IDENTIFYING GREEN AND SUSTAINABLE USES FOR LEGACY COAL COMBUSTION BY-PRODUCTS TO PROTECT MARYLAND'S NATURAL RESOURCES

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ABSTRACT

In an environment of shifting economic, regulatory, and environmental pressures, the landscape of coal combustion by-product (CCB) generation and use is changing in Maryland and across the United States. More stringent emission requirements for energy producers have resulted in power generators moving to alternative fuels and thus generating fewer CCBs. Consequently, industries that use these materials to reduce consumption of natural resources are shifting to using CCBs recovered from landfills, ash ponds, and other legacy CCB disposal sites. However, there remains an overlooked yet important need for massive, encapsulated, and environmentally friendly uses of CCBs.

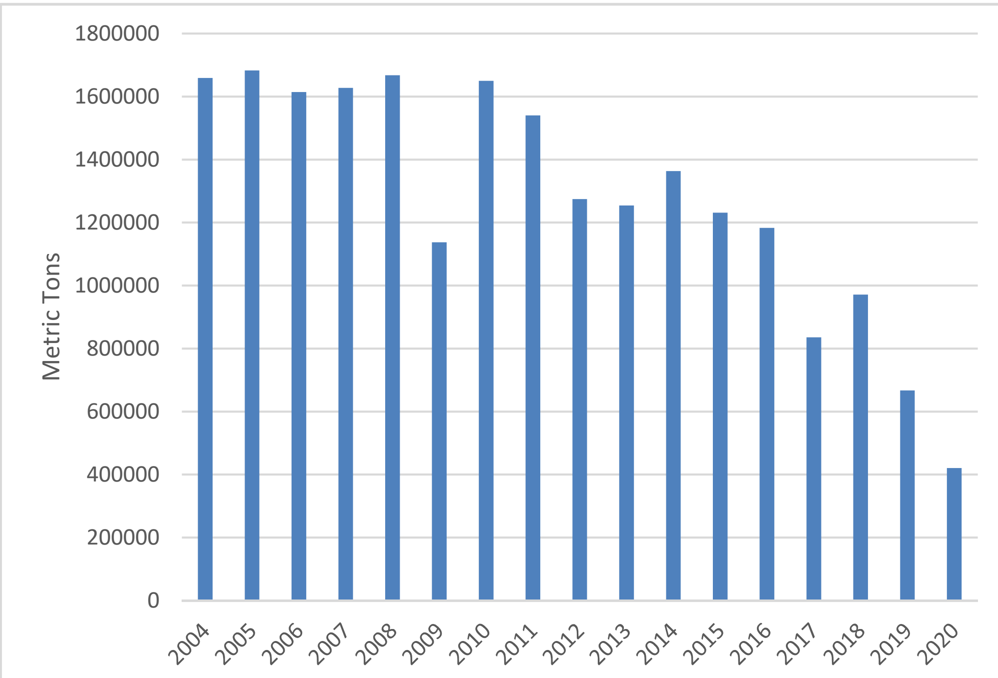
In Maryland and across the United States, decades of fossil fuel combustion have contributed to climate change. Historic mining operations have impacted surface waters by the production of acid mine drainage; CCB disposal practices have impacted ground water and surface water through leaching of metals. Removing CCBs from situations where they leach constituents to groundwater and using them in ways that improve water quality or mitigate climate change is a sustainable and green remediation option.

The Chesapeake Bay Watershed spans six states and contains more than 600 million metric tons of CCBs buried within former dump sites, landfills, and structural fill sites. These materials could be exhumed and reused in ways that offset the use of natural resources and further protect the environment. This paper explores several possibilities for massive CCB beneficial uses that provide multiple environmental benefits. Possibilities include using solidified CCBs to address acid mine drainage reduce coal mine methane emissions and prevent surface subsidence over abandoned tunnels; reclaim pits and quarries for renewable energy development; and mitigate flood risks in areas threatened by climate change.

INTRODUCTION

Generation and use of coal combustion by-products (CCBs) by Maryland's power producers are tracked by the Maryland Department of the Environment and the Maryland Power Plant Research Program (PPRP). Over the past 10 years, the rate of CCBs produced in Maryland has decreased by over 70% with more than half of this decrease having occurred within the last 5 years (Figure 1).

Figure 1: Annual CCB Production in Maryland



Nevertheless, CCBs and their disposal and/or beneficial use remain important concerns because decades of reliance on coal-fired energy production have left numerous regulated and unregulated CCB disposal sites (also referred to as legacy sites) across the State. Maryland currently has three CCB disposal sites that are regulated by the United States Environmental Protection Agency (EPA); but the 2015 Federal CCR Rule did not include legacy CCB sites that were closed prior to its enactment. A survey of CCB sites across the state of Maryland performed in 1982 and updated in 2017 identified over 60 sites containing CCBs (Figure 2). Expanding the search to the Chesapeake Bay Watershed, which encompasses all of Maryland as well as parts of Delaware, New York, Pennsylvania, Virginia, and West Virginia brought the total to more than 80 legacy CCB sites, each containing anywhere from several thousands to more than a million tons of CCBs (Figure 3). While precise data on the quantity of CCBs are not available for all of these sites, it is estimated that they may contain an aggregate of more than 600 million metric tons of material. This material is contained in a wide variety of sites with a wide range of ease of recoverability. Monofill sites that have not been closed are the simplest to recover. Closed sites and sites or wet disposal impoundments pose greater challenges, but recovery is still feasible. At locations where CCBs have been covered by buildings or infrastructure, recovery may only be possible if redevelopment takes place. Finally, in situations where CCBs were either layered or mingled with other wastes (such as construction debris, industrial wastes, or municipal garbage), recovery may not be a viable option and alternative methods to solidify CCBs in-situ may be considered to protect water quality, though these methods are beyond the scope of this paper.

As discussed by the Environmental Integrity Project of 2019, legacy CCB sites, including those that are monitored regularly, can and do impact ground water quality[1]. However, if used in properly engineered, encapsulated forms, these materials could also provide a substantial resource for environmentally friendly beneficial uses.

Figure 2: Legacy CCB Sites Across Maryland

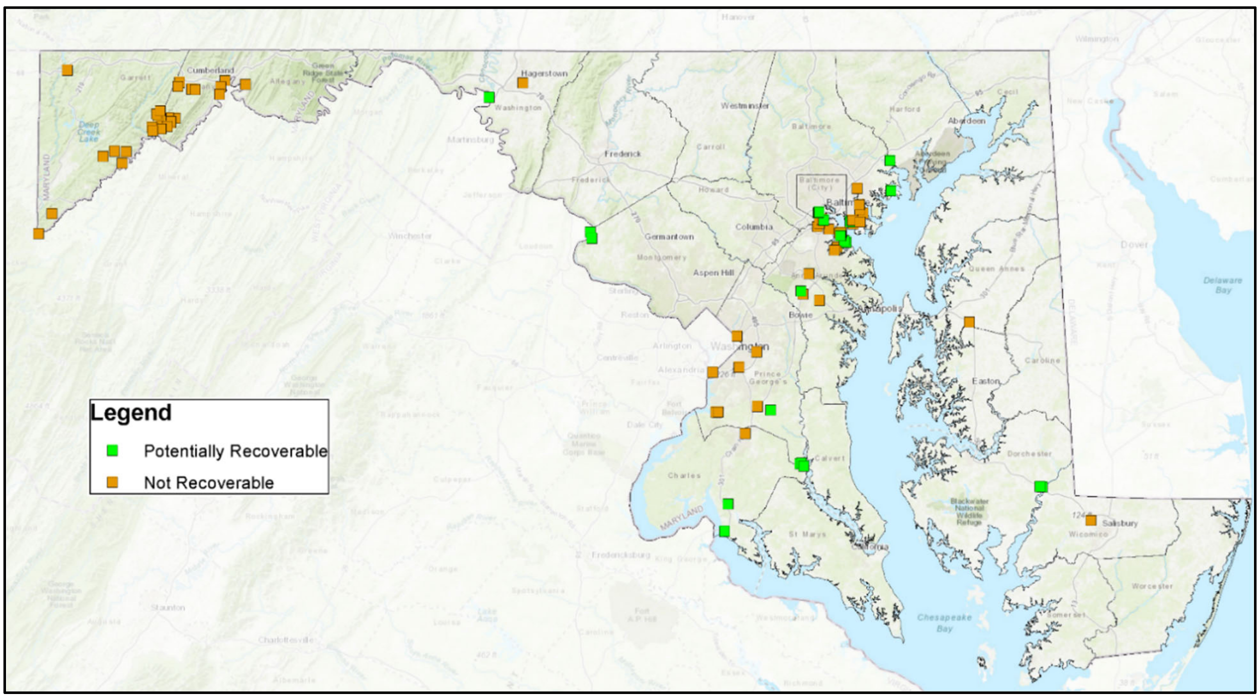


Figure 3: Legacy CCB Sites Across the Chesapeake Bay Watershed

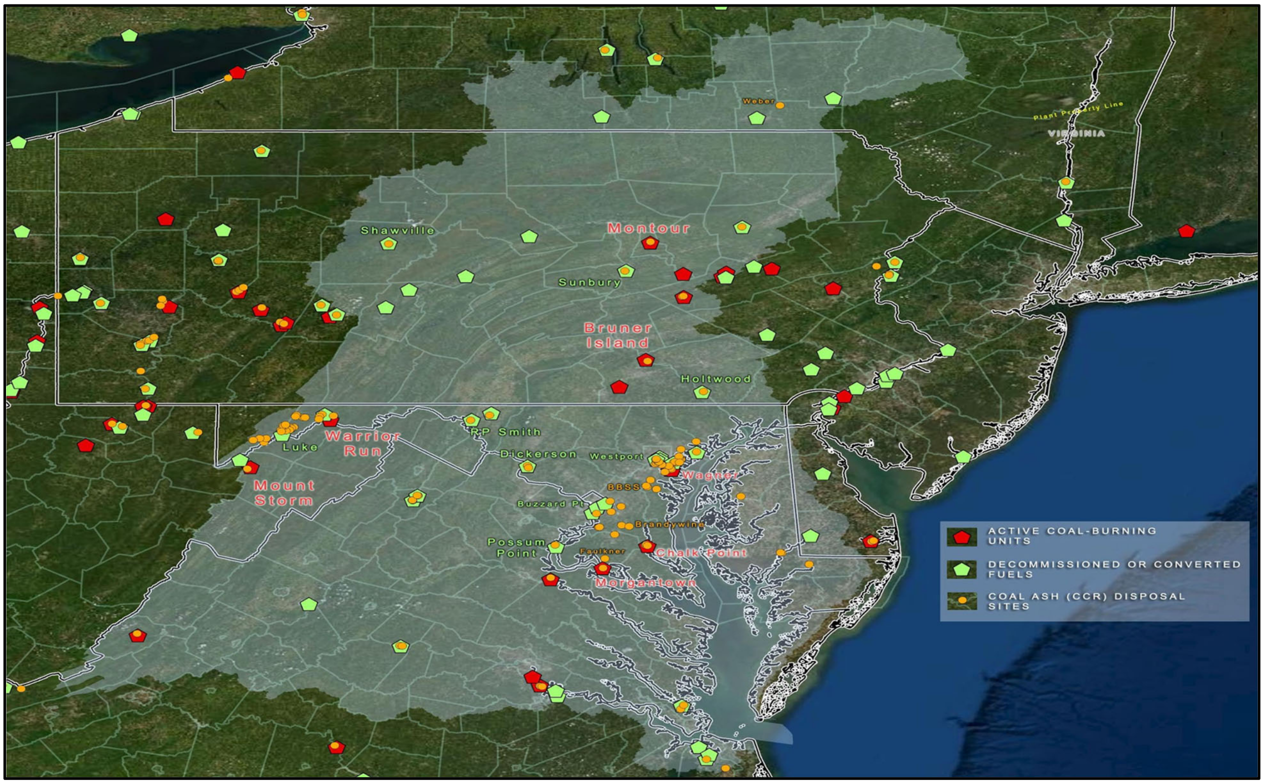


Figure provided by Western Maryland Regional GIS Center at Frostburg State University.

As annual production of CCBs decreases, industries like cement and concrete manufacturers have begun to turn to legacy CCB sites to continue to meet their raw material needs. Maryland has had two successful CCB recovery operations. The former R. Paul Smith power plant operated in Maryland until 2012, but many of its CCBs were disposed of just across the river in a landfill site in West Virginia. Between 2009 and 2020, nearly three million metric tons of CCBs were recovered from the landfill and sold for cement manufacture. Following the success of this operation, another CCB recovery project was initiated at the Westland Fly Ash Storage Site in Maryland in 2020. To date, over one hundred thousand metric tons of material have been removed from this site.

However, the demands of industry are driven/limited by market forces and consumer demands and there are limits to the quantity of material that such industry users of CCBs are able to consume. The American Coal Ash Association (ACAA) reports that in 2020, cement and concrete manufacturing consumed 15.9 million short tons (14.4 million metric tons) of the CCBs produced in that year[2]. This amount is by no means insignificant, but it is modest compared to the hundreds of millions of tons of legacy CCBs that exist across the United States. Furthermore, industrial users of legacy CCBs tend to prefer large sites that can supply them for multiple years offsetting the capital costs associated testing, permitting, plant conversion or setup, and early operating costs associated with using reclaimed CCBs. Many legacy CCB sites do not meet the economic criteria for commercial recovery and sale, but still have the potential to impact ground water. As such, there is still a need for beneficial use projects that convert potentially leachable legacy CCBs into stabilized forms, particularly if those stabilized materials can provide additional benefits to the environment.

In order to be environmentally friendly, CCBs in land applications, as described in this paper, must be stabilized into a form that does not leach heavy metals or excessive ions. A study published by EPA in 2014 found little to no leaching risk associated with CCBs used in concrete[3]. The beneficial use projects described in this paper involve the use of CCBs as flowable fill (also known as controlled low strength material (CLSM), engineered fill, self-compacting fill or grout). These materials are intended to be used as backfill in place of compacted soil. As some of their synonyms suggest, they are designed to flow and to not require compaction, meaning that they are easier to place in areas that may not be accessible with compaction equipment. However, they also cure into a solid mass, similar to concrete. Unlike concrete, however, their strength is generally designed to be lower; they can be used in situations where future excavation may occur, but also can be used to provide structural fill sufficient to support buildings, or drivable infrastructure. CCBs are often a component of engineered fill as the glassy spheres that make up fly ash improve flowability and the pozzolonic properties of CCBs can increase strength of the material, where that is desired[4]. The pozzolonic properties (meaning their ability to participate in cementitious reactions when combined with free lime and water) of Class F fly ash are well known; and alkaline CCBs, like Class C fly ash and fluidized bed combustion ash (FBC) contain free lime. The ASTM C618 standard for fly ash in concrete is a comprehensive standard for the composition, physical properties and reactive behavior of CCBs (particularly fly ash) that will be used in concrete; however CCBs that are used in flowable fill do not necessarily have to meet all of the same requirements required for concrete[5]. For this reason, beneficial use in flowable fill can be an ideal application for legacy CCBs.

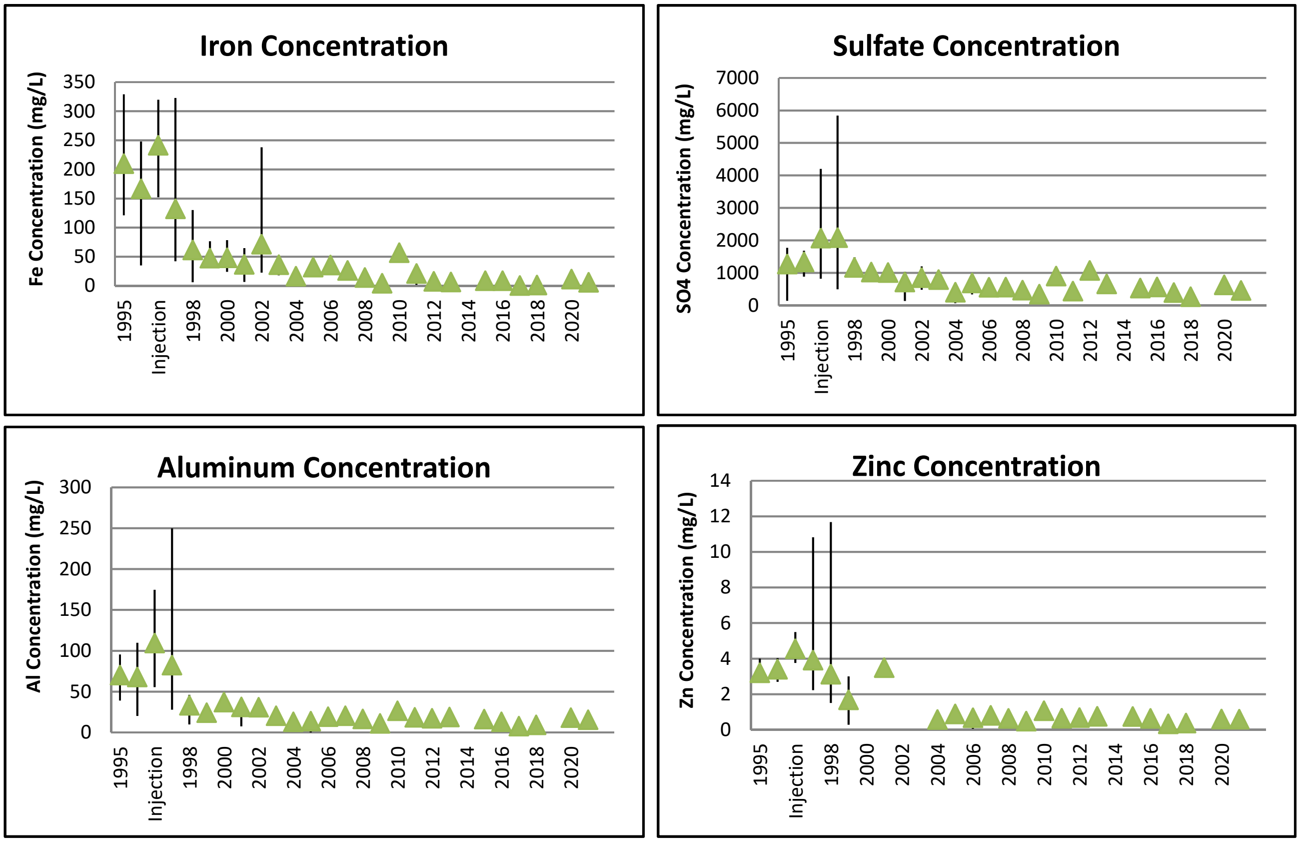
UNDERGROUND COAL MINE RESTORATION

Demonstration Project to Improve Water Quality

In 1995, ERM, PPRP, and other stakeholders initiated the Winding Ridge Project at the Frazee Mine near Friendsville Maryland. In this demonstration project, 5,600 cubic yards (4,300 cubic meters) of grout made using 100% CCBs and mine water were injected into a small, isolated, abandoned coal mine. The purpose of the injection was not to add alkaline material to neutralize the acidic mine water, but rather to coat the mine pavement and its acid-producing minerals to reduce or prevent the continued formation of acid within the mine.

Twenty-five years following the injection project, drainage continues to flow from the mine. The average pH levels are slightly higher than the pre-injection pH levels which ranged from 2.5 to 3. However, the concentrations of other parameters, including key acid mine drainage indicator parameters, like iron and sulfate have dropped, as have the concentrations of various other metals like aluminum and zinc (Figure 4).

Figure 4: Selected Major Ions and Trace Metals in Winding Ridge Discharge

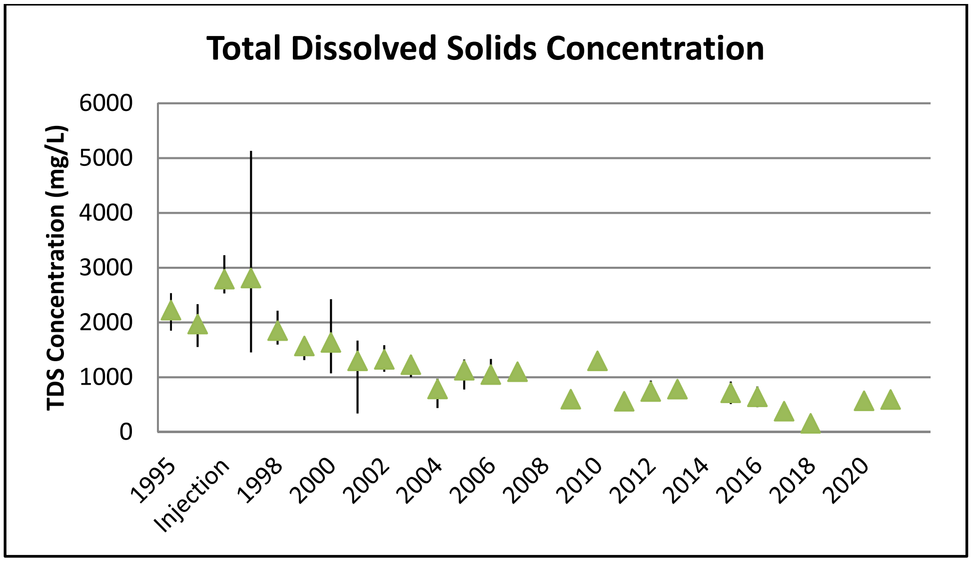


Although low pH is one of the best known characteristics of acid mine drainage, it is not the only one with the potential to cause damage to the environment. Acid mine drainage forms large volumes of sediment as it mixes with more neutral surface waters. The formation of sediment is increased even further by certain treatment methods, such as lime dosers that raise the pH of AMD by adding alkaline reagents.

The large volumes of sediment or sludge that can be precipitated by either untreated or treated AMD is also detrimental to aquatic life, essentially smothering vegetation and benthic organisms. The impaired stream quality is particularly detrimental to species like the hellbender salamander, which inhabits certain streams in Western Maryland. This “near-threatened” species is one of the largest salamanders in the world and its reproductive cycle is threatened by heavy sedimentation in streams[6].”

Total dissolved solids may be used as a qualitative proxy for potential sediment generation. Figure 5 shows the change in total dissolved solids observed over the long term at the Winding Ridge site. These water quality improvements were derived from a single injection event and have not required long term maintenance costs.

Figure 5: Total Dissolved Solids in Winding Ridge Discharge



Potential to Mitigate Methane Emissions

Another potential benefit of grouting abandoned underground coal mines with low-permeability CCB grouts is the mitigation of coal mine methane emissions. Methane is emitted from both active and abandoned coal mines[7]. The gas is best known for the explosive dangers it presents in active coal mines, but it is also a powerful greenhouse gas, a companion greenhouse gas to carbon dioxide. The gas is stored within coal which may remain in mine pavement and debris. In the Winding Ridge Project the CCB grout injection was intended to coat pyrite-containing mine debris and pavement, keeping them separate from water and oxygen. By the same logic, a low-permeability CCB grout would also coat any remaining coal debris or pavement and prevent methane contained within the coal from being released to the atmosphere. Researchers are looking into the potential to capture coal mine methane for use in energy production[8,9]. Strategic mine grouting could also be used in these types of projects to seal unwanted vents and direct methane venting to the desired capture location. This is a potential beneficial use that requires further study.

SURFACE MINE RESTORATION FOR SOLAR DEVELOPMENT

Reclaiming Surface Mines with CCBs

In Maryland, subsurface mines are present only in the western portion of the State, which limits CCB beneficial use for this purpose to one region. However, surface mines and quarries for sand, gravel, clay, and crushed stone are present across Maryland, including central and eastern areas, which contain a number of legacy CCB sites as well as an additional by-product material obtained during the dredging of important shipping lanes and dams. Reclamation of these surface mines is another potential large-scale use of both materials.

It is necessary to acknowledge that problems have been documented with the use of raw CCBs to reclaim surface mines, particularly sand and gravel mines. For example, unencapsulated CCBs were used to reclaim a former sand and gravel mine in Gambrills, Maryland. While much of the site is now paved with infrastructure that limits the infiltration of precipitation, groundwater impacts were noted in residential communities downgradient of the site during the mine backfilling. For this reason, EPA made mention of this site as a damage case in the 2015 Federal Coal Combustion Residual (CCR) Rule[10]. The 2015 Federal Rule categorizes the placement of unencapsulated CCBs into sand and gravel quarries as disposal and subject to the same liner and monitoring requirements as landfills. However, if CCBs are placed in an encapsulated, stabilized form that cures into a solid monolith, the risks of leaching are vastly reduced.

Siting Solar Generating Stations on former Surface Mines

The State of Maryland has established a Renewable Energy Portfolio Standard (RPS), which mandates that 50% of the State's electrical power come from renewable sources by 2030. The RPS further requires that at least 14.5% of this power be generated through solar facilities. Maryland is one of more than 29 states to have established an RPS[11,12]. Achievement of these RPS requirements will involve the installation of numerous solar power generating stations.

Following reclamation, surface mine sites can make ideal candidates for additional environmental beneficial use as solar power generating facilities. Utility-scale solar projects require large areas that are relatively level and not shaded by trees or large buildings; this is generally true of reclaimed surface mine sites. Furthermore, the history of use for mining means that there are generally few to no concerns with regard to rare, threatened, or endangered species or their habitats. Finally, placing solar power generation facilities on former mined land reduces the need to place such facilities on agricultural fields, which also tend to be large areas of flat, unshaded land, but can be much more controversial for solar development[13,14,15].

The concept of siting solar facilities on former surface mine sites is already being put into practice at a number of sites across the United States. Some states, like Vermont, have identified former sand and gravel pits as preferred sites for solar development[16]. Table 1 presents a list of surface mine to solar facility projects that are either proposed, under construction, or operational as of early 2022.

Table 1: Existing and Proposed Solar Facilities at Former Surface Mines

Project Name	Location	Size	Status	Notes
Shaw Brothers Construction	Maine	3.2 MW	Operational	Sited on former gravel pit. Provides power to the construction company for operations including crushing[17].
Sunmine	British Columbia, Canada	1.05 MW	Operational	Sited on a former zinc, lead, silver mine that closed in 2001. Solar facility operational since 2015[18].
Gravel Pit Solar Farm	Illinois	2 MW	Operational	Sited on a former gravel pit. Provides power for the continued operations of the sand and gravel mining business. Stoney soils required adjustments to be made to usual support structures[19,20].
Greenlantern Solar	Vermont	0.5 MW	Operational	Sited on a reclaimed gravel pit and is one of several solar facilities planned for the area[21].
Next Grid	Massachusetts	5 MW	Proposed	Planned for Cape Cod Aggregates mining site. Plan was approved by local Planning Board in 2020[22].
Blue Wave Capital	Massachusetts	5.67 MW	Operational	Began operations in 2014[23].
Copper County Power I	Michigan	Not Reported	Proposed	Proposed to be located on former gravel mine and iron tailings site[24].
GraniteRock	California	Not Reported	Operational	Located at a surface hard-rock mine. 3 projects are planned, 2 are currently operational. Provides power to the mining operation[25].
Gravel Pit Solar	Connecticuit	120 MW	Proposed	Project was approved by local state siting council in February 2021. Construction is expected to begin in early 2023[26,27].

Very little information is available about the foundations for these systems, but an engineered fill surface could provide a solid foundation for solar developments. The ability to custom-design the strength of engineered fill can allow for foundations strong enough to withstand storms but also provide corridors where underground interconnections between panels and connection to the grid can be installed easily.

Opportunities for Surface Mine Solar Projects in Eastern Maryland

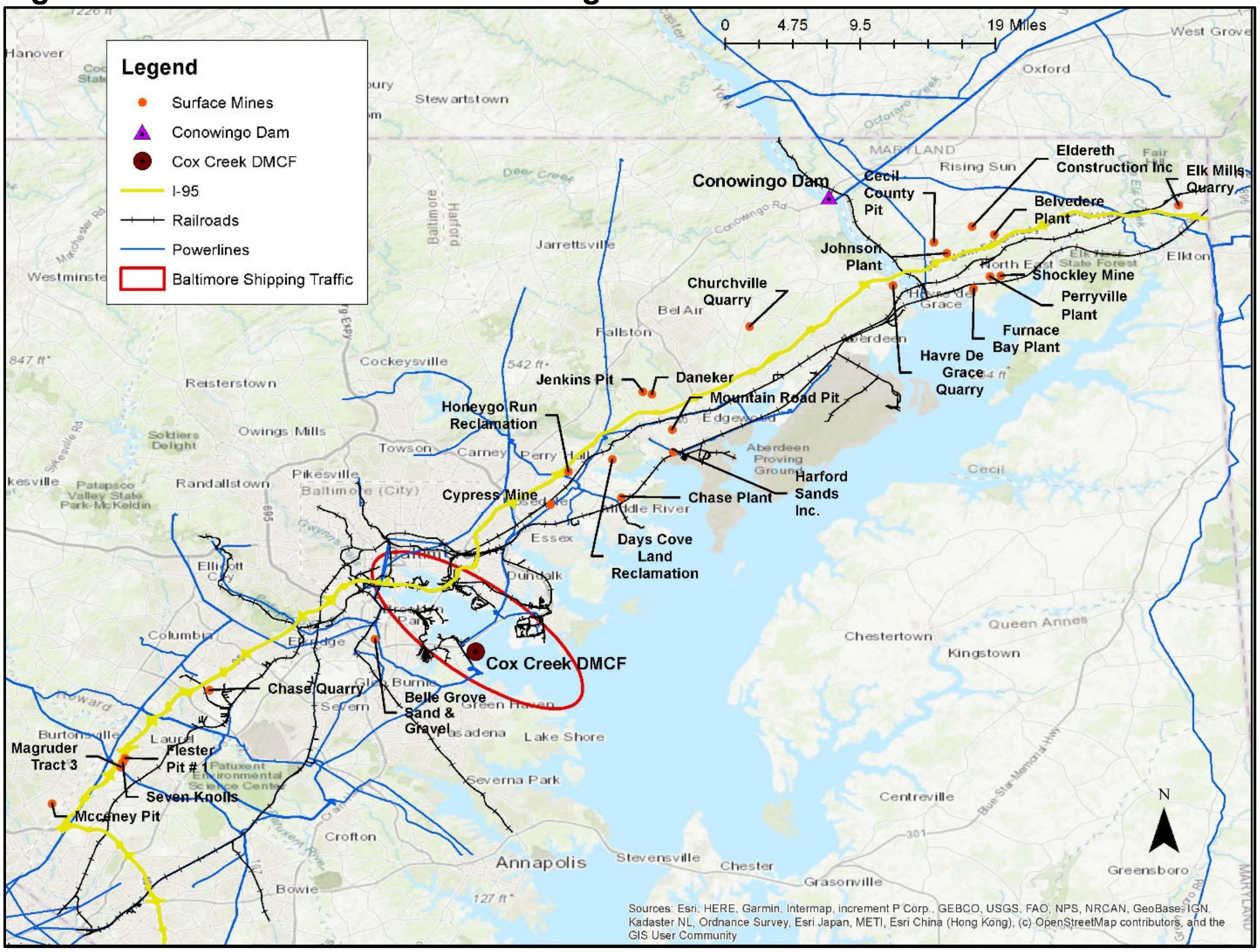
Solar developments proposed in Maryland have ranged in size between 12 acres and over 1,000 acres (4.8 to 405 hectares) but average around 200 acres (81 hectares). A review of over 300 surface mine sites in the State shows that they range in size from less than one acre (less than 0.4 hectares) to more than 600 acres (243 hectares) with more than two thirds falling into the range of proposed solar project sites.

One area of the state with a particularly large number of potential sites is the northeast corridor. The northeast corridor is a set of rail lines that runs along the north eastern portion of the state from Washington DC, through Baltimore, and up to Philadelphia, Pennsylvania. Historically they carried large amounts of freight traffic, including the transportation of sand, gravel, and clay that was mined along the tracks and transported for building projects in metropolitan areas. The history of this activity means that there are multiple surface mine sites still present, and some still active; it also means that there are a variety of transportation options available. The rail line is dominated by passenger use today, but still carries a significant amount of freight. In addition, Interstate 95 runs parallel to the rail line in this corridor. Since transportation costs are a significant factor in assessing the feasibility of beneficial use projects, the transportation options in this area make it an attractive choice. In addition, this corridor offers easy access to major electric transmission lines that could be used to connect a solar project to the electric grid.

Figure 6 presents a map of sand and gravel pits identified in the northeast corridor along with the major highways, rail lines, and electric transmission lines in the area. Also shown on the map are the locations of the Cox Creek dredge material storage site and the Conowingo Dam, which also requires periodic dredging. Stabilized engineered fills designed to support solar installations could be an environmentally beneficial way to reclaim these surface mine sites and convert them from mineral extraction to green power generation.

A total of 25 active or unreclaimed surface mine sites were identified within five miles of Interstate I-95. The sites vary in size with permitted areas ranging from just under 20 acres (8.1 hectares) to over 600 (243 hectares) acres. The total aggregate area covered by these mines is over 3,600 acres (more than 1,460 hectares). The volume of CCB or CCB/dredge material grout that would be consumed to reclaim the smallest of these sites is approximately 0.5 million cubic yards (0.4 million cubic meters). To reclaim the largest of the sites would consume more than 16 million cubic yards (more than 12 million cubic meters) of material. On average, approximately 2.5 acres (0.101 square kilometers) of area are required to generate one megawatt (MW) of electricity. If the entire permitted area of the smallest of these sites were converted to a solar facility, it could generate up to 7 MW of electricity. The larges site, if similarly converted could generate up to 274 MW. This could be a significant clean-energy addition to the power grid.

Figure 6: Sand and Gravel Mines along I-95 Corridor



Protecting Infrastructure from Flooding Risks

The impacts of climate change, particularly in coastal areas, are well publicized. In addition to gradual sea level rise, coastal storms are increasing in both frequency and intensity. These factors all lead to increased risks of flooding, particularly in low-lying coastal areas. Repeated flooding can also wash out soils underlying structure foundations leading to cracking, subsidence, or instability of the structures.

Grout injections to fill subsurface voids is a well-known and widely used technique for preventing surface subsidence, particularly in areas where roads or buildings lie on top of abandoned underground mines or natural cavities[28,29]. At the Frostburg State University campus in Maryland, this technique has been used a number of times to provide support for buildings that are constructed over deep coal mines.

Other forms of grouting are more commonly used to support structures that are threatened not by voids, but by soft soils or uneven settlement of building slabs. Compaction grouting uses a stiff grout to force loose soil grains together (compact soil) in place and improve strength[30,31]. Similar stiff grouts can also be used for slab raising (also called mud jacking); in this process the grout is pumped under pressure and used to raise and support the settled portion of the slab[30,32]. As coastal areas experience higher water tables and more frequent and higher magnitude floods as a result of climate change, such repairs may become more frequently necessary.

Some researchers have expanded upon this concept and begun to research the use of these types of injection techniques, potentially on a broader scale, to raise ground levels in areas that are prone to flooding. Some of these techniques could be combined with the concepts behind hydraulic fracturing to propose methods by which ground surface could be raised over broader areas that are susceptible to flooding. Solid Injection to Raise Ground Elevation (SIRGE) was proposed by a research group in 2010 as a possible method to protect cities threatened by sea level rise[33]. This technique involves the injection of water and coarse-grained solids under high pressure to create and widen horizontal fractures in the subsurface. Following dissipation of the water, the solids remain holding the fracture open and maintaining the uplift that was achieved.

The authors modeled an injection project designed to raise 1 square kilometer of land at a rate of 1 mm per day – over a period of years, a total uplift of more than a meter could be achieved. Although this modeling assumed use of a sand and water slurry (i.e. unencapsulated solids), the authors also reference the Povaglia test, conducted in 1971 and 1972. This test involved the injection of a clay and cement mixture into a series of boreholes to raise an area of 900 square meters in Venice[34]. In this experiment, an average uplift of approximately 10 centimeters was achieved, and when a benchmark was measured 11 years later, it had only subsided by 1 centimeter[33]. Although this is a modest elevation increase, in combination with other techniques, it could be a valuable tool in aiding communities dealing with more frequent flooding and sea level rise. In addition to minimizing the risk of leaching impacts, the use of a cementitious CCB-based grout material for this type of project, rather than unconsolidated natural material like sand could also minimize the need for future injections to maintain the uplift.

CONCLUSIONS

As power generation in Maryland, the United States, and around the world shifts away from coal, industries that have come to rely upon CCBs as raw materials are increasingly turning to legacy materials to meet their continued needs. However, the vast quantity of CCBs that have been disposed over decades of reliance upon coal for energy production means that there is more of this material available than these industries can consume within the span of a few years. Furthermore, some of this material is stored in sites that, by reason of their location or size, are not economically attractive to industry. Nevertheless, these legacy sites still have the potential to impact ground water quality and environmental interests are served by moving them out of unlined, unencapsulated fill sites and into encapsulated beneficial uses, particularly those that can directly impact the environment in other, positive ways.

Using CCB grout to reclaim abandoned underground coal mines has been shown to reduce the formation of acid mine drainage and prevent land subsidence above mine tunnels that can damage buildings and infrastructure. This technique also has the potential to help mitigate the emission of methane from abandoned coal mines, thus addressing a potent greenhouse gas. CCB grouts could also be used to reclaim surface mines, including, sand, gravel, and clay mines common in Maryland in a way that does not leach constituents to the environment. Secondarily, such use potentially provides a useful surface for the development of solar arrays supplying renewable green energy without placing such development on potentially productive agricultural land. Finally, CCBs may be a valuable resource in proven technologies that repair building slabs damaged by uneven settlement, but also in experimental techniques that could raise them to help mitigate the risk of future floods.

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