# U.S. Reclaimed Coal Lands: An Analysis of Low Risk for Indirect Land Use Change under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

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# Executive Summary

Under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), certain land types, land management practices, and innovative agricultural practices can be considered to contribute to low risk for land area change. As a result, these lands receive a value of zero for indirect land use change (iLUC) in the life cycle analysis of a batch of fuels. CORSIA specifies two approaches for low land use change risk sustainable aviation fuel feedstock production:

a) Yield Increase Approach
b) Unused Land Approach

Specific to the Unused Land Approach of CORSIA, the International Civil Aviation Organization (ICAO 2019, 10-11) states:

> "Eligible lands for the unused land approach could include, among others, marginal lands, underused lands, unused lands, degraded pasture lands, and lands in need of remediation. For a land to be eligible for the unused land approach, it needs to meet one of the following criteria:
>
> a) Land was not considered to be arable land or used for crop production during the five years preceding the reference date.
> b) Land is identified as severely degraded land or undergoing a severe degradation process for at least three years, according to criteria proposed by a Sustainability Certification Scheme recognized under CORSIA, where the criteria are based on scientific literature.
>
> For a land to be eligible for the unused land approach, it also needs to have little risk for displacement of services from that land onto different and equivalent amounts of land elsewhere."

This report focused on the unused land approach with our analysis and (1) documents why U.S. reclaimed coal lands, by and large, meet the unused land definition and (2) calculates the quantity of land that can contribute feedstock under CORSIA.

We find the following:

- Among all coal land areas (surface mined lands, mountain tops, etc.) a subset is of interest to feasibly produce sustainable aviation fuels: the surface mined areas located in the Illinois Coal Basin.
- Reclaimed coal land in these areas that meet the CORSIA definition of unused land:
    - That have not been in production for many years, and in some cases, for decades.
    - That have added high quality topsoil, nutrients, cover crops, and other soil conditioning processes to enhance land quality (essentially creating new land with a higher potential for significant agricultural production).
    - That even after initial reclamation and full bonding release, growers experienced yield lag for multiple growing seasons.
    - Due to the above outlined land conditions, reclaimed land can often be left in a state of erosion control.

Our analysis showed that each year since 2016, an average of 16,000 - 17,000 hectares nationwide would meet the CORSIA unused land definition, but the truly feasible area for actual fuel feedstock production is a subset and further focus of our analysis. Within our subset where it would actually make sense to produce fuel feedstock, like the Illinois Coal Basin, 4,000 - 9,000 hectares would meet the CORSIA unused land definition. With that said, it is important to consider that this movement of agricultural production back onto reclaimed surface mine lands has not been incentivized beyond the normal commodity prices.

## Introduction

Coal, a natural resource used for energy generation began forming during the Carboniferous Period (approximately 300,000 mya), is found on every continent, including Antarctica. While the majority of the world's coal reserves are located in Asia, 21 percent of these reserves are located in the United States. Within the US, the majority of the high quality coal resources (bituminous and anthracite) are located in three coal forming basins: the Application Basin (folded into mountains at the end of the Paleozoic Era), the Illinois Basin, and the Powder River Basin. Interestingly, it was the Appalachian Basin (in 1701) where coal was first mined commercially in the U.S. Since the establishment of this first coal mining operation in Virginia, the U.S. coal industry has expanded to an additional 26 states and, by 2000, nearly a billion tons of coal were being commercially extracted annually. Figure 1 shows the spatial distribution of these coal basins within the US, along with the temporal estimation of reclaimed hectares across the U.S.

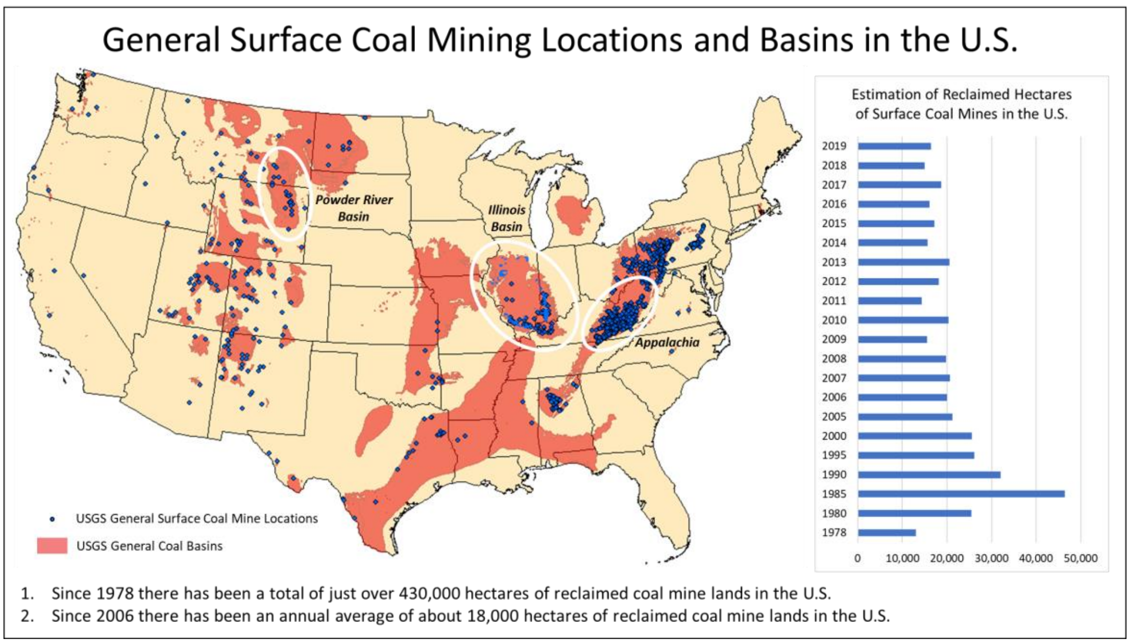



**Figure 1**: Distribution of U.S. coal basins and chart of reclamation hectares (Garside 2020; OSMRE 2020a; USEIA 2018; USGS 2013).

To date, the mining process in the U.S. has involved to a variety of extraction methods, including surface mining with a dragline, shaft mining, slope mining, and mountain top removal (Figure 2).

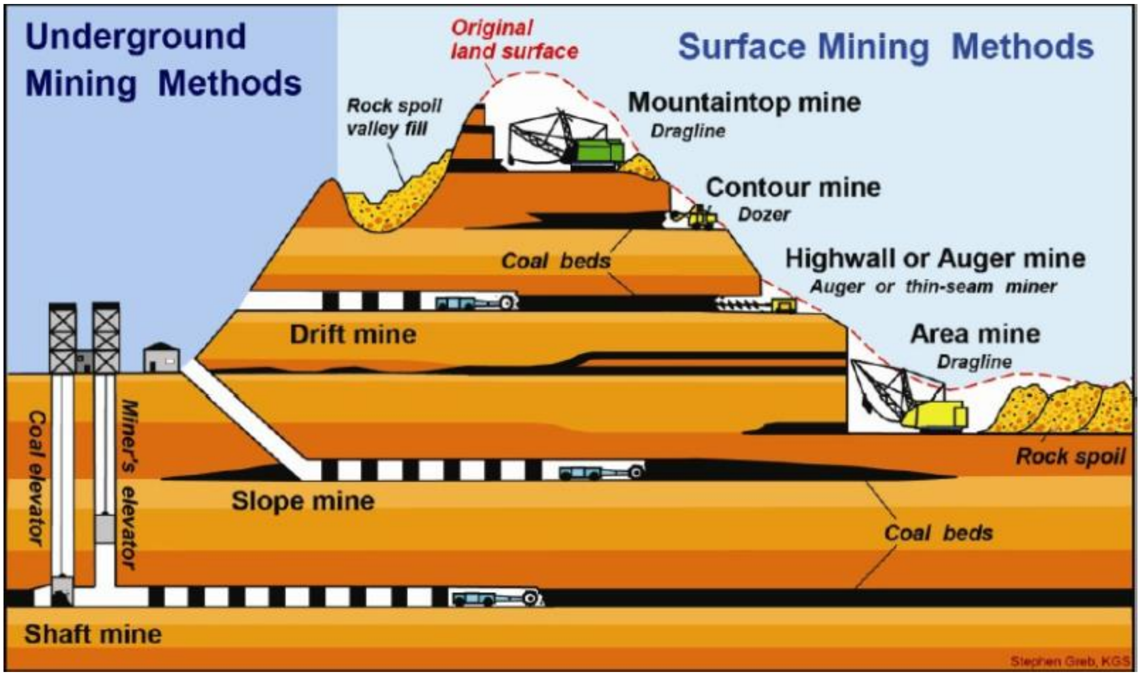



**Figure 2**: Graphical representation of typical coal extraction methods in the U.S. (USEPA 2016).

Interestingly, it took the U.S. government almost 200 years to establish guidelines for reclaiming these "degraded" lands. In 1977, Congress enacted the Surface Mining Control and Reclamation Act. And, on August 3rd, 1977 the Office of Surface Mining Reclamation and Enforcement (OSMRE) was created. OSMRE (2020b) states that:

> "OSMRE works with states and tribes to ensure that citizens and the environment are protected during coal mining and that the land is restored to beneficial use when mining is finished. OSMRE and its partners are also responsible for reclaiming and restoring lands and water ***degraded*** by mining operations before 1977.
>
> {And}
>
> OSMRE continues its efforts to meet one of the primary purposes of SMCRA - to strike the balance between protection of the environment and agricultural productivity and the Nation's need for coal as a source of energy.
>
> In its beginning, OSMRE directly enforced mining laws and arranged cleanup of abandoned mine lands. Today, most coal states have developed their own programs to do those jobs themselves, as Congress envisioned. OSMRE focuses on overseeing the state programs and developing new tools to help the states and tribes get the job done."

## Process of Land Reclamation

As mentioned above, the OSMRE established guidelines for surface mine reclamation that were enacted in 1977 that have been instrumental in reestablishing these degraded lands back to a pre-mined land cover/use base. The following section describes in detail the legal framework around mine reclamation and bond phases and release, and an overview of the description of the post-mine land use process (including regional examples in the discussion).

### Legal Framework

The U.S. federal Surface Mine Control and Reclamation Act (SMCRA) of 1977 established standards and practices for the permitting of land disturbance associated with mining activities. Most importantly, it mandated that the disturbed area must be reclaimed, and must be carried out in a way that achieves a successful post-mining land use (PMLU) based on a list of pre-approved PMLUs. In order to ensure that a mining company completes reclamation to achieve that PMLU, the company must post an escrow bond in the form of cash or a lien against physical assets; they receive the bonded cash or are released from the lien as they complete the three phases of reclamation.

**Phase I** consists of completing the "backfilling, regrading, and drainage control of a bonded area," in other words placing and sculpting the stockpiled "overburden" (earthen material overlying the mineral, excluding topsoil) across the mined or disturbed area with heavy earthmoving equipment. Up to 60 percent of the bond may be released once a government inspector has verified that the ground conditions meet the specifications of the permitted reclamation plan. This phase is generally completed within 1 to 2 years after mining operations have ceased.

**Phase II** is primarily focused on reestablishment of vegetation, unless the PMLU is based on industrial infrastructure development (not discussed here). For all other PMLUs, the mining company must sow, plant, or otherwise establish the groundcover approved in their reclamation plan. Examples include hydroseeded fescue/lespedeza mix for "hay and pastureland" PMLU, hand planting of tree seedlings for "forestry" PMLU, or establishing soil building cover crops for "prime farmland" PMLU. The milestones that must be achieved and length of time taken to satisfy the Phase II requirements are highly variable based on the PMLU; for example "hay and pastureland" must reach a certain percentage of perennial ground cover establishment, and "prime farmland" must generate a yield on at least 0.4 hectares from one of several approved crops that meets a reference standard based on the region and soil quality designation. Total dissolved solids and other runoff parameters must also be within specification for waterways originating on or traveling across the permitted area. Up to 25 percent of the bond may be released after successful inspection.

**Phase III** ensures that the revegetation that began in Phase II continues to completion, measured by additional criteria similar to those mentioned in Phase II. "Hay and pastureland" must achieve 100 percent perennial ground cover; two more yields of pre-approved crops from plots of at least 0.4 hectares that meet or exceed reference benchmarks must be achieved for "prime farmland." The remaining bond is released once an inspector has signed off on the requirements having been met, the mining company is freed of active permit obligations, and the land may be used by the landowner in any way they like.

There is a minimum 5-year bonding period, which can be spread across the three phases in any way. There is no federal maximum, and depending on state-level regulations, a site may remain in Phase II or III for decades. A total of 7 to 15 years for full bond release is most common, though it should be noted that viable crops may be grown and sold from the land while still in Phase II or III. In many cases a mining company may become insolvent and unable to finish its reclamation obligations, creating a "bond forfeiture" site wherein the remaining bond is supposed to be used by state or federal agencies to complete reclamation. In practice, the bond amount is often not enough to cover the remaining reclamation costs and thousands of hectares may remain in legal limbo for years.

## Overview of U.S. Reclaimed Mined Lands

Reclamation of mined lands in the US and post-reclamation suitability for row crop agriculture is dependent on two primary factors. First, the geology of the "overburden"[1] strata is quite variable across different regions and dictates to what extent it can be reconstituted into a versatile growing medium through the reclamation process. Second, the "post-mining land use," or PMLU, that a landowner desires is agreed upon at the time of initial permitting with the mining company, and the reclamation process is then carried out to meet that goal.

Land that qualified as "prime farmland" prior to mining and was reclaimed with that PMLU will be the most suitable for row crop production. In the case that land with this designation is limited or unavailable, other PMLUs such as "hay and pastureland" or "fish and wildlife habitat" may be considered, though they will have higher site prep costs to achieve economically viable yields. While certain regions of the country may have much more prime farmland PMLU available, other regions may be desirable because of economic development incentives.

## Reclaiming to Prime Farmland in Agricultural Regions

The Illinois Basin (southern Illinois, western Indiana, western Kentucky) and Powder River Basin (large swaths of Montana and Wyoming) are home to coal seams overlain by high quality farmland, and the surface layers are treated much more carefully than the steep slopes and narrow ridges of Appalachia. Topsoil is

[1] "Overburden" is a mining industry term meaning all non-useful material that must be moved to reach the desirable mineral (soil, rock, etc.)

removed by scrapers and stockpiled independent of other layers; subsoil layers are removed by scrapers or excavators and stockpiled or immediately distributed on adjacent mined areas, and topsoil is redistributed across the surface once subsoil layers have been replaced. Rockiness is generally not a concern, and the high quality topsoil can be over a meter in depth.

The "prime farmland" PMLU requires that the site produce three crop harvests with yields equal to or better than benchmarks based on regional crop yield data and USDA soil quality designations in order to reach full bond release. In practice, the recorded yields may come from plots as small as 0.4 ha to represent an area that could be hundreds of hectares in size, so the productivity of the entire reclaimed area is not necessarily guaranteed just because it has achieved bond release. Despite this caveat, true topsoil with non-rocky subsoil will be present, and will be more readily usable for production of crops of all kinds with economically viable yields.

Not all mining-related surface disturbance in these regions will be suitable for prime farmland PMLU. Areas that had lower quality soil, less topsoil, or scrubby groundcover (e.g. neglected pastures overgrown with small trees and shrubs) may be reclaimed into a land cover/use more suitable for erosion control; this approach is cheaper and faster since topsoil does not have to be as carefully isolated and crop yields are not used as the benchmark, only ground cover percentage. The landowner has the final say on what the PMLU will be, and will be a result of negotiations based on royalty rates, what the land is most suited for, and what reclamation the mining company is willing to do.

## Central Appalachian Post Mining Lands and Specific Projects

In Central Appalachia, a process known as mountaintop removal is used to remove overburden that overlies coal seams within steep hills that have a narrow ridge at the top. This overburden consists almost entirely of rock, as the steep forested hillsides do not develop a deep topsoil layer due to downslope drift over time. Much of this overburden is dumped into adjacent valleys to create a "valley fill" that resembles a series of smooth slopes and steps with rock drainage ditches on either side, while the remaining material is stockpiled and redistributed over the surface where the coal was mined. It is then usually compacted with heavy machinery to prevent excessive erosion.

Larger boulders are placed in the lower layers of the overburden, while smaller rock fragments and sediment are used to create the uppermost layer. This mine spoil is considered to be a "topsoil substitute" since there was not enough topsoil present originally for it to be harvested and stockpiled, and trucking in dozens to hundreds of hectares of topsoil or organic matter would be cost prohibitive. Despite burying the larger boulders, they are still often just a few centimeters below the surface since the total depth of redistributed overburden may only be 2 to 4 meters due to much of the original material being dumped into the valley fill. The most common PMLU in past decades has been "hay and pastureland," in which case the compacted overburden is hydroseeded with a mix of fertilizer, mulch, and grass/legume seed mix. Depending on survival and establishment of the initial application, additional hydroseeding applications may be necessary to achieve full bond release to satisfy the mining company's permit obligations.

Once the "hay and pastureland" ground cover has thoroughly established and all permit liabilities satisfied, the land may be used in whatever way the landowner sees fit. In general, these uses are (in order of commonality): (1) unmanaged perennial grasslands; (2) recreation such as hunting and/or horse or all-terrain vehicle (ATV) riding; (3) minimally managed cattle pasture (i.e. no fencing or paddock rotation); and/or (4) hay harvesting. There are nearly no examples of attempts at row cropping on these lands; however, examples include, a university research site that attempted very limited vegetable and row crop production, as well a handful of pilot projects aimed at exploring specialty crop production on mined lands (Powell River Project, n.d.). Two of those projects will be described later in the case study section of this report.

# Objective and Methods of Mapping and Characterizing Reclaimed Surface Mines for Agriculture

The following section will outline in detail the objective and methods used in this study to identify, map, and characterize reclaimed surface mines with agricultural lands in the Illinois Coal Basin.

## Objective

The guidance of this analysis was established to assess lands that had undergone surface mine operations and were subsequently put back into agricultural production within the Illinois Coal Basin. This specific region of surface coal mining was selected due to the availability of higher soil quality potential after reclamation and prospective reestablishment of row crop agricultural practices on these degraded lands. Based on clarification by the International Sustainability and Carbon Certification (ISCC) system via the CORSIA guidelines, the following objective was outlined for the analyses completed for this report. The reference date for land to be considered "unused" under the ISCC CORSIA approach, refers to the date when the yield increase measure (i.e., the first planting of the unused land) starts. This means that at the time of first implementation of the yield increase measure, "the land was not considered to be arable land or used for crop production during the five years preceding" that date. In line with CORSIA requirements, the following criteria were established for this analysis of "unused" lands in the Illinois Coal Basin:

- *Criteria 1* – Low LUC risk practices implemented on or after January 1, 2016 could be eligible.
- *Criteria 2* – Exceptionally, practices implemented between January 1, 2013 to December 31, 2015 may be accepted where it can be demonstrated that low LUC risk practices were implemented primarily as a result of demand for biofuels. This would have to be demonstrated on a project-specific basis.

Ultimately, these above-mentioned criteria would identify January 1, 2011 as the earliest possible date to fit the definition of the "five preceding years".

## Methods for Identifying and Mapping Land Cover/Use Change in the Illinois Coal Basin

To assess the changes of unused lands, as outlined in the criteria from ISCC, the identification of surface mine boundaries was the first step to begin the analysis. These data were obtained through three separate state-level online data portals provided by different government agencies: (1) Illinois State Geological Survey (2019); (2) Indiana Geographic Information Council (2020); and (3) Kentucky Mine Mapping Information System (n.d.).

Next, the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) provides a yearly remote sensing product—the Cropland Data Layer (CDL)—that specializes in mapping agricultural phenomenon across the conterminous U.S. at 30-meter pixel resolution (Broyan et al. 2011). These data sets use a combination of different multitemporal and multispectral satellite images collected from a multitude of platforms with various sensors (e.g., Landsat 5, 7, and 8, Sentinel-2, Deimos-1, UK-DMC-2, and AWiFS IRS-1). Over the course of a given year and across different geographies, these multitemporal and multispectral data are used along with hundreds-of-thousands of ground truth points from the Farm Service Agency's Common Land Unit database, along with other ancillary data from the National Elevation Data and National Land Cover Database across the conterminous U.S. to train and validate decision tree algorithms (Broyan et al. 2011). The classifier method used by USDA NASS has evolved over time from initially using a maximum likelihood classifier before 2006 to the more sophisticated techniques used today (USDA NASS 2021). Furthermore, there is also new exploration of using deep learning artificial neural networks with these CDL products (Zhang et al. 2020). In the end, the result is an annual land cover thematic classification of approximately 120 different classes of agriculture and non-agricultural phenomenon (the classification scheme can vary by year and geography) across the entire conterminous U.S. These CDL data were collected from the USDA NASS CropScape data portal for Illinois, Indiana, and Kentucky from 2011-2019 (USDA NASS 2019).

Each year of the CDL, for all three states and within the delineated surface mine boundaries, were used to identify areas that were not in agricultural production (e.g., grass/pasture, forest, etc.) prior to 2016, but transitioned back to agricultural production on or after 2016 (*Criteria 1*). It must be noted that this process was also conducted with an alternative to the effective date from 2016 for potential identification of *Criteria 2*. The alternative criteria was designed to identify lands in question that had attempted to implement agricultural practices prior to 2016 with either an unsuccessful attempt or potentially for meeting biofuel demand (the scope of this analysis was not able to ascertain if these lands were used to meet biofuel demand, but would at least provide an estimate of lands that potentially could meet *Criteria 2*).

To assess both *Criteria 1 and 2*, the CDL classifications for each year (from 2011-2019) were aggregated to a binary "Cropland" (e.g., corn, soybeans, wheat, sorghum, oats, etc.) or "Non-Cropland" (grasses, barren, forest, water, etc.) classification. The aggregation of individual cropland and non-cropland classes to more generalized land cover classes is a common practice with the CDL to potentially address misclassification issues that are present in the annual CDLs, specifically when conducting temporal analyses (Wright and Wimberly 2013; Lark et al 2015; Lark et al. 2017; Wright et al. 2017). It must be noted that this method does not eliminate the potential for misclassification in these data, especially since the CDL has well known issues of correctly classifying different grass-related land covers (Kline et al. 2013; Lark et. al. 2017; Sandler and Rashford 2018; USDA NASS 2021). However, for this study, *Criteria 1* required the land cover to be in a "Non-Cropland" status for all years prior to the 2016 growing season. This requirement gave this method a higher confidence since pixels that displayed any back and forth nature between "Cropland" and "Non-Cropland" were not determined to meet *Criteria 1* for this analysis. *Criteria 2* did allow for there to a transition between both aggregated classes prior to 2016 and could potentially have a slightly lower confidence in the output, but could also represent real attempts at agricultural practices instead of potential misclassification. With that said, the binary "Cropland / Non-Cropland" classification within the mined areas were analyzed for temporal change that met the above outlined criteria. This portion of the analysis was completed at the Illinois Coal Basin level and generated an area estimate that met both the criteria within the basin. Moreover, this analysis was also used to identify potential field level changes, but needed to be refined with ancillary data inputs for more reliable field level assessment and verification of true land cover/use change that met the outlined criteria of this study.

## Methods for Characterization Land Cover/Use Change in the Illinois Coal Basin

Once the entire basin was classified for identification of reclaimed change areas that met the criteria, specific field-level locations were investigated. These change areas were further assessed with aerial and satellite-based imagery for change confirmation and area calculation. Once these change areas were verified and properly delineated in detail, other key variables were mapped/generated at the field level, parcel level, and for the overall mined area. These variables included: (1) soil productivity; (2) temporal land use change from 2015-2019 by category (grass/pasture, corn, soybeans, forest, water, and other); (3) temporal vegetation index assessment of the change area and surrounding areas for biomass/overall crop health comparisons; (4) when available, landowner information and valuation of the land in the change area; and (5) if applicable, the level of any bonding status pending on a verified change area.

## Results from the Illinois Coal Basin Analysis

The following section will present and discuss the results from the Illinois Coal Basin analysis. This will include an overall assessment of potential lands identified and mapped throughout the basin, specific field level analyses, and an interview with an Indiana grower that farms row crops on over 800 hectares of reclaimed surface mine lands.

### General Illinois Basin Assessment

The total area of surface mines in the Illinois Basin (which includes Illinois, Indiana, and Kentucky) is approximately 250,000 hectares (Figure 3). This estimate is conservative because:

- Surface affected areas from subsurface mining are yet to be obtained in Illinois (or any of the other states). These areas have been delineated by the Illinois State Geological Survey and will be soon be added to the digital mine boundary archive.
- Approximately 1/3 of the Indiana surface mine boundaries are yet to be obtained (as of the writing of this report). These areas have been delineated by the Indiana Geographic Information Council and will be soon be added to the digital mine boundary archive.
- Kentucky's mine database has attribute information that still needs clarification.

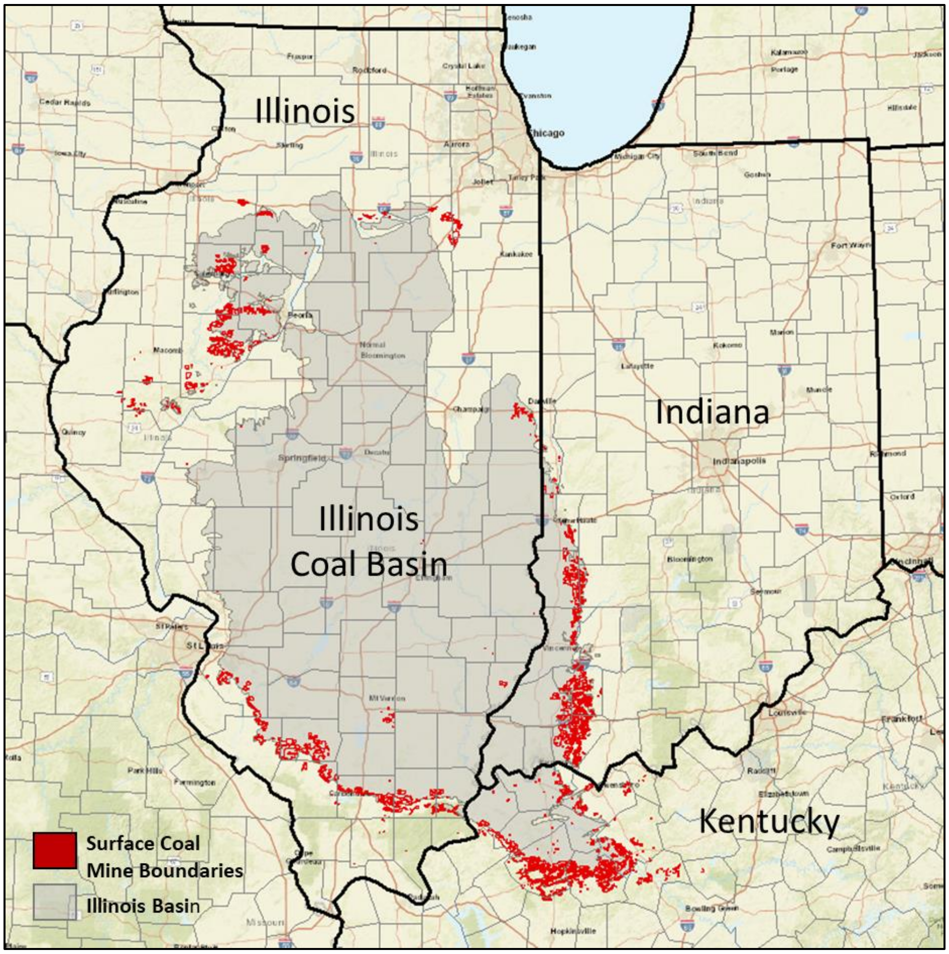


**Figure 3**: Map of Illinois Coal Basin and Surface Mine Boundaries.

The results from the Illinois Basin analysis are presented below and in Figure 4; the range in the bulleted numbers below are due to the different criteria methods outlined in the previous section (Figure 4 represents the hectares based on *Criteria 1*):

- 203,000 to 210,000 ha of reclaimed surface mine lands (or currently in surface mining operations) that have never been in agricultural production between 2011-2019.
- Between 1,000 to 7,000 ha were agricultural lands prior to 2016, but reverted to non-agricultural lands sometime after this date.
- 4,000 to 9,000 ha were not in agricultural production prior to 2016, but moved into agricultural production sometime after this date.
- Between 28,000 to 32,000 ha were in agricultural production between 2011-2019.

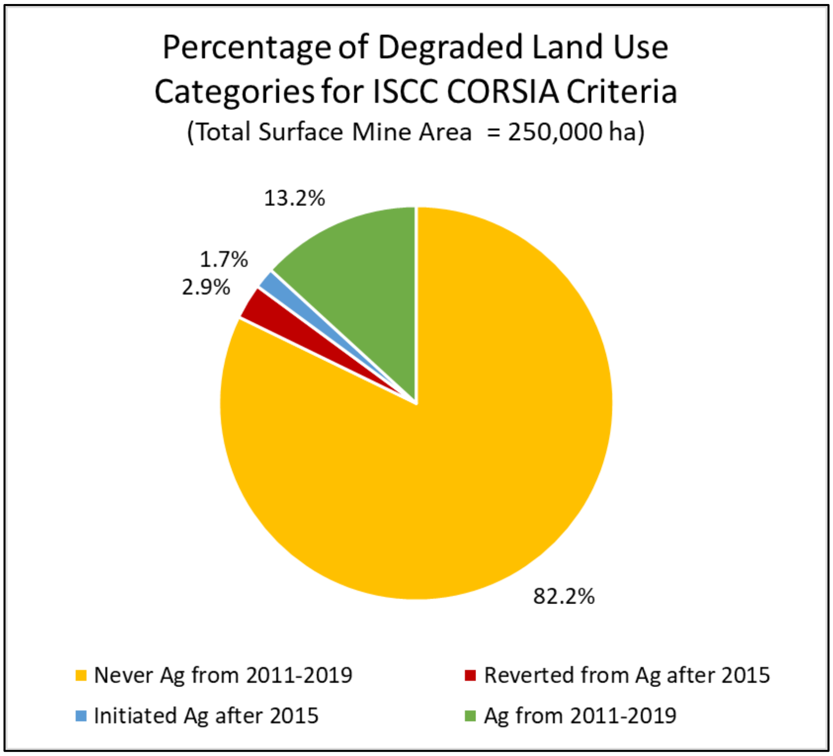



**Figure 4**: Distribution of degraded land use proportions for the Illinois Coal Basin.

The above basin-level analysis indicates that there is a significant amount of lands (over 200,000 ha or 82 percent) that could potentially be moved from a degraded or unused state into agricultural production. Currently, under *Criteria 1 and 2*, up to 9,000 ha (or 1.7 percent) of degraded or unused lands would possibly meet the guidelines established by the ISCC CORSIA approach. Lastly, the analysis above indicates that there has been significant hectarage (approximately 30,000 ha) that have been in production for the past decade, along with the 9,000 ha that have moved into agricultural production in the last five years.

## Mine-Level and Field-Level Analysis and Characterization

The following subsection will be subdivided into three parts: (1) characterization at the mine-level; (2) characterization at the field-level; and (3) temporal vegetation health assessment of crops on reclaimed mine lands.

### Mined-Level Assessment

As described in the methods section, each CDL layer for 2011-2019 was analyzed to identify areas of land change within a given surface mine boundary. The model below (Figure 5) illustrates the graphical representation of this process to map the movement of degraded land back into agricultural production (i.e., land that met the criteria established by ISCC CORSIA). Specifically, the image at the bottom-center of the graphic shows the areas in yellow that established agricultural practices after 2015. The annual CDLs show (along the top row) change areas were primarily classified as grasses prior to 2016, but moved into corn and soybeans after the 2015 growing season. This reclaimed surface mine lands change was approximately 160 ha of reestablished agriculture in the Abandoned Mine Lands (AML) Mine Index 621.


**Figure 5**: Identification of agricultural change areas within AML Index 621 in Knox County, Illinois.

To confirm this assessment from the 30-meter CDL data sets, 1-meter high resolution imagery (true color and color-infrared) was used for visual verification. The images in Figure 6 show an enlarged example of the southernmost field (approximately 27 ha) within the mined area (AML 621) that was grass in 2012 and 2015, but had moved into agricultural production by at least 2019.

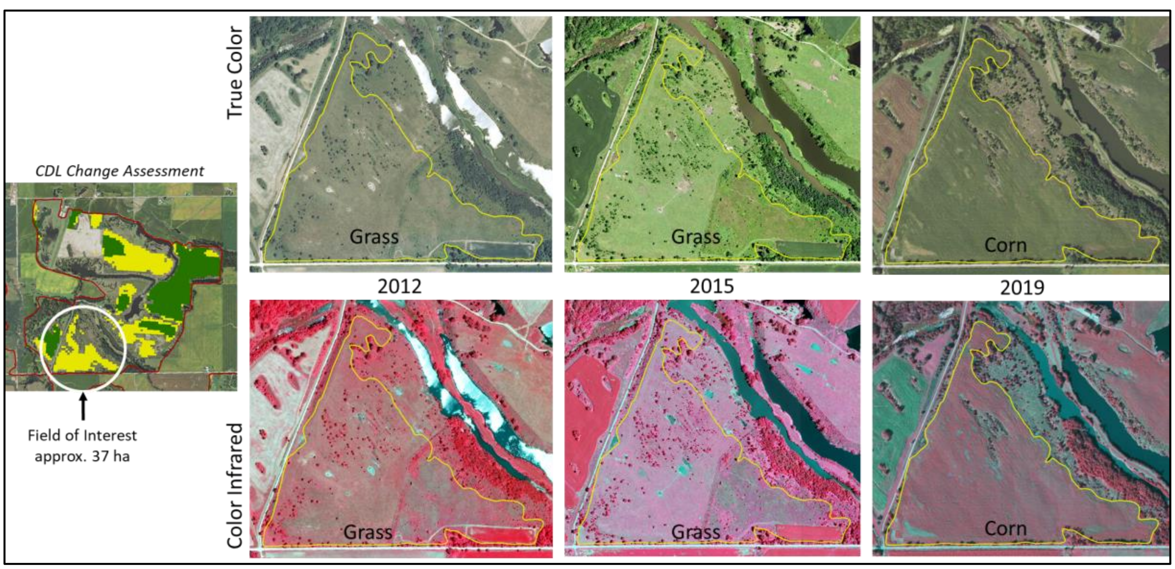



**Figure 6**: Use of aerial imagery for verification of land use change to agricultural production.

Further analysis of the reclaimed surface mine area's pre-mining soils revealed that the historic productivity of these soils was below the state and county average (Figure 7). However, the areas that moved back into agricultural production were on the better soils within the reclaimed surface mined area.

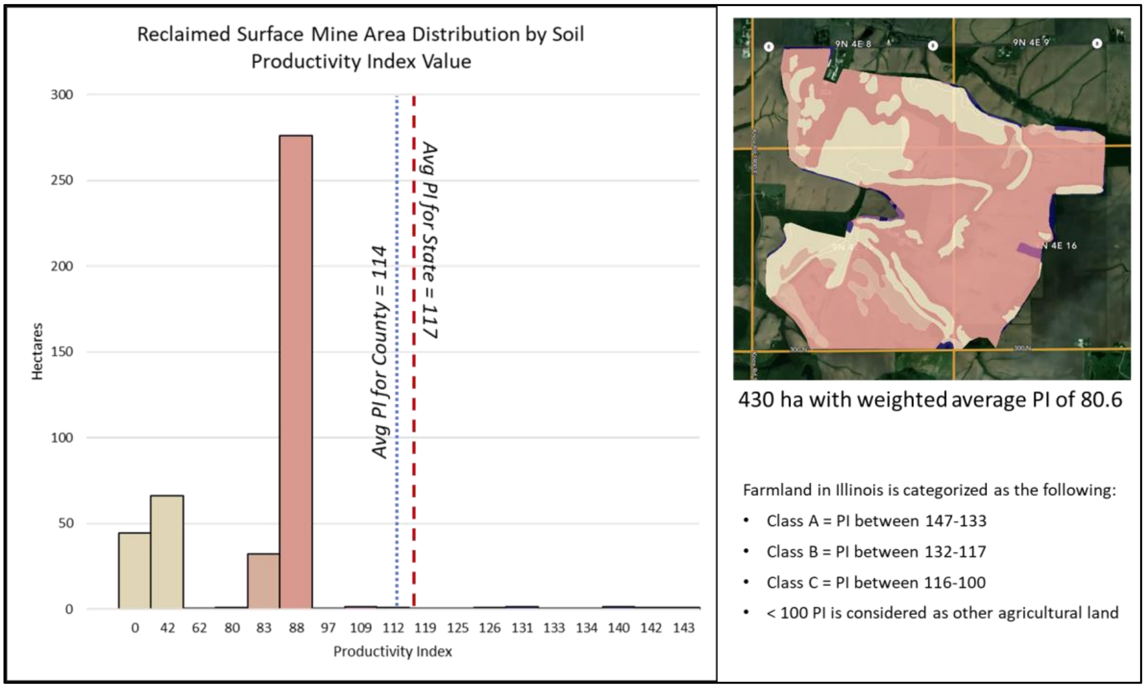
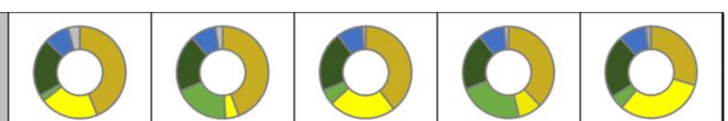



**Figure 7**: Soil productivity index and map for AML 621 (USDA NRCS 2020).

Assessment of the surface mined area in AML 621, with the CDL generalized into six categories, resulted in the following temporal land use proportions within the 430-ha area (Figure 8):

- Grass/Pasture declined by almost 15 percent from 2015-2019.
- Agriculture increased by almost 15 percent from 2015-2019.
- All other land uses stayed virtually the same from 2015-2019.

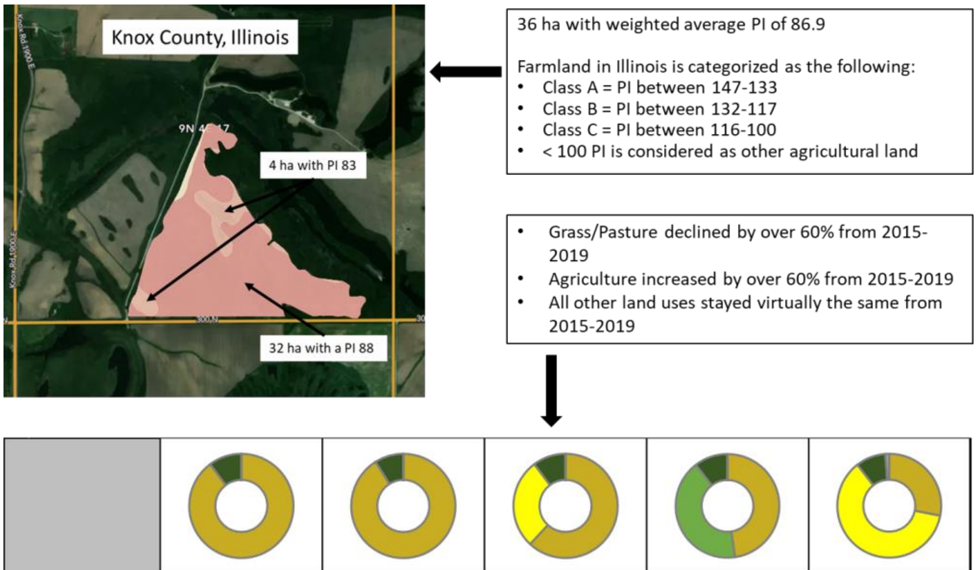


| | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| Grass/Pasture | 43.8% | 44.3% | 39.6% | 37.9% | 29.6% |
| Corn | 20.7% | 4.8% | 23.7% | 8.3% | 31.5% |
| Soybeans | 2.1% | 19.4% | 5.4% | 22.8% | 5.0% |
| Forest | 20.4% | 20.0% | 21.1% | 20.1% | 22.2% |
| Water | 8.9% | 9.0% | 9.1% | 9.3% | 9.7% |
| Other | 4.1% | 2.6% | 1.2% | 1.5% | 2.0% |

**Figure 8**: CDL derived temporal land use proportions for AML 621.

## Field-Level Assessment

While the above characterization and analysis was completed at the full surface mine level, this analysis was also conducted at the field-level. The following is an example of the southernmost field (within AML 621) that shows soil productivity index and temporal land use proportions between 2015-2019 (Figure 9).




| | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| Grass/Pasture | 89.9% | 91.1% | 61.9% | 47.7% | 28.1% |
| Corn | – | – | 27.9% | – | 61.4% |
| Soybeans | – | – | – | 41.9% | – |
| Forest | 10.2% | 8.9% | 10.2% | 10.4% | 9.3% |
| Water | – | – | – | – | – |
| Other | – | – | – | – | 1.2% |

**Figure 9**: Field-level assessment of soil productivity index (USDA NRCS 2020) and land use proportions.

## Temporal Vegetation (Crop) Health Assessment

It would be ideal if yield data for a given field on reclaimed surface mined lands could be provided by the grower. However, relying on grower records and varies methods of yield estimation, these data may not always be available or dependable. With this in mind, there are other methods of determining plant vigor and health (often correlated to crop yield) that can be employed for assessing how well cropland is adjusting to conditions on reclaimed mine lands. One example is the use of satellite imagery to compute various vegetation indices, many of which relate directly to vegetation yield (Weigand et al. 1991; Richardson et al. 1992; Shanahan et al. 2001; Chang et al. 2003; Pritsolas 2018). One of the most notable of these vegetation indices is the Normalized Difference Vegetation Index (NDVI), which was used in this study. The NDVI utilizes a biomass band (Near-Infrared) and a chlorophyll band (Red) to compute a value that correlates highly with crop yield when assessed across a growing season. NDVI has an effective range for vegetation from 0 to 1, where 0 = bare soil and 1 = most vigorously growing (or healthy) vegetation.

The temporal sequence of images in Figure 10 are a subset example of NDVIs calculated with radiometrically calibrated Sentinel-2 data, which enables temporal comparisons. Typical NDVI values for the healthiest soybeans can reach 0.9-0.92, while corn mostly reaches values between 0.85-0.87.

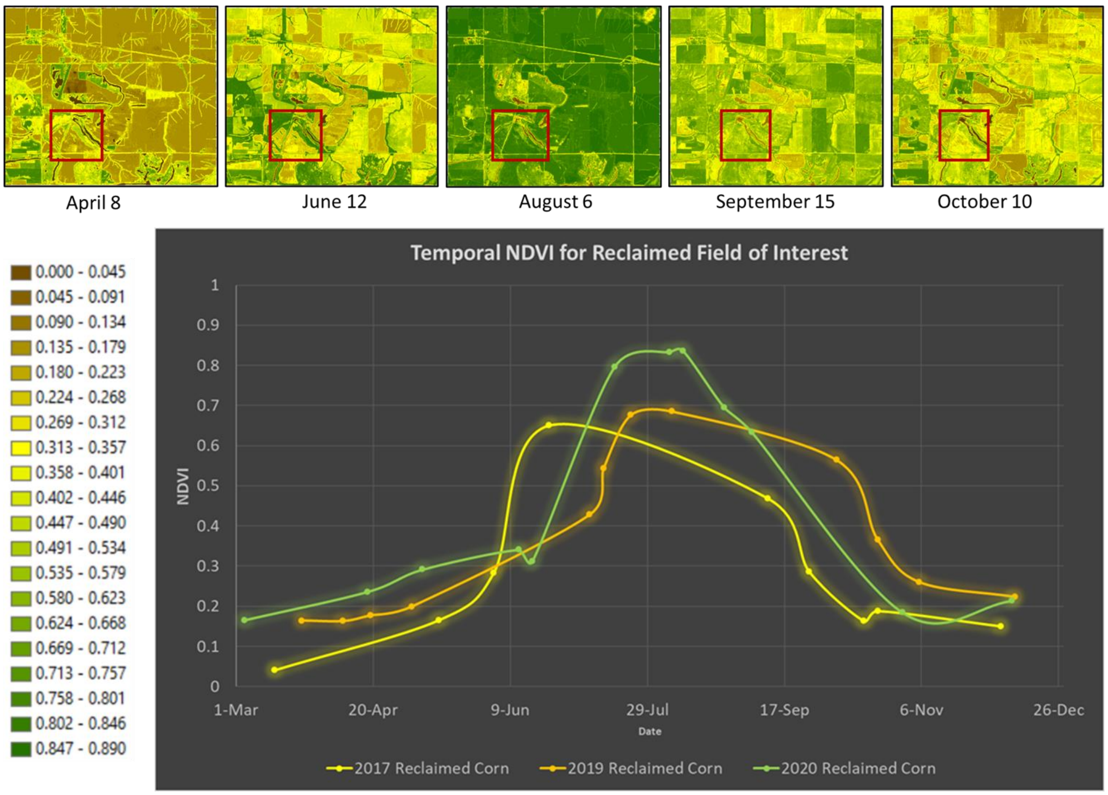



**Figure 10**: NDVI temporal curves of corn grown on reclaimed surface mine for 2017, 2019, and 2020.

The graph in Figure 10 shows temporal NDVI curves for corn grown on the reclaimed mine area within the red rectangle highlighted in the temporal NDVI image sequence. In 2017, the peak NDVI was 0.67, while in 2019 it increased to 0.69. By 2020, the corn NDVI peaked at 0.83. This shows a gradual increase in plant biomass/health and potential increases in field nutrient quality.

The graphs on the right in Figure 11 show a comparison of the temporal NDVI curves for corn over three different fields for 2017, 2019, and 2020. The yellow curve indicates the temporal vegetative health of the corn grown on the reclaimed land vs. the blue and white curves that depict corn grown on surrounding non-mined lands. In 2017 and 2019 there is a significant difference in the peak and sustained NDVI values between the reclaimed corn and surrounding area corn. However, by 2020 this difference is negligible, indicating a potential revitalization of soil nutrients and biota needed for successful agricultural production.

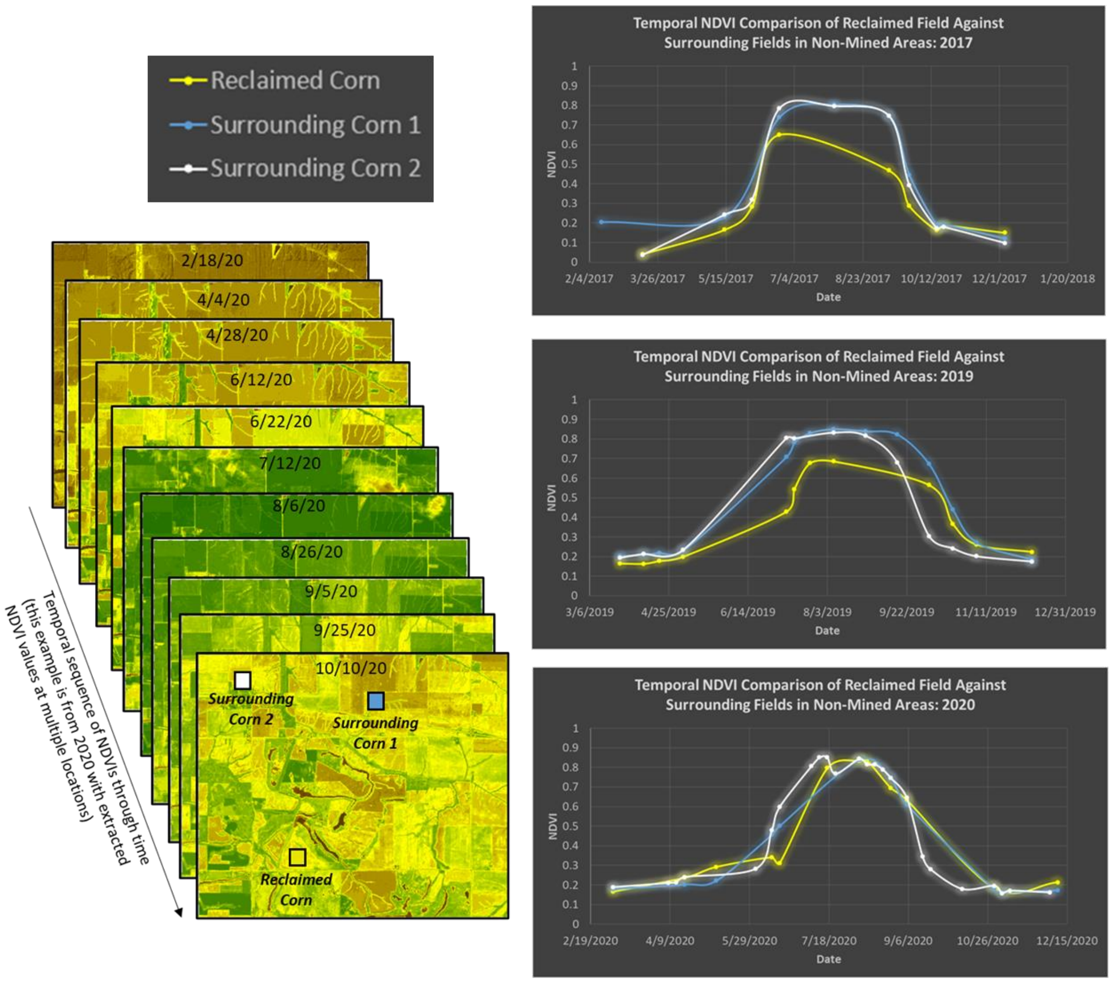



**Figure 11**: Seasonal NDVI comparisons between corn on reclaimed mine lands vs. corn on non-mined lands from 2017, 2019, and 2020. As mentioned above, NDVI has a potential to be a valuable surrogate for yield data.

# Interviews

## Interview with Indiana Grower Farming on Reclaimed Surface Mines

Below are the specifics regarding the grower from Vigo and Sullivan County, Indiana that was interviewed on Feb 25, 2021. Two maps are included that show the ownership parcels (Figure 12 Map A.) and the areas of agricultural practices within the Hymera Coal Seam surface mine (Figure 12 Map B.).

- Grower name: Denny Jarvis (Farmer Jack Land Company, LLC)
- Identified approximately 125 parcels intersecting the mined area from the Hymera Coal Seam that are owned by Farmer Jack Land Co (represented by Map A).
- Total mine area = 1,640 ha (represented by red boundary in Map B)
  - Total continuous ag from 2011-2019 = 665 ha
  - Total post-2015 ag = 320 ha
- Grower interviewed on 2/25/2021

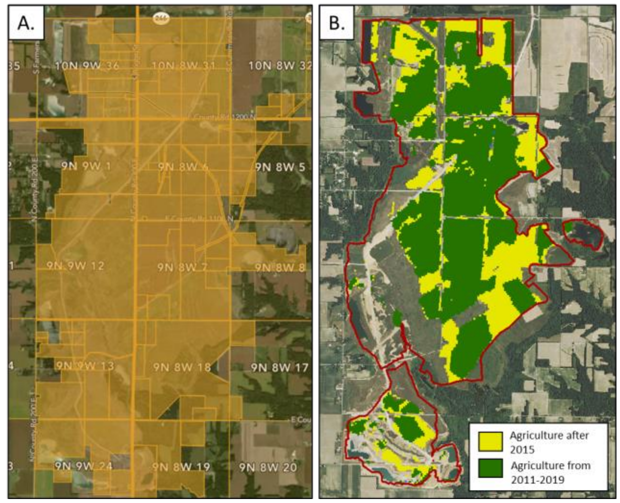



**Figure 12**: Description of Denny Jarvis' agricultural operation on reclaimed surface mine lands and the associated parcel boundaries (Map A.) and agricultural change areas (Map B.).

The following are the highlights of the personal communication between Nathan Hall of SCS and Denny Jarvis the grower from Terre Haute, Indiana:

The interviewed grower farms about 1,175 hectares total, 800 ha reclaimed, 160 ha marginal/low quality on reclaimed lands. Even on land that underwent high quality reclamation, there is often a yield reduction of up to 20 percent when compared to unmined cropland. Last year, the interviewed grower had about 444 bushel/hectare on reclaim, 497-543 bu/ha non-reclaimed in corn. Likewise, he had 99 bu/ha soybeans on reclaimed lands vs. 136-173 bu/ha on unmined cropland. The reclaimed lands were released from bond 20 years ago. On more recently reclaimed ground the interviewed Grower had 50-74 bu/ha soybeans last year on land that was reclaimed 7-8 years ago. He reiterated that yield estimates from growers farming on reclaimed lands may not be reliable, specifically when attempting to clear the bond release phases (especially on the 0.4-hectare test plots).

The majority of reclaimed lands that the grower knows of are in row crops (not hay). The grower suggested that Milo (grain sorghum) initially does better on reclaimed farmland than other crops, in his experience. Without crop insurance, there is little to no incentive for a grower to take on the risk of attempting to establish a significant footprint of production agriculture on reclaimed lands. The interviewee stressed that reclaimed lands typically have less infiltration with higher amounts of runoff. This is often due to the disruption of the soil structure and lack of organic matter, both of which reduce soil water retention causing the soils to dry out quickly. This is one of the main reasons for crop yield decreases, especially in drier years. In some cases, tile drainage and/or irrigation systems may be of value, but with current commodity prices these processes may be cost prohibitive. The grower uses cover crops extensively (approximately 400 ha/year), which are mostly seed by aircraft. The interviewee mentioned the possibility of increasing soil organic matter and soil structure with the addition of turkey and chicken litter (both are readily available at $35/ton near Denny's location).

Mining companies are motivated to get bond release as soon as possible and most mining companies aim for a 5-year minimum on full bond release. They get 30 percent once it's back to grade (Phase I), some vegetative growth gets an additional 35 percent back (Phase II), and they get the remainder when yield thresholds are achieved (Phase III). The grower said that typically about 30 cm of topsoil are removed and stockpiled, then keep good and bad quality subsoils separated. Each of these layers are put back in order after mining operations are completed. Stockpiling topsoil degrades the soil biology, causing the soil to go "stale," and it becomes much less productive after distributed back onto surface due to loss of structure and microbes.

The grower stated that having additional markets for crops such as CORSIA/RED-II could encourage reclaimed lands currently in grasses/erosion control to be used for sustainable biofuel crop production, and could also encourage more intensive soil building practices (manure applications, more intensive cover cropping, no-till or reduced tillage, etc.).

## Interview with Grower from Appalachia

### Fiber Hemp on Reclaimed Mountaintop Mined Land in Eastern Kentucky

In 2015 and 2016, the author took part in an informal trial to assess the viability of growing fiber hemp with typical small/medium scale farming equipment on a piece of reclaimed land very much like that described above (former mountaintop surface coal mine with "hay and pasture" PMLU, minimally managed cattle pasture prior to hemp trial) near Ivel, Kentucky. This work was carried out with a very limited budget and no direct university affiliation during the early years of Kentucky's hemp pilot program, one of the first states in the US to legalize hemp production after 8 decades of being outlawed due to its relation to marijuana. Though useful yield data was not captured due to lack of resources and lack of market, the process and learnings will be detailed below.

The roughly 200-hectare mountaintop removal coal mine site used for the project was mined and reclaimed from the early 1990s until the mid-2000s. The hemp trials were carried out on two separate 0.8 hectare sections: one in which reclamation had completed in 1995 and organic matter from perennial grasses and cattle manure had just started to rebuild a surface humus layer ("old reclaim," or OR), and the other completed in 2007 with very little organic matter present ("new reclaim," or NR).

In 2015, the only equipment available was a 50hp 2wd tractor, rotary brush mower, disc harrow, broadcast spreader, manure spreader, and no-till seeder, all borrowed. The 1.6 total hectares were broken down into eight 0.2-hectare plots, and the treatments were replicated across the OR and NR areas. Treatments compared use of synthetic glyphosate herbicide on pasture grasses prior to tillage and synthetic NPK pre-planting fertilizer versus purely mechanical vegetation removal (mowing and more extensive discing), fertilizing with a mix of municipal biosolids and biochar, as well as comparing drill seeding with broadcast seeding followed by light discing to incorporate. None of the plots were irrigated.

Across all plots, the primary challenge was the extremely compacted, rocky nature of the growing medium. This was expected and anticipated, but despite breaking an entire section of the disc from the frame and rewelding at a crucial time, ground prep and planting were completed to a sufficient degree in the appropriate time window. The summer of 2015 was very rainy, which was very beneficial since the rocky mine spoil has very poor moisture retention. Drill seeded plots had much higher germination and survival than broadcast seeded, and the biosolids/biochar/mechanical cultivation plots outperformed the conventional herbicide and fertilizer plots.

However, none of the plots produced commercially viable yields or mechanically harvestable stands, as germination and growth were uneven and patchy even on the best plots. This was most directly caused by irregular seed to soil contact as a result of the rough, rocky, uneven surface present across all plots. Like many row or field crops, hemp prefers to be seeded about 0.6 cm deep into a soft, level, loamy seedbed with adequate moisture. The surface present across all of the mined land plots was both (1) too rocky on the surface which prevented uniform seed to soil contact and planting depth, and (2) too compacted which prevented deep root penetration. The result was patchy stands that did not meet minimum harvestability levels even in the best cases.

In 2016, a similar set of trials was devised on these same plots, but in this case a ripper attachment was used on some of the plots to break up the ground prior to discing. This alleviated the compaction issue, but exacerbated the problem of an uneven surface by bringing up many more rocks than had present initially which could not be smoothed out even with repeated discing. It bears repeating that Appalachian surface mined lands do not have a lot of rocks in the ground; the ground is quite literally nothing but rocks with some fine sediment on the surface. The summer weather was almost inverse to 2015, with a strong heatwave drought affecting large parts of the U.S. Since the plots were not irrigated and the rocky mine spoil has very poor moisture retention, the yields were even poorer than in 2015 and no harvesting was attempted. Thus concluded the strip mine hemp trials, as it was determined that hemp is simply not tenacious and resilient enough of a crop to be viably grown on landscapes as harsh those present on Appalachian mined lands without significant investment in ground prep and irrigation.

### Reforestation of Appalachian Mined Lands

The rocky spoil of Appalachian mined lands is quite suitable for tree growth if the compaction is mitigated or never created in the first place. Some mining companies choose "reforestation" as their PMLU, in which case the top 1.5 to 2 meters of overburden is loosely dumped with one or two passes of heavy machinery to stabilize it without over compacting. Tree seedlings are hand planted into the rocky ground at roughly 1,500 stems per hectare along with a hydroseeded non-competitive ground cover. The total cost to the mining company is generally higher than other options due to much higher labor and seedling costs vs equipment costs incurred in more typical reclamation such as "hay and pastureland," so it is less commonly chosen despite the higher suitability of the land for this PMLU.

In some cases, post-bond release lands are reforested through an environmental restoration NGO known as Green Forests Work. This group uses grant funding to convert surface mined lands reclaimed to non-native pasture grasses into native mixed hardwood forests. The most important (and expensive) step in this process is the "deep ripping" of the compacted rocky surface by pulling 1 to 1.5 meter long, 5 cm thick ripper shanks through the ground behind a large bulldozer. This causes boulders, rocks, and sediment to all be churned up into a very rough surface that is quite difficult to traverse but which is well-suited to tree growth. Large groups of volunteer tree planters (school groups, environmental clubs, etc.) are then directed in the hand planting of the tree seedlings, with some sites requiring the use of professional tree planting contractors.

### Conversion of Appalachian Mine Spoil into Medium Suitable for Row Crops

Only one known attempt has been made to demonstrate the conversion of Appalachian reclaimed surface mine ground into a tillable soil substitute free of large boulders and rocks at scale. About 7 hectares of a mountaintop removal site (mined and reclaimed to "hay and pastureland" PMLU in the mid-2000s) was addressed with a Seppi Supersoil PTO-driven stone crusher implement attached to a 330hp Deutz-Fahr farm tractor. No implements of this type were available in the eastern US, and the Seppi unit had to be shipped directly from Italy. Tractors of this size are also very uncommon in Appalachia since it is not an agricultural region, necessitating the delivery of a rented tractor from over 320 km away.

A shallow ripping preparatory step was carried out with a Seppi multi-tine farm ripper, which is far less intensive than the bulldozer deep ripping used for reforestation. This broke up the top 30 cm of rocky material so that the stone crusher could operate at a 25 cm working depth. The ripper did not work perfectly however, as the rubber tired tractor often did not have enough traction to pull through especially compacted areas and the shanks would have to be lifted, leaving compaction that put more strain and wear on the stone crusher. A tracked machine such as a medium sized bulldozer would have been more ideal, though it was fairly effective and managed to dislodge and surface many rocks up to 70 cm diameter.

The stone crusher was quite effective in grinding the top 25 cm of material (including solid sandstone rock up to 70 cm in diameter) into soil-like particles, ranging from 0.1 mm to 10 cm in size. One of the primary goals in this experiment was to ascertain an approximate cost per hectare of converting land in this way, which came out to roughly € 4,000/ha. This cost incorporated measured fuel usage, replacement of carbide teeth, depreciated cost of equipment over an estimated 80 hectares per year, and hourly operator labor. Additional costs for cover crop seeding, organic matter application, and/or fertilizer would be incurred in order to produce a viable row crop harvest, which were beyond the scope of this demonstration. The project was not able to move forward due to the difficulty in finding reclaimed mined land for sale at a low enough cost (or long term lease) that could justify the high initial cost for land preparation, but the learnings could be applied to future projects in which Appalachian reclaimed land is desirable.

## Conclusion

This study laid the framework for assessing the potential of agricultural production on reclaimed surface mine lands. Based on the methods outlined in this project, accurate mapping of the ISCC CORSIA criteria has proven to be quite feasible. With this in mind, our nationwide analysis indicated that each year since 2016, an average of 16,000 - 17,000 hectares would meet the CORSIA unused land definition. However, a more realistic area for actual fuel feedstock production was identified as the Illinois Coal Basin due to the high level of historic agricultural productivity in that region, along with the extensive amount of surface mines. Using our mapping methods within the Illinois Coal Basin, we identified 4,000 - 9,000 hectares (in production since 2016) that would meet the CORSIA unused land definition.

It should be noted that this approximate 4,000 - 9,000 ha only accounts for about 1.7 percent of the total mined area in the Illinois Coal Basin, while there is still approximately 80 percent (200,000 - 210,000 ha) that has been or is in the process of being reclaimed. Although this potential hectarage has a multitude of different land covers (e.g., forest, grasses, water, etc.), there appears to be a steady movement of reclaimed mine lands back into agricultural production.

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