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# Life cycle assessment of sunflower cultivation on abandoned mine land for biodiesel production

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ABSTRACT

Producing biofuel feedstock on marginal lands is a viable way to offset fossil fuel production, global warming, and other adverse environmental impacts, while at the same time performing positive ecosystem services by reclaiming unused areas with value producing activities. This research study explored low-input production of sunflower biodiesel feedstock on abandoned mine land (AML) from coal mining refuse treated with bauxite residue (alkaline clay) through the lens of Life Cycle Assessment (LCA).

An attributional LCA was conducted from the gate of an aluminum production facility (which produces the bauxite residue), through AML amelioration and low-input agricultural activities, to the gate of a biodiesel production facility. A 26 ha (ha) coal mine refuse pile located in Mather, PA, (91 km south of Pittsburgh), was used as an example location. Analysis of published agricultural data and greenhouse research led to a conservative sunflower oilseed yield of 500 kg/ha estimate, with a subsequent biodiesel yield of 190 kg/ha (217 l/ha).

Results show substantial impact from the initial soil amendment process, however, when compared to complete restoration of the AML and other similar fuel production activities, overall environmental impacts over a twenty-year production cycle are sensible. An alternative allocation of the bauxite residue transport (i.e. associating transport impacts to aluminum industry) and addition of other fuel conversion pathways would show an improved energy return and better environmental outlook from biofuel production on AML.



## 1. Introduction

Environmental impacts of modern human activity continue to grow at rates incompatible with sustainable development. Among the most complex impacts are global climate change, ecosystem deterioration, and resource depletion. Abandoned mine lands (AML) and associated refuse piles contribute to local ecosystems deterioration, while expanded use of fossil fuels depletes petroleum resources while simultaneously adding to greenhouse gas emissions (Worrall et al., 2009). A body of literature on the capability of biofuels cultivated using traditional agricultural techniques to reduce greenhouse gas emissions and offset fossil fuel use exists – more recently on second and third generation biofuel feedstocks, including cellulosic biomass and algae (Singh and Singh, 2010). However, as of 2015, there were no publications on the subject of biofuel cultivation on AML.

AML and associated refuse piles, also known as legacy mine land (collectively AML for the purposes of this paper, but not to include slurry containment areas) occupy over 600,000 sites and 3 million hectares in the United States (BLM, 2013; Mining, 2002; Worrall et al., 2009). Acid and toxic mine drainage, resulting in severe ecosystem deterioration, is one of the major consequences of AML which plagues ecosystems and watersheds (Worrall et al., 2009). Acid mine drainage (AMD) creates acidic runoff in the range of 2.2–3.5 pH that completely destroys local ecosystems and hinders regional economic development (Sheoran et al., 2010). Current regulations by the EPA – including the Surface Mining Control and Reclamation Act of 1977 (SMCRA) and Clean Water Act of 1972 (CWA) – require mining companies to follow “standards to minimize damage to the environment and to productivity of the soil and

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to protect the health and safety of the public" (Interior, 2012). Despite these regulatory changes in the '70s, many locations from decades and even centuries past, most in the eastern mining district in the Appalachian states, are still in need of reclamation, remediation, or other value creating activity (Ditsele and Awuah-Offei, 2012; Powell, 1988; Wei et al., 2011).

AML have the potential for economic, recreational and esthetic use, by recognizing the unique potential of the marginal land by using sustainable technologies and measures for transformation (Cao, 2007). The EPA has been successfully experimenting with producing biofuels on AMLs in "sustainable energy parks" (Butler et al., 2013). Studies in Appalachia have shown that apt reclamation practices improved water quality in nearby watersheds over time (Wei et al., 2011). Phytostabilization has been proposed as a low-cost method for reducing the mobility of heavy metals in marginal lands by strategic plant growth (Conesa and Faz, 2011). It has also been proposed that the industrial ecology methodology, including the integrated biotechnological approach, can enhance the restoration of AMLs by using waste streams from other industries to treat the soil (Chen et al., 2013; Deng, 2013; Juwarkar et al., 2010; Mercuri et al., 2005).

The methods for treatment of AML and acid mine drainage (AMD) include both active and passive methods (Sheoran et al., 2010). The most common method is to cover the polluted area with a layer of soil and passively allow the local biota to reclaim the land. Composts, manure, biochar and other organic materials have also been proposed as passive soil amendments to increase the productivity of AML and other marginal lands (Beesley et al., 2011; Fellet et al., 2011). The typical active acidic soil neutralization technique used by the agricultural industry, liming the soil, is known to have negative environmental impacts including metallic sludge runoff and continuing treatment requirements (Johnson and Hallberg, 2005).

Another method of neutralizing AML acidic soil – using concepts of industrial symbiosis and byproduct synergies – is to utilize alkaline wastes from other industries to mix with and amend the soil. Bauxite residue is an alkaline, high pH, clay substance generated as a byproduct from bauxite mining and the aluminum industry. Bauxite is an aluminum ore used to produce commercial aluminum. Alcoa Inc. demonstrated that high pH value (10–12) and alkalinity of bauxite residue can neutralize the acidity (pH < 5.5) of the coal mine refuse by mixing the two co-products, allowing resilient plants to germinate and develop successfully at an AML site near Mather, PA (Alcoa, 2010; MSDS, 2007). However, the Alcoa study only used typical reclamation plants (such as *Lygeum spartum*, *Piptatherum miliaceum* and *Helichrysum decumbens*), not evaluating the feasibility of biofuel feedstock cultivation on AML (Conesa and Faz, 2011). Conversely, the EPA sponsored several projects under their Superfund Redevelopment Initiative and the RE-Powering America's Land Initiative, which focuses on biofuel and renewable energy on contaminated lands (EPA, 2011). Research has shown that bioenergy crops cultivated on Brownfields do not have significantly different yields than on other agricultural lands (Smith et al., 2013). This study brings the two concepts together.

A refuse pile occupying approximately 26 ha of land near the small town of Mather in southwest Pennsylvania was produced from a coal mine closed in 1965 (Alcoa, 2010; GoogleEarthPro, 2014). The Mather coal mine refuse pile is also known for its severe AMD and ecosystem deterioration, resulting in rivers colored red as seen in Fig. 1, since the mine closure and abandonment in the 1960s (Deng, 2013; McCaa and Howarth, 1928). The refuse pile has gone through several phases of reprocessing (dismantling onsite buildings, covering of a creosote plume, railroad tie removal, and grading) and agricultural experimentation with limited reclamation success (Alcoa, 2010; Matesic, 2013).

A greenhouse experiment was conducted at University of Pittsburgh, PA (Pitt) and was focused on biofuel feedstock phytotransmission of metal contaminants found in the coal mine refuse; while a greenhouse experiment at Arizona State University, AZ (ASU) was to test the growth of several biofuel feedstock plant species on a soil treatment with 10% by volume bauxite residue (aka alkaline clay) mixed with coal mine refuse collected from the Mather site, compared to respective growth in commercial topsoil. The aim of the ASU greenhouse study was to determine if feedstock growth was possible in the treated soil. As seen in Fig. 2, four biofuel plant species showed adequate growth on the AML refuse treated with bauxite residue: sunflower, sorghum, canola, and camelina, while the control showed none.

There has been a surge in research on biofuel feedstock cultivation on marginal lands because of the "food, energy and environment trilemma" (Ajanovic, 2011; Butterbach-Bahl and Kiese, 2013). By producing biofuel on marginal lands, food production will not be offset by biofuel feedstock production, fossil fuel depletion may be reduced, global warming may be mitigated, and other environmental impacts removed. However, to gain these benefits, several constraints must be employed: energy consumption through agricultural production must be minimized, local biofuel production facilities must be available, and appropriate feedstock must be produced (Gelfand et al., 2013; Iglesias et al., 2012; Johnson et al., 2013). The proper choice of feedstock is one of the most important factors for the viability and sustainability of biofuel cultivation on AML. Some considerations are yield, low agricultural input demands, tolerance to unfavorable conditions, plant root penetration, soil carbon sequestration potential, and beneficial ecosystem services (Braimoh and Vlek, 2008; Cherubini et al., 2009; Yusuf et al., 2011).

Sunflower (*Helianthus annuus* L.) was a valid selection and has proved successful for biofuel feedstock production on marginal lands (Niblick et al., 2013; Olson and Fletcher, 2000; Zhao et al., 2014). One study has even shown that on mine polluted lands, oil content of sunflower seeds is greater than that of sunflower grown in nearby non-polluted areas, and measured levels of toxic elements in the plant matter were below those harmful to plants, animals, and humans (Madejón et al., 2003). The sunflower plant is extremely resilient with relatively high tolerance to drought, salinity, trace element contamination, and other agricultural stresses (NSA, 2010).

The goal of this study was to explore one possible novel, sustainable, and valuable use of abandoned mine lands (AML), particularly the cultivation of sunflower as a biodiesel feedstock on bauxite residue treated coal AML, via Life Cycle Assessment (LCA) methodologies. A legacy coal mine refuse pile located near Mather, PA, was used as a reference site to determine the feasibility of treating the acidic abandoned coal mine lands with industrial co-products, namely bauxite residue from aluminum production, to neutralize the soil and safely enable biofuel feedstock cultivation.

LCA is a quantitative tool used to evaluate environmental performance of products, services and processes, provide quantitative and aggregated information to decision makers, select environmental indicators and measurement techniques, and in some cases to help market products as environmentally sound (Hunt et al., 1996; ISO, 2006a,b). LCA is the ideal tool for evaluating the feasibility of cultivating biofuel feedstocks on AML because of its ability to foresee unintended environmental impacts, allow decision makers to choose the best course of action and minimize negative consequences and tradeoffs (Cherubini et al., 2009; Sanz Requena et al., 2011). LCAs demonstrated environmental impacts from first generation biofuels (i.e. corn ethanol and soybean biodiesel) were arguably just as bad, or worse, than petroleum production itself, inspiring the US Environmental Protection Agency's (EPA) push