an amount equal to, or greater than, the CCTF dollars they sought. SER managed the review of the proposals with outside experts as reviewers. The Task Force recommended the winning proposals to the Joint Minerals, Business, and Economic Development Committee who then concurred on the awarding of funds.

Over the course of the program—which came to an end on June 30, 2016—the CCTF provided over $41 million (including interest from the 2007 appropriation) to 52 research projects. Of the 52 projects originally funded, 46 were completed, three projects were terminated prior to completion and three projects failed to negotiate a contract. Projects receiving awards are identified on the SER website at: http://www.uwyo.edu/ser/research/advanced-conversion-research/.

The CCTF program was completed by June 30, 2016. Because researchers seldom spend their budgets down to a zero balance and because three projects were terminated early, about $900,000 was returned to the state in July 2016.

From 2011 to 2015, SER hosted an annual research symposium to provide a forum for researchers funded through the CCTF to present the results of their work to the public. Researchers from each of the 46 completed projects presented their results in the public forum. Each symposium was well attended by a diverse audience of industry experts, academicians, government representatives, and the general public. In addition to publicly presenting research findings, each researcher submitted a final executive summary and final technical report of their work. The executive summaries for each of the funded and completed projects can be found on the SER website at: http://www.uwyo.edu/ser/research/advanced-conversion-research/final-executive-summary-reports.html.

Finally, SER was required by legislation to present an annual report to the Joint Mineral, Business and Economic Development Committee no later than October 1 of each year. These reports can be found on the SER website at: http://www.uwyo.edu/ser/about-us/annual-reports.html.

Wyoming Carbon Underground Storage Project (WY-CUSP)

The Wyoming Carbon Underground Storage Project (WY-CUSP) was overseen by SER's Carbon Management Institute (CMI), then led by Dr. Ronald Surdam. WY-CUSP was a pioneering five-year research program designed to characterize two potential carbon storage reservoirs (the Weber Sandstone and Madison Limestone, both deep saline aquifers) at the Rock Springs Uplift in southwestern Wyoming. The WY-CUSP program was funded by the DOE ($12 million) and the State of Wyoming ($14 million), and included scientists from UW and Los Alamos National Laboratory, along with industry partners Baker Hughes, Geokinetics, EMTEK, ExxonMobil, and others.

Through extensive field and laboratory research, sophisticated digital modeling and analysis, and exacting risk assessment protocols, WY-CUSP produced a detailed site characterization of the two deep saline aquifers for potential pilot- and commercial-scale CO_2 storage. Significantly, during the WY-CUSP project UW drilled a 13,000 ft well on the Rock Springs Uplift near Point of Rocks and the Jim Bridger Power Plant (Figure 21). The well was designated as RSU#1, and was drilled at an expense of over $4 million. The project thoroughly sampled and analyzed rock and fluid samples to assess both storage reservoirs and seals. The research team published a book entitled "Geological CO_2 Storage Characterization: The Key to Deploying Clean Fossil Energy Technology," (Surdam et al., 2013) and wrote a series of reports to document the findings and communicate best practices for CO_2 disposal reservoir characterization.

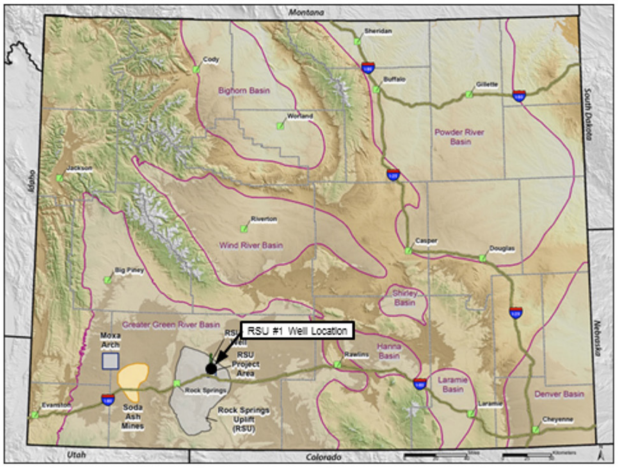

Figure 21. Rock Springs Uplift and the RSU #1 Well, (University of Wyoming, School of Energy Resources photo archive).

Currently, the Rock Springs Uplift represents one of the most thoroughly analyzed CO_2 storage sites in North America. Results of the extensive modeling done under the WY-CUSP project suggest that the Weber Sandstone and Madison Limestone reservoirs could safely store 13 billion tons of CO_2 thousands of feet below the closest drinking water aquifers. As a result of what was learned during the WY-CUSP program, it is likely that a commercial CO_2 storage facility of global significance could be established on the Rock Springs Uplift as rapidly as anywhere else in North America.

Finally, and importantly, the five-year WY-CUSP project established UW as a leading CO_2 research center in the US. The success of the WY-CUSP program paved the way for millions of dollars in additional grants to study pressure management, produced water treatment, and mineral extraction from brines.

Joint US/China Clean Energy Research Consortium – Advanced Coal Technology Center (CERC)

The Joint US/China Clean Energy Research Consortium – Advanced Coal Technology Center (CERC) is a collaborative effort between the DOE and the Chinese Ministry of Science and Technology. The CERC program aims to stimulate cooperative research between leading institutions and commercial entities in each country to solve common problems in the energy sector. The partnership will accelerate the rapid development of clean coal technology in both countries while forging meaningful relationships between US and Chinese researchers, and advancing US and Chinese leadership in energy technology and innovation. The presidents of both countries have acknowledged the importance of the CERC programs.

CERC was originally established as a five-year program. DOE provided $2.5 million each year and required an equivalent amount in match for US partners. UW has received about $700,000 annually for its part of the program. CERC was recently extended for an additional five years. SER and CMI were founding partners in the CERC program. West Virginia University is the lead institute, and UW researchers play significant roles. The full list of partners that have participated on the US side can be found on the CMI website at: http://www.uwyo.edu/cmi/research-projects/project-uschina-clean-energy.html.

UW researchers have been working closely with Chinese researchers from Shaanxi Province and the Yanchang Oil Company to characterize and evaluate the geologic CO_2 storage potential of the Majiagou Limestone at a site near Yulin in the Ordos Basin of Shaanxi Province, which also contains China's largest coal resource. The research will also evaluate the potential for CO_2-EOR in the basin. Post-characterization research will involve subsurface CO_2 injection simulation and risk assessment. This research is imperative because existing coal-to-liquid and coal-to-chemical plants in this area currently vent more than 30 million tons of highly concentrated CO_2 annually. UW and its partners aim to use the results of this research to pave the way for successful CO_2 storage in the Ordos Basin, thereby gaining and transferring important knowledge for future storage efforts in Wyoming.

Carbon Engineering Initiative – New, Non-Energy Market for Coal

The UW Carbon Engineering Initiative is based on the premise that there is significant non-energy value in PRB coal. The vision of this initiative is to develop coal as a feedstock for a manufacturing sector in Wyoming to make carbon-based chemicals and materials.

The first oil refinery in the US was built more than 150 years ago by Edwin L. Drake to upgrade coal-oil. However, as demand for transportation fuels increased, refiners turned to abundant cheap crude oil to meet the growing demand and to manufacture most of the products that had been made from more expensive coal tar.

A wide range of products can be made from coal and manufacturing plants that do so exist and continue to be built in China, Germany and India. Most of these products are in high demand and attract premium prices. The growing demand for carbon-based products is motivated by:

- Light weighting of engineered components to save energy and reduce engineering costs;
- Increasing cost and decreased availability of corrosion resistant metals and alloys; and
- Breakthroughs in understanding carbon materials and development of new classes of materials that have mechanical, thermal, chemical or physical properties superior to any other currently known material.

Consumptive growth of carbon-based materials is greater than GDP in many markets today and is likely to continue to grow. Preliminary investigation has shown that Wyoming has potential to become a major player in manufacturing of carbon-based chemicals and materials for the following reasons:

- The composition of PRB coal is well suited as a feedstock;
- Wyoming is well located geographically, with major transportation assets to access markets for products;
- Wyoming has a well-trained workforce to support manufacturing, as well as the ability to develop programs to provide training for the future; and
- Wyoming offers significant advantages for new business investment and expansion.

UW's approach to carbon engineering to accomplish coal conversion is similar to the approach taken by an oil refinery (Figure 22) in obtaining useful chemicals and materials from the raw material through a sequential series of processes. What differentiates UW's approach from standard practice in converting coal to other products is the focus on low-intensity, non-gasification processes, at least in the early stages of conversion.

Computer simulation and other carbon engineering activities have taken place at UW over the past 18 months to understand the properties of PRB coal, to maximize the yield of carbon-based intermediates and finished products, and to evaluate high-level economics of a PRB coal-based manufacturing enterprise. Important constraints that have guided this work from the beginning are: zero or minimal CO_2 emissions (or 100% utilization of any CO_2 produced), zero effluent discharge, and water consumption neutrality. The results to date have been positive.

During the 2016 Wyoming Budget Session, the Legislature specified an appropriation of $2 million in one-time funding to the University of Wyoming for the purpose of carbon engineering research. Early in FY 2017, SER and the College of Engineering and Applied Science jointly issued an RFP on campus. The RFP sought to allocate those funds across several categories of research that are required to address critical technology gaps that must be closed in order to achieve the value chain for coal-to-valuable products. Table 2 lists the projects that were selected as a result of that RFP. A large number of faculty and graduate researchers will be conducting research to complete these projects. All of these projects can be completed during the current biennium, and all of the principle investigators intend to use the awarded funds to leverage other sources of funding to continue research in these areas.

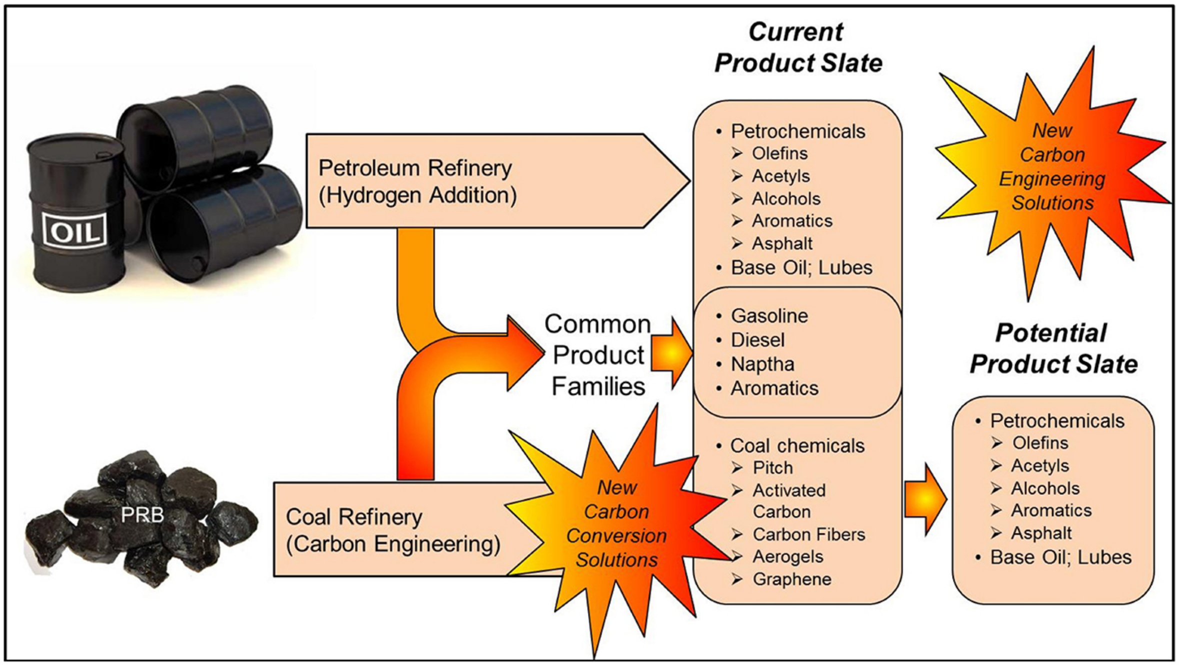

Figure 22. UW's representation of a "coal refinery," (Source: University of Wyoming, School of Energy Resources, 2015)

Finally, UW has spent considerable time and effort to generate interest and enthusiasm in the private sector for collaboration with UW in this important new area. To date, UW has received more than a dozen expressions of interest, resulting in solid partnerships.

As an example, a memorandum of understanding was recently signed by Governor Meade with JCOAL (Japan Coal Energy Center). JCOAL is a large, Tokyo-based trade association and research organization that defines its role as to support "the development, commercialization, transfer and dissemination of coal technologies…" UW will work with some of JCOAL's 165 member companies in a variety of ways to advance carbon engineering and other clean coal technologies. To kick off this partnership, SER is organizing a joint workshop in 2017 in Wyoming for both sides to discuss current capabilities and identify early areas for cooperative research.

Research Category	Project Title
Process Conversion Platforms	Characterization of coal intermediate products for various process routes
	Supercritical extraction of coal and biomass
	Ionic separation & decomposition of Wyoming coal
	Carbon fiber from solvated coal tar pitch
Coal Based Intermediate Products	Magnetic properties of Wyoming coal residues and product possibilities
	Coal residue as a soil amendment
	Road paving and asphalt from coal
	Green building materials from coal
	Carbon fiber precursors from coal
Coal Based Derivative Products	Graphene production from Wyoming coal
	Advanced carbon engineered products from coal
	Manufacture of nitrogen containing graphitic materials for energy applications
	Manufacture of silicon carbides from coal
	Advanced manufacture of silicon carbide composites from coal
Gas Clean Up & Treatment	CO_2 + H_2 dry reforming process feasibility evaluation using cerium doped Ni catalyst

Table 2. Project titles selected for research funding under the Carbon Engineering Initiative, (Source: University of Wyoming, School of Energy Resources, 2016).

Conclusions

Coal is an important part of Wyoming's past, its economy and its future. Production of coal in the state is facing unprecedented challenges due to reduced coal-fired generation capacity in the US. While the need for coal to fuel base-load capacity in the US will not disappear anytime soon, future demand for Wyoming coal will be dependent upon a complicated mix of policy, economic and technical factors. PRB coal appears to have an advantage over coal from other regions of the US due to its low sulfur content and a low cost of production. As such, PRB coal will likely continue to gain market share against other US coals. However, the overall market volume is not expected to grow.

Three main factors exert an outsized influence on coal markets in the short-to-medium term:

1. Competition with abundant and cheap natural gas supply;
2. National and international CO_2 emissions policies; and
3. Growth of renewable energy resources – incentives and cost reduction.

All projections indicate future supplies of natural gas in the US will remain plentiful, and thus will ensure a low-price environment for the foreseeable future. Policy and regulatory pressure aimed at reducing the use of coal is likely to increase, notably through the regulation CO_2 emissions. Construction of new renewable energy assets will continue to accelerate, especially with continuation of tax incentives and on the assumption that the Court upholds the validity of the CPP. CCUS technology development and implementation is progressing, but high capital and operating costs associated with introduction of available technologies, together with high costs of demonstration at scale and lack of infrastructure and markets for CO_2 are barriers to full-scale deployment. These factors represent a significant challenge for both the existing coal-fired generation fleet—where retrofit will undoubtedly add to the cost of electricity produced—and for the construction of new coal-fired generation plants in the future.

Erosion of demand for coal is likely to abate somewhat in the near-term due to the urgency of preserving base-load generation capacity. On the other hand, reduced demand will likely result in response to implementation of new clean energy policy. Coal demand is likely to reach a steady, albeit reduced state over the long term, largely because of the difficulty and impracticality of switching out all of the coal-fired generation fleet. Access to export markets for coal would ameliorate the reduced coal demand in the US and progress in identifying and developing suitable infrastructure and export facilities is important. The western Pacific Rim and India are the most promising markets for export of PRB coal.

Investment by the state and UW in new technology to preserve existing markets for Wyoming coal should focus on efficiency gains in coal-fired generation, CCUS and other emission reduction technologies. UW should capitalize on its leading position in CO_2 storage and CO_2-EOR technology and further its work to target efficient coal combustion and integrated CO_2 capture. Remaining distinguished and pioneering in approach are imperative for gaining an advantage in capturing outside funding for research, demonstration, and deployment of commercial projects.

Developing new markets for coal as a feedstock to manufacture non-fuel and energy products holds promise for developing a manufacturing sector with associated product conversion industries in the state. Doing so shows promise for creating significant positive economic impacts, particularly in terms of jobs creation and other local economic benefits.

It is recognized that the magnitude of future revenue contribution to the state's economy will be dependent upon how tax considerations are handled by the Legislature. This said, UW will continue to leverage the funds provided by the state by strategically and sharply focusing research on high-impact areas, aggressively pursuing external funding with external agencies and developing collaboration with private industry and national laboratories to address technology needs. Supporting development of a product manufacturing base in the state—built upon the abundant and inexpensive natural mineral wealth—will be a priority. These pursuits will involve deepening the ongoing relationships with other state entities such as the Wyoming Business Council and the Wyoming Infrastructure Authority.

BIBLIOGRAPHY

Bibliography

Anderson, C. L. (2016). A History of Coal and Mining in Wyoming. Retrieved from http://www.wsgs.wyo.gov/energy/coal-history

Anderson, C. L. (2016). The Coal Business in Wyoming. Retrieved 2016, from WyoHistory.Org: http://www.wyohistory.org/encyclopedia/coal-business-wyoming

Berman, A. (2015, July 31). A Reality Check for U.S. Natural Gas Ambitions. Retrieved from OilPrice.com: http://oilprice.com/Energy/Natural-Gas/A-Reality-Check-For-US-Natural-Gas-Ambitions.html

Bradley, D. (2016, March 16). NGI's Daily Gas Price Index. Retrieved from Natural Gas Intel: http://www.naturalgasintel.com/articles/105713-natgas-to-hold-onto-power-generation-lead-over-coal-this-year-eia-says

Cleaves, B. (2015, August 6). Biomass's Role in Clean Power Plan. Retrieved from Biomass: http://biomassmagazine.com/articles/12317/biomassundefineds-role-in-clean-power-plan

Clyde Bergemann Power Group. (2016). PRB Coal Properties. Retrieved from Clyde Bergemann Power Group: http://www.boilercleaning.org/Applications/knowledgeBase/PRBcoal/PRBcoalProperty.htm

Coddington, K., & et al. (2016, October). CO_2 Building Blocks. Retrieved from National Coal Council: http://www.nationalcoalcouncil.org/Documents/CO_2-Building-Blocks-2016.pdf

Dorgan, R. (2016, January 25). Wyoming Coal Production hit a 13-year low in 2015. Retrieved from Casper Star Tribune: http://trib.com/business/energy/wyoming-coal-production-hit-a--year-low-in/article_3c713427-48ee-5100-9b69-49e815b4e5d0.html

Feaster, S. (2016, January 13). Data Bite: US Coal Production is Down Almost Everywhere, and Off by Double Digits in Key State. Retrieved from Institute for Energy Economics and Financial Analysis: http://ieefa.org/10251-2/

Feldscher, K. (2016, August 17). Natural gas expected to pass coal in carbon emissions. Retrieved from Washington Examiner: http://www.washingtonexaminer.com/natural-gas-expected-to-pass-coal-in-carbon-emissions/article/2599562

Global CCS Institute. (2016). Boundary Dam Carbon Capture and Storage Project. Retrieved from Global CCS Institute: https://www.globalccsinstitute.com/projects/boundary-dam-carbon-capture-and-storage-project

Global CCS Institute. (2016). Petra Nova Carbon Capture Project. Retrieved from Global CCS Institute: https://www.globalccsinstitute.com/projects/petra-nova-carbon-capture-project

Godby, R. & Coupal, R. (2015, August). A Comparison of Clean Power Plan forecasts for Wyoming Coal: What impact do modeling choices make? Estimated Impacts on Wyoming Coal Production, Employment and State Revenues of the Clean Power Plan using EIA Simulation Data. Retrieved from UW Center for Energy Economics and Public Policy: http://www.uwyo.edu/cee/_files/docs/ej%20-%20eia%20cpp%20impact%20analysis-8-27-2015_rc-corrected.pdf

Godby, R., Coupal, R., Taylor, D., Considine, T. (2015). The Impact of the Coal Economy on Wyoming. University of Wyoming, Center for Energy Economics and Public Policy. Laramie, Wyoming: University of Wyoming. Retrieved May 29, 2016, from http://www.eenews.net/assets/2016/04/13/document_gw_11.pdf

Goldfuss, C. (2016, August 1). Final guidance for federal department and agencies on consideration of greenhouse gas emissions and the effects of climate change in National Environmental Policy Act Reviews. Retrieved from Whitehouse.gov: https://www.whitehouse.gov/sites/whitehouse.gov/files/documents/nepa_final_ghg_guidance.pdf

Green, M. (2015, April 14). Fueled by oil and natural gas - now and in the future. Retrieved from Energy Tomorrow: http://www.energytomorrow.org/blog/2015/04/14/fueled-by-oil-and-natural-gas-now-and-in

Hislop, J. (2016, May 25). Future Power Sector Carbon Dioxide Emissions Depend on Status of Clean Power Plan. Retrieved from North American Energy News: http://theamericanenergynews.com/energy-news/future-power-sector-carbon-dioxide-emissions-depend-status-clean-power-plan

International Energy Agency. (2007, January). Biomass for Power Generation and CHP. Retrieved from https://www.iea.org/publications/freepublications/publication/essentials3.pdf

LNG World News. (2012, June 12). EIA: US Dry Gas Production Growth Levels Off Following Decline in Gas Prices. Retrieved from http://www.lngworldnews.com/eia-u-s-dry-gas-production-growth-levels-off-following-decline-in-gas-prices/

Matek, B. (2015, February). 2015 US & Global Geothermal Power Production Report. Retrieved from http://geo-energy.org/reports/2015/2015%20Annual%20US%20%20Global%20Geothermal%20Power%20Production%20Report%20Draft%20final.pdf

MIT. (2016). Kemper County IGCC Fact Sheet. Retrieved from http://sequestration.mit.edu/tools/projects/kemper.html

Platts. (2016). US coal export terminals. Retrieved from Platts: http://www.platts.com/news-feature/2012/coal/coalexports/map

Solar Energy Industries Association. (2016). Solar Industry Data. Retrieved from http://www.seia.org/research-resources/solar-industry-data

Surdam, R. C. (Ed.). (2013). Geological CO_2 Storage Characterization: The Key to Deploying Clean Fossil Energy Technology". (R. C. Surdam, Ed.) New York: Springer-Verlag.

United Nations Framework Convention on Climate Change. (1992). Retrieved from http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf

United Nations Framework Convention on Climate Change. (2016, September 21). Retrieved from https://en.wikipedia.org/wiki/United_Nations_Framework_Convention_on_Climate_Change

University of Wyoming, School of Energy Resources. (2016) Advanced Conversion Technology Task Force Annual Report. Retrieved from http://www.uwyo.edu/ser/about-us/annual -reports

US Department of Energy. (2015) Renewable Energy. Retrieved from Energy.Gov: http://energy.gov/science-innovation/energy-sources/renewable-energy

US Department of Energy. (2015, March). Wind Vision: New Era for Wind Power in the United States. Retrieved from http://energy.gov/eere/wind/maps/wind-vision

US Energy Information Administration. (2010). Assumptions to the Annual Energy Outlook 2010. Retrieved from http://www.eia.gov/oiaf/aeo/assumption/electricity.html

US Energy Information Administration. (2012, August 27). Today in Energy. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=7710

US Energy Information Administration. (2015, May 4). Today in Energy. Retrieved from http://www.eia.gov/todayinenergy/detail.php?id=21072

US Energy Information Administration. (2015, December 17). Wyoming State Profile and Energy Estimates. Retrieved from http://www.eia.gov/state/?sid=WY

US Energy Information Administration. (2016). Shale in the United States. Retrieved from https://www.eia.gov/energy_in_brief/article/shale_in_the_united_states.cfm

US Energy Information Administration. (2016, May 11). International Energy Outlook 2016, Chapter 4. Coal. Retrieved from http://www.eia.gov/forecasts/ieo/coal.cfm

US Energy Information Administration. (2016, August). Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2016. Retrieved from http://www.eia.gov/forecasts/aeo/pdf/electricity_generation.pdf

US Energy Information Administration. (2016, September 15). Annual Energy Outlook 2016. Retrieved from http://www.eia.gov/forecasts/aeo/

US Energy Information Administration. (2016, October 12). Today in Energy. Retrieved from http://www.eia.gov/todayinenergy/detail.php?id=28312

US Energy Information Administration. (2016, October 26). Coal Markets Archive. Retrieved from http://www.eia.gov/coal/markets

US Department of Interior. (2016, January 15). Discretionary Programmatic Environmental Impact Statement to Modernize the Federal Coal Program. (Order No. 3338). Retrieved from http://www.blm.gov/style/medialib/blm/wo/Communications_Directorate/public_affairs/news_release_attachments.Par.4909.File.dat/FINAL%20SO%203338%20Coal.pdf

US Department of Interior, Bureau of Land Management. (2015, March 31). High Plains District; Powder River Basin Coal. Retrieved from http://www.blm.gov/wy/st/en/programs/energy/Coal_Resources/PRB_Coal/history.html

US Department of Interior, Bureau of Reclamation. (2016, March 3). Hydropower Program; Reclamation/Hydropower/Hydropower Industry Information. Retrieved from http://www.usbr.gov/power/edu/history.html

US Environmental Protection Agency. (2011, December). Power Plants Likely Covered by the Mercury and Air Toxics Standards (MATS). Retrieved from https://www.epa.gov/mats/power-plants-likely-covered-mercury-and-air-toxics-standards-mats

US Environmental Protection Agency. (2016). Evolution of the Clean Air Act. Retrieved from https://www.epa.gov/clean-air-act-overview/evolution-clean-air-act

Walton, R. (2015, May 15). SNL: Over 12,000 MW of coal plants will retire in 2015. Retrieved from http://www.utilitydive.com/news/snl-over-12000-mw-of-coal-plants-will-retire-in-2015/398232/

WildEarth Guardians. (2011, August). Coal Power. Retrieved from https://www.flickr.com/photos/wildearth_guardians/6082364625

World Nuclear Association. (2016, August). "Clean Coal" Technologies, Carbon Capture & Sequestration. Retrieved from http://www.world-nuclear.org/information-library/energy-and-the-environment/clean-coal-technologies.aspx

Wyoming Mining Association. (2015). The 2015-2016 Concise Guide to Wyoming Coal. Retrieved from http://www.wyomingmining.org/wp-content/uploads/2015/10/2015-16-Concise-Guide-to-Wyoming-Coal.pdf

Wyoming Mining Association. (2016). Coal. Retrieved from http://www.wyomingmining.org/minerals/coal/

Wyoming State Geological Survey. (2016). Coal Resources and Reserves. Retrieved from http://www.wsgs.wyo.gov/energy/coal-resources-reserves