Virginia Department of Energy study on the economic and environmental impacts of eliminating waste coal piles in Southwest Virginia

Report to the Governor and the General Assembly

January 10, 2024

Report Overview

This report is created pursuant to Senate Joint Resolution 258 that was passed by the 2023 Virginia General Assembly. The resolution states that the Virginia Department of Energy (Virginia Energy) is requested to study the environmental and economic impacts of eliminating waste coal piles in Southwest Virginia, including a range of use case scenarios. Here is the statutory request and instructions:

RESOLVED by the Senate, the House of Delegates concurring, That the Department of Energy be requested to study the economic and environmental impacts of eliminating waste coal piles in Southwest Virginia.

In conducting its study, the Department of Energy (the Department) shall convene a work group of stakeholders featuring representatives from state and local governments, investor-owned utilities, environmental organizations, the waste coal reclamation industry, and others deemed appropriate by the Department. The Department shall hold at least one public meeting and shall create a mechanism to receive public comment for consideration during the study.

The Department shall examine various use case scenarios ranging from capping all existing waste coal piles in place to combusting all the material at VCHEC or other approved facilities. Each scenario considered by the Department shall contain an analysis of the direct and indirect economic and environmental benefits of that particular scenario.

All agencies of the Commonwealth shall provide assistance to the Department for this study, upon request.

The Department shall complete its meetings by November 30, 2023, and shall submit to the Governor and the General Assembly an executive summary and a report of its findings and recommendations, if any, for publication as a House or Senate document. The executive summary and report shall be submitted as provided in the procedures of the Division of Legislative Automated Systems for the processing of legislative documents and reports no later than the first day of the 2024 Regular Session of the General Assembly and shall be posted on the General Assembly's website.

In executing the General Assembly's request, Virginia Energy convened a work group of stakeholders to identify key data points, assist with data collection and review draft materials. Virginia Energy also engaged TRC Companies to conduct a technical study comparing the carbon equivalent emissions (CO2e) and other air quality factors between leaving the waste coal in place and combusting it at the Virginia City Hybrid Energy Center (VCHEC). A public comment portal was posted on the Virginia Townhall website and a meeting for public input was held in Lebanon, Virginia on October 2, 2023. No public comment was provided through either channel.

Members of the workgroup were Adam Wells (Appalachian Voices), Tom Ballou (DEQ), Ava Lovain (DEQ), Larry Barton (Dickenson County), Geoffrey Hensley (Dominion), Larry Kuennen (Dominion), Gina Pisoni (Dominion), John Matney (Russel County Reclamation), Patrick Carr (SCC), Mike Cizenski (SCC), David Dalton (SCC), Brad Kreps (The Nature Conservancy), Jeff Taylor (Ultra Production Company), Will Clear (Virginia Energy Strategies) and Mike Hatfield (Wise County). The contents of this report do not necessarily reflect the opinions of the individual workgroup participants and should be solely attributed to the Virginia Department of Energy unless otherwise stated.

Background on Waste Coal

What is Waste Coal?

Coal refuse piles, known as GOB (Garbage of Bituminous) piles, are accumulations of waste coal and other discarded mining refuse from mining and coal cleaning processes.[1] In the context of coal mining, when coal is extracted from the Earth, it often contains various impurities such as rock, shale and other non-coal materials. These impurities are separated from the coal, and the waste material is typically piled up in an area near the mine, creating a GOB pile. GOB piles can vary in size and composition depending on the mining methods used and the geological characteristics of the coal seam.[2]

The term GOB is particularly used in bituminous coal mining regions, such as Virginia. GOB piles can vary in size and composition depending on factors such as the mining techniques employed and the geological characteristics of the coal seam. In southwest Virginia, these piles can reach weights of tens of thousands of tons. Due to limited environmental regulations, pollutants leach from the coal refuse, causing erosion in local streams and soil. These GOB piles pose significant threats to health and safety, actively degrading both environmental and economic conditions in the region.

Environmental Impacts

Abandoned coal refuse piles represent a legacy environmental hazard in Virginia as well as throughout the Appalachian coal producing region of the United States. Due to the sheer magnitude of legacy coal refuse abandoned in Virginia, existing coal refuse piles represent a well-documented threat to the natural environment.[3] GOB piles present adverse impacts on water

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[1] Belleville, M., Cole, C., Englander, G., & Callahan, J. (2023). Addressing Virginia's legacy gob piles. *Appalachian Journal of Law, 22 (1).* Retrieved from: https://appalachian.scholasticahq.com/article/73814-addressing-virginia-s-legacy-gob-piles
[2] U.S. Department of the Interior, Office of Surface Mining Reclamation and Enforcement. (n.d.). Glossary of Mining Terms. Retrieved from: https://www.osmre.gov/resources/glossary
[3] Trout Unlimited, (2020). The West Branch Susquehanna - A Watershed in Recovery. Retrieved from: www.tu.org

quality, air quality, the risk of hazardous collapses, such as the 1966 Aberfan disaster in Wales in the United Kingdom, and potential injuries resulting from unsafe recreational activities.

The 1977 Surface Mining Control and Reclamation Act (SMCRA) acknowledges waste coal as a potential "toxic forming material" because of its elevated sulfur levels, which contribute to acid drainage. Waste coal piles leach iron, manganese and aluminum pollution into waterways and cause acid drainage that kills neighboring streams. These piles also pose a risk of in-place combustion, releasing toxins and GHGs into the air.

The historical coal mining activities in Southwest Virginia have given rise to enduring environmental challenges. A tangible outcome of this legacy is the presence of GOB piles, which consist of mining waste and discarded coal accumulated by mining operations over several decades. Compromised water quality and greenhouse gas emissions are the main environmental impacts of gob piles.

Water Quality Impacts

Acid Mine Drainage (AMD) is a distinctive issue within the mining sector, resulting in significant negative externalities valued in billions of dollars. AMD arises as surface and groundwater permeate through discarded coal piles, initiating a reaction involving pyrite, oxygen and water (whether on the surface or underground). This reaction produces acidic runoff that includes sulfuric acid and dissolved iron compounds, each exerting distinct effects on the environment. Overall, gob piles undermine, disturb and degrade ecosystems, impeding their capacity to support marine and plant life.[4]

Virginia's Stone Creek is an example of the negative effects that AMD can impose on waterways and their habitability, as well as the potential for environmental recovery. A buildup of sedimentation and the continuation of dissolved solids from abandoned mine lands resulted in the degradation of the 5,251-acre watershed. The Virginia Department of Environmental Quality (DEQ) determined that the body of water lacked the capacity to sustain aquatic life, classifying it as a "severely impaired" to "moderately impaired" waterway (See footnote 5). Subsequent to the DEQ reclaiming the disturbed mine lands adjacent to Stone Creek, there has been a remarkable improvement in the Total Maximum Daily Load (TMDL)[5]. The water quality of Stone Creek has improved tremendously since then, resulting in readings above the minimum required TMDL threshold in the fall of 2009 and 2010 (See footnote 2) and Virginia Stream Condition Index (VASCI)[6] scores that indicate that the biological conditions in Stone Creek now fully support the designated uses for aquatic life. Consequently, the previously impaired 3.33-mile segment of Stone Creek was removed from the list of impaired waters in the state's 2014 Clean Water Act (CWA) 305(b)/303(d) Water Quality Assessment Integrated Report.[7]

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[4] Belleville, M., Cole, C., Englander, G., & Callahan, J. (2023). Addressing Virginia's legacy gob piles. Appalachian Journal of Law, 22 (1). Retrieved from: https://appalachian.scholasticahq.com/article/73814-addressing-virginia-s-legacy-gob-piles

[5] Total maximum daily load refers to the maximum daily load of pollutants a body of water can sustain (Mueller et al., 2015).

[6] To assess aquatic life condition of a stream, the Commonwealth of Virginia now uses the Virginia Stream Condition Index (VASCI) based on biometrics analysis. A waterbody achieving a rating score 60 or above is considered to be supporting biological integrity and attaining the aquatic life designated use. https://www.deq.virginia.gov/home/showpublisheddocument/5155/637490875744330000

[7] Reclaiming Acid Mine Drainage Areas and Implementing Control Measures Improve the Biological Health of Stone Creek. Retrieved from: https://www.deq.virginia.gov/home/showpublisheddocument/5155/637490875744330000

GOB piles have a direct impact on Virginia's streams and waterways, releasing acidic runoff containing sulfuric acid and dissolved iron compounds that seep into these water systems, adversely affecting their habitability. The accumulation of dissolved iron compounds is particularly detrimental to aquatic species, elevating levels of siltation and sedimentation in the affected waterways.

The following figure demonstrates the concentration of GOB piles around the waterways of southwest Virginia; this pattern heightens the probability of impairment and the loss of aquatic life. Notably, 27 piles are situated within a 10-mile radius of the Powell River, and four piles exist within a 10-mile radius of Virginia’s Clinch River watershed. These watersheds are integral components of Virginia's aquatic network, connecting to numerous other waterways and tributaries. The detrimental and pollutant impact of each GOB pile intensifies as the affected waters traverse these extensive watershed systems.

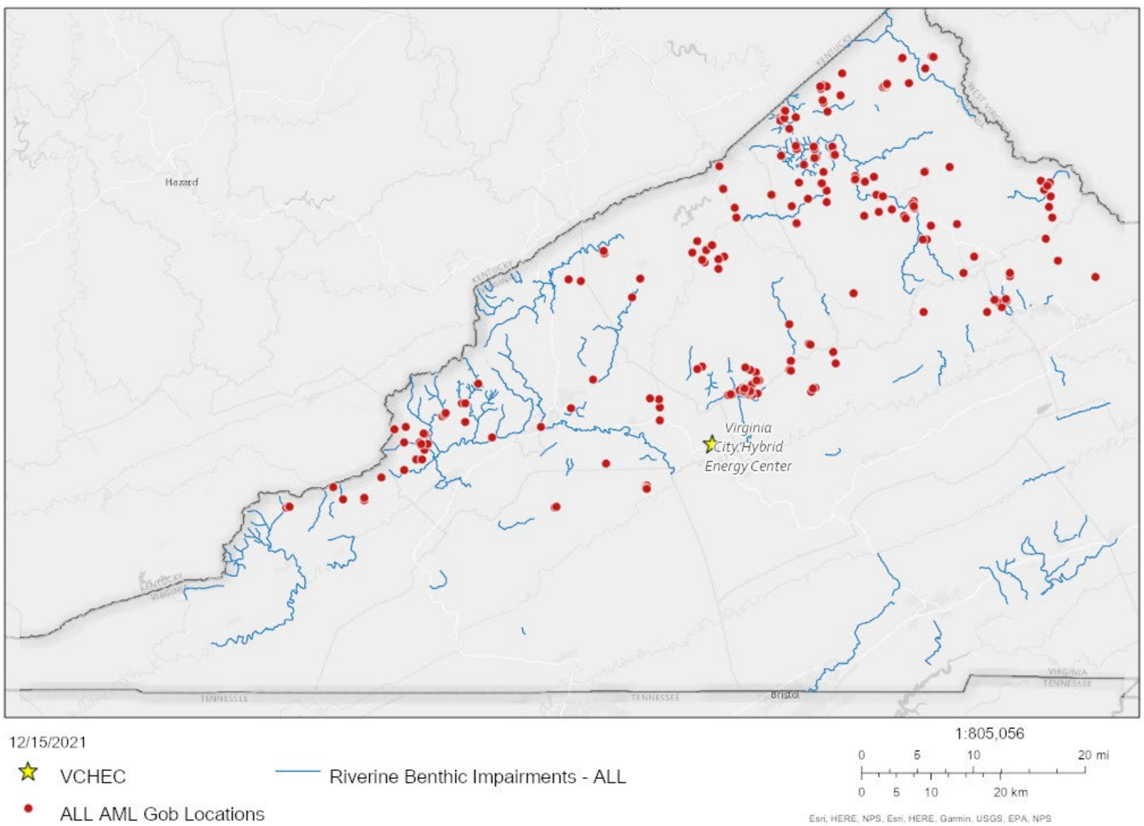

Figure: GOB Piles and Impacted Waterways in Southwest Virginia (Source: https://appalachian.scholasticahq.com/article/73814-addressing-virginia-s-legacy-gob-piles).

GOB piles pose a negative impact on vegetation. Sloped surface piles pose several challenges to the process of revegetation, including, (1) challenges in applying soil amendments on an inclined surface; (2) hindrances for soil in absorbing and retaining water due to heightened runoff, compounded by the compaction of refuse piles; and (3) the impact of the climate on sloped surfaces, influenced by the direction they face.

Air Quality Impacts

Coal dust emanating from these piles is carried by the wind. It extends into nearby communities and causes detrimental effects.[8] While the detrimental effects of rainwater runoff are extensively documented, the inventory of abandoned coal refuse also serves as a significant and continuous source of uncontrolled air emissions that encompass greenhouse gases and other fugitive air pollutants.

Legacy GOB piles emit substances inherent to their composition. These emissions increase when GOB is burned, often in uncontrolled incidents like pile fires. Abandoned waste coal in Virginia releases the highly potent greenhouse gas methane throughout its lifecycle. This poses a significant challenge to reduce GHG emissions as these in-situ legacy waste coal piles essentially act as persistent sources of GHGs. With currently available means, breaking this cycle practically requires re-mining waste coal piles and permanently eliminating the methane emissions through efficient combustion, converting the output into the less potent greenhouse gas CO_2.

Background in Virginia – industry history, volume

The first documented coal discovery in Virginia was in the early 1700's. In his diary, Colonel William Byrd noted commercial coal mining in present-day Goochland County by 1709. In the late 18th century semi -anthracite coal deposits were discovered in Montgomery and Pulaski counties and small-scale pit mining was recorded by 1790. In 1750 Thomas Walker noted coal deposits in present-day Tazewell County near Pocahontas and in 1751 coal deposits were reported in Wise County by Christopher Gist.

While coal was mined commercially for local markets, it was in 1883 that the first shipment of coal from Southwest Virginia was delivered by rail to Norfolk. This spawned the era of large-scale commercial mining in the Southwest Coalfields. (Hibbard, 1990)

Earlier mining operations had less sophisticated methods of processing coal for markets. For many years the main criteria for marketable coal was size. Coal was screened after removal and the coal that met requirements was shipped while the remaining unmarketable coal and slate were dumped over hillsides, into stream beds, or stored in large fills known as gob piles. During this era there were no regulations on how to manage coal waste so mine operators left the material in place.

Based on the Virginia Department of Energy Gob Pile Inventory that accounts for the piles subject to the AML program there are an estimated 128 gob pile sites that contain over 14 million cubic yards of material in the Southwest Coalfields.[9] Additionally a 2022 study identified the presence of 151 waste coal piles, including the AML sites, which total over 80-million cubic yards of material.[10]

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[8] Mueller, S. et al. (2015). Variability of natural dust erosion from a coal pile. *Applied Meteorology & Climatology*, 54. Retrieved from: file:///C:/Users/rrb/Downloads/apme-jamc-d-14-0126.1.pdf

[9] Retrieved November 2023 at https://vadmme.maps.arcgis.com/apps/dashboards/32b3cd5eac064becb7ff6ab787b19561

[10] Virginia Department of Energy, *Waste Coal Piles Identification And Use Of Coal Ash Report HB657/SB120* (December 2022)

Relevant federal rules or programs

In 1999 the Office of Surface Mining and Reclamation Enforcement (OSMRE) amended 30 C.F.R. 707 and 874. The amendments relaxed requirements that previously required AML programs to cover at least 50% of a project's costs. The new requirements allowed AML programs to finance a portion of the costs while the sale of incidental coal removal would offset the remainder of the project costs. In Virginia most of the removed coal is used for combustion at VCHEC.

Relevant state rules or programs

In January 2000 OSMRE approved Virginias Enhancement rule. This marked a transition in how Virginia Energy approached gob pile reclamation by creating an option for removing a large portion of waste material from the site. The contractor reclaiming the site was now allowed to sell the coal at a site to offset reclamation costs. Prior to the amendments, coal waste reclamation was limited to onsite reclamation techniques such as grading material for stability, capping material with topsoil, revegetation and building clean water diversion structures to reduce site instability and erosion issues.

In 2022, the General Assembly passed HB 1326 which declared that "the removal of waste coal from previously mined sites in the coalfield region of the Commonwealth... is in the public interest" and gave the Commission on Electric Utility Regulation (CEUR) the authority to review information on the approximate volume and number of waste coal piles present in the coalfield region and the options for cleaning up such waste coal piles.

Previous waste coal reports and Inventory

In 2022 Virginia Energy in response to House Bill 657 created a report that created a coal waste inventory in Virginia and outlined options for cleaning up coal waste sites. Virginia Energy contracted with Marshall Miller & Associates (MM&A) to assist in creating the inventory and estimate volumes of coal waste piles. Virginia Energy also contracted with Dr. Michael Karmis of Karmis LLC to produce a report that provides "a basic background of waste coal storage features and practices in the Southwest Virginia coalfields and addresses potential cleaning, utilization and reclamation options." The study confirmed the presence of 151 waste coal sites which total over 80-million cubic yards of material. Of this material around 14 million cubic yards are eligible for AML funded reclamation.

There is a distinction to be made between waste coal and GOB coal, particularly as it pertains to the VCHEC plant. What is referred to as "waste coal" is generally managed impoundments that have been permitted since the implementation of SMCRA in 1977. While there will be variation in these structures, they are built specifically to store waste coal from permitted mining operations. In general, they are built to keep material stable and to minimize erosion and runoff issues. As a result, coal waste impoundments are not as prone the same environmental impacts as AML GOB piles, but they can be a source of GHG emissions and will have to be eliminated to ensure long-term environmental protection. The Virginia Energy Coal Waste Inventory estimates that there are over 65 million cubic yards of coal waste material contained in such structures.[11]

The exact acreage of refuse in the Southwest Virginia coal fields is difficult to estimate, but modern and fully stabilized and reclaimed disposal facilities, generated since the passage of the SMCRA

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[11] Virginia Energy Coal Waste Informational Dashboard (Retrieved at https://vadmme.maps.arcgis.com/apps/dashboards/32b3cd5eac064becb7ff6ab787b19561 on 12/4/23)

Act in 1977, cover thousands of acres and abandoned refuse piles dot the landscape in almost every major mined watershed.

AML program

Since 1981 Virginia Energy has completed 84 projects that addressed coal waste issues. The issues addressed include combustion/fire, pile instability and erosion. The project type break out is as follows:

- 15 Fire Related
- 29 Enhancement
- 24 Cap/Grade
- 2 Removal to upland site
- 14 Other (grading, drainage)

Since the enhancement rule amendments, Virginia Energy has experienced substantial cost savings for coal waste pile reclamation due to the contractor's ability to sell material from the site to offset project costs. Virginia Energy's obligations on enhancement GOB pile projects are limited to revegetation costs.

Environmental Justice

Per § 2.2-235 of the Code of Virginia, "[i]t is the policy of the Commonwealth to promote environmental justice and ensure that it is carried out throughout the Commonwealth, with a focus on environmental justice communities and fenceline communities".

The coalfields region of Virginia has seen reduced economic activity in recent years due to the decline in the thermal coal market.[12] Many of the census tracts in the area qualify for economically distressed statuses, such as the Justice 40 designation associated with the federal Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA) and the historically economically disadvantaged community (HEDC) status created by the Virginia Clean Economy Act (VCEA).

Additionally, the region has experienced environmental degradation as a result of historic coal extraction, including the environmental harms associated with waste coal piles. Whereas the entire economy of Virginia benefitted from the industrial activity coal energy facilitated and lower energy prices from the absence of waste coal clean up requirements prior to 1977, many of the environmental costs of coal production were confined to southwest Virginia. Most of the areas where waste coal piles are located would be considered environmental justice communities. An increase in clean-up efforts, whether through remediation programs or combustion at VCHEC, could be viewed as having positive effects for these communities through reduced environmental harms and increased economic opportunity.

Pennsylvania

The state of Pennsylvania has a substantial volume of waste coal piles that present similar challenges to the waste coal piles of southwest Virginia. A 2020 inventory of refuse piles kept by

[12] Thermal coal is used for electrical production and its extraction has declined substantially in the Commonwealth. Mining of metallurgical coal, which is used for industrial processes, most notably steel production, has remained steady as demand for steel is high and there are currently no viable alternatives that are less expensive or less GHG emitting.

the Pennsylvania Department of Environmental Protection (DEP) identified 840 piles throughout Pennsylvania, which are estimated to consist of nearly 443.9 million metric tons of coal refuse, covering approximately 18,170 acres.[13] Pennsylvania permits waste coal combustion for electrical generation as a Tier II resource in its Alternative Energy Portfolio Standards (AEPS). Previously out-of-state entities, such as VCHEC, could qualify for the Tier II credits but a law passed in 2021 now restricts these credits to in-state operators only. A 2023 report produced by Lehigh University calculated that in-place coal refuse pile GHG emissions exceed by a factor of two to five times the corresponding emissions if burned under controlled conditions in Pennsylvania's waste coal electricity facilities.[14]

Comparison of VA and PA Waste Coal Assets

The study that Virginia Energy engaged TRC to perform (see TRC Report Summary and Appendix 1) is intended to provide a similar calculation to the Pennsylvania study for Virginia and the VCHEC facility, however, there are some important differences to note between the Pennsylvania fleet of waste coal facilities and VCHEC.

Operational Differences

The Pennsylvania waste coal burners, although similar in design to VCHEC, have been burning waste coal since they were put into service. Over the years, they have fine-tuned their fuel handling and operations to facilitate this. VCHEC, however, has not burned as high a percentage of GOB as the Pennsylvania plants and has also been required, by permit, to burn 10% wood biomass. Burning GOB at VCHEC has resulted in challenges to the fuel handling equipment due to the excessive amounts of moisture and fines. VCHEC has already experienced escalations in Operation and Maintenance costs from burning GOB due to increased equipment wear from the higher ash content. Higher GOB burn rates will add costs from additional wear and landfill use.

In Pennsylvania, the overall volume of GOB is larger with numerous, concentrated areas of piles. Coupled with most of the GOB-burning plants being much smaller than VCHEC, this has resulted in available, economical GOB being exhausted more slowly, however, some of the Pennsylvania plants are also beginning to procure material from greater distances with subsequent cost increases.

Unlike the larger Pennsylvania stations, VCHEC does not own the fuel supply coming into the facility. Nor does VCHEC have covered, short term storage which would minimize the impact of wet fuel plugging the fuel handling systems for the boilers. Ownership of the fuel sources allows for complete sampling and analysis well in advance so proper blending can occur at the fuel loadout points. Heat content, moisture and particle size are all considered in their blending process with the goal of eliminating flowability issues in fuel conveying systems. In addition, some stations have large blending yards that further enhance the drying and blending capabilities.

Emission Differences

When constructed VCHEC had the most stringent air permit ever administered in the U.S. and the facility has air emission requirements that are much more restrictive than those for the

[13] Lehigh University Energy Research Center, *Comparison Of The Impact On Greenhouse Gas Emissions Between Unabated Coal Refuse Piles And Reclamation-to-energy Power Plants,* P2
[14] Lehigh University Energy Research Center, *Comparison Of The Impact On Greenhouse Gas Emissions Between Unabated Coal Refuse Piles And Reclamation-to-energy Power Plants,* P3

Pennsylvania GOB burning plants. This requires higher performance from VCHEC's air pollution control (APC) equipment. Dominion Energy has stated that it expects to maintain VCHEC's environmental emission limits performance standards, even while burning higher amounts of GOB.

Byproduct Differences

The Pennsylvania waste coal burners are allowed to haul the high calcium CFB ash back to coal refuse remediation sites to help with overall acid neutralization. In Virginia, utilizing CFB ash for neutralization is not allowed, increasing the cost of landfilling as opposed to Pennsylvania.

Options for addressing waste coal

No action

It is assumed that the eventual outcome of a coal waste pile is either combustion or erosion. If left in place the gob piles will continue to degrade stream quality and air quality through erosion and combustion. If the decision is made to leave the piles in place and not reclaim, the sites will remain a liability to Virginia Energy's AML program. There is no other agency that routinely reclaims this type of hazard, and the responsibility for emergency abatement will fall to the agency and require the use of government funds. If this option is chosen there will be environmental repercussions from lack of action. Sites will eventually have to be addressed as individual piles that reach emergency status in the event of extreme instability or a fire. The "do nothing option" ends up requiring the agency to quickly react to more extreme conditions and the reclamation costs are far more expensive for emergency fire projects. To address hazards as they emerge at all remaining gob piles in the Virginia Energy coal waste inventory in the event of uncontrolled combustion could cost up to $268 million based on costs for emergency projects that address burning gob on a per/acre basis.

Encapsulation/remediation

Grading and capping the site with topsoil was a common method of reclamation before the enhancement rule allowed contractors to remove coal from the site to offset reclamation costs. This method consists of grading the gob into a stable configuration, constructing drainage controls around the site, capping the gob with topsoil and revegetating the site. Capping and grading a site addresses the potential for landslides and erosion issues but is considered a non-permanent form of reclamation because the material remains on site and is still prone to combustion. The sites are a continuing liability and sometimes need to be addressed with maintenance action to correct erosion issues and failed drainage controls. To cap and grade all remaining gob piles in the Virginia Energy coal waste inventory it would cost an estimated $100 million based on previous AML projects. Funding this work would create economic benefits, including additional jobs in the remediation sector.

VCHEC

VCHEC is a 610 MW electric generating facility located in Wise County, Virginia that utilizes a combination of waste coal, waste wood and run-of-mine coal as fuel. It entered service in 2012 and has the potential to operate for more than fifty years. Since beginning commercial operations in July 2012 until August 2021 VCHEC had generated more than 22.2 million MWh of electricity.[15] The Virginia Clean Economy Act (VCEA) of 2020 required the closure of all investor-owned utility coal plants by 2024, however, VCHEC, and one other facility that is jointly owned with a cooperative, were exempted and can operate until 2045 when all carbon-emitting plants are mandated to retire. In VCHEC's case this exemption may be due to the environmental benefits described below.

Environmental Impacts

Combustion is currently the only viable option that allows for permanent restoration of affected areas as it removes the waste coal piles entirely where other remediation efforts leave the piles in place while reducing their environmental impacts. This avoids future generations having to address unremediated piles or reapply impermanent remediation measures to encapsulated piles. Waste coal combustion produces coal combustion residuals (CCRs) which is subject to federal and state laws for proper disposal, transferring the associated toxins from the waste coal piles to regulated storage facilities and potentially into safe reuse applications.

Certain environmental benefits of remediating or combusting waste coal are confined to those places that have waste coal piles but others have state-wide or global benefits. The greenhouse gas reduction in combusting waste coal for electric production compared to allowing it to combust in place is a global benefit and aligns with the intent of the VCEA and other emissions-reducing regulations. In the event that VCHEC began using waste coal from other states for its operation, the GHG benefits would similarly be experienced as a global benefit.

Economic Impacts

Per Dominion, VCHEC supports approximately 121 direct jobs and an additional 180 indirect jobs, generating $25 million in labor income and $156 million in economic output in the region. Increased operation would likely result in higher indirect jobs as waste reclamation businesses could add staff to process and transport greater volumes of waste coal to the facility. Based on an Appalachian School of Law report, Dominion estimates that it would have cost over $250 million to otherwise reclaim, transport and store the four million tons of GOB VCHEC has already converted to energy.[16][17]

Energy Considerations

VCHEC is a dispatchable resource that can provide electricity at any time of day and ensure grid reliability. In February 2023, PJM, the regional transmission operator (RTO), for Virginia and twelve other states conducted research on resource adequacy through 2030 that showed "increasing reliability risks during the [energy] transition, due to a potential timing mismatch between resource retirements, load growth and the pace of new generation entry".[16] With existing

[15] Virginia Electric and Power Company, *Report on Virginia City Hybrid Energy Center Pathways for Economic Viability submitted as part of SCC Docket PUR-2021-00114 Application of Virginia Electric and Power Company, For revision of rate adjustment clause: Rider S, Virginia City Hybrid Energy Center for the Rate Years Commencing April 1, 2022 and April 1, 2023* (November 2022), 1
[16] Virginia Electric and Power Company, *Report on Virginia City Hybrid Energy Center Pathways for Economic Viability submitted as part of SCC Docket PUR-2021-00114 Application of Virginia Electric and Power Company, For revision of rate adjustment clause: Rider S, Virginia City Hybrid Energy Center for the Rate Years Commencing April 1, 2022 and April 1, 2023* (November 2022), 14
[17] Mark Belleville et al., *Addressing Virginia's Legacy GOB Piles*, 22 Appalachian Journal of Law (2023).

dispatchable resources retiring at a faster rate than renewables are coming online, there is potential for the supply of energy to be insufficient to meet demand. Per Dominion's 2023 IRP, it forecasts a need for additional dispatchable resources including 4GW of new natural gas facilities.[17] Environmentalists have objected to these proposed facilities and increased operation of VCHEC may offer an environmentally beneficial alternative for a portion of this capacity while addressing the reliability concerns identified by PJM and Dominion, however, there are additional costs to an increased dispatch of VCHEC. Burning GOB at VCHEC has resulted in challenges to the fuel handling equipment due to the excessive amounts of moisture and fines. VCHEC has already experienced escalations in Operation and Maintenance costs from burning GOB due to increased equipment metal wear from the higher ash content. Higher GOB burn rates will add even more costs from wear and additional landfill use.

The waste coal combusted at VCHEC is a Virginia-based resource that can help to ensure resiliency and security from market volatility or other external factors. Waste coal piles across the border in Kentucky and West Virginia would also represent relatively secure fuel sources as the VCHEC plant is their most viable path to market based on transportation factors. A key factor in the facility failures during Winter Strom Elliott was that supplies of natural gas were not delivered in sufficient quantities. VCHEC is capable of maintaining a local inventory of fuel and is therefore not as affected by weather or infrastructure availability as other generators further demonstrating its reliability value. However, in the event that market conditions, state incentives or other factors lead to higher GOB consumption at VCHEC, proper fuel procurement will be a challenge. As described in the Pennsylvania section, Dominion does not own the fuel supply coming into the facility and cannot fully optimize the fuel for combustion.

Market conditions may become more favorable to VCHEC as other dispatchable units across PJM retire and the capacity and energy markets in PJM provide increased compensation to the remaining dispatchable units. Similarly, future spikes in natural gas prices may provide more favorable economic conditions for VCHEC and see waste coal's value as a hedge fuel increase. Despite the high load increases forecasted in Dominion's 2023 IRP, the dark spread, the difference between the price of coal and the market price of energy, is forecasted to be lower which currently offsets against the anticipated higher demand for energy.

New Waste Coal to Generation Facilities

VCHEC, even operating at full capacity, cannot combust all the waste coal material that is present in southwest Virginia. Building additional waste coal burning facilities would increase the amount of waste coal that could be permanently remediated. New facilities could be located near waste coal piles that are long distances from VCHEC, reducing the cost of transportation which affects those piles viability as a fuel for VCHEC. Such facilities could be more flexible, with potentially smaller and modular units that could be moved to different locations as onsite fuel is used up. At this time, such a solution does not appear commercially viable as existing waste coal units are dispatched at low levels under prevailing market prices. Increased operation of VCHEC would likely be a prudent first step before considering the expansion of the waste coal fleet.

Potential Source of Rare Earth Minerals (REEs)

Rare earth minerals (REEs) are a group of 17 chemical elements in the periodic table with unique properties that make them crucial components in a wide range of modern technologies, including electronics, renewable energy systems, electric vehicles, defense applications and more. The lack of domestic production of rare earth minerals and a heavy reliance on Chinese production raise significant strategic concerns for the modern economy. Despite no active mines or known commercially viable deposits in Virginia, the state is actively involved in initiatives to identify such deposits.

Although there are confirmed rare earth element (REE) occurrences in Virginia, the concentrations found are not economically feasible for commercial production. However, coal mine waste could be a potential source for extracting REEs, which could, in turn, assist with waste remediation. Coal mine waste in southwestern Virginia is being explored as a potential source of REEs. The Virginia Department of Energy's Geology and Mineral Resources program is engaged in a number of grant-funded research projects addressing REEs and critical minerals, including the Evolve Central Appalachia (Evolve CAPP) project. The Evolve CAPP project which aims to identify Central Appalachian sources of rare earth elements and critical minerals has received $500,000 in federal funding to continue through the end of March 2024.[18] The project's researchers collect and analyze REEs samples in the coal waste and find its beneficial uses for industries that utilize REEs. Moreover, pulling rare earths from coal waste also helps clean up the pollution.[19] While critical mineral extraction is not currently commercially viable and would not fully remediate the coal waste, it is possible that in the future it would represent an additional value stream for waste coal reclamation projects.

TRC Report Summary

Virginia Energy engaged a contractor, TRC Companies ("TRC"), to conduct a study calculating the total GHG emissions (carbon dioxide equivalent or CO2e) from the inventory of waste coal piles in Virginia using methods derived from scholarly articles, peer-reviewed research and other scientific literature, and the total GHG emissions (CO2e) generated by waste coal combustion at VCHEC (see Appendix 1 for full report).[20]

TRC estimates that there is potentially up to 14 million tons of CO2e emitting into the atmosphere every year from Virginia's gob piles. Per their calculations, combusting a ton of waste coal results in a lifetime reduction of C02e of 52.6 tons. This is because as portions of waste coal piles spontaneously combust in place they release methane which is considered by EPA to be 81 times more potent as a greenhouse gas than carbon dioxide in the near-term (next 20 years) and 25-28 times more potent over the long-term (100 years). When the waste coal is combusted the carbon is emitted primarily as carbon dioxide with a resulting benefit in terms of net GHG emissions expressed as CO2e. Based on this per ton reduction, waste reclamation through combustion at VCHEC in 2022 of 618,510 tons of coal refuse may have resulted in a GHG emissions reduction as high as 31.9m tons of CO2e. The value in this study exceeds the Pennsylvania values as that study only accounted for one year's emissions from the waste coal piles and did not incorporate the ongoing emissions that would occur if it was not removed. GOB piles can persist for longer than a century without fully combusting and there is significant variation between piles in terms of how frequently they combust and the volume combusted. TRC assumed

[18] Busse, M. (2023). Quest for rare earth elements and critical minerals in Central Appalachia gets new boost. *Cardinal News.*
[19] Wayman, E. (2023). Rare earth elements could be pulled from coal waste. *ScienceNews.*
[20] Values are generally expressed as carbon dioxide equivalent (CO2e) as this normalizes the different GHG potencies of different gases. For example, one ton of carbon dioxide would equate to one ton CO2e while one ton of methane would equate to between 25 and 81 tons CO2e depending on the timespan under consideration.

that the piles would continue to emit over a longer period and assigned a value of ten times the year one emissions over its full lifecycle.

TRC concludes that "[i]t is very challenging to think of another economically viable and environmentally beneficial technology of any kind that could come close to providing a net CO2e benefit of this magnitude, at little cost to the Commonwealth of Virginia, while permanently eliminating further collateral environmental problems created by coal refuse".[21]

Policy options

Business as usual

In the event the Commonwealth took no further action on waste coal, remediation would continue to occur at the pace dictated by federal funding and the market conditions for VCHEC. Waste coal piles would persist as an environmental hazard for decades to come, barring a currently unforeseen technological advance in remediation, and no further economic development benefits would be realized.

Incentivize remediation

The state could offer funding to augment the remediation efforts that are currently funded through the federal AML program. This would increase the pace of remediation and create additional jobs in the remediation field. However, as described above, the practice of encapsulation currently employed does not significantly reduce the GHG emissions impact as it is focused on water quality protection.

Any form of incentivization that is pursued should ensure that it achieves additionality as it is vital that funding generates new activity rather than simply increasing the compensation for activities at their current level. This could take the form of more piles encapsulated or more tons of waste coal combusted at VCHEC and any incentive mechanism should include effective verifications standards.

Incentivize combustion

Incentives could range from dedicated funding for waste coal consumption at the generator dispatch or reclamation operator level to goal-based incentives, such as carbon reduction credits.

Dominion has provided a retrospective analysis of the effect that monetary incentives could have had on the capacity factor and subsequent GOB consumption of VCHEC over the past five years in a scenario that maximizes GOB consumption. They have estimated, based on the five-year historical average of pricing in the PJM region, that an incentive of $10 per nMWh of output would have enabled the VCHEC facility to operate at an average capacity factor of 58% between 2018-2022, almost double the 31% capacity factor that was actually experienced during that time period. Under this methodology, the incentives are applied only on days that the facility would not normally run economically and the incentive required on those days is calculated as am amount only sufficient to get the facility dispatched into the market, allowing it to operate at a break-even rate with the utility receiving no profit from the sale of the incentivized power. On days that the facility would operate economically, no incentive is applied and no profit is taken from the facility

[21] TRC Companies, *Net Air Emission Benefits from the Remediation of Abandoned Coal Refuse Piles* (December 2023), 4

to be used as a monetary offset on days it does not operate economically so profit is made on those day but at no cost to the incentivizing entity.

Incentivizing the facility at the $10 per nMWh level would have resulted in the consumption of over 7.6 million tons of waste coal over the five-year period, over 4.5 million tons of which is GOB. Given the necessity to utilize run-of-mine coal to increase the quality of waste coal fuel utilized in VCHEC's boilers, there would also have been over 2.5 million tons of additional run-of-mine coal consumed during this same period. When the carbon equivalent emissions from combustion of the entire portfolio of coal-based fuel (2.4 tons CO2e emissions per ton fuel consumed) are subtracted from the carbon equivalent emissions from the decomposition and oxidation of GOB in the environment (52.6 tons CO2e emissions per ton of GOB decomposed in the environment) there remains a net reduction over ten years of 44.9 tons CO2e per ton of GOB consumed, which equates to nearly 400 million tons of CO2e emissions avoided.[22] At the $10 incentive level this would have equated to a value of $0.43 per ton of CO2e reduction, in addition to eliminating hundreds of thousands of tons of GOB, with an annual spend of $8.4 million.

Table 1. Dominion estimated annual expenditure of incentivizing increased GOB consumption at VCHEC from 2018-2022

Incentive $/nMWh	GOB Coal Used	Capacity Factor	$/Ton GOB	Average Total Cost per Year
$ -	482,760	31%	$ -	$ -
$ 5.00	746,496	47%	$ 3.96	$ 2,958,682.06
$ 10.00	913,680	58%	$ 9.20	$ 8,404,902.46
$ 15.00	959,040	61%	$ 11.33	$ 10,862,955.62
$ 20.00	971,352	62%	$ 12.18	$ 11,828,903.76
$ 25.00	979,776	62%	$ 12.94	$ 12,682,724.03
$ 30.00	983,016	62%	$ 13.29	$ 13,067,349.53

Based on Table 1 there would have been an increase in GOB consumption with an incentive of up to $15 per mWh. After that point there is little gain for additional incentive. Operating the facility at a higher capacity would result in higher operations and maintenance costs but, these are likely to be minor expenses compared to the monetary incentive. It should be noted that the data presented reflects what would have happened from 2018-2022. Recent factors, in particular high inflation, may imply that the effective incentive range would be slightly higher moving forward. Any level of incentive would allow for increased capacity at VCHEC but, per this analysis, meeting the $10 per nMWh amount would allow for more substantial coal waste elimination and create a more sustainable market for waste coal suppliers with positive impacts in terms of jobs and capital investment. An incentive of this nature should be tailored to ensure that is maximizing GOB consumption at that plant, which is reflected in the Dominion analysis, and not simply incentivizing additional plant operation regardless of fuel type.

[22] EIA, Carbon Dioxide Emissions Coefficients, (retrieved at https://www.eia.gov/environment/emissions/co2_vol_mass.php on 12/27/2023)

Based on estimates for both the value of carbon reduction and the cost for other GHG reduction measures, additional waste coal combustion at VCHEC appears to be very competitive at potentially less than a dollar a ton of CO2e. The VCEA requires that the SCC include the social cost of carbon as a benefit or a cost in any application to construct a new generating facility.[23] This figure can be calculated using different methodologies and the value assigned by the federal government has changed with different administrations. The report cited in the Code, the Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, published by the Interagency Working Group on Social Cost of Greenhouse Gases from the United States Government in August 2016, placed a value of $42 on the coal cost of carbon at the time of the VCEA in 2020.[24] In November 2023, the EPA published a new study that places the social cost of carbon at $120 or greater depending on the scenario.[25] The Trump administration used a value between $1 and $7 a metric ton for the social cost of carbon.

Another means of comparison is the dollar per CO2 ton saving for renewable assets. A 2018 Harvard University study calculated that the cost of converting from existing coal generation to utility-scale solar was $29 per ton of CO2 reduction.[26][27] A 2022 study by Columbia University's Center of Global Energy Policy calculated that the cost of converting from existing natural gas generation to utility-scale solar in California was $60 per ton of CO2 reduction.[28]

The benefits of remediating coal piles through combustion at VCHEC are not uniform across all the affected communities. Those communities could be based on region, for example southwest Virginia compared to the whole Commonwealth, funding source, for example, taxpayers or ratepayers, or other factors. In terms of region, the GHG reductions associated with VCHEC are experienced across the Commonwealth while other environmental benefits, such as improved water quality, would primarily be experienced by the residents of the coalfields. Similarly, Dominion ratepayers would experience the GHG benefits of VCHEC but not the other environmental benefits as the coal piles are outside of Dominion's service territory. Utility customers could benefit from increased capacity from an existing, dispatchable resource through avoidance of some new construction of fossil fuel plants and increased output from a plant that is already connected to high-capacity transmission. Including the proportion of generation attributable to waste coal from VCHEC as an eligible resource under VCEA could enhance the economics of the facility. While waste coal combusted at VCHEC is neither a renewable nor a zero-carbon resource when used in energy production, the conversion of methane to carbon

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[23] § 56-585.1 A(6)

[24] Interagency Working Group on Social Cost of Greenhouse Gases, United States Government, *Technical Support Document: - Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 12866* (August 2016), 4

[25] EPA, *Supplementary Material for the Regulatory Impact Analysis for the Final Rulemaking, "Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review" EPA Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances* (November 2023)

[26] Based on an approximate 25% inflation rate between 2017 and 2023 that would place the figure at $36.25 in today's dollars.

[27] Gillingham, Kenneth and James Stock (2018) The Cost of Reducing Greenhouse Gas Emissions. *Journal of Economic Perspectives*, 32(5): 1-20.

[28] Columbia University Center on Global Energy Policy, *Levelized Cost Of Carbon Abatement: An Improved Cost-assessment Methodology For A Net-zero Emissions World (*October 2020*)*

dioxide in the combustion process for energy production provides a clear benefit in terms of reduced GHG emissions and would appear to meet the ultimate intent of the legislation.

At its current output VCHEC makes significant contributions to the economy of southwest Virginia and these economic benefits would be amplified if more waste coal were being collected and combusted. While incentives to increase activity at VCHEC or accelerate remediation programs would be beneficial to the economy of southwest Virginia there would be costs to other citizens of the Commonwealth, through taxes or rates, that need to be considered. As described in the AML Program section reclamation for combustion does have the benefit of reducing the amount of taxpayer-funded engineering work to remediate piles in place.

While it is possible that a more economical and environmentally beneficial process for remediating waste coal piles will emerge in the future, there are no strong prospects at this time and the piles will continue to cause significant environmental damage in the intervening period. Incentivization of remediation efforts and increased combustion at VCHEC could be considered public interest actions based on the declaration of the 2022 General Assembly in HB 1326.

Further Study

There are limitations to the available data that was employed in this report and the TRC emissions study. Most notably there is an absence of data specific to the waste coal piles of southwest Virginia with current emissions estimates based on EPA literature that does not directly address the Virginia coal waste. While it is reasonable to assume that the waste coal piles in Virginia emit at comparable rates, site specific data would clarify the emissions profile of the Virginia waste piles and help to refine the value proposition for the different policy options presented above. An in-depth study could also quantify the effects of waste coal piles on water quality and other environmental impacts. This could allow the Commonwealth to prioritize piles for remediation based on emissions, water quality impacts or other factors.

TRC has provided an estimate for executing a detailed sampling and measurements plan and protocol (see Appendix 2). This estimate is provided for reference only and neither the Commonwealth nor TRC are obligated in any manner to execute a contract. The project description includes identifying spontaneous combustion occurring at waste coal piles and onsite emissions testing and the preliminary estimate is $100,000. In the event that further study is deemed necessary, available funding should be adjusted to reflect the actual requirements and expectations set out by the General Assembly.

Recommendations

1. The General Assembly should consider incentivization of waste coal combustion. There is a clear GHG emissions benefit to combusting material and the only alternative method of remediation does not address the GHG emissions or substantially eliminate the waste coal. There are also ancillary economic benefits in maintaining a dispatchable generating facility in VCHEC and increasing economic activity in southwest Virginia. Waste coal combustion incentivization should be used as a point of comparison for other proposals to reduce GHG emissions, remediate environmental hazards or create economic development opportunities in southwest Virginia.

2. The Commonwealth should pursue all suitable federal funding opportunities for remediation efforts.

3. Virginia Energy will continue to monitor technological advances or market developments that open new pathways to address waste coal and report such developments, including the prospects for critical mineral extraction from waste coal.

4. In the event that further study is deemed necessary to provide greater detail on the GHG emissions and other environmental impacts associated with waste coal and its combustion, a more detailed technical study, to include field testing of waste coal piles, could be conducted. Available funding should be adjusted to reflect the actual requirements and expectations set out by the General Assembly.

Conclusion

Waste coal piles present a serious and ongoing hazard to the environment and public safety in southwest Virginia. The remediation of waste coal piles through encapsulation and similar projects protects water quality but has a weaker effect on emissions reduction and does not ultimately eliminate the waste coal. Currently, waste coal combustion is the only viable means to entirely remove the waste coal piles and it creates a significant emissions benefit. Waste coal combustion appears to have great potential to reduce environmental harms and is deserving of consideration and comparison with other efforts to enhance the environment and the economy of the Commonwealth.

Appendix 1 TRC Report

Appendix 2 TRC Conceptual Recommendations to Improve CO2e Emissions Data from Abandoned GOB Piles in VA

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Virginia Energy

Net Air Emission Benefits from the Remediation of Abandoned Coal Refuse Piles

December 2023

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Executive Summary

Abandoned and managed coal refuse piles represent a legacy environmental hazard in Virginia as well as throughout the Appalachian coal producing region of the United States. Due to the sheer magnitude of legacy coal refuse in Virginia and Appalachia in general, existing coal refuse piles represent a well-documented threat to the natural environment[1]. While the adverse impacts of rainwater runoff are well documented, the inventory of abandoned and, to a lesser extent, managed coal refuse also represents a substantial ongoing source of uncontrolled air emissions, including planet warming greenhouse gases and other fugitive air pollutants[2]. As measured in terms of carbon dioxide equivalent (CO_2e), annual greenhouse gas (GHG) emissions due to legacy coal refuse piles can no longer be ignored simply because the material has were historically deposited, were of little commercial value, and/or the companies that deposited this waste as much as a century ago are long gone, leaving behind only a lasting legacy of pollution. Virginia Department of Energy (Virginia Energy) sponsored this study originally to evaluate Abandoned Mine Land (AML) sites for which the Commonwealth is responsible. However, upon further discussion it was agreed that consideration should also be given to air emissions potential of post 1977 Surface Mining Control and Reclamation Act (SMCRA) waste coal surface impoundments in VA, in order to characterize the full scope and extant of all coal refuse in the State. SMCRA created an Abandoned Mine Land fund to pay for the cleanup of mine lands abandoned before the passage of the statute in 1978. 80% of AML funds are distributed to states with an approved reclamation program to fund reclamation activities. The remaining 20% are used to respond to emergencies such as landslides, land subsidence and fires, and to carry out high priority cleanups in states without approved programs. **Virginia Energy is primarily responsible for ultimate reclamation of the estimated 14,956,951 cubic yards (~ 16 million tons) of pre-SMCRA coal refuse abandoned in VA that is subject to AML funding.** However, it is also useful to consider Virginia Energy's estimate that an additional 64 million cubic yards of coal refuse is also being managed in regulated impoundments, for a total of about 80 million cubic yards of total VA coal refuse potentially emitting GHG (or other) air emissions to the environment (VA DOE Report, 12/1/22 [32]).

This study seeks to characterize the magnitude of GHG and other air pollutants being emitted via the air pathway to the environment every day from abandoned and managed coal refuse piles in Virginia. It is well documented that abandoned coal refuse piles are subject to a natural oxidation process leading to a process of spontaneous combustion, which releases fine particulate and products of incomplete combustion including carbon dioxide (CO_2) and methane (CH_4) to the atmosphere[3]. Fugitive (area-source) criteria and hazardous air pollutant emissions from abandoned coal refuse sites affect air quality locally as well as GHG emissions globally. The gradual emission of GHGs (such as methane and CO_2) from the natural process of partial oxidation of existing abandoned coal refuse, if unabated, will remain virtually “forever emitters” of GHG and other air pollutants due to the sheer quantities of coal refuse in the VA inventories. When characterizing potential adverse air quality emissions from abandoned coal refuse piles, it is particularly useful to compare potential in-situ annual and potential lifetime air pollution impacts with the highly controlled and well documented air emissions from permanently remediating an equivalent annual of coal refuse by the reclamation-to-energy industry. For purposes of this study, we have estimated possible emissions assuming that post SMCRA waste coal impoundments likely also emit air pollutants at a similar rate.

The Appalachian region has relied for years on the coal refuse reclamation-to-energy industry to permanently remediate abandoned coal mining waste, which represents a cost-effective and permanent solution to this significant environmental problem[4]. Virginia has been permanently remediating existing in-state GOB (“Garbage of Bituminous”) pre SMCRA abandoned waste coal piles by responsibly destroying them while recovering needed energy via controlled combustion at the state-of-the-art Virginia City Hybrid Energy Center (VCHEC). According to representatives of VCHEC, the facility accepts both pre-SMCRA and post SMCRA coal refuse; the global GHG budget makes no such distinction. In addition to addressing the multitude of soil and water environmental benefits obtained by permanent removal (total remediation) of these existing legacy tailings piles and managed impoundments, as cited in prior studies, the highly controlled combustion-remediation of coal refuse eliminates its ability to emit additional air pollutants every year, as it has since being originally piled. Combustion of coal refuse in a highly controlled manner in Virginia during 2022 permanently removed an estimated 299,000 tons of actively emitting abandoned coal refuse from the global emission inventory every year[5], plus another 319,000 tons of post SMCRA coal refuse. There is no question that coal refuse reclamation-to-energy plants, by permanently breaking the fossil GHG decomposition emission chain, also emit CO_2. It is therefore the purpose of this study to numerically compare air quality and GHG emissions from ongoing permanent remediation of coal refuse in facilities like VCHEC to the uncontrolled and ongoing air emissions of allowing existing coal refuse piles and impoundments to continue emitting methane and other air pollutants in situ (including potential re-planting alternatives).

This study estimates that coal refuse destruction by the reclamation-to-energy industry in Virginia alone <u>reduces the equivalent *net* GHG emissions</u> that would otherwise be emitted from the same amount of coal refuse left in situ by at least < 2.7 Million tons > of CO_2e in a single year, and as much as < 32.5 million tons > of CO_2e over an assumed lifecycle vs, coal refuse piles left in-situ. The emission factors characterized in this report represent an average of annual GHG emissions for portions of GOB piles from various emission factors cited from the literature on an annual basis. However, that same GOB pile will continue to emit CO_2e the next year, and the next year and so on until all of its total carbon content has been completely diminished, whereas the coal refuse-to-energy industry destroys its ability to emit any more CO_2e forever. For this reason, we multiplied annual emissions from a typical GOB Pile by a factor of ten in an effort to conservatively characterize its eventual potential lifetime emissions for comparison with the net benefit of permanent destruction once and for all. The Lifetime Potential CO_2e emissions from a GOB Pile abandoned in situ is an area that would benefit from further study. The numerical GHG emissions reduction over many years as CO_2e is summarized in Table ES-1 below. The avoided GHG emissions estimated from the permanent remediation of abandoned coal refuse in Virginia are presented below in **(red)**[6,7,8].

Table ES-1

Pollutant	Global Warming Potential(2)	Weathering + Burning/Smoldering Typical GOB In-Situ					618,510 Tons of Coal Refuse GOB Combusted by VCHEC CFB Boilers - 2022		Net Air Quality Benefit of Remediation via Controlled Combustion (tons)		
		Emission Factor (ton/ton Coal Refuse Oxidizing)	Estimated Emissions for 618,510 tons of Coal Refuse Weathering (tons)	Estimated Emissions for 618,510 tons of Coal Refuse Smoldering / Burning (tons)	Estimated Total Annual Emissions Associated with 618,510 tons of GOB Remaining in-situ (tons)	Assumed 1-yr GOB Pile Emissions Multiplied by 10 to reflect Potential Lifecycle Emissions to Completely Decompose 618,510 tons (tons)	Emission Factor (lb/MMBtu)	Estimated VCHEC Coal Refuse GHG Emissions Attributed to Remediation of 618,510 tons (tons)	Net Comparison based on Estimated Emissions per ton of Coal Refuse Being Oxidized in Situ (tons)	Net Comparison based on Estimated Potential Lifecycle Emissions (tons)	Tons of Estimated Potential Lifecycle net GHG Emissions (as CO2e) per ton of Waste Coal Permanently neutralized
CO_2	1	1.180(4)	14,602	729,842	744,443.6	7,298,418	181.5(5, 6)	645,506	(84,336)	(6,652,912)	(10.8)
CH_4	25	0.163 (33)	2,016	100,817	102,833.5	1,008,171	3.37E-2(5, 6)	120	(100,697)	(1,008,051)	(1.6)
CO_2e			**65,010**	**3,250,270**	**3,315,280**	**33,152,804**		**648,505**	**(2,666,775)**	**(32,504,299)**	**(52.6)**

1. From VCHEC 2022
2. 40 CFR 98 Subpart A Table A-1
3. *Environmental Influence of Gaseous Emissions from Self-Heating Coal Waste Dumps in Silesia, Poland,* Fabiańska M, Ciesielczuk J, Nádudvari Á, Misz-Kennan M, Kowalski A, Kruszewski Ł. Environ Geochem Health. 2019 Apr;41(2):575-601. doi: 10.1007/s10653-018-0153-5. Epub 2018 Jul 24.
4. Gielisch H, Kropp C., *Coal Fires a Major Source of Greenhouse Gases- a Forgotten Problem.* Environmental Risk Assessment and Remediation 2017; 2(1): 5-8;

   https://www.alliedacademies.org/articles/coal-fires-a-major-source-of-greenhouse-gases-a-forgotten-problem-8871.html

33 ARIPPA substituted value for CH4 reduced from 0.7625 to 0.163, substituted to add conservatism and consistency with reported values

The coal refuse to reclamation industry in VA (VCHEC) permanently remediated a total of 618,510 tons of total coal refuse in 2022. The values presented in Table ES-1 show that permanent remediation of this amount of coal refuse in Virginia by the coal refuse reclamation-to-energy is responsible for as much as the net lifecycle estimated reduction of over 32 million tons of CO_2e that might otherwise have eventually been emitted to the Global Warming global budget. On this basis, similar net lifecycle CO_2e emissions to the environment will continue to be reduced by a similar amount every year that permanent remediation at VCHEC continues at comparable levels. According to VCHEC representatives, VCHEC is capable of significantly increased capacity firing VA Coal refuse. Coal refuse reclamation-to-energy plants are very efficient in terms of converting nearly 100% of the hydrocarbon component of coal refuse to CO_2 while efficiently producing useful power. When they do so, they destroy the ability of that amount of coal refuse to emit that same carbon as methane rather than CO_2, including over many more years.

The net climate change benefit of the coal refuse reclamation-to-energy industry is that of converting methane that would otherwise be eventually emitted from waste coal decomposition over many years directly and efficiently to CO_2. ***Methane is considered to be about 81 times more potent in terms of warming the climate in the <u>near-term</u> (during the next 20 years after its release to the atmosphere)***[9], and when normalized over 100 years for direct comparison to CO_2 emissions as standardized by the U.S. Environmental Protection Agency (USEPA), is characterized as 25-28 times more potent of a greenhouse gas over the *long-term*[10]. For this study we have assumed that CH_4 is only 25 times as potent a GHG as CO^2. The permanent elimination of naturally occurring methane emissions from existing coal refuse piles and impoundments (as a virtually forever emission source) has a much greater benefit to reversing global climate change than the one-time and final conversion of existing coal refuse to CO_2 and useful energy. As such, it is important to compare the bottom row in Table 1, which sums net GHG emissions in units of net CO_2e per ton remediated comparing lifecycle emissions of the same amount of coal refuse either allowed to remain in situ passively emitting uncontrolled air pollutants or remediated forever via responsible and highly regulated energy recovery by the coal refuse reclamation-to-energy industry.

The coal refuse reclamation-to-energy industry was found to eliminate as much as 52 net tons of potential lifecycle CO_2e emissions per ton of Virginia GOB coal refuse that it permanently eliminates from the environment and converts almost completely to CO_2 and useful energy. Emissions of CH_4 and CO_2 from waste coal decomposition would otherwise continue to be released into the environment over the coal refuse emission lifecycle. In 2022, VCHEC combusted 618,510 tons of total coal refuse, resulting in as much as a potential net lifecycle reduction of CO_2e that might have otherwise eventually been emitted uncontrolled from coal refuse of (32,504,299) net tons CO_2e reduced. On a per ton of coal refuse basis, a net reduction of at least (2,666,775) tons of potential CO_2e is being reduced by VCHEC annually (while leaving residual GOB in situ to continue emitting). According to the facility, VCHEC has additional capacity to remediate more. Operations at these levels will yield proportional levels of net environmental benefits every year that this industry continues its important mine-land and waste coal reclamation mission.

As demonstrated in this study, combusting the same quantity of coal refuse permanently remediated by the coal refuse reclamation-to-energy industry in 2022 (618,510 tons) has been estimated to result in a potential lifecycle net CO_2e reduction benefit of as much as 32.5 million net tons of lifecycle CO_2e emissions EVERY YEAR that it does so. Very simply, while the combustion of coal refuse certainly does emit the greenhouse gas CO_2 now, doing so avoids the more harmful ongoing GHG emissions of the potent greenhouse gas methane that would otherwise have been emitted during that same GOB Pile's lifecycle from abandoned coal refuse if allowed to remain in existing impoundments or piles. It is very challenging to think of another economically viable and environmentally beneficial technology of any kind that could come close to providing a net CO_2e benefit of this magnitude, at little cost to the Commonwealth of Virginia, while permanently eliminating further collateral environmental problems created by coal refuse, as part of a national strategy to achieve "net zero" GHG emissions by 2050.

Introduction

It has long been recognized that the enormous inventory of coal refuse piles abandoned by the legacy coal mining industry in Appalachia represents an ongoing ecological threat to the environment. Adverse environmental impacts to soil, stormwater runoff, surface water, and groundwater from these un-remediated, abandoned environmental hazards are well documented[11]. Comparatively fewer examinations of the adverse air quality and CO_2e greenhouse gas emission impacts of un-remediated abandoned refuse piles have been identified in the literature. It is the premise of this study that post-SMCRA impoundments are designed to mitigate impacts to soil and water resources, but likely also may emit air pollutants at some as-yet undocumented rate.

During the 1970s through the 1990s, environmental advocates and government agencies promoted and enabled investment in coal refuse reclamation-to-energy facilities capable of remediating abandoned coal refuse by recovering the useful thermal energy of this abandoned waste material to produce needed electricity. At present, the Virginia City Hybrid Energy Center (VCHEC) is currently (CY2022) permanently remediating an estimated 618,510 tons of Virginia coal refuse every year, and is capable of processing more in the future. Unfortunately, lack of understanding that such coal refuse reclamation-to-energy facilities operate, in large part, to address legacy environmental damage in Virginia has become confused with the environmental movement to shutter utility-scale coal-fired electric generating units (EGU's).

Today, we broadly recognize the goal of achieving "net zero" GHG emissions by 2040-2050[12]. In recent years, there has been a groundswell of public sentiment that coal combustion should be phased out of existence in favor of renewables that do not emit the greenhouse gas CO_2. Lost in the translation is the unique environmental role, including important net reductions in air pollutants and GHG emissions, provided by the coal refuse reclamation-to-energy industry. While the industry continues to help reverse coal refuse pile runoff pollution to water and soil, it is now incumbent to re-evaluate this industry in the context of achieving net GHG <u>reductions</u> as part of the fight to reduce anthropogenic contributions to climate change. This statement is likely counter-intuitive, however abandoned waste coal in Virginia emits the very potent greenhouse gas methane over its lifecycle, which will continue to frustrate efforts to attain net zero GHG emissions by 2050, since left in-situ legacy waste coal piles are essentially "forever sources" of CO_2e. This chain can only be practically broken by re-mining waste coal and permanently destroying this source of methane via efficient combustion to the much less potent GHG CO_2, once and for all.

This study seeks to document the coal refuse reclamation-to-energy industry's significant contribution to the net reduction of global CO_2e concentrations by permanently remediating abandoned and managed coal refuse in Virginia. The coal refuse reclamation-to-energy industry has found a way to finance the permanent cleanup of abandoned coal refuse, reducing presently occurring emissions of anthropogenic methane (a very potent GHG), while also displacing net GHG emissions from other fossil generation sources actively being phased out. Absent the coal refuse reclamation-to-energy industry, legacy coal refuse piles would remain essentially abandoned to the environment and will frustrate regional air quality and climate change goals for multiple additional generations as the abandoned piles themselves continue to emit products of incomplete combustion, CO_2, and the potent greenhouse gas methane[13]. Based on published emission estimates from the literature, the authors have compared CO_2e emissions from the remediation of 618,510 tons of waste coal annually (as at present) by the coal refuse reclamation-to-energy industry in Virginia vs. lifecycle CO_2e emissions being naturally emitted to the environment by not remediating that same amount of coal refuse. The emissions of methane from abandoned coal refuse piles, based on measurements by USEPA[14] and others, are at least 25 times more potent GHG emissions than the CO_2 emitted from controlled and permanent combustion of coal refuse for remediation. This study indicates that, based on published literature, the coal refuse reclamation-to-energy industry in Virginia plays a very important role in reducing global and regional emissions of CO_2e.

Background

The Eastern US Coal Mines fueled America's Industrial Revolution of the 1800s as well as electricity demand through the 1990s. Eastern Bituminous coal from SW VA was mined as a low-cost fuel to produce steam power and later electricity for the factories and lifestyle that built the American economy.

The early technology of burning coal on stoker grates created demand for “stoker coal”, meaning lump coal with minimal fines and tramp material content. To produce stoker coal, run-of-mine coal was processed and sized, including removal and discard of inert material (such as pyrites and rock) as well as coal fines prior to shipment. In every case, coal mined in Virginia needed to be transported to its point of use via some combination of barges, railroads and trucks. Depending on logistics, transportation often cost as much as the coal itself. These economics drove the practice of “coal washing” prior to transportation as a cost reduction measure. When mining coal, the useful fuel was often contaminated with naturally occurring inert materials such as soil, rocks and stone. There was no value to the end user in paying to ship inert, non-combustible impurities that were mined together with the coal, and the inert content also lowered its heating value which made the delivered product less desirable/valuable. For these reasons, it became economically advantageous to “wash” out as much of these “fines” and inert contaminants as practical prior to shipment. It was also noted that much of the sulfur content in as-mined coal was contained within the inert pyrites, and that pre-washing the coal prior to shipment also reduced its sulfur content.

In coal washing, a specific gravity separation was performed to remove unwanted fines and heavier inert materials such as shale rock and pyrites as unmarketable waste. After removal of these fines and incombustible inert materials, the coal to be shipped became more valuable in that it contained more British thermal units (Btu) per ton shipped, less fines, ash and sulfur. The result was that the waste materials from overburden, size separation and washing prior to shipment had little heating value and no residual commercial value; they were simply discarded as unlined landfills near the mine or preparation plant as waste over approximately 100 years of mining operations, creating enormous legacy coal refuse piles in Virginia as well as throughout Appalachia.

Coal mining refuse (a.k.a. culm, gob, tailings, boney, silt, among other names) tends to be wetter, as fines retain more moisture, and higher in ash and sulfur content than the native coal originally mined. The typical remaining heating value of coal refuse, especially after years of weathering, is at least less than half the specification for steam coal, averaging only about 5,750 Btu/lb (USEPA AP-42) vs. about 11,000-12,000 Btu/lb for commercial Eastern Bituminous coal). We note that the actual heating value of coal refuse varies pile-to-pile and mine-to-mine, and even varies within piles as various layers were deposited on top of each other over many years. Due to this variability, coal refuse can range from less than 3,000 Btu/lb to over 7,000 Btu/lb. We have therefore assumed the US EPA AP-42 value of 5,750 Btu/lb as representative of coal refuse generally.

Up until the late 1970s, there was no industrial coal combustion technology capable of utilizing low heating value coal refuse. It was, therefore, a true waste byproduct with no economic value to anyone. As a result, coal refuse was simply landfilled, piled up and abandoned to the elements. Under the Surface Mining Control and Reclamation Act of 1977 (SMCRA), landowners and companies responsible for abandoning legacy coal refuse piles are no longer liable for remediating these abandoned piles that now litter the historic coal fields of Virginia.

This pre-SMCRA abandoned coal refuse is categorized as AML (abandoned mine land) material in VA, and is colloquially referred to as GOB, while post SMCRA coal refuse is colloquially referred to as "Non-GOB waste coal". Importantly, the coal refuse is substantially the same material regardless of its date of placement, and is indistinguishable in terms of its potential to emit CO_2e to the atmosphere as it naturally decomposes. The traditional cost of remediating just the existing AML piles in VA is currently estimated by Virginia Energy at more than $360 million to the State and Federal government, with limited resources to resolve this massive environmental problem. Even with 25 states expected to receive more than $11 billion in additional federal funding to reclaim abandoned mine land (AML) sites over the next 15 years under the bipartisan Infrastructure Investment and Jobs Act of 2021, this amount will be insufficient to even nearly fund the currently identified AML problems throughout Appalachia.[16] TRC has no case-specific CO_2e estimates for Non-GOB waste impoundment air emissions, but for purposes of this study we consider that since the material is virtually identical that it exhibits similar reactivity, rates of decay and potential air emissions during impoundment.

In the late 1970s, partially in response to the Arab Oil Embargo, a new technology called circulating fluidized bed (CFB) combustion emerged with the promise of being able to cleanly burn a wide range of difficult-to-burn fuels, including low Btu, high-sulfur and high inert content coal refuse. For the very first time, this technology enabled responsible re-mining and energy recycling of abandoned coal refuse piles and newly generated coal refuse while producing electricity for sale to pay for the permanent remediation of these legacy environmental scars. Since that time, the industry has remediated more than 250 million tons of polluting coal refuse across Appalachia. The continued operation of these coal refuse reclamation-to-energy facilities, including VCHEC in VA, provide ongoing environmental reclamation and clean up benefits to land, water, air quality and greenhouse gas emissions to the environment while offsetting the funding shortfall for permanent remedial cleanup of polluting legacy coal refuse piles.

Permanent Coal Refuse Remediation

Absent permanent remediation, the legacy abandoned coal refuse piles littering Appalachia (including VA) represent virtually "forever emitters" of air pollutants and greenhouse gases due to their shear depth and volume. Such pollutants include windblown fugitive particulate fines (referred to as the inhalable pollutant, PM_{10}), hazardous air pollutants such as mercury, hydrogen sulfide or arsenic deposited as formerly trace constituents of mined coal, and Clean Air Act (CAA) regulated criteria air pollutants, as they have been for over 100 years since being originally discarded. This is an important concept. When a ton of coal refuse is instantly forever eliminated via useful energy recovery, it can never again emit air pollutants or greenhouse gases, let alone continue to contribute to acidification of soil and water resources. This concept has similarities to our approaches to cleanup of buried drums of hazardous waste or historic disposal of coal ash landfills or municipal solid waste in unlined landfills. It is because of the sheer magnitude of coal mine waste generated over many years that coal refuse such as Garbage of Bituminous (GOB) has been allowed to fill pristine valleys, create new mountains, remain abandoned in-situ and left to subsequent generations.

When considering the air emissions profile of these unmitigated coal refuse piles, it is meaningful to contrast them with their permanent forever destruction by the coal refuse reclamation-to-energy industry. We must consider the air quality benefits of permanent remediation of coal refuse under highly controlled

CFB combustion conditions, employing USEPA Best Available [emissions] Control Technology (BACT) against the uncontrolled combustion pyrolysis continuously emitting air and climate pollutants within legacy abandoned coal refuse piles.

Emissions from the coal refuse reclamation-to-energy industry are often inappropriately compared to traditional coal-fired electric utility generating units (EGUs); however, the coal refuse reclamation-to-energy industry produces fundamentally different environmental benefits than coal-fired EGUs because they primarily provide mine land reclamation services while co-producing useful energy. These facilities do not directly compete in this regard with electric generating unit (EGU) coal-fired power plants, which are presently being phased out of operation largely due to their CO_2 GHG contributions to global climate change. Those pulverized coal-fired generating units are not capable of remediating abandoned coal refuse to clean up the environment in the same manner as CFB boiler technology. Coal that is mined to produce power in pulverized coal-fired power plants has been effectively sequestering carbon beneath the earth for millions of years. Mining, processing, and combustion of that previously sequestered carbon of newly mined coal indeed re-emits long dormant CO2. Abandoned refuse piles, however, have already been mined and left behind as an abandoned environmental legacy pollutant, free to continue emitting greenhouse gases and other harmful air emissions without any further human intervention over hundreds of years.

While air pollutants and GHGs are emitted at once during controlled combustion in a CFB boiler, those boilers incorporate Best Available emissions Control Technology (BACT), are optimized to achieve complete combustion of hydrocarbons, and are highly regulated by both state and federal air emissions requirements. Air emissions from abandoned coal refuse piles are not. Societal goals such as net zero GHG emissions by 2050 will be frustrated by this waste coal "sleeper" source of nearly continuous "forever" emissions of methane unless abandoned coal refuse is re-mined and permanently converted from a source of pollution to useful energy, enabling further displacement of newly extracted fossil fuel emissions.

As examined quantitatively in this study, USEPA and others have measured and characterized air emissions from smoldering and spontaneously combusting rogue coal refuse piles[17]. Coal refuse energy recovery and permanent remediation facilities operate very responsibly, are aggressively regulated, and operate in continuous compliance with all applicable state and federal air quality regulations and standards. State and Federal Environmental Regulatory Authorities monitor these facilities to ensure that they do not cause or contribute to a "condition of air pollution", while air emissions from abandoned coal refuse piles are unregulated and accepted as "naturally occurring" sources of air pollutant emissions. Their ability to slowly emit polluting emissions over enormous surface areas and almost unimaginable volumes constitute a source of ground-level anthropogenic air emissions that should also be evaluated through the lens of local air quality impacts, including Environmental Justice Communities in the abandoned coal fields of Appalachia.

For any hydrocarbon fuel to be theoretically completely combusted to CO_2 and water vapor (H_2O) requires the ability to provide at least the ideal, or stoichiometric, air-to-fuel ratio and high combustion temperatures needed to completely convert the hydrocarbons in the fuel. Insufficient, off-stochiometric air-to-fuel ratios and/or smoldering at low temperatures cause incomplete combustion of fuel. This means when there is insufficient oxygen, any fossil fuel will be only partially combusted, emitting intermediate products of incomplete combustion such as the potent greenhouse gas methane, hydrogen sulfide (H_2S), and likely the even more potent greenhouse gas nitrous oxide (N_2O) instead of nitrogen dioxide (NO_2).

The combustion of coal refuse in piles, lacking the stoichiometric amount of air to complete combustion therefore releases different, more polluting, and much more potent GHG intermediates such as methane and nitrous oxide, uncontrolled mercury (which is highly controlled in CFB boilers[18]), odorous and toxic hydrogen sulfide (H_2S), carbon monoxide (CO), uncontrolled fine particulate (PM_{10}) and others directly to the local airshed as ground-level "area sources" of air pollutants transported by the wind. Sulfur emissions can be identified by their distinct odor, which is easily recognized near coal refuse piles. This is important because in the alternative, coal refuse reclamation-to-energy facilities are equipped with advanced air pollution control systems, including Government oversight, emissions monitoring and reporting to maintain continuous regulatory compliance with stringent emission limitations, and only emit highly controlled flue gases at elevated temperature and velocity from tall stacks that are maintained according to USEPA Good Engineering Practice (GEP) to protect human health and welfare via compliance with NIH and USEPA National Ambient Air Quality Standards (NAAQS)[19].

Coal refuse pile emissions on the other hand are largely forgotten, neglected and unpermitted emission sources that naturally emit toxic and criteria air pollutants with minimal dilution at ground level, where downwind residents of affected communities live and breathe. Being emitted at surface level, and particularly for air pollutants that are heavier than air, they can form choking clouds of smoke-laced pollutants that can be detected as visible haze and the odor of sulfur downgradient and downwind. These forms of incomplete combustion, which are emitted in Virginia every hour of every day, are far more problematic than the highly controlled combustion environment and resultant controlled emissions of a CAA-permitted coal refuse reclamation-to-energy CFB combustion unit.

Based on these factors, the authors sought to characterize a literature-based net comparison of the GHG and other air pollutant quantities of "forever" air emissions continuously emitted from legacy abandoned coal refuse piles with the documented net air emissions produced by VCHEC and other coal refuse reclamation-to-energy facilities as they permanently remediate (destroy) abandoned coal refuse while recovering it's useful thermal energy[20]. Our comparison shows that the coal refuse reclamation-to-energy industry throughout Appalachia prevents millions of the tons of CO_2e and other partial combustion products being otherwise emitted by abandoned coal refuse piles at ground level every single year. The very real CO_2e net reduction offsets will, in the future, become a necessary component of plans to actually achieve net zero GHG emissions in these States by 2050. Indeed, the authors suggest that the coal refuse reclamation-to-energy industry should be recognized in any program for limiting, banking, or trading GHG emissions for its factual ability to permanently generate substantial net CO_2e offsets. Maximum benefits to the environment warrant maximum capacity operation of such remediation assets for many years to come.

Coal Refuse Pile Air Emissions

Many of the environmental problems associated with coal refuse begin as a result of pyrite and sulfur oxidation with production of acidity. Historic refuse piles are the legacy of extraction, crushing and screening impurities of coal formerly existing as undisturbed solid coal seams. Coal refuse, then, is high in coal fragments and discarded as loose, unconsolidated waste piles that allow oxygen to interact easily with the high surface area of the fines discarded in the piles. One of the most well-known and noticeable environmental impacts of coal refuse piles is that they create acidic runoff, meaning that precipitation picks up pollutants that are liberated to leach into surface and ground waters – a process known as Acid Mine Drainage (AMD)[21]. AMD entering a stream from a nearby coal refuse pile can cause the stream to turn orange in color due to the iron precipitating out of solution as the solid, iron hydroxide ($Fe(OH)_2$). Much of the total sulfur in coal refuse is present as pyrite such as iron disulfide (FeS_2) and other sulfides that oxidize to sulfuric acid in the presence of water and oxygen.

Often overlooked is that pyrite oxidation is an exothermic, or heat-producing, reaction. Coal refuse pile fires typically evolve as a smoldering, oxygen starved incipient fire, producing limited necessary oxygen from the generation of steam from the moisture in the coal refuse itself [22]. The occurrence of this internal combustion process within coal refuse piles is often not outwardly visible, but may be identified via warmer temperatures developing within the pile itself. Clear evidence of the slowly developing combustion of burnable material within the pile is observed via the presence of a reddish-brown slate called "red dog". Red dog has often been found within VA GOB piles upon disturbance, indicating their history of previous combustion. The presence of red dog, a nonvolatile combustion product of the oxidation of coal refuse, therefore, provides visual evidence of a history of uncontrolled spontaneous combustion of the GOB piles of Virginia. Gradually, as internal temperatures increase and the process of spontaneous combustion continues to develop, avenues for oxygen migration through the refuse expand as telltale steam and smoke coupled with the odor of sulfur transitions to open flame. The visible flames from a burning coal refuse pile are primarily fueled by the release of flammable coal gas in a process similar to the production of "manufactured gas" in the late 1800's upon internal heating, gasification and ignition.

The primary sources of polluting air emissions from coal refuse piles are a result of weathering leading to spontaneous combustion, eventually evolving to pyrolysis and surface emissions of products of incomplete combustion[23]. It is well documented that all coal, including coal refuse, decays in carbon content when left for extended periods exposed to the weather (sunlight, wind, oxygen and acid precipitation) and that a continuing process of slow oxidation occurs within abandoned refuse piles that inevitably and eventually leads to spontaneous combustion[6]. During low temperature gradual oxidation, the carbon atoms that give coal refuse its heating value as a low grade hydrocarbon fuel gradually self-oxidize to the greenhouse gases methane and carbon dioxide, which will continue to be emitted along with other fuel-bound air pollutants and fine particulates as long as there is any remaining carbon left to be oxidized – perhaps over hundreds of years given the massive total inventory of coal refuse abandoned in Virginia as well as throughout Appalachia. While slow oxidation may not be noticeable to the naked eye, when thousands of acres of incipient and visible coal refuse in various stages of spontaneous combustion are exposed to the open air, abandoned coal refuse becomes a significant source of air and methane pollution in addition to combustion products of smoldering, and ultimately open flame. These "pop-up" air emission sources continue every year for as long as abandoned coal refuse piles are allowed to persist. Putting out these fires (Virginia Energy estimates a potential lifecycle cost of over $260 Million to remediate AML GOB at all VA sites) on a "pop-up" basis does not break the spontaneous combustion cycle – the same piles will only reset and restart the process of passive combustion.

The slow oxidation process known as weathering generates heat within the pile, eventually leading to the runaway chemical reaction of increasing temperature, unlimited hydrocarbon fuel supply and partial oxygen, causing the phenomenon known as spontaneous combustion. Spontaneous combustion occurs first within the interior of coal refuse piles themselves because formerly crushed coal refuse contains voids, known as interstices, between the discreet broken coal fragments whose surface area is much greater than mined deposits of coal, are exposed to oxygen between particles[24]. Temperature rise is most pronounced in the interior of the piles since the inner layers are not subjected to radiational or rainwater cooling as at the surface. Thus, heat from the gradual oxidation process results in increasing internal temperatures, culminating in partial, incomplete combustion as evidenced by steam and/or smoke being emitted from a pile. Inside the pile, there is never sufficient oxygen to fully burn out all of the coal to CO_2 and H_2O – rather, once coal refuse begins to smolder within an existing coal refuse pile, it can continue to smolder in the absence of an ideal stoichiometric fuel to air ratio for months or years. The Centralia Coal Mine Fire in PA is an extreme example. Unlike the carefully controlled excess air and ratio combustion of a CFB boiler where the carbon and hydrocarbon content of coal refuse is efficiently burned out to water and CO_2, smoldering coal refuse is only partially converted to CO_2 with the balance emitted as the far more potent greenhouse gas methane (CH_4).

Finally, runaway temperatures within a smoldering pile will ultimately erupt into open flame where combustion of coal gas still occurs at far from the ideal stoichiometric air to fuel ratio. It is the gases generated due to pyrolysis (starved air combustion) that burn as open flame from the combustion of volatile hydrocarbons at the pile surface. From the heat so generated, the char (solid carbon) residue itself begins to burn to the extent sufficient oxygen is available. These types of higher temperature, but still oxygen-starved combustion not only release the greenhouse gases CO_2 and methane, but other uncontrolled air pollutant emissions such as NO_x, mercury, fine particulate (smoke), volatile organic compounds, oxides of nitrogen, carbon monoxide, sulfur compounds, and likely the extremely potent greenhouse gas nitrous oxide, at a higher rate than would otherwise be minimized in the well-controlled combustion conditions found at coal refuse reclamation-to-energy facilities. It is clear that the ubiquitous abandoned coal refuse piles and managed impoundments dotting Virginia and all of Appalachia are an existing and very significant existing source of uncontrolled CO_2e, hazardous air pollutants and CAA regulated criteria air pollutants simply due to their continued existence.

Various researchers have measured emissions from abandoned coal refuse piles, including US EPA. TRC performed an internet Literature search to identify such published emission factors for use in this study. These are presented in Table 1 below.

Table 1

Emission Factors for Coal Refuse Combustion

Pollutant	kg/hr per tonne of Burning Coal Refuse[1]	lb/hr/ton Smoldering Coal Refuse[1]	ton/1000 kg of Combusted Coal Refuse[2]	lb/ton of Combusted Coal Refuse[2]	lb/ton of Combusted Coal Refuse[33]	kg/tonne of Combusted Coal Refuse[4]	lb/ton of Combusted Coal Refuse[4]
NO_x	6.70E-05[1]	1.34E-04				3.00E-02	6.00E-02
CO	8.70E-03[1]	1.74E-02				9.70E+01	1.94E+02
CH_4			8.00E-01	1.45E+03	**3.26.E+02**		
CO_2			1.30E+00	2.36E+03	2.54E+03		
Total PM	3.40E-07[1]	6.80E-07				4.50E-01	9.00E-01
PM_{10}	8.70E-09[1]	1.74E-08				4.50E-01	9.00E-01
SO_2	7.40E-05[1]	1.48E-04			6.62E+01	8.40E-01	1.68E+00
SO_3	1.80E-07[1]	3.60E-07					
VOC	6.70E-05[1]	1.34E-04					
NH_3	4.30E-05[1]	8.60E-05					
H_2S	3.00E-04[1]	6.00E-04				6.10E-01	1.22E+00
Hg	4.60E-09[1]	9.20E-09			7.89E-04		
POM	1.30E-08[1]	2.60E-08					

1. *Coal Refuse Piles, Abandoned Mines and Outcrops, State of the Art,* EPA-600/2-78-004v, July 1978, Table 4
2. Gielisch H, Kropp C., *Coal Fires a Major Source of Greenhouse Gases- a Forgotten Problem.* Environmental Risk Assessment and Remediation 2017; 2(1): 5-8; https://www.alliedacademies.org/articles/coal-fires-a-major-source-of-greenhouse-gases-a-forgotten-problem-8871.html
3. https://www.epa.gov/sites/production/files/2015-07/documents/chapter_11_other_fuels_and_fuel_emission_factors.pdf
4. *Environmental Influence of Gaseous Emissions from Self-Heating Coal Waste Dumps in Silesia, Poland,* Fabiańska M, Ciesielczuk J, Nádudvari Á, Misz-Kennan M, Kowalski A, Kruszewski Ł. Environ Geochem Health. 2019 Apr;41(2):575-601. doi: 10.1007/s10653-018-0153-5. Epub 2018 Jul 24. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6510838/
5. EPA, *Emissions & Generation Resource Integrated Database (eGRID)* https://www.epa.gov/egrid

33. ARIPPA substituted value for CH4 reduced from 0.7625 (Gielisch) to 0.163, substituted to add conservatism and consistency with reported values

Extent and Distribution of Abandoned Coal Refuse Piles in Virginia

The enormity of existing abandoned coal refuse sites in SW Virginia is alarming. According to publicly available inventory data provided by Virginia Energy, 523 total acres of pre-SMCRA abandoned coal refuse pile surface area is continuously exposed to the elements (Table 2-1). At a typical bulk density of coal refuse of 60-80 lb/ft^3 (TRC has assumed an average of 80 lb/ft^3 to capture the high end of the range), the published VA inventory accounts for up to 16 million tons of AML coal refuse abandoned in the Commonwealth from the legacy mining industry[32].

It has been estimated that an additional 64 million tons of non-AML qualified coal refuse is being managed in surface impoundments ("non-GOB" coal refuse) for a total inventory estimate of around 80 million cubic yards of mining legacy waste coal (Table 2-2). In the following Tables, TRC has separately evaluated passive emissions from the VA AML Gob Pile inventory, as well as the estimated total 80 million total cubic yards of material including GOB and Non-GOB coal refuse in Virginia[32].

Based on estimated pile depths, the total estimated volume of existing AML GOB coal refuse piles in VA is estimated to equate to almost 15 million cubic yards of material (for perspective, a typical dump truck holds only about 10 to 14 cubic yards). Assuming coal refuse may average up to 80 lbs/ft^3, the total inventory of 80 million cubic yards would equate to an estimated 86,400,000 tons of total coal refuse identified within Virginia. Considering that abandoned legacy piles are known to cause continuing and significant adverse environmental and ecological impacts to soil, water, air quality, climate change, land use, habitat degradation, and aesthetics, these numbers are staggering. No other fossil fuel land disposal activity would today be allowed to remain deposited and abandoned in the U.S. without first requiring environmental remediation. The VA AML GOB inventory alone accounts for an estimated 16,153,507 tons of GOB coal refuse continually subjected to gradual internal thermal rise, products of incomplete combustion and potential runaway thermal oxidation. The first several feet of depth of this entire surface area is continuously undergoing the weathering process, also emitting fugitive fine particulate matter (smoke and windblown dust), otherwise regulated air pollutants, and greenhouse gases over a tremendous area of SWVA at a slow, but relentless rate. Tables 2-1 and 2-2 summarize the estimated inventory of AML GOB and total coal refuse extant in Virginia.

Table 2-1

Commonwealth of VA Estimated Extent of AML GOB Coal Refuse			
Pre SMCRA Abandoned AML GOB Coal Piles	**Acres**	**Cubic Yards**	**Estimated Tons @80 lb/ft^3**
VA State Coal Refuse AML GOB Inventory	523	**14,956,951**	**16,153,507**

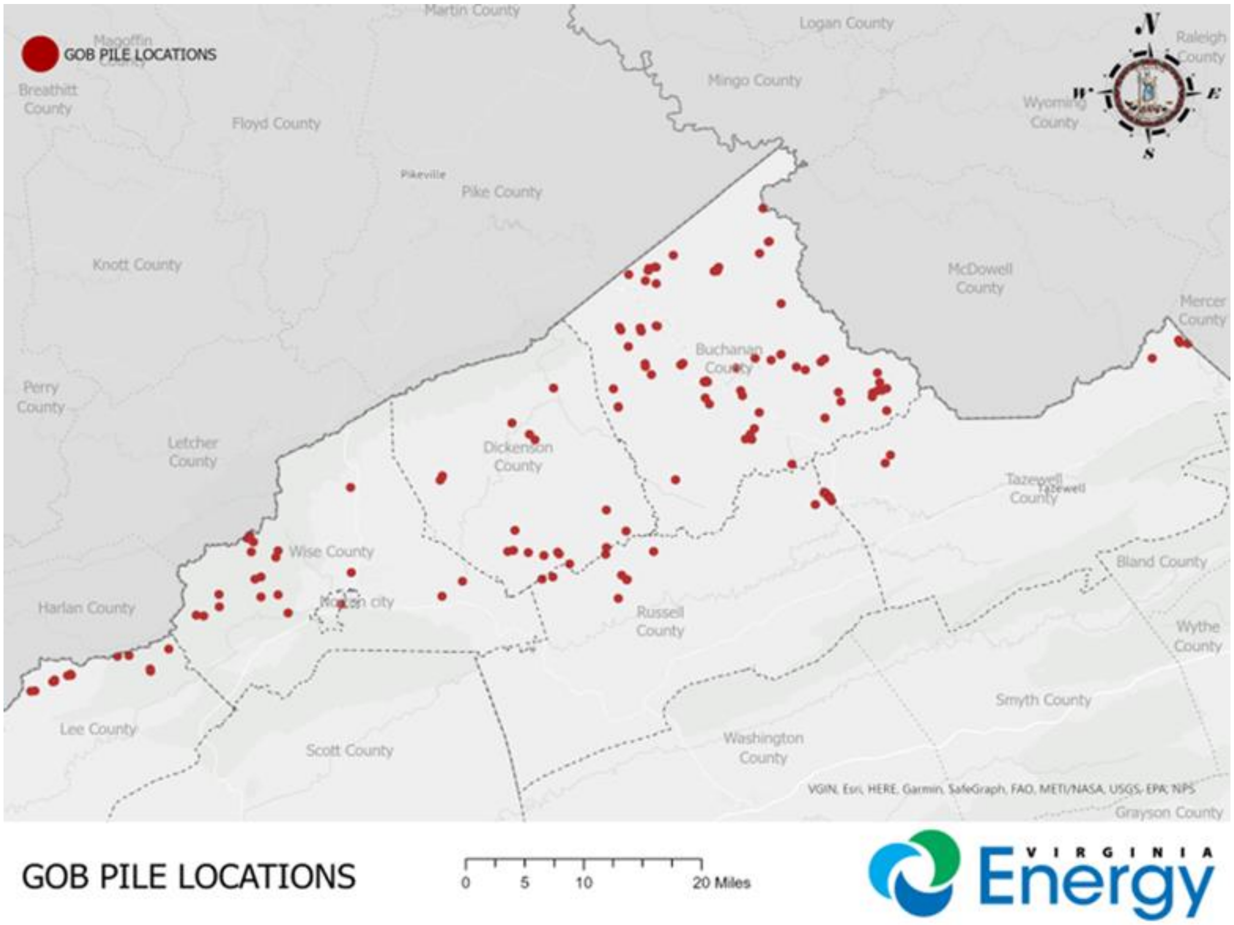
Table 2-2

Commonwealth of VA Estimated Extent of GOB and Non-GOB Coal Refuse			
Total Estimated AML GOB +Non-GOB Coal Piles	**Acres**	**Cubic Yards**	**Estimated Tons @80 lb/ft^3**
VA State Coal Refuse AML GOB + Non-GOB Inventory	2,615	**80,000,000**	**86,400,000**

The magnitude of mining legacy waste material in the Commonwealth of Virgina is stunning. Any portions of this material that may be slowly emitting GHG's or other pollutants, even at a very low rate, becomes a very significant source of total air and GHG emissions simply given that the area and volume data are estimated in millions of tons.

Figure 1 below shows the locations of pre-SMCRA, AML qualified coal refuse (GOB) piles in the State Inventory of Virginia.

Figure 1



Projected Life Cycle Air Emissions Due to Surface Weathering

As stated previously, all coal refuse placed in piles or impoundments gradually and eventually weathers (oxidizes)[30]. This process is very slow and not dis-similar to the inevitable rusting of abandoned farm implements, for example. While weathering is an imperceptibly slow process, due to the extraordinary acreage, surface area exposure and volume of AML GOB and Non-GOB coal refuse that has been discarded or being managed over many years, coal refuse piles represent a virtually “forever source” of weathering emissions unless either sealed (impermeably capped like a landfill with active GHG gas collection), nitrogen blanketed or permanently remediated. Table 2-1 summarizes estimates of pre SMCRA abandoned coal refuse in VA at over 523 acres (22,781,880 ft^2) of surface area). If we assume that only the first two feet of depth from the surface of every pile is exposed to continuous weathering (oxygen, sun damage, freeze/thaw cycles, acid rain, etc.) every hour of their “forever” life, the amount of AML coal refuse in the slow process of weathering in VA amounts to an estimated 45,563,760 ft^3. At the USEPA AP-42 bulk density range of 60-80 lb/ft^3, the amount of un-remediated coal refuse material continuously weathering within the top two feet of AML qualified existing piles in VA is estimated to be on the order of 1.8 million tons (at 80 lb/ft^3). This likely represents a conservative estimate because coal refuse piles drain readily, and it is likely that oxygen and acid rain reach more deeply into the piles. If we consider the entire estimated VA (GOB +Non-GOB) inventory (80 million yds^3), at the same surface area ratio of the known AML piles, that translates to an estimated total surface area of 2,797 acres. Assuming the top two feet of that total area is exposed to weathering, the VA total potentially exposed to weathering would be estimated at over 9.7 million tons of coal refuse continuously emitting air pollutants due to surface weathering of coal refuse in VA.

As will be discussed, the weathering of coal slowly generates heat due to oxidation which can and does eventually lead to spontaneous combustion. Air emissions due to spontaneous combustion dwarf air emissions associated only with weathering, however the Authors set out to quantify both phases of coal pile degradation. The International Journal of Coal Geology (2017)[23] states that in situ weathering of coal causes a measurable decrease in its carbon content over time, resulting in a proportional percentage decrease in its Gross Calorific (heating) Value (GCV). Jha (2016)[27] states that in situ weathering of coal showed a loss of 5% in calorific value over a period of 25 years. Since the GCV of any hydrocarbon fuel is proportional to its hydrogen/carbon molecular content, a 5% decrease in calorific value can be roughly estimated to also indicate a similar loss in carbon and hydrogen content, which will have slowly oxidized to the Greenhouse Gases methane and CO_2. According to the North American Combustion Handbook[28], bituminous coals average about 80% carbon and from 2-5% hydrogen. Thus, a 5% decrease in calorific value via the weathering oxidation process may oxidize (reduce) the 80% carbon content of the coal portion of GOB by about 5% every 25 years, or an annual decay rate of about 0.2% of the carbon content of coal refuse each year that it weathers.

USEPA and others have published emission factors[3,8] from the in-situ combustion of coal and coal refuse in piles. These emissions have been reported by Gielisch and Kropp (reference 4) during the process of spontaneous combustion at 2.7 tons of CO_2 per metric ton of waste coal, and 0.8 tons of CH_4 per metric ton of waste coal in some stage of spontaneous combustion (2,360 lb CO_2/short ton and 1,450 lb CH_4/short ton of coal content consumed). However, we note that coal refuse is less reactive than the mined coal evaluated by Gielisch and Kropp, and we turned to the Trade Association ARIPPA (Appalachian Region Independent Power Producers Association) for additional input. For conservatism and consistency, a lower methane evolution value of 326 lb CH_4/short ton of coal refuse has been substituted based on emission factors provided by ARIPPA[33]. To account for the gradual combustion of coal due to weathering, those values have been adapted to this much slower process of gradual oxidation which is an identical process but at a much lower rate. Jha (2016)[27] states that weathering oxidizes standing coal at a rate of about 5% every 25 years. While weathering due to the entire coal refuse inventory alone is responsible for some lifecycle emissions of CO_2e, this factor is less significant than the process of spontaneous combustion documented by USEPA emission factor measurements from smoldering coal refuse. Air Emissions from the VA Energy AML GOB inventory are (the emission factors from Table 2 applied to the weathering surface areas and partial volumes of coal refuse in the state inventory are provided in Tables 2-3 and 2-4.

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Table 2-3 - GHG Emissions from AML GOB Coal Refuse Inventory Weathering Annually

Assumptions

Table 2-1 AML Inventory in VA			523 acres
Estimated Surface Area of in-situ waste coal in VA, ft^2			22,760,141 ft^2
Times 2 ft Surface Depth of coal exposed to weathering			2.00 ft
Conservative Assumption that weathering takes place within the two feet of the surface exposed to sun, oxygen and acid rain (Ft^3)			45,520,283 ft^3
Typical In-situ waste coal bulk density			80 lb/ft^3
Amount of weathering coal refuse in Virginia			1,820,811 tons
In-situ weathering of coal showed a loss of 5% in calorific value over a period of 25 years.			0.20% per yr
Total AML GOB waste coal impacted per year (tons)			3,642
Pollutant	**smoldering/combustion Emission Factor (lb/ton)**	**Coal Refuse Weathering In-Situ**	**Annual GHG Emissions (tons/yr), AML GOB Coal Refuse Weathering in-situ**
CO_2	**2,361[(1)]**	**3,642**	**4,299**
CH_4	**326 (33)**	**3,642**	**594**
CO_2e	**10,511**		**19,138**

1. Gielisch H, Kropp C., *Coal Fires a Major Source of Greenhouse Gases- a Forgotten Problem.* Environmental Risk Assessment and Remediation 2017; 2(1): 5-8;

   https://www.alliedacademies.org/articles/coal-fires-a-major-source-of-greenhouse-gases-a-forgotten-problem-8871.html

2. The GWP of CO_2 and CH_4 are 1 and 25, respectively. The GWP of N2O is 298. Although there is certainly some N2O emitted, we have yet to establish a published emission rate of N2O from weathering.

33. ARIPPA substituted value for CH4 reduced from 0.7625 (Gielisch) to 0.163, substituted to add conservatism and consistency with reported values

Table 2-4 - GHG Emissions form Entire Coal Refuse Inventory Weathering Annually

Assumptions

Table 2-2 Total AML GOB and Non-GOB Inventory in VA (80,000 yds3)			2,615 acres
Estimated Surface Area of in-situ waste coal in VA, ft^2			113,909,400 ft^2
Times 2 ft Surface Depth of coal exposed to weathering			2.00 ft
Conservative Assumption that weathering takes place within the two feet of the surface exposed to sun, oxygen and acid rain (Ft^3)			227,818,800 ft^3
Typical In-situ waste coal bulk density			80 lb/ft^3
Amount of weathering coal refuse in Virginia			9,112,752 tons
In-situ weathering of coal showed a loss of 5% in calorific value over a period of 25 years.			0.20% per yr
Total GOB + Non-GOB waste coal impacted per year			18,226
Pollutant	**smoldering/combustion Emission Factor (lb/ton)**	**Coal Refuse Weathering In-Situ**	**Annual GHG Emissions (tons/yr) , All Coal Refuse Weathering in-situ**
CO_2	**2,361(1)**	**18,226**	21,513
CH_4	**326 (33)**	**18,226**	2,971
CO_2e	**10,511**		**95,782**

1. Gielisch H, Kropp C., *Coal Fires a Major Source of Greenhouse Gases- a Forgotten Problem.* Environmental Risk Assessment and Remediation 2017; 2(1): 5-8;

   https://www.alliedacademies.org/articles/coal-fires-a-major-source-of-greenhouse-gases-a-forgotten-problem-8871.html

2. The GWP of CO_2 and CH_4 are 1 and 25, respectively. The GWP of N20 is 298. Although there is certainly some N2O emitted, we have yet to establish a published emission rate of N2O from weathering.

33. ARIPPA substituted value for CH4 reduced from 0.7625 (Gielisch) to 0.163, substituted to add conservatism and consistency with reported values

Also noteworthy is that as coal refuse weathers and the surface layers oxidize, they also become more friable and continue to generate new windblown fugitive dust (PM_{10}). This dust will continue to be emitted from the entire surface of every pile whenever there is a sufficient wind speed to scavenge newly created coal dust and ash to become airborne and therefore transported offsite in ambient air currents that may affect local communities. This fine particulate matter, together with visible smoke (which is also fine particulate) is emitted at coal pile surface level where it can be transported on the prevailing wind to local homes, schools and sensitive receptors still residing in the former mining regions where it was initially deposited.

Projected Annual Air Emissions Due to Spontaneous Combustion

According to the EPA study (Chalekode and Blackwood[3)]), coal refuse piles undergo a virtually continuous process of spontaneous combustion and maturity to open flame, depending on natural or anthropogenic extinguishment as they have over a century of their existence and still observed today. Chalekode and Blackwood defined a representative coal refuse pile as one with a volume of about 60 million ft^3 (1.7 million m^3) and a typical burning pile being one with 21% of it burning (or 12.6 million cubic feet/pile smoldering, smoking or openly burning). At an in-situ bulk density they assumed at 60 lb./ft^3, Chalekode and Blackwood calculated a representative estimate of the amount of coal burning in Northern Appalachia at any time from spontaneous combustion = 12.6 million ft^3 x 60 lb./ft^3 x 1 ton/2000 lbs. = 378,000 tons of coal per piles actively burning in situ. That same report identified that in 1972 there were 116 coal refuse piles actively burning in PA and WV alone, or about 40% of all identified coal refuse piles extant in those states. These Authors also provided measured emission factors for traditional criteria air pollutants in units of Kg/hr per ton of burning refuse[(4)], as well as an estimate of representative source emissions in units of Kg of pollutant per year. Emission factors of GHG from open openly smoldering or burning coal in stationary piles have been assessed in the paper "Quantifying Emissions from Spontaneous Combustion"; Lesley Sloss, 2013[29]. These emission factors as applied to coal refuse piles weathering is summarized in Tables 3-1 and 3-2.

If we refer to the Virginia AML GOB Piles inventory provided by Virginia Energy, and noting that over 100 individual piles are mapped in Figure 1, 16,153,507 tons divided by 100 piles provides an average pile size of SW VA GOB at about 16,535 tons per pile. Assuming the same ratios of 40% of piles smoldering/burning, and 21% of coal in each actively burning, we get an estimated 16,153,507 tons X .4 X .21 divided by 10 years duration = **135,689 tons of Abandoned Virginia AML GOB in some state of smoldering or actively burning in any given year.** These are enormous numbers. Such smoking or open coal fires require emergency response to dig out the source of fire to be extinguished, essentially re-setting the process to emerge again at some future time. Annual estimated emissions from just this subset of AML GOB in Virginia, are provided in Table 3-1.

Table 3-1

AML GOB Inventory Emissions due to Spontaneous Combustion

Assumptions:

Amount of in-situ AML GOB (only) waste coal in VA	16,153,507 tons
Referenced Ratios "as typical", 40% of all piles spontaneously combusting, and 21% of each combusting pile is actively burning[18]	135,689 tons
Piles spontaneously burning	40%
Amount of pile that is burning	21%
Estimated % of State AML GOB inventory burning at any one time	8%

Table 3-1 Estimated Air Emissions from AML GOB Piles in Virginia due to 8% Continuously in Active Spontaneous Combustion

Pollutant	Emission Factor (lb/ton from AML GOB Piles Burning)	Annual Estimated Emissions Assuming 8% of Inventory Burning (tons per year)
NO_x	0.06[(1)]	4
CO	194[(1)]	13,162
PM_{10}	0.9[(1)]	61
SO_2	66.2[(1)]	4,491
H_2S	1.22[(1)]	83
Hg	0.0008[(1)]	0.0535
CO_2	2,361[(2)]	**160,168**
CH_4	**326 (33)**	**22,117**
N_2O		
CO_2e	10,511[(2)]	**713,102**

(1) *Environmental Influence of Gaseous Emissions from Self-Heating Coal Waste Dumps in Silesia, Poland,* Fabiańska M, Ciesielczuk J, Nádudvari Á, Misz-Kennan M, Kowalski A, Kruszewski Ł. Environ Geochem Health. 2019 Apr;41(2):575-601. doi: 10.1007/s10653-018-0153-5. Epub 2018 Jul 24.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6510838/

(2) Gielisch H., Kropp C., *Coal Fires a Major Source of Greenhouse Gases- a Forgotten Problem.* Environmental Risk Assessment and Remediation 2017; 2(1): 5-8;

https://www.alliedacademies.org/articles/coal-fires-a-major-source-of-greenhouse-gases-a-forgotten-problem-8871.html

(33) ARIPPA substituted value for CH4 reduced from 0.7625 (Gielisch) to 0.163, substituted to add conservatism and consistency with reported values

Application of the same assumptions to the entire estimated 80,000,000 yds^3 (estimated 86,400,000 tons at 80 lb/ft^3) of total AML GOB plus Non-Gob coal refuse in VA. Assuming the same ratios of 40%

of piles smoldering/burning, and 21% of coal in each actively burning, we get an estimated 86,400,000 tons X .4 X .21 divided by an assumed 10 years duration = 725,760 tons of Virginia AML GOB plus non-GOB in some state of smoldering or actively burning in any given year. If a representative subset of the estimated 86,400,000 tons of total AML eligible GOB plus managed non-GOB coal refuse in Virginia were in some state of smoldering or actively burning at the equivalent rate, in any given year, that would equate to 725,760 tons of total coal refuse emitting air pollutants and CO_2e as shown in Table 3-2.

Table 3-2

AML GOB + Non-GOB Inventory Emissions due to Spontaneous Combustion

Assumptions:

Amount of in-situ AML GOB + Non-GOB waste coal in VA	86,400,000 tons
Referenced Ratios "as typical", 40% of all piles spontaneously combusting, and 21% of each combusting pile is actively burning[18]	725,760 tons
Assumed Duration	10 years
Piles spontaneously burning	40%
Amount of pile that is burning	21%
Estimated % of State AML GOB inventory burning at any one time	8%

Table 3-2 Estimated Air Emissions from AML GOB + Non-GOB Piles in Virginia due to 8% Continuously in Active Spontaneous Combustion

Pollutant	**Emission Factor (lb/ton from AML GOB Piles Burning)**	**Annual Estimated Emissions Assuming 8% of Inventory Burning (tons per year)**
NO_x	0.06(1)	22
CO	194(1)	70,399
PM_{10}	0.9(1)	327
SO_2	66.2(1)	24,021
H_2S	1.22(1)	443
Hg	0.0008(1)	0.286
CO_2	2,361(1)	**856,687**
CH_4	**326 (33)**	**118,299**
N_2O		
CO_2e	10,511(2)	**3,814,159**

(1) *Environmental Influence of Gaseous Emissions from Self-Heating Coal Waste Dumps in Silesia, Poland,* Fabiańska M, Ciesielczuk J, Nádudvari Á, Misz-Kennan M, Kowalski A, Kruszewski Ł. Environ Geochem Health. 2019 Apr;41(2):575-601. doi: 10.1007/s10653-018-0153-5. Epub 2018 Jul 24. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6510838/

(2) Gielisch H., Kropp C., *Coal Fires a Major Source of Greenhouse Gases- a Forgotten Problem.* Environmental Risk Assessment and Remediation 2017; 2(1): 5-8; https://www.alliedacademies.org/articles/coal-fires-a-major-source-of-greenhouse-gases-a-forgotten-problem-8871.html

(33) ARIPPA substituted value for CH4 reduced from 0.7625 (Gielisch) to 0.163, substituted to add conservatism and consistency with reported values

Tables 3-1 and 3-2 indicate the estimated magnitude of potential annual emissions of CO_2e due to the natural processes of smoldering and open burning of as much as 3.8 million tons (Table 3-2) of CO_2e potentially being added to the global GHG budget every year, just due to the process of spontaneous coal refuse combustion of an assumed 8% of the entire GOB + Non-GOB inventory in the Commonwealth of Virginia.

Projected Annual Air Emissions from Un-remediated Coal Refuse Piles in VA due to Gradual Weathering plus Spontaneous Combustion

Based upon the source material relied upon and the Virginia Energy inventory of the quantity of AML abandoned coal refuse, and AML GOB plus Non-GOB, summing the estimated annual air emissions from doing nothing about these piles and impoundments suggests that left abandoned and undergoing weathering plus spontaneous combustion, they represent an important impediment to achieving net zero GHG emissions in the region, Virginia, U.S. and globally. The environmental community has focused on phasing out extraction and burning of fossil fuel from its long-sequestered state within the earth, however abandoned or impounded coal refuse has already been extracted and then discarded – it can never be returned to a naturally occurring underground coal seam.

As stated, all coal continuously weathers when left exposed to the elements, generating similar emissions at a much slower rate – primarily as the carbon content of the coal refuse gradually weathers to CO_2 and CH_4. In this estimate, we assumed that the top 2 feet of the entire estimated surface area of AML GOB piles in Virginia are undergoing slow oxidation, and estimating the annual emissions from that many tons of coal refuse, and applying the emission factors from the Literature, we estimated annual emissions due to annual weathering of the top two feet of coal refuse acreage.

In Table 4-1, we sum the estimated annual air emissions of weathering plus spontaneous combustion of the AML legacy coal refuse piles in VA, to identify the sheer magnitude of their continuous contribution of air pollutants to the environment, frustrating the progress being made elsewhere in improvements to air quality and climate change.

Table 4-1

Estimated Air Emissions from Existing pre SMCRA AML GOB Coal Refuse Piles in Virginia due to Weathering plus Spontaneous Combustion

Pollutant	Annual Emissions (Tons)		
	Annual Air Emissions (tons/yr) AML GOB Coal Refuse **Weathering In-situ** (From Table 2-3)	Annual Air Emissions (Tons) AML GOB Coal Refuse **Smoldering or Burning In-situ** (From Table 3-1)	**Total Estimated Annual Air Emissions, Weathering plus Smoldering or burning in-situ**
NO_x		4	4
CO		13,162	13,162
PM_{10}		61	61
SO_2		4,491	4,491
CO_2	4,299	160,168	164,466
CH_4	594	22,117	22,711
H_2S		83	83
Hg		0.1	0.1
CO_2e	19,138	713,102	**732,241**

The researchers did not identify any information regarding formation of the ultra-potent GHG N2O from natural oxidation of coal refuse piles, and this represents a potential area for additional research

In Table 4-2, we performed the same methodology to estimate the potential total GHG emissions potential of the entire AML GOB and Non-GOB State estimate for the sum of gradual weathering plus the process of spontaneous combustion. Assuming that all 80 million cubic yards of total coal refuse in PA can generate GHG at the same rate as abandoned AML GOB, potential annual GHG emissions due to coal refuse in Virginia could represent **as much as 3.9 million tons of CO_2e every year**!

Table 4-2

Estimated Air Emissions from Total AML GOB + Non-GOB Coal Refuse in Virginia due to Weathering plus Spontaneous Combustion

Pollutant	Annual Emissions (Tons)		
	Annual Air Emissions (tons/yr) AML GOB Coal Refuse **Weathering In-situ** (From Table 2-4)	Annual Air Emissions (Tons) AML GOB Coal Refuse **Smoldering or Burning In-situ** (From Table 3-2)	**Total Estimated Annual Air Emissions, Weathering plus Smoldering or burning in-situ**
NO_x		22	22
CO		70,399	70,399
PM_{10}		327	327
SO_2		24,021	24,021
CO_2	21,513	856,687	878,200
CH_4	2,971	118,299	121,270
H_2S		443	443
Hg		0.3	0.3
CO_2e	95,782	3,814,159	**3,909,941**

The researchers did not identify any information regarding formation of the ultra-potent GHG N2O from natural oxidation of coal refuse piles, and this represents a potential area for additional research

Managed impoundments may emit less air pollutants than abandoned piles subject to SMCRA, however even 50% of the cited emissions from impoundments would still represent millions of tons per year of CO_2e being emitted.

Beyond the magnitude of the sheer tons of pollutants being emitted every year from VA coal refuse, the local community impacts compared to well-controlled combustion are much greater since products of incomplete combustion, generation of air toxics (such as hydrogen sulfide gas) and the much more potent greenhouse gases methane and nitrous oxide, are effectively oxidized to more benign pollutants when combusted fully and treated in the VCHEC CFB boilers. Controlled oxidation CFB emissions such as the sulfur dioxide (SO_2) product of oxidizing hydrogen sulfide, or oxides of nitrogen (NOx) from oxidizing the potent greenhouse gas nitrous oxide, together with fine particulate (PM_{10}) which is also emitted uncontrolled from coal refuse piles as fugitive dust, are then captured and removed at high efficiency using USEPA mandated Best Available Control Technology (BACT) emission controls. Finally, CFB boilers disperse those trace residual air pollutant concentrations through EPA regulated emissions from engineered stacks and are shown via USEPA air dispersion models to document that the resulting air emissions comply with all U.S. health-based National Ambient Air Quality Standards (NAAQS).

Conversely, uncontrolled air emissions from the surface of un-remediated abandoned coal refuse piles are emitted without the benefit of controlled oxidation, any emission control, dispersion in the atmosphere, regulated health-based air concentration standards, or any USEPA or state air quality oversight and regulation. Ground level emissions from these piles can be observed from the smoke wafting from the piles and the odor of sulfur compounds impacting nearby populations. Air emissions from abandoned coal refuse piles throughout Virginia can present clear and present impacts to local ambient air quality.

Projected Net Air Emissions From Remediating (Combusting) Coal Refuse

Based on the sheer magnitude of both CO_2e and criteria air pollutants estimated to be emitted uncontrolled, unregulated and at ground level every year from un-remediated coal refuse piles in Virginia, it is then useful to compare those ongoing air impacts on an equivalent tons remediated per year basis with the air emission limitations required by USEPA from the VCHEC coal refuse reclamation-to-energy facility actively remediating them. In 2022, the VCHEC facility permanently remediated (and permanently neutralized) a reported 618,510 tons of abandoned coal refuse, and this rate is expected to continue or increase significantly in future years. Obviously, once the organic content of each ton of coal refuse is permanently removed from the legacy coal refuse inventory, that same amount can never again emit products of incomplete combustion. Absent permanent remediation, coal refuse will continue to generate air emissions well beyond 2050, as some of the oldest piles already have been for over one hundred years.

Initially, we apportioned the actual annual emissions in calendar year 2022 from the VCHEC facility for that portion of total facility fuels reported as GOB and Non-GOB coal refuse. We then compared the allocated air emissions from combusting a total of 618,510 tons of waste coal in VA with the annual emissions that would have been released from the same amount of un-remediated AML GOB coal refuse if allowed to simply remain in situ. Since VCHEC combusts multiple fuels, including renewable biomass, it is difficult to assign specific emissions from the totals to that portion of fuel that is coal refuse. We therefore assumed the VHEC Permit Limits for criteria pollutants, emission factors for Bituminous coal firing reduced by % capture and control and proportioned the heat input of total waste coal time published emission factors for GHG emissions from Eastern Bituminous Coal. That comparison provides a summary of the GHG and criteria pollutant impacts of permanent remediation of coal refuse through controlled energy recovery that occurred in one year (Table 5). Table 5 shows that VCHEC's apportioned waste coal combustion emits somewhat more NOx in a single year than the same amount of coal refuse emitting nitrogen products in situ, because NOx formation is extremely combustion temperature dependent. However, VCHEC controls its NOx emissions generated by 80-90% prior to release from its stacks. It is important here to consider that both NOx and volatile organic compounds (VOC) contribute to downwind ozone formation and that the same factors that cause higher methane emissions from waste coal similarly cause higher uncontrolled emissions of VOC in the process of spontaneous combustion.

Net GHG emissions as measured in units of CO_2e from remediating an annual quantity of coal refuse compared to allowing that same amount of material to continue to emit air pollutants passively was the most compelling question for this study. As shown in the bottom row of Table 5, permanent remediation of existing abandoned coal refuse in SW Virginia by the coal refuse reclamation-to-energy industry is responsible for the net reduction of at least 2,601,765 net tons of CO_2e every year that they continue to operate as in cy 2022.

Coal refuse reclamation-to-energy plants are very efficient in terms of converting nearly 100% of the hydrocarbon component of abandoned coal refuse to CO_2. When they do so, they remove the ability of that amount of abandoned coal refuse to emit any carbon, ever again. The tremendous net benefit of the coal refuse reclamation-to-energy industry is that purposefully converting hydrocarbons efficiently to CO_2 to produce needed energy nearly eliminates all of the emissions of methane that would otherwise be emitted over many more years.

Since Methane reductions are far more beneficial near-term (as much as 81 times more potent than CO_2) in frustrating climate recovery goals, and even according to USEPA's 100-year CO_2e equivalency standard[10] methane is 25-28 times more potent of a greenhouse gas than CO_2, CH4 emissions are much more impactful in frustrating net zero CO_2e reduction goals. Elimination of existing methane emissions in favor of CO_2 has a much more important benefit in terms of reversing climate change now, as it is estimated to persist in the atmosphere for only about 20 years compared with the 100-year life of CO_2. According to the literature, in the near term (i.e., by 2050), preventing ongoing emissions of methane in place of the same amount of carbon as CO_2, will have about 81 times the global GHG benefit of reducing any ton anywhere in the U.S. of CO_2 [9]. For conservatism in this analysis, these near-term "super benefits" have been ignored in favor of the 100-year lifetime convention of 25-28 times the GHG potency of CO_2 as commonly referenced in most Scope 1 GHG sustainability comparisons.

It is important to compare the bottom row of Table 5 (also presented in the Executive Summary, Table 1), which compares the net benefit to lifecycle GHG emissions measured in CO_2e from coal refuse either allowed to remain in situ passively emitting pollutants or remediated forever for responsible energy recovery. At the current rate of coal refuse reclamation, the global GHG inventory will have been reduced by a quarter billion tons or more of CO_2e over the next ten years for each year the existing Northern Appalachian coal refuse reclamation-to-energy plants alone continue operating.

Table 5 Shows that in 2022 VCHEC may have **reduced passive CO_2e emissions to the environment between 2.6 million tons** (based on 618,510 tons of coal refuse remediated) **to as much as 32.5 million tons accounting for a lifecycle** of continuing CO_2e emissions that may have been otherwise emitted from being abandoned in place and never remediated.

Either way, permanent destruction and conversion to needed electricity by the coal refuse-to-energy Industry is capable of reducing millions of tons of CO_2e otherwise being continuously emitted to the environment, while also permanently remediating substantial quantities of legacy waste coal every year at little to no additional costs to the Commonwealth. As such, coal refuse to energy facilities should be supported and encouraged to continue and to expand their important role in the permanent remediation of coal refuse and also reigning in CO_2e contributions from the Commonwealth of Virgina, Appalachia, the US and Globally.

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Table 5

Pollutant	Global Warming Potential[2]	Weathering + Burning/Smoldering Typical GOB In-Situ					GOB Combustion in VCHEC CFB Boilers - 2022		Net Air Quality Benefit of Remediation via Controlled Combustion (tons)		
		Emission Factor (ton/ton Coal Refuse burning)	Estimated Emissions for 618,510 tons of Coal Refuse Weathering (tons)	Estimated Emissions for 618,510 tons of Coal Refuse Smoldering / Burning (tons)	Estimated Total Annual Emissions Associated with 618,510 tons of GOB Remaining in-situ (tons)	Potential 10-yr Lifecycle Emissions Associated with 618,510 tons of GOB Remaining in-situ (tons)	VCHEC Emission Factor (lb/MMBtu)	Estimated VCHEC Waste Coal Emissions attributed to remediation of 618,510 tons of Coal Refuse in 2022 (tons)	Net Comparison based on Estimated Emissions per ton of Coal Refuse Being Oxidized in Situ (tons)	Net Comparison based on Estimated Potential Lifecycle Emissions (tons)	Estimated Tons of Potential Lifecycle net Emissions per ton of Waste Coal Neutralized
NO_x		0.00003		18.6	18.6	185.6	0.07000	249	**230**	63	0.0001
CO		0.09970		61,665	61,665.4	616,654	0.10000	356	**(61,310)**	**(616,299)**	(0.9964)
PM_{10}		0.00045		278.3	278.3	2,783	0.00900	32	**(246)**	**(2,751)**	(0.004)
SO_2		0.00084		519.5	519.5	5,195	0.02200	78	**(441)**	**(5,117)**	(0.01)
CO_2	1	1.180[4]	14,602	729,842	744,443.6	7,298,418	181.5	645,506	**(84,336)**	**(6,652,912)**	(10.76)
CH_4	25	0.163 (33)	2,016	100,817	102,833.5	1,008,171	0.03374	120	**(100,697)**	**(1,008,051)**	(1.63)
N_2O	298	---									
CO_2e			65,010	3,250,270	3,315,280	33,152,804		648,505	**(2,601,765)**	**(32,504,299)**	(52.55)

1. From VCHEC 2022
2. 40 CFR 98 Subpart A Table A-1
3. *Environmental Influence of Gaseous Emissions from Self-Heating Coal Waste Dumps in Silesia, Poland,* Fabiańska M, Ciesielczuk J, Nádudvari Á, Misz-Kennan M, Kowalski A, Kruszewski Ł. Environ Geochem Health. 2019 Apr;41(2):575-601. doi: 10.1007/s10653-018-0153-5. Epub 2018 Jul 24.
4. Gielisch H, Kropp C., *Coal Fires a Major Source of Greenhouse Gases- a Forgotten Problem.* Environmental Risk Assessment and Remediation 2017; 2(1): 5-8;

https://www.alliedacademies.org/articles/coal-fires-a-major-source-of-greenhouse-gases-a-forgotten-problem-8871.html

33. ARIPPA substituted value for CH4 reduced from 0.7625 to 0.163, substituted to add conservatism and consistency with reported values

Alternatives to Permanent Coal Refuse Pile Remediation

Governments and environmental advocates have been seeking practical alternatives for the remediation of abandoned coal refuse piles for generations – yet smoking piles persist.

Sporadically extinguishing individual coal refuse pile fires and/or non-impermeable capping and grading with re-vegetation to mitigate acid runoff and/or to improve their aesthetics does not eliminate their air and water quality impacts to the environment. It has been postulated that increased taxpayer funding could be used to plant abandoned coal refuse piles with “green” shallow root system plants, such as beach grass. It is important to note that naturally occurring and undisturbed seams of bituminous or anthracite coal prior to mining are essentially uniform prehistoric deposits of CO_2 and other pollutants already sequestered within the earth and have existed there in the lack of oxygen for millions of years. Coal refuse piles, on the other hand, have been mined and placed in the open, and contain mechanically shattered remnants, fragments, and fines of coal brought to the surface that exhibit tiny voids in the interstices between the crushed and broken chips. These voids are open to oxidation surrounding every coal particle surface. They are, on a gaseous level, porous. GHG's generated within a vegetated GOB pile are not permanently sealed within – gas production products that are lighter than air (such as CO_2 and methane) will find their way out.

These facts draw upon our collective experience and regulations regarding municipal waste landfills. Municipal solid waste is largely organic (hydrocarbon) based material that has been placed and compacted on top of an impervious liner, typically in multiple ten-foot "lifts". U S EPA regulations require such landfills to be lined and encapsulated ("capped") with impermeable liners, to prevent gaseous release of continuously generated methane to the air. In fact, methane emissions are required to be collected and burned to CO_2 in reciprocating engines or turbines to produce "renewable" electricity. Lessons learned from this industry indicate that unless abandoned coal refuse piles could also be somehow permanently capped with a "forever" impervious barrier, they would still generate methane gas over many years requiring an engineered methane collection system and then a mandate to combust that methane to the less potent GHG CO_2. It is not an accepted or allowed practice to simply plant over municipal waste landfills with beach grass or other vegetation, as those plantings could not prevent the generation and emission of evolving methane gas. The authors believe that USEPA municipal waste landfill closure requirements hold parallels to the much larger problem of abandoned coal refuse piles throughout Appalachia. There are two main differences, however – most active municipal landfills are still managed by an existing ownership, and secondly are much smaller in extent than abandoned coal refuse piles shown in Figure 1. Simply, maintaining an oxygen free deep pile via capping and collection of methane does not represent an economically or logistically sustainable possibility simply due to the sheer magnitude of legacy coal refuse piles in Appalachia. Even just planting and/or maintaining shallow root system plantings over thousands of acres of abandoned coal refuse is not self-funding nor economically sustainable. While planting abandoned coal refuse piles may reduce impacts from wind-blown dust and rainwater runoff entering downstream soil and surface water, planting or reforestation would not eliminate the presence of oxygen, remove the hazard of spontaneous combustion beneath the shallow roots, or permanently prevent future emissions of the potent greenhouse gas methane.

One-time and permanent removal of the root cause of CO_2e emissions from abandoned coal refuse by the coal refuse reclamation-to-energy industry is therefore the only known forever remediation process that is permanent, proven over many years of operation, already in place and economically sustainable. While alternatives may have aesthetic and acid run-off merits, they cannot avoid the passive GHG emission legacy of the potent GHG methane.

USEPA studies of potential alternatives to prevent spontaneous combustion of coal refuse piles[3,8] suggest that every pile would need to be permanently and anaerobically sealed from the air and that methane collection systems or padding with an inert gas such as nitrogen would need to be continuously maintained to preclude the possibility of future spontaneous combustion and surface emissions. A simple field of beach grass growing on top of a coal refuse pile could not materially eliminate the ability of the pile to spontaneously combust or vent products of incomplete combustion to the surface from deep within.

In the authors' opinion, only permanent removal of the coal refuse itself, impermeable capping with methane collection systems , or active nitrogen blanketing is capable of eliminating forever air emissions of gaseous methane resulting from oxidation and incomplete combustion of coal refuse piles. As with municipal waste landfills, once collected the most environmentally responsible solution is to then reduce its global warming potential by 25-28 times by simply combusting it to CO_2 in a highly controlled manner. Of course, this is exactly what the coal refuse reclamation-to-energy industry has already been doing, at a significant savings to taxpayers, for over thirty years.

Conclusions

This study seeks to provide a characterization of the role of abandoned and managed coal refuse piles and impoundments located in Virginia (and Appalachia in general) in terms of frustrating local, national and global efforts to achieve ambitious net-zero greenhouse gas emissions goals by some target date, as well as understanding how these existing abandoned sources of pollution are disproportionately impacting the local remaining residents of once thriving coal mining areas in the Commonwealth. It is well documented that abandoned coal refuse piles will and do gradually emit uncontrolled and unregulated air pollutant emissions as long as such existing piles remain abandoned and, in many cases, "under the air quality radar".

The region relies heavily on the coal refuse reclamation-to-energy industry, which is presently the only practical permanent solution to remediate this legacy environmental hazard. Having characterized the potential adverse air quality emissions from abandoned coal refuse piles if allowed to continue releasing greenhouse gases and other air pollutants unabated, it is particularly useful to compare their estimated lifetime air pollution impacts with the highly controlled and Government regulated emissions from permanently remediating them by the coal refuse reclamation-to-energy industry. A comparison of the air emissions from not remediating existing legacy coal refuse piles shows that this industry is providing very significant net air quality and CO_2e benefits to the environment every year and should be further encouraged to do so. The data evaluated indicates that the coal refuse reclamation-to-energy industry in Virginia eliminated more than 2.6 million net tons of CO_2e (Scope 1) in 2022 by combusting 618,510 tons of VA GOB and Non-GOB coal refuse that is now permanently eliminated forever from the environment by converting its residual energy to useful power. That same amount of "net carbon reduced" energy will offset the equivalent grid produced CO_2e for that same amount of electricity that it would not have to produce in Scope 2. This added benefit to global GHG emissions will vary over time (as the electric grid continues to expand its reliance on renewables) and has not been quantified in this study.

The negative impact to our environment of doing nothing to break the methane degradation cycle of existing coal refuse is much greater than actively remediating coal refuse by harnessing its useful thermal energy with CFB technology, thereby dramatically reducing (especially in the near- term) the global budget of CO_2e emissions annually, eliminating future pollution while improving local air, water and soil quality. By conducting a side-by-side comparison of uncontrolled coal refuse emissions versus controlled emissions in coal refuse-to-energy facilities, we arrive at a compelling conclusion. The impactful net benefit to the environment resulting in substantial reductions in CO_2e more than justifies maintaining and encouraging this important, environmentally friendly niche waste coal remediation industry.

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Draft for Review
Task 3 – Conceptual Recommendations to Improve CO2e Emissions Data from Abandoned GOB Piles in VA

December 29, 2023

Background

The Virginia Department of Energy agrees with US EPA and others that AML GOB Piles (and other impoundments) in the Commonwealth emit the Greenhouse Gases CO_2, Methane (CH_4) and potentially N_2O over their lifetime due to weathering, smoldering and spontaneous combustion. TRC has prepared a White Paper for Virginia Department of Energy to characterize the magnitude of such emissions from an estimated 80 million cubic yards (including that identified as AML GOB) present in the Commonwealth based on available emission estimates extracted from the Literature.

Based on its review of the White Paper prepared by TRC, VA Energy may wish to improve the accuracy of the emission estimates cited and has asked TRC what a program to do so might entail.

At this stage, TRC has framed a conceptual measurements Program in an effort to perform additional measurement specific to VA GOB Piles using today's state of the art measurement techniques. The first Task in doing so would require a detailed sampling and measurements plan and protocol with a Program design to best meet the needs of the Commonwealth. In general, however, TRC envisions a measurements Program that may consist of the following activities.

1. Perform additional Literature search from the coal gasification industry to better characterize the split of CO_2 to CH_4 at various levels of sub-stoichiometric oxygen (as practiced in industry for the purpose of generating methane (i.e., coal gas).

2. Identify specific coordinates of piles undergoing spontaneous combustion as identified by the presence of smoke, steam (visual) or thermal imagery. This may involve from between a few to a dozen or more locations amid well over 100 individual piles subject to AML stewardship.

3. Initially, we would consider the use of Open Path Measurement Technology to gather data for CO, CO_2, CH_4 and N_2O across the extent of a single coal refuse hot spot. These measurements, perhaps averaged over several days multiplied by

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the area of the hot spot can provide emission estimates of actively smoldering waste coal that can be extrapolated into units of lbs/ft^2 (or acre).

4. If that measurement series is successful, it would be useful to adapt EPA's measurement scheme (Kropp) by setting up a temporary enclosure ("tent") of at least 10' by 10' area to capture the fumes issuing from the portion of the pile (and by characterizing the thermal signature of the column of refuse beneath it estimate the volume of refuse (ft^3 and tons)). Assuming a passive thermal "chimney" from the tent area, it would be proposed to use the same open path measurement device equipment to log the same CO2e emissions for a week of hourly data.

5. It may also be useful to take periodic passivated summa canisters for offsite laboratory analysis for both CO2e pollutants plus targeted others such as H_2S, HCl, PAH's, A_S and Hg.

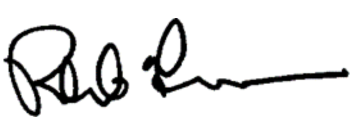
6. The design of the measurements Program may need to be tweaked during this initial pilot study. If it is able to provide the targeted information regarding air emissions emanating from spontaneous combustion, we would suggest expanding the sampling program to another five representative smoldering piles to assess variability pile to pile.

Budgetary Cost Estimate

A precise cost estimate cannot be generated prior to finalizing a detailed test plan. Hover we would budget for around $100 k of labor, expenses, instrumentation and Lab fees based on up to five weeks x 2 staff in the field plus senior support to design, plan and execute such a Program.

We are pleased to offer this assistance to the Commonwealth of Virginia Department of Energy. Please contact either me via e-mail or at (978) 302-0104 if you would like to discuss any aspect of our proposal.

For TRC;



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