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Written Testimony of James F. Wood to the U.S. Senate Committee on Energy and Natural Resources
February 7, 2019

Chairwoman Murkowski, Ranking Member Manchin and members of the Committee, thank you for the opportunity to offer relevant testimony and to answer your questions in my areas of experience and expertise.

I am the Interim Director of the Energy Institute, the Director of the National Research Center for Coal and Energy (NRCCE), and the Director of the U.S.-China Clean Energy Research Center, Advanced Coal Technology Consortium, all based at West Virginia University in Morgantown, West Virginia. The Energy Institute serves to facilitate collaborative and innovative solutions for the energy future of West Virginia and the United States. The NRCCE conducts sponsored and grant-funded research programs. The Advanced Coal Technology Consortium is one of five consortia created through a bi-lateral Protocol signed in 2009 between the United States Department of Energy and two agencies of the People's Republic of China: the Ministry of Science and Technology and the National Energy Administration. Each consortium is funded 50%-50% by the Department of Energy with matching cost share from U.S. private sector enterprises including universities. The initial phase of Center's Protocol spanned five years (2011-2015) and in 2015 was extended an additional five years (2016-2020). From 2009 to 2012, I was the Deputy Assistant Secretary for what is now called the Office of Clean Coal and Carbon Management in the U.S. Department of Energy's Office of Fossil Energy. That position is responsible for the agency's coal research program and the large demonstration projects co-funded with industry under the third round of the Clean Coal Power Initiative, including funds added from the American Recovery and Reinvestment Act of 2009.

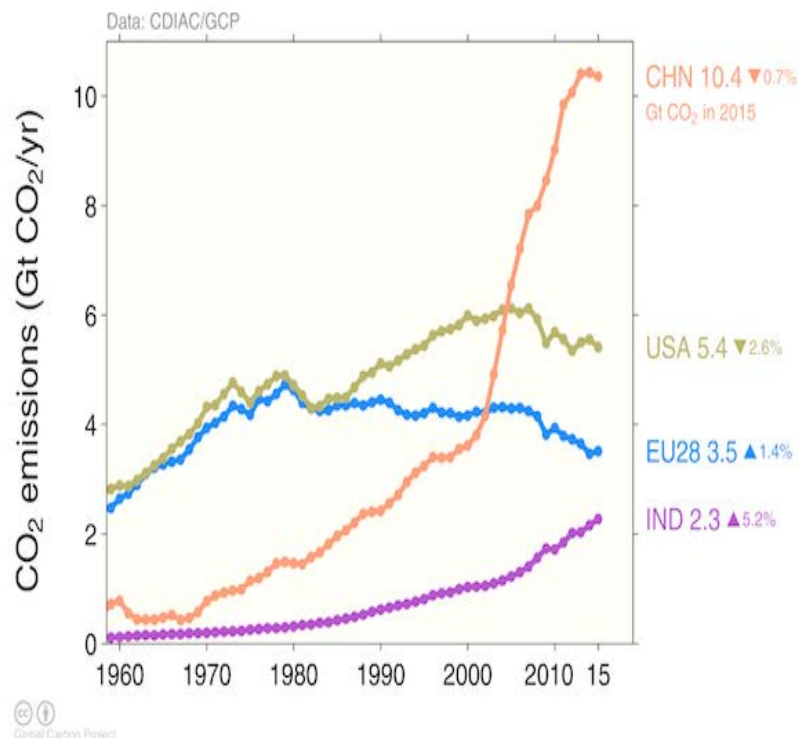
West Virginia University is a public, land-grant, research-intensive university founded in 1867. It is designated an "R1" Doctoral University (Very High Research Activity) by the Carnegie Classification of Institutions of Higher Education; funding for sponsored research programs and grants exceeded \$185 million in 2017. In addition to the Energy Institute and NRCCE, the Morgantown campus houses the Center for Alternative Fuels, Engines and Emissions (CAFEE) which discovered the Volkswagen diesel engine emissions software installation that allowed its diesel engines, in test mode, to meet emissions compliance standards, but to operate out of compliance when not in test mode.

The university conducts innovative research related to operating improvements on existing coal-fired power generation, the recovery of rare earth elements from coal wastes, instrumentation and sensor development to accurately measure fugitive emissions from shale gas wells, produce analyses of sub-surface geological structures and their applicability to store natural gas liquids (NGLs), store carbon or produce natural gas. The university also has developed sophisticated software and algorithms that can

model complex fossil fuel combustion systems, as well as complex electric transmission grids responding to variable generation from intermittent sources like solar and wind.

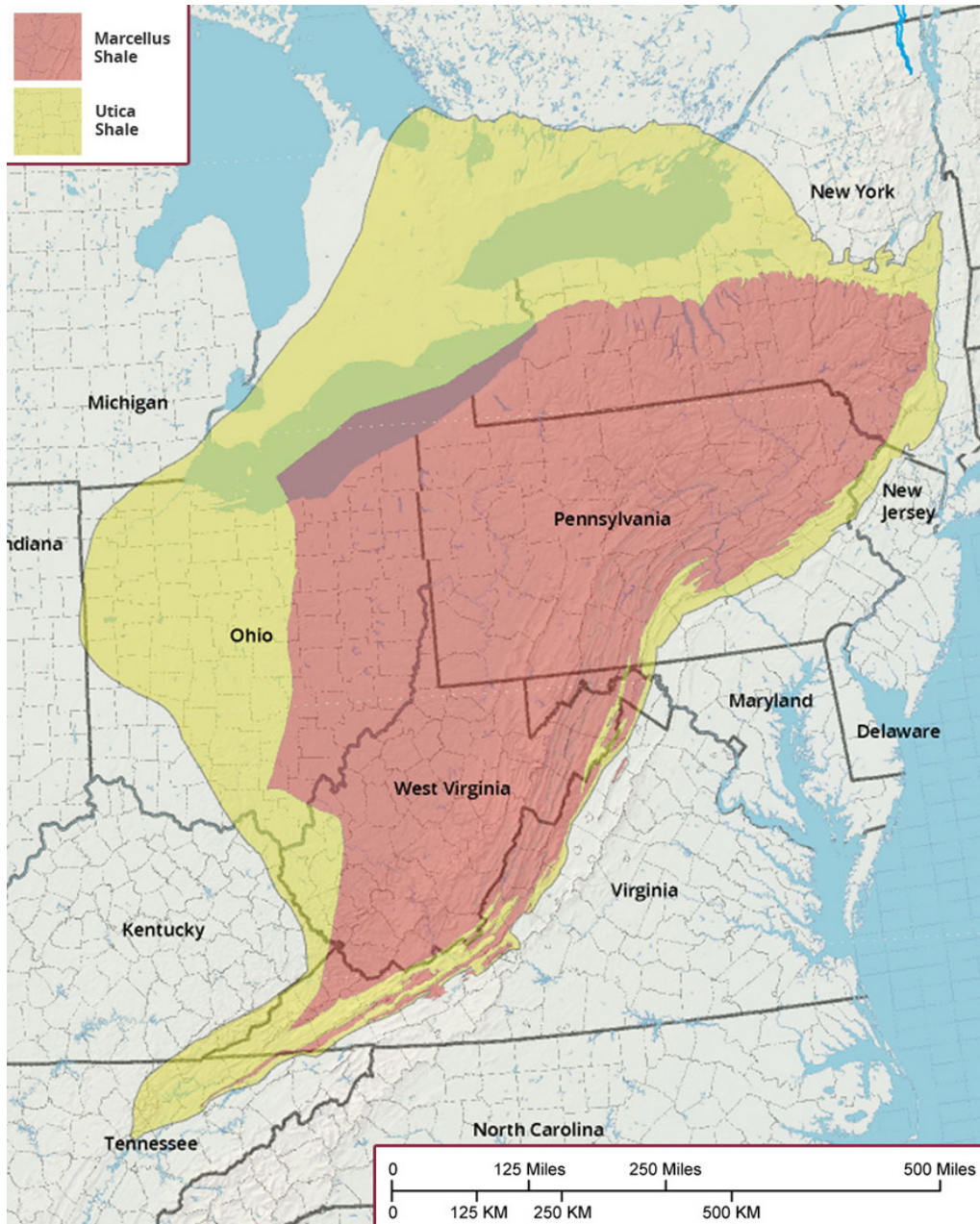
The United States has an abundance of diverse electric generation sources. Diverse sources of generation improve transmission grid operation, moderate retail electricity costs, and reduce unhealthy emissions levels. Benefits of this diversity are not unlike risk mitigation from diversity in savings and investment portfolios. Research into carbon emissions reduction is an important strategy to preserve the diversification of generation enjoyed by the United States. Carbon emissions have begun to decline in absolute numbers. This is due to substitution of lower carbon emitting and renewable generation for coal-based generation. Part of this is also due to the reduced growth of energy demand over the last decade and one might expect this growth rate to increase as U.S. GDP growth rates increase. Having economic and commercial technologies to capture, reuse or permanently store carbon before its emissions are atmospheric, should be part of strategies to maintain the diversification of generation, and indeed provide economic benefits when these technologies are exported.

Many parts of the world are not equally blessed with diverse generation, and to a larger extent must rely on inexpensive local fuel sources high in carbon and resulting carbon emissions. Among these are the two most populous countries in the world, China and India. In the 2000 World Energy Outlook, the International Energy Agency estimated China's emissions would be 18% of the global total in 2020. In 2015 the actual value was 29%. Recently, Chinese President Xi Jinping announced China's carbon emissions would peak in 2030.



West Virginia has significant quantities of steam and metallurgical coal reserves. Along with Ohio, Pennsylvania, western New York and south eastern Kentucky, West Virginia shares portions of huge natural gas and natural gas liquids (NGLs) reserves in the Utica and Marcellus shale formations. West

Virginia desires to harness the economic value of these reserves to grow its economy, attract industry, provide jobs, improve education opportunities, and increase its citizens' wealth.



Examples of West Virginia University's innovative research activities that support these aspirations include:

1. Developing concentrated rare earth element oxide extraction processes from U.S. coal mine wastes, including acid mine drainage. This work is being done in collaboration with Virginia Tech and Rockwell Automation. WVU has constructed a lab scale operation producing commercial concentrations of rare earth oxides. Rare earths are critically important in defense and industrial products--- and are now produced in countries that often set prices and control availability;
2. Another area of promising research at WVU involves replacing high carbon emitting steam methane reforming processes with catalyst-based, non-oxidative thermochemical conversion of methane to CO₂-free hydrogen and solid, highly pure crystalline carbon nanotubes. Collaboration includes PNNL and Southern California Gas.
3. Development of techniques and technologies to integrate state of the art down-well innovative fiber optic and micro seismic sensors; improvement in data collection, and production tools with advanced big data and machine-learning applications for accurate reservoir characterization and modelling of the Marcellus and Utica shales. These advances will better describe formation performance during formation stimulation and drilling, including gas production flow paths and flow paths of stimulation fluids and proppants that improve safety and well bore efficiency while simultaneously reducing the environmental footprint;
4. In conjunction with the National Energy Technology Lab (NETL), development of tools, techniques and above-well sensors that detect even small releases of greenhouse gasses during stimulation, drilling or production operations of shale gas wells. This work involves multiple researchers, including CAFEE, and has led to improvements in fuel efficiency of surface equipment and reductions of fugitive methane emissions further reducing the environmental footprint;
5. Models of complex combustion systems that burn fossil fuels in pure oxygen in order to explore the thermodynamic properties of flame development, which is a precursor to designing pilot and demonstration combustors with low cost carbon capture and efficient heat transfer properties;
6. Models of complex combustion systems that burn fossil fuels in vessels containing inexpensive oxidants, like iron oxide, or aluminum oxide, that can be used to develop technical solutions for combustion without air, which may generate pure dense phase supercritical CO₂, ready to transport to a safe storage repository, for reuse in enhanced oil recovery from wells that no longer have sufficient pressure to continue producing, and for new uses that are currently in research;
7. Research into technical and economic advances of renewable geothermal sources of energy. Eastern West Virginia has a valuable source of geothermal energy and WVU, in conjunction with LBNL, Cornell and the WV National Guard is researching designs for the deep direct use of this resource on campus and in Morgantown;
8. WVU also led a tri state (WV, PA, OH) effort with Ohio and Pennsylvania Geologic Societies and State Departments of Commerce to undertake rigorous sub-surface analyses of proposed Appalachian Storage Hub locations for NGLs that will greatly reduce fugitive emissions of shale gas produced in Appalachia as compared to emissions released if that gas was transported to hubs south or east of Appalachia.

9. Models of complex electric transmission systems that must maintain voltage, frequency and capacitance stability when multiple sources of diverse generation are competing to supply a demand curve that does not match the intermittent properties of the diverse sources of generation;

West Virginia University's role in managing the U.S.-China Clean Energy Research Center Advanced Coal Technology Consortium gives the university good visibility into China's research and development on solutions to carbon emissions and coal-to-products. Consortium members include the University of Wyoming, the University of Kentucky, Washington University (St. Louis), the National Energy Technology Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Alstom (now GE) Power, Arch Coal, Duke Energy, the Electric Power Research Institute, the Gas Technologies Institute, Peabody Energy, the Southern Company, and Stock Equipment Company. Research undertaken by the consortium includes advanced combustion technologies, including chemical looping and pressurized oxy-combustion of coal, pre- and post-combustion carbon capture technologies and techniques, including micro-algae absorption of CO₂ with co-production of medicinal chemicals, and advances in carbon conversion technologies.

In the seven years subsequent to the Protocol signing ceremony, a number of important relationships have developed between U.S. and China consortium members. West Virginia University has ongoing collaborations with China Energy Investment Corporation Ltd., the world's largest power company and China's largest coal producer. There is evidence through these academic relationships that China depends on coal for approximately 85% of its energy needs. About 50% of its coal consumption is used in the generation of electricity. The balance is used to derive chemicals, and liquid fuels from coal. China's dependence on coal should not be underestimated, nor should effects of the lack of generation diversity on its transmission grid. As a consequence, China has made large commitments and investments into cleaner utilization of coal and particularly criteria and climate change emissions reductions. The chart below compares China's current regulations for criteria emissions with those of the U.S. and EU. The *, **, *** notations refer to location- relevant (usually Provincial) limits now overridden by the lower National Limits:

TABLE 1

Coal-fired power emission standards in China, the United States, and the European Union

Conventional air pollution standards for new and existing power plants, in milligrams per cubic meter (mg/m³)

		China	United States	European Union
Nitrogen oxide	Existing	100*	135	200
	New	50	95	150
Sulfur oxide	Existing	50/100/200**	185	200
	New	35	136	150
Particulate matter	Existing	20/30***	19	20
	New	10	12	10

<https://www.vox.com/energy-and-environment/2017/5/15/15634538/china-coal-cleaner>

<https://www.americanprogress.org/issues/green/reports/2017/05/15/432141/everything-think-know-coal-china-wrong/>

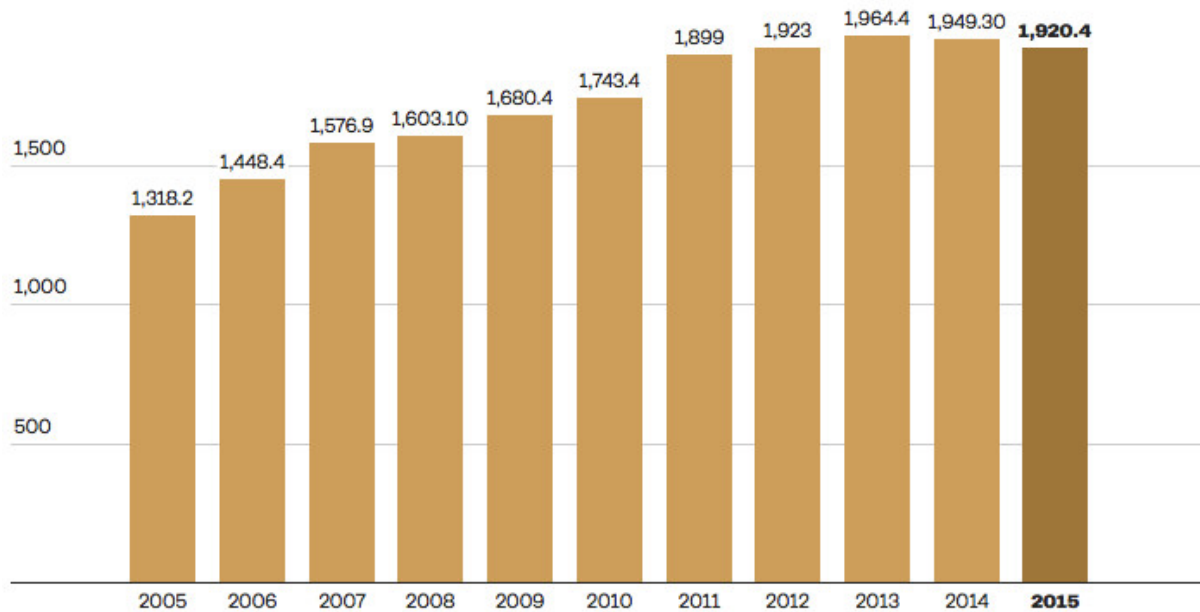
China is an observant partner; it studies decisions other countries have made, and the consequences of those decisions. It appears that China’s principal choice to reduce emissions from coal-fired electrical generation is efficiency increases to its coal-fired fleet. China’s most efficient coal-fired plant is the 1000 MW Guodian Taizhou plant which operates at about 45% thermal efficiency (<http://www.powermag.com/who-has-the-worlds-most-efficient-coal-power-plant-fleet/>).

By comparison, the most efficient coal-fired plant in the U.S. is the privately-owned Longview Power LLC which operates at about 40% thermal efficiency. There is evidence that China’s consumption of coal is declining. Some attribute this to an increase in renewable energy. While China is installing as much renewable energy as possible, it also has 36 nuclear power plants in operation, 21 under construction and plans to have 150 Gw, or approximately ten percent of its electric generation, in operation by 2030 (<http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx>).

China also is decommissioning its old, low efficiency coal fleet and replacing it with renewables and with high efficiency, low emissions power fueled with indigenous coal. For every megawatt of old coal capacity China replaces with new coal capacity, its criteria and carbon emissions decline 10% on a per unit of electricity generation basis, as does its coal consumption.

China's declining coal consumption

In millions of tons of oil equivalent



Source: BP Statistical Review of World Energy 2016



The low generation costs from renewable and natural gas-based electricity are putting pressure on the U.S. coal-fired base-load fleet principally because it operates, on average, at 32% thermal efficiency. Most of the operating capacity has been retrofit with criteria emissions controls and is well-maintained. However, because these units are called into service later in the daily dispatch cycle, they often operate below full load, and undergo frequent pressure and temperature cycles that were not accounted for in those plant designs. Operation at reduced load also reduces a plant's thermal efficiency, which increases its carbon footprint.

The U.S. Department of Energy's Office of Fossil Energy is leading an effort to develop design and manufacturing specifications required to develop a small-scale, modular, coal-based power plant of the future. Late last year, it launched the Coal FIRST (Flexible, Innovative, Resilient, Small and Transformative) initiative, which seeks to design smaller, more flexible coal plants. These plants are envisioned to be lower cost, able to load-follow the intermittency requirements of the evolving grid, and highly efficient (in excess of 40%). WVU's research on in-situ instrumentation and grid stability associated with intermittency will be important contributions to controls vendors who will need to imbed algorithms into control systems in order to safely manage load changes in these plants.

Since 2011, roughly 350 coal-fired generating units have shut down according to the Energy Information Agency (<https://www.wsj.com/articles/coins-decline-spreads-far-beyond-appalachia-1497870003>).

When an owner determines a plant is no longer viable it is mothballed and ceases to be maintained. The rotating equipment, electrical and controls systems decay rapidly. A similar issue faces the U.S. nuclear fleet which is not a carbon emitter. In both cases diversity of generation is reduced, investors or customers have expensive stranded assets to deal with, jobs are lost, and local property tax revenues decline, often with serious economic consequences to host communities.

There may be gigawatts of operating coal-fired generation that under some circumstances could be upgraded with technologies that would improve operating efficiency and reduce emissions, thereby allowing those units to compete for more operating hours and minimize the effects of cyclic operation. This month, the Department of Energy offered \$38 million in funding for technologies that make the existing coal fleet more flexible and efficient. Some of these technologies could include conversion from coal to natural gas, replacing old turbine blades, condenser and feedwater heater upgrades, and control system upgrades. Increased interest from electric generators in efficiency improvements could benefit research centers and U.S. vendors that have largely exited this sector, or moved operations to Asia. To the extent these units then continue to operate economically, local host communities will continue to enjoy economic benefits associated with jobs and property taxes.

West Virginia University is committed to maintaining active, innovative, and outcomes-based research that will improve the carbon footprint of the resources available in the Appalachian Basin so that industry and commerce may continue to grow and provide opportunities to its citizens. The university also is committed to maintaining robust business and academic relationships with partners in Europe- and Asia. Trans-global collaborations like these accelerate the development of electric generation technologies that improve safety, improve maintenance and operating efficiencies, and promote adoption of technologies that control emissions and improve air quality. This helps regional economic expansion, promotes low cost electric generation from diverse sources, and improves transmission grid stability.