Living with the legacy of Coal

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ABSTRACT

Coal has played a crucial role in the advancement of humankind and the development of civilization. It fueled the industrial revolution, the creation of the electrical grid that powers developed countries and helped build Pittsburgh into a major American city. This legacy, however, is tempered by the environmental and human health costs. A major contributor to the increase in atmospheric carbon dioxide and concomitant global warming, it has also resulted in diminished air quality with smoke and particulates, especially PM2.5. The need for proper disposal of coal combustion byproducts (CCB) produced by power plants has resulted in a number of suggested beneficial uses including soil augmentation. These applications, however, must be tempered by the understanding that microbial activity can impact the mobility and toxicity of the metals and metalloids in the CBB, increasing the risk of soil, surface water and groundwater contamination.

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1. Introduction

Historically coal has seen many uses, for heating, metallurgy, and smelting. Since the beginning of the industrial age, however, it saw greater use as a fuel to power steam engines. Pennsylvania has a long history of coal use and mining (NETL, 2018). Mount Washington in Pittsburgh was known as Coal Hill, where the coal was used localling for heating and transported elsewhere on the Monongahela River with canoes (Davidson, 1979). Later it was used in glass manufacturing in Fayette County and then to produce coke for the production of steel. The abundance of coal in southwestern Pennsylvania was a contributing factor to Andrew Carnegie locating his steel mills in Pittsburgh. George Westinghouse started his own company (Fuel Gas and Electric Engineering Company) to produce natural gas from coal for his operations and street lighting in the late 1880's. Coal fueled the railroads, built industry, and later, the power grid, with the proliferation of coal fired power plants, again because of its abundance. By the 1960's, coal was the chief source of electricity generation (NETL, 2018) so that by the 1990's the mining of coal had exceeded 1 billion tons annually (US EIA, 2017). Although the abundance of natural gas over the last decade has resulted in a tectonic shift away from coal, you can still see coal barges being towed up and down the Allegheny, Monongahela, and Ohio the three rivers of Pittsburgh.

For all that coal has provided, it also has contributed significantly to the degradation of air quality and the increase in atmospheric carbon dioxide and particulates, a history that is shared by both United States and Germany (Uekoetter, 2009). During the golden age of steel production, Pittsburgh was known as "Hell with the lid off" (James Parton writing about the city in 1868) and the "The Smokey City". There were the Edgar Thompson Works and the Homestead Works among the many steel mills. Bituminous coal was also being used for heating and cooking, and steam locomotives propelled the railroads that lined the rivers' shores; all added to the steel mills output (Davidson, 1979). In 1898, even Carnegie himself railed about the "smoke nuisance" but attempts to institute ordinances to control it were challenged and overturned or not enforced (Davidson, 1979). Nevertheless, multiple attempts were made to address smoke abatement at the turn of the century (Grinder, 1978). Although passed in 1941 but delayed five years due to World War II, a smoke control ordinance was finally enacted in 1946. It promoted the use of anthracite and automated stokers for bituminous furnaces. Abatement was further aided by the conversion to diesel engines for trains and boats and the expanded use of natural gas (Davidson, 1979). The Group Against Smog and Pollution (GASP) was organized in 1969 to work on air quality issues in the region and remains active today (gasp-pgh.org). More recently, a multi-institutional collaborative involving citizens, activists, non-profit organizations (e.g., Heinz Endowments), public health advocates, and academics called the Breathe Project was begun in order to monitor and educate communities about "black carbon" or PM2.5 particulates (breatheproject.org). According to a recent U.S. EPA report, Pittsburgh has finally met 2015 ground-level ozone standards, however is still not in compliance for NOx (nitrogen oxides) and PM2.5 (Hopey, 2018). Nevertheless, Pittsburgh has been recognized multiple times in recent years as a "Most Livable City" by both Forbes and the Economist magazines.

2. Coal waste and its beneficial reuse

There are four types of coal, Anthracite (hard black), Bituminous (most common, high Btu value), Subbituminous, and Lignite (brown coal) (AGI, 2018). Metallurgical coal is low in ash, sulfur, and phosphorus, most often bituminous coal, that is used to make coke for steel manufacturing. Lignite, also known as brown coal, is the lowest grade of coal. It is this type of coal that has been primarily used in power plants. With high organic content, the various grades of coal can also contain a suite of salts and metals at various concentrations. Coal combustion byproducts (CCB) from power plants include fly ash, bottom ash, boiler slag, and flue gas desulfurization residue (Kalyoncu, 1999). Fly ash particles are 0.1 – 1 um, whereas bottom ash and boiler slag are coarser. Flue gas desulfurization is done by "scrubbers" that typically use limestone or lime to remove the sulfur (SOx) emissions, generating calcium sulfate (e.g., gypsum) or calcium sulfite in the process (Kalyoncu, 1999). These wastes are then collected and placed into dedicated landfills and impoundments or recycled through beneficial reuse (Manz, 1997; Kalyoncu, 1999; Skvara et al., 2009). CCB are primarily composed of silicon, iron, aluminum, calcium, magnesium, sodium, potassium, and titanium, but can also be enriched in heavy metals and metalloids including arsenic, selenium, cadmium, mercury, lead, and chromium. Arsenic concentration, in particular can range from 0.5 to 279 mg/kg (Korcak, 1998).

It has been proposed that CCB can be used as a source of carbon, nitrogen, macro and micro nutrients (Bannwarth, 2018). In fact, there have been quite a few studies and reviews that have looked at the impact of CCB amendment on soils and plants (Korcak, 1998; Rautaray et al., 2003; Pandey and Singh, 2010; Nayak et al., 2015). Toxic metals, however, can be readily leached from CCB (Mudd and Kodikara, 2000) a process which may be enhanced by the presence of humic acids in soil (Zhao et al., 2017). Another important aspect to be considered is that plants may hyperaccumulate certain metals and metalloids. This impact has been underscored by the recent realization that rice, especially brown rice, can contain high concentrations of arsenic as a result of irrigation with arsenic laced waters (Williams et al., 2007). Furthermore, it should be realized that microbial activity can have a significant impact on the mobility and toxicity of toxic metals, as their metabolism can change the chemical species and oxidation state (Stolz and Oremland, 2011). Over 60 elements are now known to have some biological function, and as a result are cycled through the biosphere (Stolz and Oremland, 2011). These include many metals and metalloids including uranium, tellurium, selenium, and mercury. Amazing as it may seem, there is a robust arsenic cycle (Oremland and Stolz, 2003; Stolz et al., 2006). Arsenic oxyanions can be used as an electron donor (arsenite, As(III)) or acceptor (arsenate, As(V)) in anaerobic respiration. As(III) can even be used as an electron donor in photosynthesis (Kulp et al., 2008). Methylation and demethylation of arsenicals is well documented and arsenic resistance, in which As(V) is transformed to As(III), is found in most clinical bacterial isolates (Stolz et al., 2006). More significant to this discussion, is that we have found active arsenic metabolizing bacteria resident in CCB from a large coal ash facility (Reiter, 2015). Using microcosms constructed from cored material from several depths (0-0.6m, 0.6-1.2m, 1.2-1.8m, and 1.8-3m), these communities were shown to readily use As(V) in anaerobic respiration producing As(III) and arsenic trisulfide (e.g., orpiment) in the process (Reiter, 2015). Given the ubiquity of arsenic metabolizing microbes (Oremland and Stolz, 2003), the transformation and mobilization of arsenic species where CCB is being used as a soil amendment is a definite possibility.

3. The legacy

Coal has been instrumental in the industrialization of the developed nations, the US and Germany included. It has led to an expansive electrical grid and the benefits thereof. However, the legacy is also one of pollution and environmental degradation. We now have 415 ppm of carbon dioxide in the atmosphere, up from about 270 ppm before the industrial revolution (Stolz, 2017). Paradoxically, global warming could be even more significant were it not for the albedo effect of the coal combustion particulates. It is also estimated that 260 people in the Pittsburgh area die prematurely each year from cardio-vascular disease and stroke linked to exposure to aerosol particulate matter (e.g., black carbon). The allure for the continued use of coal comes from the still abundant deposits that have yet to be harvested as well as the continued loss of mining jobs. The latter, however, has been the combination of automation and the low cost of natural gas. Destructive mining practices such as mountain top removal and long wall mining (in which surface subsidence is a given), are a continuing threat to natural habitats and health. The quality of the coal itself is declining and the incidents of black lung (due to the higher silica content) continues to rise at an alarming rate, putting the miners themselves at risk (Blackley et al., 2018). Furthermore, the long term storage of CCB in large unlined impoundments is a constant threat to both surface and subsurface water sources. The time for coal has past, as we now have viable alternatives in solar, wind, and hydro (Jacobson et al., 2015). Although this assertion has been challenged, as to whether we can truly meet a 100% renewable power grid (Clark et al., 2015), both analyses failed to include renewable biogas. Multi-stage biodigester systems that employ both a thermophilic process to generate acetate from a variety of feed stocks, and the mesophilic process that generates the methane from acetate and carbon dioxide, are efficient and effective. When combined with municipal waste water treatment, in addition to clean water, the residual sludge is a "Class A" waste that can be used as fertilizer. And unlike the burning of fossil fuels, the process is carbon neutral as the methane has been generated from recently formed organic matter and carbon dioxide, and the remaining organic matter is returned to the soil.

4. Conclusions

The legacy of coal has been both a blessing and a curse. It has directly contributed to the advancement of humankind and the development of civilization. However, it has come at the cost of environmental degradation and health. Today we face the growing challenge of climate change and the continued growth of developing nations. We also still need to deal with the coal waste. The beneficial reuse of CCB, however, should be approached with caution. Although it may be possible to combine it with materials such as concrete, that should render it inert, other applications may not be as suitable. The potential for unintended leaching and transformation of toxic metals due to microbial activity cannot be underestimated. Thankfully we do have a viable alternative in renewables and can wean ourselves from a sooty past.

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