Potential of LFH Mineral Soil Mixes for Reclamation of Forested Lands in Alberta

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REPORT SUMMARY

LFH salvaged with small amounts of upper horizon mineral soil for land reclamation (hereafter LFH mineral soil mix) has proven to be an important source of seeds and vegetative propagules for forest plant communities. Until recently in Canada, LFH mineral soil mix was not selectively salvaged from upland forest sites prior to disturbance and was mainly incorporated with deeper mineral soil horizons or subsoil as part of conventional salvage and placement practices. The Alberta government is beginning to require oil sands and mountain and foothills coal mines to salvage and store this material separately from underlying mineral soil and subsoil for use in reclamation. The potential of LFH as a source of native propagules for revegetation of disturbed landscapes and a source of organic matter and nutrients in soil reclamation has not been widely tested. This report summarizes available literature on potential use of LFH material in Alberta and provides an analysis of the current state of knowledge and future directions.

Although donor soil seed banks have been successfully used as a revegetation technique on mine sites and land disturbances in other ecosystems for some time, only recently has research been conducted using forest LFH for mine revegetation in Alberta. Most of this research has been conducted on a small scale with few operational scale studies and a rigorous experimental approach is often lacking. Currently there are only a few peer reviewed publications on the use of LFH as a propagule source or reclamation soil in Canada.

Recent research shows LFH mineral soil mix is a good source of propagules for native and woody species that are not readily available commercially or by wild collection. Most plants in LFH mineral soil mix establish from seed and resultant communities have greater plant cover, more upland species and fewer non-native species than with traditional peat mineral soil mix used in oil sands mines. Stockpiling before placement reduces seed viability and species diversity, thus direct placement is recommended although stockpiling still results in more diverse and abundant plant communities than peat mineral soil mix. Placement depth has greater effect on plant community development than salvage depth. Thresholds for salvage and placement have not been determined and are dependent on donor soil texture, ecosite, topography, forest type and substrate placed on.

Besides using LFH mineral soil mix to revegetate disturbed landscapes, it can be used to improve soil quality. Compared to conventional peat mineral soil mixes in the oil sands, LFH mineral soil mix has a texture and pH more similar to natural forest and provides greater available phosphorus and potassium. Soil microbial activity and diversity is also greater which may lead to a more productive and resilient plant community in the long term.

Recent research on LFH mineral soil mix for forest reclamation has led to development of regulatory requirements. Short term research results (< 10 years) clearly show benefits of LFH mineral soil mix for reclamation. However, whether short term effects will persist with time and lead to a more natural, diverse and sustainable plant community than conventional reclamation techniques is unknown. Enhanced soil properties and native regeneration strongly suggest reclaimed communities are on a trajectory towards the structure and function of self-sustaining

natural forest. By researching a few key operational and ecological questions, benefits of LFH mineral soil mix can be maximized and ongoing reclamation costs reduced.

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1 INTRODUCTION

Reclamation is the process by which disturbed land is returned to its former or other productive uses. Reclamation is required by provincial legislation in Alberta and carried out by a diversity of industries including oil sands and coal mining. Some of the greatest challenges to reclamation in these industries are due to the scale and intensity of disturbances. Alberta oil sands are the third largest proven reserve of oil in the world and provide half of Canada's crude oil production (Government of Alberta 2012). Alberta is the largest coal producer in Canada, with 48% of its land underlain by coal bearing formations, comprising 70% of the country's reserves (Alberta Environment 2012). Reclamation of these disturbances will enable Albertans, now and in the future, to benefit not only from an abundance of natural resources but also from productive post-reclamation landscapes.

The overall goal of land reclamation in the forested regions of Alberta, where oil sands and coal mining are prevalent, is to reclaim the land so that it is capable of supporting self-sustaining locally common forest ecosystems (Alberta Environment 2011a, b, c). This land reclamation goal is usually accomplished by attempting "to steward to ecosite phases" (Alberta Environment and Water 2012). Ecosite phases are groupings of forest ecosystems with similar inherent soil water regimes, nutrient properties and associated vegetation cover; thus this ecosite phase level is "quite specific and results in a unique context for each reclamation area" (Alberta Environment and Water 2012).

Reclamation generally consists of six main phases: pre-disturbance data collection and tree clearing, salvage and storage of reclamation material for use in current or future reclamation, recontouring disturbed land, placing reclamation material, revegetation, and monitoring and maintenance. Historical soil salvage and replacement practices involved unselective salvaging of soil material from upland and lowland communities. For oil sands mines this involved use of peat and peat mineral soil mixes, as these materials were plentiful and were thought to provide appropriate growing conditions for desired vegetation. The value of surface soil (LFH and A horizons) as a key source of organic matter and nutrients for mine reclamation has long been recognized (Depuit 1984, Fedkenheuer et al. 1985, Johnson and Bradshaw 1979). While organic amendments may provide some of the properties of surface soils they cannot provide the exact properties of local site specific soils (Land Resources Network Ltd. 1993). Benefits of salvaging and storing topsoil separately for use as a coversoil in mine reclamation have been reported in other regions (Farmer et al. 1982, Fresquez and Lindemann 1982, Hall et al. 2010, Lindemann et al. 1989, Nichols and Michaelson 1986, Potter et al. 1988). This approach, however, has only recently been tested in the forested areas of Alberta where much large scale mining occurs.

Initial research in the Athabasca oil sands documented the benefits of LFH mineral soil mix use in reclamation to upland forest including its potential to more readily re-establish native plant communities relative to conventional reclamation materials (e.g., Lanoue and Qualizza 2000, Mackenzie 2006). Based on these preliminary findings, Alberta Environment and Alberta Sustainable Resource Development attended three Energy Resources Conservation Board hearings for oil sands mines in 2006 and recommended that industry be required to use LFH materials for reclamation. The Alberta government was concerned there was a risk that the conservation and reclamation practices at the time might not meet all end land use objectives and requested the Energy Resources Conservation Board support inclusion of specific improvements in future approvals (see, for example, Alberta Energy and Utilities Board 2006). The government requested prioritizing salvage of LFH and upper mineral soil horizons for reclamation rather than using peat mineral soil mixes, salvaging all LFH and upper mineral soil horizons unless not feasible, placing priority on good over fair categorized subsoils, and increasing minimum and average depth of peat mineral soil mixes to be used. Justification for the request was that using LFH mineral soil mixes, rather than constructed soils based on wetland soils such as peat mineral soil mixes, would provide a better environmental outcome after reclamation of upland areas. This approach would be consistent with soil salvage and replacement approaches on most Alberta industrial sites. Peat mineral soil mixes would continue to be required where LFH mineral soil mix volumes are insufficient to reclaim all disturbed lands.

In the recent document *Best Management Practices for Conservation of Reclamation Materials in the Mineable Oil Sands Region of Alberta*, upland surface soil (the regulatory term for LFH mineral soil mix) is described as “the most valuable reclamation material available for use as coversoil” (Alberta Environment and Water 2012). Its value is associated with provision of an “important and unique source of organic matter, plant nutrients and woody debris”. If directly placed it is also expected to provide seeds, plant propagules and soil biota. Since it developed under and has supported boreal forest prior to disturbance, its use as a cover soil in upland reclamation was considered low risk. With a considerably larger area of wetland versus upland being disturbed, most of the post-disturbance landscape will be reclaimed using peat mineral soil mix as cover soil. Thus salvage of upland surface soil, wherever possible, on the pre-disturbance landscape could maximize the volume available for reclamation. Upland communities are less common on the pre-disturbance landscape and therefore their re-establishment following mining should be a priority to ensure successful landscape function.

The Alberta government has requested mountain and foothills coal mine companies to undertake a similar salvage and replacement approach and move away from the past practice of mixing LFH, upper mineral horizons and some subsoil horizons during soil salvage. This practice of salvaging and separating topsoil horizons from subsoil to preserve and maintain quality reclamation material has been implemented by plains coal mines for some time. Hence the importance of better understanding effects of LFH mineral soil mix on mountain and foothills coal mine reclamation.

LFH mineral soil mix has two key properties that may result in different reclamation outcomes. Salvaged soils can provide desired native plant propagules, including trees and shrubs; and physical, chemical and biological properties of soil materials may improve soil quality on the reclaimed landscape. There is no long term documentation of what successful reclamation with LFH mineral soil mix would look like on a large scale, what the long term environmental outcome will be, and how this is better than success achieved with conventional mine reclamation practices. Hypothetically, LFH mineral soil mix should provide a more sustainable cover soil for upland forest reclamation than alternatives because of its desirable physical, chemical and biological properties that are more suited for reclaiming upland landscapes. Directly placing LFH mineral soil mix transfers propagules of species adapted to local climates and disturbance regimes. Newly established species from in situ propagules in LFH mineral soil mix would add to existing propagule banks, creating a forest community resilient to future disturbance[1]. Alberta Environment (2010a) refers to evidence of effectiveness of LFH mineral soil mix such as increased abundance and diversity of upland plant communities including woody stem counts and establishment of most herbaceous species found at the soil donor site. Clearly defined success criteria would provide for clearer comparisons of reclamation practices based on LFH mineral soil mix versus conventional methods.

The longevity of benefits provided by use of LFH mineral soil mix in reclamation are unknown, and some in academia, industry and government question whether there is an economical or environmentally sound basis for its implementation. Hypothetically this should not be a concern for direct placed LFH mineral soil mix as the seed bank or propagule bank is mostly conserved, creating a resilient cover soil for long term benefits. However, long term research with its supporting empirical data, including forest resilience to future disturbance, would be required to dispute the demonstrated benefits of using LFH mineral soil mix to reclaim to local forest ecosystems. Certainly there are assumptions, speculations and predictions around the use of LFH mineral soil mix as a soil reclamation material. Most research to date has been conducted using LFH mineral soil mixes developed in the oil sands region. The longevity of effects has not been determined. There is little research to indicate what could be expected with LFH mineral soil mix if handled under various conditions. Thus this review and analysis were undertaken to determine what is known about using LFH mineral soil mix in land reclamation practices, what knowledge gaps exist, and how those gaps might be filled.

1.1 What Is LFH

The Soil Classification Working Group in Canada developed a commonly used definition of the LFH layer for the Canadian System of Soil Classification (Soil Classification Working Group 1998). They define LFH as organic soil horizons (L, F, H) developed primarily from the accumulation of leaves, twigs and woody materials, with or without a minor component of mosses, that are normally associated with upland forest soils with imperfect drainage or drier. The L horizon is characterized by the accumulation of organic matter in which the original structures are easily discernible including leaves and twigs. The F horizon is characterized by accumulation of partially decomposed organic matter; some original structures are difficult to

[1] For more information on ecological resilience in upland forest reclamation see Welham, C., 2013. Factors Affecting Ecological Resilience of Reclaimed Oil Sands Uplands. OSRIN Report No. TR-34. 44 pp. http://hdl.handle.net/10402/era.31714

recognize. Material may be partly comminuted by soil fauna (as in moder) or may be a partly decomposed mat permeated by fungal hyphae (as in mor). The H horizon is characterized by accumulation of decomposed organic matter in which the original structures are indiscernible. This horizon has greater humification than the F horizon, mainly due to the action of organisms. It is frequently intermixed with mineral grains, especially near mineral horizon junctions.

In Alberta the LFH layer of upland forest ecosystems is variable in depth but generally not greater than 20 cm. In some soils in the forest regions of the province, not all three organic horizons are discernible. In reclamation, LFH layers are rarely stripped on their own as it is not operationally feasible to do so with large equipment and large areas to clear. Instead, LFH is salvaged with varying amounts of upper horizon mineral soil for land reclamation, generally termed "over stripping". The LFH material used in reclamation is known by many different words and terms. Use of these terms and their interpretations differ among and within academia, industry and government. Some of those common terms are forest floor material, topsoil, cover soil, LFH mineral mix, LFH mineral soil mix, forest floor mineral mix, LFH and shallow mineral horizons, forest litter, litter, LFH topsoil and upland surface soil. This plethora of words and terms can cause considerable confusion among users.

Alberta Environment and Sustainable Resource Development in its guidelines for reclamation to forest vegetation in the oil sands (Alberta Environment 2010a) uses the term *LFH* to describe forest floor materials accumulated on the mineral soil surface under upland forests. The term *upland surface soils* describes shallow salvaged materials consisting of LFH layers and upper 10 to 30 cm of underlying mineral soils (LFH layers plus A horizon). The term *LFH amendment* describes salvaged upland surface soil materials used as capping or cover during reclamation.

Many Alberta Environment and Sustainable Resource Development approvals use the term *upland surface soil* for LFH mineral soil mixes. For example, definitions in the Total E & P 2011 (Alberta Environment 2011a), Coal Valley Resources Obed Mountain Mine 2011 (Alberta Environment 2011b) and Cardinal River Coals Luscar Mine 2011 (Alberta Environment 2011c) approvals appear to represent the current government approach. In these approvals, the *LFH layer* is forest floor that accumulates on the mineral soil surface under forest vegetation, including litter and unincorporated humus. *Upland soil* is mineral soil developed on mineral material under forest in locations with imperfect drainage or drier, typically including LFH and A, B and C horizons. *Upland surface soil* is the stratum salvaged from an upland soil including LFH, A horizon and in some cases, part or all of the B horizon.

Whether the term upland surface soil includes woody debris must be clarified, since some reclamation practices use woody debris and some use mixes of LFH and woody debris. Woody debris classification terms are not always clearly independent of LFH terms. *Woody debris* is defined as all dead woody material in a forest ecosystem, including wood on the forest floor such as logs, fallen limbs, twigs and woody fruit; wood below ground such as dead roots and buried wood; and standing wood such as snags and stumps (Pyle and Brown 1999). Woody debris can be termed logging waste, slash residue, forest residue or habitat logs (Brennan et al. 2005). Woody debris constituents can be classified by diameter (e.g., Harmon et al. 1986), leading to further divisions of coarse and fine woody debris. Stumps and roots above ground are classified as coarse root debris (Yan et al. 2006). Coarse woody debris is often categorized by decay class (e.g., Brunner and Kimmins 2003, Yan et al. 2006). Woody debris can be quantified by volume (Siitonen 2001), biomass or area percent cover (Harmon et al. 1986, Ståhl et al. 2001). Alberta Environment and Sustainable Resource Development is beginning to promote the use of woody materials as amendments for land reclamation projects (Vinge and Pyper 2012).

Authors of scientific, industry and consulting reports have used a multitude of terms to describe the surface soil material salvaged for reclamation. A clear understanding of the LFH and mineral soil material salvaged and placed is required to effectively interpret results and draw conclusions from various experiments and trials conducted with LFH materials to date. This includes type of forest community, ecosite, soil classification and depths as these factors influence propagule abundance, diversity and soil water and nutrient status. Depths alone are not adequate as soil horizons included vary greatly with soil unit and ecosite. Extant vegetation does not always indicate depth of LFH as topography and site age are also factors. Therefore in this document, detailed descriptions of the unique material used in each study or trial are provided, if it was provided in the reviewed documents.

For the purpose of this review and analysis, the term *LFH mineral soil mix* refers to salvaged material used in each of the experiments, unless they are distinctly LFH alone or mineral soil alone. LFH mineral soil mix addresses some of the inadequacies of other terms in common use. This term includes, but is not limited to, the Canadian System of Soil Classification's definition of LFH. Using the term LFH alone is not accurate as all operational trials and experimental research to date include some mineral soil from below the LFH layers. It can include residual coarse woody debris following logging, such as slash and stumps as this is an important component of the reclamation material and operationally difficult to separate. The definition is similar to that used by Alberta Environment (2010a) for upland surface soils, however, LFH mineral soil mix is confined to include mineral soil layers in the 10 to 30 cm depth regardless of the soil horizons included and can include coarse woody debris.

1.2 Availability of LFH

Availability of LFH mineral soil mix is a serious consideration for its use in reclamation. How much is available must be taken into consideration when determining its widespread use in both oil sands and coal mine reclamation. Depth of the LFH layer is dependent on soil unit, ecosite, topography, forest type and disturbance history. Macyk (2006a) found the LFH layer in the Athabasca oil sands region was only 2 or 3 cm deep in some samples from the Fort Hills and Mildred soil units, but could be up to 25 cm deep in the Bitumont soil unit. There was generally a 5 to 10 cm range in LFH depth within soil units. Ae horizons were 2 to 20 cm deep and only the Bitumont soil unit contained an H horizon and an Ae horizon. LFH layer thickness is positively correlated with soil water and nutrient status (Beckingham and Archibald 1996, Lowry 1975). Disturbances such as forest clearing or forest fires, particularly intense ones, are known to reduce the thickness of the natural LFH layer (Bock and Van Rees 2002, Bonan and Shugart 1989, Mackenzie et al. 2004, Pennock and Van Kessel 1997).

Upland soils generally comprise a small portion of the total soil volumes available for use in mineable oil sands reclamation. From recent environmental impact assessments, percent upland soil of the available soil for reclamation ranges from 13.5% for the Jackpine Mine expansion area to 33.6% for the Jackpine Mine Phase I (Shell Canada Limited 2007a); Joslyn North Mine has 18.7% (Deer Creek Energy Limited 2007) and Pierre River Mine 21.1% (Shell Canada Limited 2007b). An exception is the proposed Frontier Mine which is composed almost entirely of upland soils (Teck Resources Ltd. 2011).

Salvage of LFH mineral soil mix in the mountain coal mine region has the added constraint of slope. Even if suitable soil is present, operationally it cannot be salvaged from slopes greater than 27 degrees (Macyk 2000). At higher elevations LFH and A horizons may be very shallow and/or patchy in distribution making salvage difficult. This scarcity determines the areal extent of reclaimable land upon which upland soils can be used and means that care must be taken to obtain maximum value from this resource.

Due to the limited availability of LFH mineral soil mix in the oil sands and mountain and foothills mine regions, there is not insufficient material to place on all reclamation sites. Both industry and government have recognized this and the question of where to place the scarce material to maximize its benefits has been raised. Direct placement, the process of placing a cover soil material onto a reclamation site immediately following salvaging, is most cost-effective, however is not always feasible if reclamation sites in near proximity to the salvage site are not available. In these cases, LFH mineral soil mix is stored in windrows or large stockpiles for anywhere from a few months to many years.

The intent is to reclaim progressively in the mountain and foothills coal mine region, with portions of a mine reclaimed as mining activities cease. Advantages of this approach are that reclamation sites are smaller, and salvaged soil is potentially stockpiled for a shorter period of time which may result in placement of higher quality soil with increased microbial activity and viable plant propagules (Macyk 2000). However, in the mountain and foothill coal mine region, storage is not always possible if level land for stockpiling is not available. Operationally, progressive reclamation can be challenging in this region due to the configuration of mine planning and sequencing. If there is insufficient soil on a salvage site it may need to be salvaged from other, often lower elevation or lowland sites. Organic soils may be more abundant in the boreal, mountain and foothills natural regions, however, if upland forest is the reclamation end goal then local soil from the desired community is best for establishing the diversity and abundance of native species (e.g., Dobbs et al. 1976). Research from other areas shows that not only can seed and vegetative propagules be present in the relict soil seed bank, but microbial and mycorrhizal communities can remain (Chee-Sanforda et al. 2006), Lennon and Jones 2011) and thus potentially facilitate and accelerate reclamation.

The alternative to using LFH mineral soil mix as a native propagule source for reclamation is to purchase commercially available native seed or wild collect native seed. However, seed of very few native species is produced at a commercial scale and most species available are grasses. If native grasses are sown at high rates to provide erosion control, colonization of other native species may be inhibited and tree plantings smothered. If sown at low rates to allow native ingress and establishment of planted trees, aggressive non-native plant species often dominate due lack of adjacent native seed sources and slow rates of natural colonization; this is more a concern in the oil sands region than mountain coal mine region. The cost per hectare for seed and fertilizer to obtain acceptable vegetation cover is often prohibitive. Some companies collect wild native seed on their leases, specifically seed that cannot be purchased such as trees, shrubs and a few forbs, then grow it out in on-site nurseries. This is resource intensive and subject to seasonal and annual variability in seed set and quality.

Besides the need for rigorous science to provide evidence to support the reported benefits of LFH mineral soil mix use in reclamation over conventional reclamation practices, novel approaches to use of LFH mineral soil mixes are required to maximize the benefits over large areas to be reclaimed. The ratio of LFH to mineral soil salvaged, effects of handling and stockpiling practices, timing and depth of placement, and the relative success of patches of LFH mineral soil mix versus broadcast application need to be further evaluated.

1.3 Regulatory Context

According to the *Environmental Protection and Enhancement Act* (Government of Alberta 2000) and associated *Conservation and Reclamation Regulation* (Government of Alberta 1993), mining operators in Alberta are required to conserve land and to reclaim the lands they disturb to meet the objective of a return to equivalent land capability. They are also required by the Act to obtain a reclamation certificate once their site has been successfully reclaimed. Specific operational practices that mining operators are required to follow are included in regulatory approvals issued pursuant to the *Environmental Protection and Enhancement Act* at the beginning of operations and updated periodically, at a minimum every 10 years. Reclamation certificate applications and mine closure plans are important components of the regulatory process and address reclamation methods.

Regulators, in consultation with industry, draw on guidelines, best management practices, research and site specific conditions to develop approvals with the intended goal of reclaiming soils and landscapes to locally common forest ecosystems. Over the years, terms, definitions and requirements for reclamation soil salvage, storage and replacement have changed in oil sands approvals (Alberta Environment 2004a, b, 2007a, b, c, d, 2009, 2011a) and coal approvals (Alberta Environment 1997, 1999, 2000a, b, 2005a, b, 2010b, c, 2011b, c). Since 2007 the Alberta Government has required oil sands companies to salvage all available upland surface soil. Due to the limited availability relative to land to be reclaimed, placement on all reclaimed sites is not required. The approval for the Total Joslyn North Oil Sands Processing Plant and associated Mines (Leases 24, 452 and 799) is the most recent oil sands approval (Alberta Environment 2011a); the most recent coal mine approvals are Obed Mountain Coal Mine (Alberta Environment 2011b) and the Luscar Mine and Coal Processing Plant (Alberta Environment 2011c). These approvals are thus most likely to have terms, definitions and requirements that reflect the current state of reclamation materials handling policy. The approval terms for LFH and upland surface soil were discussed in Section 1.1.

More recent approvals and guidelines recommend direct placement when possible. Direct placement refers to "a combined salvage and placement operation wherein surface soil is moved directly from the area of salvage to the area of placement" (Alberta Environment 2011b). Longer term monitoring has shown revegetation is most successful on direct placed sites (Leskiw et al. 2007, Strong 2000). The most recent coal mine approvals (Alberta Environment 2011b, c) stipulated the approval holder shall stockpile "all surface soil separately (mineral and organic soil stockpiles shall be separate) from suitable overburden". Stockpiles must be on stable foundation, on land with surface soil removed, and erosion prevented through vegetation and other methods. In the *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region, Second Edition*, specific recommendations are made for revegetation of reclaimed soils with or without LFH amendments (Alberta Environment 2010a). The term LFH amendment is used for upland surface soil once it has been salvaged from a donor site, pushed into windrows, placed in stockpiles or placed in reclaimed areas. Effective salvage and application of LFH amendments is considered to have "the potential to be the most successful technique for re-establishment of understory species density and diversity".

Directly placed LFH amendments are expected to contribute 0 to 800 stems ha^{-1} of *Pinus banksiana* (jack pine), 700 to 2,000+ stems ha^{-1} of trembling aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*), and more than 700 stems ha^{-1} of shrubs (Alberta Environment 2010a). Stockpiling reduces the tree and shrub contributions from the LFH amendment, with no contributions expected for LFH stockpiled for more than a year. Small stockpiles are expected to contribute 0 to 300 stems ha^{-1} of pine, 0 to 800 stems ha^{-1} of poplar and 200 to 600 stems ha^{-1} of shrubs. Larger stockpiles < 1 year of age, > 3 m in height and > 5 m wide are expected to contribute 0 to 300 stems ha^{-1} each of trees and shrubs. These contribution values were based on assumptions related to the operational use of upland surface soil materials where upland surface soil was salvaged to a depth no greater than 30 cm and LFH amendment was applied at a depth of at least 10 cm. These contribution values for jack pine are only considered applicable if the upland surface soil was salvaged from coarse textured xeric or submesic to subxeric ecosites.

The guidelines include when and where to use LFH amendments in reclamation and emphasize their value and scarcity (Alberta Environment 2010a). LFH amendment is recommended on sites where a "robust and diverse understory" is desired or required, such as sites that are to be used for wildlife habitat or for traditional aboriginal use, rather than those sites that are designated for commercial forestry. Soil nutrient and water regimes of both donor and receiver (replacement) sites should ideally be similar, but using mismatched upland surface soil at a receiver site is considered better than to not use this soil at all, or to stockpile it for longer than one year. The value of LFH amendments is considered to be primarily in its supply of native plant propagules and is required to be managed accordingly. The soil amelioration that LFH mineral soil mix provides is considered secondary, and any losses in soil quality are considered to be more easily supplemented during reclamation on an operational scale than can the losses of propagule viability incurred.

Best management practices recommended for conservation of reclamation materials in oil sands operations recommend that all available LFH and underlying A horizon soil be salvaged from lands to be disturbed (Alberta Environment and Water 2012). Appropriate salvage depths will depend on soil texture with a maximum salvage depth of 15 cm, or to bottom of the Ae horizon (whichever is greater), on coarse textured soil and a maximum of 30 cm, or to bottom of the Ae horizon (whichever is less), on fine textured soil. Best management practices recognize that operationally these guidelines cannot always be met, but emphasize that deviations will result in trade-offs between soil quality and plant propagule abundance and volume of salvage material. Soil quality and propagule abundance decrease as salvage material volume increases and vice versa. Consideration of end land use goals and placement site conditions are important in determining where it is most appropriate to use salvaged upland soils in reclamation given their limited availability relative to land to be reclaimed.

1.4 Report Objectives and Methods

The purpose of this report is to provide a review of available literature on the use of LFH mineral soil mixes for reclamation to forest ecosystems in Alberta and to critically assess these studies to identify what can be concluded about the use of LFH mineral soil mix in reclamation in the province, and where gaps in the knowledge base exist. The intended audience is land managers, regulators and researchers from industry, government and academia.

The review focused on the available literature on reclamation based on LFH mineral soil mix of forested lands in the boreal, mountain and foothills natural regions of Alberta. Although LFH mineral soil mixes have been used for reclamation and restoration of grasslands and other forested areas (e.g., Bellairs and Bell 1993, Nichols and Michaelsen 1986, Rokich et al. 2000, Tacey and Glossop 1980, Vecrin and Muller 2003), this literature was not explicitly included, to keep the analysis focused but was used to support findings within Alberta.

University, government and industry library databases were searched. Web databases (Web of Science, Environment Complete, BIOSIS Previews, Google Scholar) were searched for peer reviewed literature. Reference lists found in procured papers, graduate student theses and dissertations and already collected papers were reviewed to further expand the document search. The focus of the literature search was on papers that described experimental topsoil or LFH transfers in a land reclamation or ecological restoration context and that addressed seed banks of undisturbed plant communities to assess their regeneration potential. Studies of natural seed bank composition unrelated to its use in land reclamation following a disturbance in ecosystems other than the boreal, mountain or foothills forest were not included.

Non-peer reviewed literature from industry reports that provided information on use of LFH materials in land reclamation, whether intentional or incidental, were reviewed. Current and historical provincial government regulations and approvals were reviewed to determine requirements and recommendations for LFH mineral soil mix use in reclamation. Approvals for

Alberta oil sands and mountain and foothill coal mines were downloaded from the approval viewer[2] section of the Alberta Environment and Sustainable Resource Development web site.

Some verbal discussions were undertaken with knowledgeable individuals within industry, government and academia. These discussions were specifically aimed at locating any existing information or documents that might be useful in addressing questions within the scope of this literature review and analysis.

Plant nomenclature for this report follows Moss (1983) and origin of plant species follows the Alberta Conservation and Management Information System (2012). Common names are used throughout the report, however, if the scientific name was included in a document, it was provided the first time used in each document. If scientific names were not included in documents, there is low confidence in species referred to by common name alone.

Expected benefits of LFH mineral soil mix for forested mine reclamation relative to conventional reclamation soil mixes, such as peat, peat mineral soil mix, peat and tailings sand mix and peat mixed with mineral and overburden materials in the oil sands, and peat or mineral soil and subsoil mixes in mountain and foothills coal mines are summarized. Appropriate scientifically based criteria to evaluate success of conventional reclamation methods and those based on LFH mineral soil mixes are proposed. Gaps have been identified, and further research to substantiate the requirement for reclamation based on LFH mineral soil mix on mine sites has been proposed. Main questions have been articulated surrounding LFH mineral soil mix, including those that have been answered in a scientifically proven way, those that need to be supplemented with data, those specifically addressed from different perspectives, and those which have not been answered at all, except perhaps in a rudimentary demonstration type manner.

Section 2 provides information on LFH mineral soil mix as a propagule source and how it has been used for this purpose in reclamation. Section 3 provides information on the use of LFH mineral soil mix as a reclamation soil. Section 4 provides an analysis of what is known, where the gaps are and what research would help address the gaps regarding knowledge for reclamation with LFH mineral soil mix. Section 5 concludes the report.

2 LFH MINERAL SOIL MIX AS A PROPAGULE SOURCE IN RECLAMATION

Much of the interest in use of LFH mineral soil mixes in reclamation in Alberta is focused on their potential to more readily re-establish native plant communities than with conventional reclamation materials. The most recent approvals for oil sands and coal mines stipulate an end land use of self-sustaining, locally common forest ecosystems and therefore the need to place reclaimed sites on a trajectory towards the native abundance and diversity present in adjacent areas must be addressed. Based on research and experiences elsewhere (e.g. Dobbs et al. 1976),

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[2] See http://envext02.env.gov.ab.ca/pls/xedp_apv/avwp_avwh1000_02.startup?Z_CHK=0

it is reasonable to anticipate that if the local plant propagule bank is replaced during reclamation, the desired plant community will develop and provide benefits to plant diversity and sustainability.

Research from diverse ecosystems, including tropical forests (Grant and Koch 1997, Grant et al. 1996, Koch 2007, Koch et al. 1996, Parrotta and Knowles 2001, Tacey and Glossop 1980, Ward and Koch 1996), grasslands (Bellairs and Bell 1993, Scoles-Scuiulla and DeFalco 2009), arid and semi-arid communities (Iverson and Wali 1982, Shuman and Power 1981), temperate forests (Farmer et al. 1982, Hall et al. 2010, Wade 1989) and alpine forests (Smyth 1997) show salvaged topsoil is a good source of native propagules for mine reclamation. There is a general consensus that seed abundance and emergence is reduced with seed burial depth. Most seeds are found in the upper 5 cm of these soil propagule banks and application of fresh topsoil results in greater native species abundance and diversity than the application of topsoil that has been stockpiled.

2.1 Oil Sands

Very little research has been conducted in boreal forest ecosystems in Alberta on the use of LFH mineral soil mix as a source of plant propagules for land reclamation. With the exception of two studies, all of this work has taken place in the Athabasca oil sands region (Table 1).

2.1.1 *Propagule Bank*

After 6 months of monitoring at research sites in the Athabasca oil sands, 3,614 and 9,108 emergents m^{-2} were found in the upper 10 cm depth of soil of pre-mined peat lands and upland forests (fine texture), respectively (Mackenzie and Naeth 2010). Most of the emergents (92% for both propagule banks) were native species with almost 90% of them from seed in forest soil and 60% from peat. There were more emergents from 0 to 5 cm soil depths than 6 to 10 cm depths. Woody species were less abundant in upland forest samples than in peat samples (627.2 versus 882.3 emergents m^{-2}), with most woody species in the upper 5 cm of soil (92% in peat, 60% in upland). A common target plant density in many reclamation scenarios is approximately 50 plants m^{-2}. In forest and grassland regions of Alberta this is generally sufficient to provide the required canopy cover and erosion control, although results are dependent on type of plant species present. Even with considerable variability in the desired end use plant density, there is considerably high potential for native plant species establishment from the boreal forest soil propagule banks.

Table 1. Field scale research using LFH mineral soil mixes for establishment of locally common native plant communities.

Study Location	Data Years	LFH Mineral Soil Mix Description	Salvage Depth	Placement Depth	Placement Method	Site and Substrate	Controls and Replication
Syncrude Mildred Lake Tailings Dyke	1998 to 2008, 2011	LFH, sandy Ae horizon, LFH 0 to 5 cm, deadfall and litter, dry upland aspen	7.8 cm	Direct 11 to 13 cm, stockpiled 18 cm	Direct placed, stockpiled windrows 5 months	Direct placed 18 cm peat mineral over 35 cm secondary, stockpiled 23 cm secondary	Barley control, three replicates, two for control, none for stockpile over secondary
Suncor Steepbank North Dump	2000 to 2005, 2007	Type 1 = LFH and A horizon, Type 2 = LFH, fine texture, mesic, patches (15% area) subxeric, submesic	Type 1 = 20 cm, Type 2 unknown	Type 1 = 20 cm 35:65 peat mineral, Type 2 = 5 cm over 15 cm peat mineral	Direct placed within 2 weeks	West facing, lean overburden slope (4:1), barley cover crop, aspen and spruce plantings, fertilized	Control, two replicates
Suncor Tailings Dyke 11A South	2006 to 2007	Unknown	Unknown	25 cm over 30 cm clay	Direct placed	South facing tailings sand slope, barley cover crop, tree and shrub plantings, fertilized	Control, three replicates each in upper (9%) and lower (2%) slope
Syncrude Base Mine W1 South Overburden Dump	2004 to 2011	LFH and A horizon, fine texture, subxeric submesic	LFH, 5 to 20 cm mineral soil	10 and 20 cm	Stockpiled windrows 3 months	South east facing saline sodic overburden slope, 90 cm non-saline, non-sodic overburden cap, D10R Cat crawler tractor smoothed surface	Control, three replicates

Table 1. Field scale research using LFH mineral soil mixes for establishment of locally common native plant communities. (continued).

Study Location	Data Years	LFH Mineral Soil Mix Description	Salvage Depth	Placement Depth	Placement Method	Site and Substrate	Controls and Replication
Suncor Southeast Overburden Dump	2008 to 2012	LFH, Ae horizon, mesic, aspen-white spruce, ecosites d and b	20 cm	20 cm	Stockpiled 3 months	South east facing saline sodic overburden slope, 30 cm B and C horizon over 100 cm clean overburden, black spruce or aspen woody debris, fertilized	Control 30 cm peat over 100 cm clean overburden, three replicates in each of two slope positions
Syncrude Aurora North Mine Overburden	2006 to 2011	LFH 2 to 8 cm, underlying mineral soil, coarse texture, xeric, subxeric submesic	10 and 25 cm	10 and 20 cm	Stockpiled in small windrows 6 months	1 m sand and 1 m of peat mineral soil mix with sand (50:50) over overburden	Peat mineral soil mix and sand control, three replicates
Genesee Coal Mine	2010	LFH, A, some B horizon (not Bt), LFH 5 cm, aspen, medium to fine texture	15 and 40 cm	15 and 40 cm	Direct placed within 2 weeks	East facing overburden slope 5 to 12 degrees	No control
Genesee Coal Mine	2008 to 2012	LFH and A horizon, LFH 9.5 to 15.5 cm, Ae 10 to 13.7 cm, aspen, medium to fine texture	20 cm	20 cm	Direct placed within 1 to 2 months	Northwest facing sodic overburden slope 5 to 9 degrees	No control

Total species richness was greater in forest soil (37 species) than in peat (19 species), as was the number of propagules of grasses, sedges, rushes, forbs, native species, perennials, annuals and biennials (Mackenzie and Naeth 2010). In comparison, Fedkenheuer and Heacock (1979) found much lower species richness (5 species) in fresh peat. Depth of sampling was unknown for the Fedkenheuer study, and seed bank dilution could have occurred if sampling occurred at great depths. Field plots were established on a tailings sand base with 15 cm of fresh peat or with stockpiled peat (1 to 1.5 years old) over 10 cm of mineral fines (clay) and rototilled to 30 cm depth (Fedkenheuer and Heacock 1979). After two growing seasons stored peat had greater species richness (8) than fresh peat (5), although fresh peat had more emergent overall. Species composition was similar on both stored and fresh peat treatments. Other studies found there was reduced plant establishment and increased species richness with depth of propagule burial (Grant et al. 1996, Hills and Morris 1992, Tacey and Glossop 1980). Incorporation of peat to a depth of 30 cm in the Fedkenheuer and Heacock (1979) study may have caused a reduction in total species relative to that found in the more recent study by Mackenzie and Naeth (2010).

Mackenzie and Naeth (2010) studied the propagule bank immediately after soil placement at 10 and 20 cm, finding 29 species in LFH mineral soil mix and 16 species in peat mineral soil mix. Density of emergents from the propagule bank was much lower than in undisturbed soils in the area. There was a 95% loss of emergents in LFH mineral soil mix (both depths) compared to undisturbed LFH, and there was a 91% and 77% loss in 10 and 20 cm peat mineral soil mix, respectively, compared to that of undisturbed peat. Application thickness played a larger role in determining propagule density than did the propagule source, with an estimated 99% loss of vegetative parts for both materials. Decreases in emerging propagules were attributed to dilution effects and loss of viability during 3 months of stockpiling. Native species still comprised the majority of emergents (94% to 97%), although woody species were considerably less abundant. The LFH mineral soil propagule banks were more similar to vegetation of its donor site than the peat mineral soil mix propagule banks were to vegetation of its donor site.

The soil propagule bank in a coarse textured soil contained 1,189 emergents m^{-2} from combined depths; emergents were from 31 plant species (Mackenzie 2012). Total propagule density and species richness significantly decreased with increased depth in the following order: lower LFH > upper LFH > 0 to 2.5 cm > 2.5 to 5 cm = 5 to 10 cm = 10 to 15 cm = 15 to 20 cm. Emergents from seed and vegetative propagules were significantly greatest in LFH layers and emergents from vegetative propagules were significantly greater at 0 to 2.5 cm depth than at other depth intervals in mineral soil. There was no significant difference in emergents between mineral soil depth intervals. LFH layers contained 73% of the total propagules. Woody plants accounted for 50% of total emergents, forbs 19%, grasses 14%, pteridophytes (ferns) 9%, sedges 4%, lily and *Typha* 4%. From combined depths, 24 species emerged from rhizomes and 19 from seed. The proportion of plants emerging from rhizomes (71%) increased with depth. Results from this study show how important vegetative propagules or the bud bank can be in contributing to plant establishment when used as a propagule source in reclamation. Dry and nutrient poor forest stands contain a diverse and abundant propagule bank for revegetation, including many species that are not commercially available.

Since direct placement is not often achievable, further research was conducted to determine the effects of handling and stockpiling on viability of seeds and vegetative propagules in LFH mineral soil mix. In 2006, four experimental sets of large (36 m long x 20 m wide x 6 m high) and small (15 m long x 4 m wide x 3 m) stockpiles were established at different oil sands mines (Mackenzie 2012). Three sets were constructed with coarse textured material and one with fine textured material. One coarse textured set of stockpiles was built in winter, the others were built in fall. Seeds of 10 shrub species and one tree species, and rhizome cuttings from three shrub species, were buried in mesh bags at various depths in the stockpiles. In large stockpiles, most seeds and rhizomes buried deeper than 1 m lost viability after eight months; in small stockpiles viability of seeds and rhizomes was lost after 12 months. Loss of viability occurred more slowly in winter constructed stockpiles, although after 12 months results were the same regardless of season of stockpile construction. Anaerobic conditions in large stockpiles caused seed mortality; aerobic conditions leading to premature seed germination in the stockpile or seed rot was the cause in small stockpiles.

Anyia (2005) compared richness and abundance of viable propagules in topsoil from undisturbed vegetation and soil stripped for reclamation (peat mineral soil mix) at Shell Albian Sands, and investigated effects of water, light, temperature and smoke water on germination. Natural soil was collected in fall and reclamation soil was collected in winter; soil type or depth of soil sampling and salvaging was not provided in their document. Emergent densities from natural soils (unspecified undisturbed vegetation) ranged from 0 to 175 ± 83 plants m^{-2}; which was higher than for reclamation soil of unspecified origin or depth under the same treatments (0 to 133 ± 70 plants m^{-2}). Low species richness (18) in both soil types and emergent densities led to the conclusion that seeds alone would not be sufficient for reclamation and vegetative propagules and ingress via wind and animal dispersal was important. Water was the most important environmental variable affecting germination. In natural soils germination was higher in dry soil with summer temperatures, while in reclaimed soils germination was higher with saturated soils and spring temperatures. Compared to other studies on natural forest soils or LFH mineral soil mixes, propagule bank species richness was low and abundance was very low. The reasons for this are difficult to assess without more information on sample sites and methods.

Methods to physically or chemically enhance native seed germination have been studied (Geographic Dynamics 2002, Smreciu et al. 2001), although operational scale application is often not feasible and not applicable when seeds of multiple species are mixed in soil. An exception is use of plant derived smoke water to increase germination in salvaged seed banks. This method has been successfully applied at a field scale at bauxite mines in Australia (Roche et al. 1997, Rokich et al. 2002). Two studies investigated its use in the oil sands (Anyia 2005, Mackenzie 2012).

Mackenzie (2012) tested 18 native boreal species of grasses, forbs and shrubs. Smoke water (45 kg plant biomass in solution with 20 L distilled water) enhanced germination of most of these species if the seed was cold stratified before smoke water was applied. Cold stratification occurs naturally over winter in the field, and may be required for germination of many native species. Blueberry had the greatest increase in germination with smoke water (~15%) relative to the control. Cold stratification in combination with smoke water reduced the germination of cut leaf anemone (*Anemone multifida*) and purple oat grass (*Schizachne purpurascens*).

Smoke water enhanced plant emergence from natural oil sands soil under most temperatures (Anyia 2005). Greatest number of emergents m^{-2} occurred with warm, dry, homemade smoke water (12 kg plant biomass in solution with 20 L distilled water) (175 $\pm$ 83); lowest number of emergents occurred with cool temperature, soil water at field capacity and no smoke water conditions (8 $\pm$ 8). Overall emergence was highest in dry treatments, with or without smoke water. In reclamation soil, biologically significant differences in emergent density between smoke water and control treatments were only observed with cool temperatures, saturated, homemade smoke water and with warm, saturated or field capacity, commercial smoke water. Three species in controls that did not establish with smoke water were prickly rose, Bicknell's geranium (*Geranium bicknellii*) and dandelion (*Taraxacum officinalis*). Two unidentifiable shrubs were only found in smoke water treatments. Few significant differences were detected due to high variability in the data.

2.1.2 *Revegetation*

Syncrude Canada Ltd. initiated a study on use of LFH mineral soil mix from upland forest as a propagule source in reclamation of a tailings dyke. LFH mineral soil mix was salvaged in late August 1998 from a dry upland aspen site with shallow LFH (5 cm) underlain by a sandy Ae horizon (Lanoue and Qualizza 2000). The site had been cleared in 1996 as part of pre-mine activities. LFH mineral soil mix was salvaged with a D8N Cat dozer with the operator instructed to salvage all material to the clay interface. Salvaged material was LFH, including surface deadfall and leaf litter, and some underlying mineral soil. Average salvage depth was 7.8 cm. Some salvaged material was placed immediately on research plots on a tailings dyke. Some material was stockpiled in a small windrow and placed in January 1999 to compare summer and winter placement (Lanoue and Qualizza 2000, Pollard and Qualizza 2001). LFH material was spread with a D5H Cat dozer. No other equipment traffic occurred over the LFH material during placement and operators were instructed to minimize passes. The very dry summer reduced equipment impact at salvage and placement sites.

Winter and summer placement of 11 to 13 cm of LFH material over 18 cm peat mineral soil mix over 35 cm secondary material (3 replicates each), and winter placement of 18 cm LFH material over 23 cm secondary material (no replicates) have been studied (Lanoue and Qualizza 2000). Controls were 18 cm of peat mineral soil mix over 35 cm secondary (2 replicates), and 18 cm peat mineral soil mix over 23 cm secondary (no replicates) (Lanoue and Qualizza 2000, modified by Pollard 2001). Natural forest plots (3 replicates) were added for study in 2001 (Pollard and Leskiw 2002). Secondary material is obtained from suitable upland soil or surficial geologic material salvaged to a depth no longer considered suitable for plant growth (Yarmuch 2003) and is generally fine textured, non-saline and non-sodic. Peat mineral soil mix was fertilized once at 500 kg ha^{-1} with 10-30-15-4 nitrogen:phosphorus:potassium:sulfur and seeded to common barley (McMillan et al. 2007, not reported in Lanoue and Qualizza 2000). LFH mineral soil mix was left to natural recovery. Lack of full replication on all treatments precluded full statistical analyses in this study.

In 2008, after 10 years of monitoring, LFH mineral soil mix on peat mineral soil mix, whether placed in summer or winter, or placed on secondary material had more native and woody species and fewer undesirable (non-native) species than peat mineral soil mix (Navus Environmental Inc. 2009). While authors of early reports concluded summer placement was superior to winter placement (Brown et al. 2003, Mapfumo 2003, Pollard and Leskiw 2002), effects were variable with no conclusive evidence (Navus Environmental Inc. 2009). Species richness in summer and winter placed LFH mineral soil mixes, respectively, was 20 and 24 native species, 3 and 4 woody species, and 6 non-native species in both. LFH mineral soil mixes were more similar to undisturbed forests. Native cover was 67% in summer placed, 68% in winter placed and 31% in controls. Peat mineral soil mix controls had significantly greater moss and lichen cover (4% and 5% in summer and winter placed LFH versus 22% in the control) and weedy species cover (15% and 16% versus 36%) than the comparable LFH mineral soil mix treatment. Native legumes were most abundant with LFH. Canopy cover and species richness were numerically higher on LFH mineral soil mix over peat mineral soil mix than LFH mineral soil mix over secondary. Woody stem density and woody species diversity were similar for both treatments (Navus Environmental Inc. 2009). Species data for individual treatments were not provided and thus could not be evaluated.

Suncor Energy Inc. began a similar experiment on the Steepbank North Dump in 2000 (AMEC Earth and Environmental 2007). An LFH mineral soil mix consisted of LFH and a sandy Ae horizon (to 20 cm depth) from a fine textured, mesic ecosite with patches of xeric ecosite. The site was cleared three years prior to soil salvage. The four treatments evaluated were 20 cm of LFH mineral soil mix, 20 cm of LFH mineral soil mix (30% to 40% by volume) combined with peat mineral soil mix (60% to 70%), 5 cm cap of LFH (no information on salvage, may be similar to LFH mineral soil mix above but labeled differently in reports) over 15 cm peat mineral soil mix, and a control of 20 cm peat mineral soil mix. Each treatment was replicated twice on a west facing, 4:1 slope of a lean oil sand overburden dump. Materials were directly placed within two weeks of salvage. Plots were seeded with barley (*Hordeum vulgare*) at 75 kg ha^{-1}, and planted with 2,076 stems ha^{-1} trembling aspen, 132 stems ha^{-1} white spruce (*Picea glauca*) and 123 stems ha^{-1} alder from 2001 to 2003 (AMEC Earth and Environmental and Golder Associates 2010b). A 24-25-8 nitrogen:phosphorus:potassium fertilizer was aerially applied at 300 kg ha^{-1} in summer 2000 and a maintenance fertilizer of 32-16-5 was aerially applied at 250 kg ha^{-1} in summers 2001 to 2003.

The dominant growth form on all treatments after five years was forbs (58% to 70% cover), particularly non-native species such as sow thistle (*Sonchus arvensis*) and hawksbeard (*Crepis tectorum*) and native species such as fleabane (*Erigeron philadelphicus*) and yarrow (*Achillea millefolium*) (AMEC Earth and Environmental 2007). Non-native forbs comprised 23% to 37% of canopy cover, roughly half the overall forb cover. Grasses were next most abundant, followed by shrubs, then trees. Few significant differences in grass, forb, shrub and tree composition were found, except for consistently greater grass cover on 20 cm LFH mineral soil mix and on LFH mineral soil mix combined with peat mineral soil mix, which was considered a potential concern for tree establishment (AMEC Earth and Environmental and Golder Associates 2010b). Height and survival of planted trees were not affected by capping treatments. Controls had less grass cover and higher tree cover than all other treatments, however, differences were only significant between the control and LFH mineral soil mix combined with peat mineral soil mix. Balsam poplar was the dominant tree species in the control and not found elsewhere. Red raspberry was the most common shrub and present in all treatments (2% to 7% cover). Rose was the most abundant species (10% cover) but only present in the LFH mineral soil mix treatment. In 2005 (last year data available) two samplings, one more intense than the other, yielded slightly different results. In the detailed survey, more significant differences were found than with the standard annual survey. Total litter, vegetation, forb and grass cover were significantly higher in LFH mineral soil mix with peat mineral soil mix than in all other treatments. This treatment had significantly higher shrub cover than the control. In 2005, LFH mineral soil mix had greater forb richness than peat mineral soil mix alone. Species richness was not further analyzed.

Geographic Dynamics Corp (2006) compared diversity in each of the above treatments as part of a study on potential for natural ingress, the natural appearance of plant species without direct intervention to promote establishment on reclamation sites in the oil sands. LFH mineral soil mix combined with peat mineral soil mix and LFH mineral soil mix alone had more species than LFH over peat mineral soil mix. Shrub richness was higher in these treatments, with rose, red raspberry and saskatoon most prominent. Based on data in the last year of reporting (AMEC Earth and Environmental 2007), LFH mineral soil mix alone had considerably greater total and shrub species (33 total, 7 shrubs) richness than all other treatments (20 to 22 total, 1 to 2 shrubs) including standard peat mineral soil mix (19 total, 3 shrubs). Rose and red raspberry were dominant in LFH mineral soil mix and absent in other treatments including LFH mineral soil mix combined with peat mineral soil mix.

Suncor Energy Inc. initiated another study in 2006 to investigate effects of various reclamation substrates, reclamation soils, including LFH, and amendments on biodiversity on a tailings dyke (Suncor Energy Inc. 2008). Treatments were a 25 cm depth of standard peat mineral soil (70:30) mix, 25 cm of LFH over 30 cm of clay, 25 cm of peat mineral soil mix over 30 cm clay, and 25 cm peat mineral soil mix with 10% ground cover of trembling aspen and white spruce coarse woody debris. No details on LFH source or salvage method were provided in the report. Each treatment was replicated three times on upper (9%) and lower (2%) slope positions of the dyke. Plots were seeded with annual barley in June and planted with 792 stems ha^{-1} trembling aspen, 1,152 stems ha^{-1} jack pine, 200 stems ha^{-1} white birch (*Betula papyrifera*), 101 stems ha^{-1} buffalo berry, 60 stems ha^{-1} rose, 134 stems ha^{-1} alder and 177 stems ha^{-1} blueberry. A portion of aspen and jack pine seedlings were marked for monitoring. Plots were fertilized with 23.5:25:8 nitrogen:phosphorus:potassium at 300 kg ha^{-1}. In 2007, a 31:16:5 fertilizer was applied at 250 kg ha^{-1}.

In the second growing season (2007), LFH mineral soil mix over clay had twice as much cover (31%) as peat mineral soil mix over clay (14%), peat mineral soil mix alone (18%) or peat mineral soil mix with woody debris (14%). Fireweed (*Epilobium angustifolium*) and an unknown sedge (*Carex* species) were dominant in LFH mineral soil mix over clay and peat mineral soil mix over clay, however, cover was greater in LFH. Sow thistle was dominant in both treatments but with equal cover. Standard peat mineral soil mix was dominated by sow thistle and the unidentifiable sedge but had low fireweed cover. Other dominant species in the LFH treatment were Bicknell's geranium, wild strawberry (*Fragaria virginiana*) and peavine (*Lathyrus* species). Species richness was similar among treatments without coarse woody debris (25 to 29 species) and highest in peat mineral soil mix with woody debris (34 species), even though woody debris cover in this treatment in 2007 (3%) was no different from that of other treatments (0% to 2%). A number of wetland species including bent grass (*Agrostis* species) and rushes (*Juncus* species) were found in peat mineral soil mix but not in LFH. Over half the plots were flooded in 2007 making results difficult to interpret. Interestingly no LFH plots flooded despite being randomly located on the tailings dyke, suggesting LFH over clay may provide better drainage than peat mineral soil mix. Aspen and jack pine survival was similar in 2006 between LFH over clay and peat mineral soil mix over clay, however, in 2007, survival of both species was lower on lower slope positions of LFH than in comparable peat mineral soil mix treatments. Plots were not monitored in 2008 and were planned to be monitored in 2009 (Suncor Energy Inc. 2009), however, no further documentation was located.

Mackenzie and Naeth (2010) established research plots on a saline sodic overburden dump at Syncrude base mine in 2004. LFH mineral soil mix was salvaged from a fine textured mesic ecosite (average LFH 7.5 cm) in November 2003 which contained LFH and 5 to 20 cm of underlying mineral soil. The site had been cleared and drained in 2002. LFH mineral soil mix and peat mineral soil mix were placed at 10 and 20 cm in February 2004. Applications of 10 and 20 cm of LFH mineral soil mix had greater species richness (47 and 49 species, respectively) and plant abundances (20% and 36%, respectively) than peat mineral soil mix (25 and 24 species, 6% and 5%) after two growing seasons. Species that emerged on LFH mineral soil mix were more suited to mesic, upland conditions of the reclaimed site than species from peat mineral soil mix. LFH had higher woody plant densities in the first three years, with 20,000 and 69,000 stems ha^{-1} on 10 and 20 cm applications, respectively, in the third year (unpublished data from Mackenzie and Naeth 2008, 2010 cited in Alberta Environment 2010a). Dominant shrubs were red raspberry, prickly rose and gooseberry (*Ribes* species). After two years LFH mineral soil mix had higher total (20% to 36%), forb (17% to 29%), grass (2% to 3%), native species (15% to 24%), perennials (17% to 31%), annuals and biennials (3% to 5%) canopy cover than peat mineral soil mix (5% to 6%, 3% to 4%, < 1%, 4%, 3% to 4% and 2% canopy cover for total, forb, grass, native species, perennials, annuals/biennials, respectively). Non-native species cover was greater with 20 cm than 10 cm of LFH mineral soil mix (12% versus 5%) than peat mineral soil mix (1% to 2%).

Further work by Mackenzie and Naeth (2008, unpublished) on a similar overburden dump site at Syncrude Canada Ltd. investigated effect of LFH mineral soil mix patch size and slope position on initial plant establishment. LFH mineral soil mix was shallow stripped and included 2 to 5 cm of mineral soil. The same three dominant shrubs as the previous study were found but with higher densities (unpublished data from Mackenzie and Naeth 2008, 2010 cited in Alberta

Environment 2010a). After the third growing season shrubs had 77,000 to 100,000 stems ha^{-1}, with larger values attained with larger patches and on lower slope positions. There was some flooding of research plots which was disadvantageous for woody plant growth.

Mackenzie (2012) investigated LFH mineral soil mix placed on sandy substrates at an overburden site on Syncrude Aurora mine. LFH mineral soil mix was salvaged at 10 and 25 cm, from coarse textured, xeric and submesic to subxeric ecosites. LFH ranged from 2 to 8 cm on the donor site. Salvage occurred in September 2005 and placement in March 2006. LFH mineral soil mix was placed at 10 or 20 cm, on two research sites, one consisting of 1 m of sand over overburden and the other 1 m of peat mineral soil mix combined with sand in a 50:50 ratio (peat sand) over overburden. The control was 1 m of peat sand over overburden without LFH mineral soil mix. By year three, species richness, evenness and diversity were significantly greater with LFH mineral soil mix than without. Cover was considerably greater for most plant groups. LFH mineral soil mix over peat sand had higher woody plant establishment (33,000 to 62,000 stems ha^{-1}) relative to the control with 7,000 stems ha^{-1}. Shrub densities increased over time, being significantly greater in LFH mineral soil mix than the control each year. Tree density was greater in most LFH mineral soil mix treatments each year but only significantly with 10 cm salvage and 20 cm placement in years two and three. Even with only 2 cm of LFH, more native species established and native plant density and cover were greater than in the control with no LFH. LFH mineral soil mix contained most upland species from the donor site and was most similar to the donor site; peat mineral soil mix and sand contained more wetland species. By the third year, upland species were encroaching onto controls and establishing.

LFH mineral soil mix application depth (10 or 20 cm) was more important than salvage depth (10 or 25 cm) (Mackenzie 2012). There were few differences in plant diversity, density or cover between 10 and 25 cm salvage depths. By year three total species richness was greater with deep salvage than shallow, however, tree densities were consistently greater with shallow salvage. Thicker application of LFH mineral soil mix had no effect on plant densities but resulted in greater plant cover than shallow application. Application depth differences were greater when LFH mineral soil mix was placed over sand versus peat mineral soil mix and sand.

Effects of ecosite the LFH mineral soil mix came from, salvage and placement depth, and underlying substrate on the placement site were investigated using small (1.5 x 1.5 m) research plots (Mackenzie 2012). LFH mineral soil mix was salvaged from fine and coarse textured ecosites at 10, 30 and 60 cm and placed at 2, 5 and 10 cm on mineral or peat mineral soil mix substrate derived from fine or coarse textured soil. When fine textured LFH mineral soil mix was placed on fine textured mineral substrate, total species richness, density and cover were greatest with shallowest salvage. All plant group densities, except woody species, were also greatest at this depth. On coarse textured mineral substrate (submesic or xeric ecosites), shallow salvage (10 or 30 cm) had greater plant density than 60 cm salvage by year 3 and submesic 10 cm salvage resulted in significantly greater cover of all plant groups, except woody species, than deep salvage. Peat mineral soil mix had greater species richness and abundance than mineral soil substrates and effect of salvage depth on plant establishment was more difficult to interpret. LFH mineral soil mix placed on fine textured peat mineral soil mix was dominated by sow thistle (*Sonchus arvense*) and blue joint (*Calamagrostis canadensis*) by year 2. When placed on coarse textured peat mineral soil mix, by year 3, there was no difference among salvage depths in species richness although native cover was significantly greater in the 10 cm depth. Extraneous variables such as competition from plants establishing from in situ propagules in peat mineral soil mix substrates and erosion occurring on LFH mineral soil mix placed on sand substrate made it difficult to determine statistical differences and clear trends among salvage depths.

Placement depth effect on plant community establishment and development varied with substrate and competing plants (Mackenzie 2012). Regardless of ecosite and substrate, 2 cm placement provided greater species richness and abundance than the control, but less than 5 and 10 cm placements. Deeper placement of fine textured, mesic ecosite LFH mineral soil mix on fine mineral substrate resulted in greater species richness and cover than shallower depths; more nutrients and soil water with increased placement depth may explain this. With LFH mineral soil mix from coarse textured soils, placement depth had no significant effect on species richness. Native species cover was greater with increased placement depth for LFH mineral soil mix salvaged at 10 cm on coarse textured mineral and peat mineral substrates. On peat mineral substrates, increased depth generally decreased densities of native and non-native plants emerging from outside the LFH mineral soil mix.

Brown and Naeth (Brown 2010, Brown and Naeth 2012) studied effects of coarse woody debris addition to reclamation substrates on soil quality and plant community development on a saline sodic overburden dump at Suncor Energy Inc. Treatments were 20 cm LFH mineral soil mix (LFH, Ae horizon from a mesic, aspen-white spruce community, ecosites b and d) over 30 cm of B and C horizon material or 30 cm of peat mineral soil mix. Both were placed over 100 cm of clean overburden. Controls had no coarse woody debris added. In the second growing season, LFH mineral soil mix had higher species richness (34 versus 25), canopy cover (57% versus 30%) and native species richness and cover (43% versus 15%) compared to the peat mineral soil mix. With LFH mineral soil mix cover of forbs (42% versus 27%), grasses (9% versus 2%), sedges (6% versus 1%), perennial (40% versus 15%) and annual and biennial species (22% versus 17%) were higher than with peat mineral soil mix. After two growing seasons, woody species cover was low in both treatments, however, higher with LFH mineral soil mix (4% versus 2%). In the first growing season, cover of non-native species was slightly higher in LFH mineral soil mix than in peat mineral soil mix but by the second growing season, it was higher in peat mineral soil mix (15% versus 10%). Continued research on these sites in third and fourth growing seasons showed woody species density and cover was greater in LFH mineral soil mix than in peat mineral soil mix (K. Forsch and M.A. Naeth unpublished). Species composition was different between the two covers, with peat mineral soil mix having more ruderal herbaceous and weed species than successional native plants. LFH amendment is currently promoting plant community and soil development; final analyses and conclusions will be available in 2013. Coarse woody debris addition was also investigated in both studies showing its surface application to either LFH mineral soil or peat mineral soil mixes increased microsites and therefore plant establishment and growth.

In 2010 and 2011, four of the above discussed research sites were further monitored to determine longer term success of LFH mineral soil mixes and to provide direct comparisons among studies (H.A. Archibald and M.A. Naeth unpublished manuscripts in preparation). At the time of assessment Syncrude research sites ranged in age from 5 years (Aurora) to 13 years (Mildred Lake) and the Suncor research site was 4 years old. Native plant species richness and woody species density were significantly greater in LFH mineral soil mix than in peat mineral soil mix at Mildred Lake. At Aurora, all LFH mineral soil mix treatments had greater woody species density than peat mineral soil mix treatments, however, only the 10 cm LFH mineral soil mix on peat sand substrate had greater native species richness than the peat sand control. Native species richness at the other sites (Suncor SE overburden dump, Syncrude W1 overburden dump) was similar among treatments. Plant diversity did not differ among cover soil types. Total vegetation cover was 35% to 40% greater in LFH mineral soil mixes at Mildred Lake, although not statistically significant likely due to high variability. Cover was greater in 20 cm of LFH mineral soil mix over sand or over peat sand than in the control at Aurora, and in 20 cm of LFH mineral soil mix at the Suncor SE overburden dump relative to the peat mineral soil mix control. There were enough significant differences to show that LFH mineral soil mix is a better cover soil than peat mineral soil mix to support development of biodiverse, native plant communities, with effects repeatable across multiple sites. Final results from this study are anticipated by middle of summer 2013.

2.2 Coal

XXXLFH mineral soil mixes have potential to improve revegetation of coal mines in the boreal, mountain and foothills natural regions. Currently, agronomic and native species are used to revegetate disturbed areas. Recent approvals and closure plans encourage the increased use of native species, for example, “continue to evaluate the opportunities for incorporating native species into the final landscape and shall consider maintaining native vegetation islands; maximum direct placement of salvaged surface soil; elimination of all agronomic species from the mix that have proven to be invasive and persistent under the climatic conditions existing at the mine; and maximum incorporation of native seed in the seed mix” (Alberta Environment 2011b, s.6.5.3). Use of native species may become a higher priority if requirements such as those in the Obed Mountain approval (Alberta Environment 2011b) are added to other approvals. As with past approvals, the Obed Mountain approval requires reclamation to equivalent land capability, but also indicates the “approval holder shall reclaim the land so that the reclaimed soils and landforms are capable of supporting self-sustaining, locally common forest ecosystems” (Alberta Environment 2011b). This could be facilitated through the use of the seed and propagules contained in LFH, similar to what has occurred in the oil sands.

2.2.1 *Propagule Bank*

Very little research has been conducted on soil propagule banks of ecosystems in the Rocky Mountain natural region, where most mountain coal mines are located. A few mines are within the boreal forest and research conducted in the oil sands would be relevant to these mines as climate conditions are similar between the two regions (Government of Alberta 2006).

Only one study in the boreal region assessed the soil propagule bank at a coal mine. The seed bank in a young aspen forest, 11 years since cutting, at the southern edge of the dry mixedwood boreal subregion on the Genesee coal mine in west central Alberta, had lower species richness than those in the Athabasca oil sands region (Fair 2011). Seed bank samples were spread to a depth of 2 cm and fertilized with slow release 13:13:13 nitrogen:phosphorus:potassium. In the upper 10 cm of forest floor, 42 species (4 grasses, 35 forbs, 3 shrubs) were identified, 32 of which were native. Dominant species were ruderal or early successional and included sedges, red raspberry, blue joint (*Calamagrostis canadensis*), dandelion, neckweed (*Veronica peregrine*), hemp nettle (*Galeopsis tetrahit*) and willow herb (*Epilobium ciliatum*). Depth affected species richness but not density of emergents, with the upper 5 cm depth having more forb and non-native species than the 6 to 10 cm depth. Species composition of the seed bank was not similar to the plant community; 19 species from the plant community were missing from the seed bank and 27 species from the seed bank were not present in the plant community. Light, temperature and nutrient addition may have affected which species emerged under controlled conditions.

2.2.2 *Revegetation*

Experimental research comparing use of LFH mineral soil mixes and conventional reclamation practices for revegetation of reclamation sites has not been conducted on mountain coal mines, however, there have been two studies on use of LFH mineral soil mix for reclamation (Table 1) and many operational trials. The mountain and foothills coal mine industry has commonly salvaged organic soil horizons together with underlying mineral soil horizons for placement on sites to be reclaimed, as topsoil is a limited resource in the region. This includes highly organic soils in lower lying mine areas, and Luvisols, which include LFH layers, in many higher elevations. A complicating factor to evaluating success of operational trials is that sites were regularly seeded with a mix of native and agronomic species, as this was necessary to control erosion particularly on slopes and in some cases to meet approval requirements[3] and few details were provided on salvage and placement of LFH mineral soil mix. Both of these factors will influence revegetation from soil propagule banks.

A long term soil and vegetation monitoring program initiated in 2002 at Obed Mountain Mine provides insight into late 1980s and 1990s reclamation practices (Leskiw et al. 2007). On five sites reclaimed between 1987 and 1998 plant cover, species richness and composition were assessed. Four sites had direct placed LFH mineral soil mix, two in 1997, one in 1989 and one in 1987. All were seeded with agronomic mixes at 75 kg ha^{-1} and fertilized at 150 kg ha^{-1} with

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[3] This tension between competing reclamation objectives (in this case erosion control vs. native species) shows the importance of taking a holistic view when determining "success" of a particular reclamation practice or setting regulatory requirements related to a particular practice.

12:51:0 nitrogen:phosphorus:potassium, except the 1987 site Two sites were planted with pine and spruce seedlings, including the unseeded research site. Three sites had LFH mineral soil mix with 30 cm average placement depth. Placement depth for the 1987 site was likely 30 cm based on approvals and other sites. A 1994 site that did not receive a cover soil and two logged references sites, one logged in 1983 and the other logged and burned in 2001 were also assessed.

Without LFH mineral soil mix, no native species established (Leskiw et al. 2007). Native species richness was considerably greater on unseeded LFH mineral soil mix than on LFH mineral soil mix seeded with an agronomic mix. Red clover (*Trifolium pratense*) and dandelion were dominant species on seeded sites, which may have prevented establishment of native species through shading and resource competition. A unique community of native species established on unseeded LFH mineral soil mix, contributing considerably to total cover. Native species richness declined from 2002 to 2006 on seeded sites, but increased on unseeded LFH mineral soil mix and references sites. Moss cover was very high on unseeded LFH mineral soil mix and planted trees had good survival; trees were doing poorly on seeded LFH mineral soil mix. Direct placement was more effective for native plant species establishment and provided a superior rooting environment.

A similar plant community assessment on recently reclaimed sites with LFH mineral soil mix was conducted at Cardinal River Coal Mine (Arregoces et al. 2008, Leskiw and Pollard 2001). LFH mineral soil mix was direct placed on two sites and seeded with a grass mix in 2001. Placement method was rough mounding, which resulted in variable soil depth and increased microtopographic heterogeneity. After the first growing season, vegetation cover was < 5% and was comprised mainly of horse tail (*Equisetum arvense*), with willow and ground juniper (*Juniperus* species), two types of fescue (*Festuca* species, large and small) and white clover (*Trifolium repens*). Woody debris cover was < 5% compared to 25% on the reference site. Species richness on one reclaimed site was similar to that of the reference site (23 versus 20 species), however, composition was different. The other reclaimed site had 12 species.

Three more research sites were assessed in 2007, two reclaimed and a reference (Arregoces et al. 2008). LFH mineral soil mix was stockpiled for approximately 10 years prior to placement using rough mounding on two reclaimed sites in 2005. One site was seeded with a native and agronomic species mix in 2006, and both were planted with pine and spruce in 2007. Vegetation cover was 23% and species richness 34 on unseeded LFH mineral soil mix, and 40% cover with 21 species on seeded LFH mineral soil mix. Of these 21 species, 18 were natural colonizers from propagule banks or adjacent areas. Moss, shrub and tree species richness and cover were greater in unseeded LFH mineral soil mix than seeded, although total cover was low compared to the reference. Non-native agronomic plant species, specifically clover and creeping red fescue (*Festuca rubra*), whether seeded or not, were on all reclaimed sites and likely invaded from the adjacent areas.

In winter 2008-09, LFH mineral soil mixes salvaged from different aged aspen stands placed over sodic overburden at Genesee coal mine were assessed as a revegetation method for forest species (Navus Environmental Inc. 2012). Donor sites were aspen dominated with medium to fine textured soil harvested from 30 year (mature) and 10 year (young) stands. A 20 cm salvage depth included LFH and A horizons. Trees from different stands were either bladed off using a bulldozer or mulched and incorporated into salvaged material. Salvaged soil was directly placed on suitable overburden. Following a 20 cm placement, coarse woody debris, straw or no amendment were applied on top of the placed surface soil to conserve soil water and create microsites for vegetation establishment.

Vegetation establishment was assessed on placed surface soil in 2009 and 2010. Numerous native species (54) established; in 2010 the young stand had significantly more native species (34) than the mature stand (23). Common species in the bladed mature stand included American vetch, creamy peavine (*Lathyrus ochroleucus*), prickly rose, wild red raspberry and trembling aspen. Common species in the bladed young stand included American vetch, rough cinquefoil (*Potentilla norvegica*), wild red raspberry, black gooseberry (*Ribes lacustre*), common snowberry and balsam poplar. Numbers of native species in 2009 and 2010 were not significantly different between amendments and there was no interaction between salvage and amendments. Coarse woody debris had more native species followed by the control or no amendment, then the straw amendment. Salvaging a large amount of mulched woody debris (15 to 25 cm) with LFH mineral soil mix from the old stand resulted in a large reduction in native plant species number and abundance.

In 2009, placed surface soil sourced from the mature bladed forest, had average native shrub densities up to 80,000 stems ha^{-1} and native tree densities up to 12,000 stems ha^{-1}. By 2010 a large population of non-native species, mainly clover, established and decreased tree and shrub densities due to competition and dieback. Clover was likely in the seed bank of salvaged material as salvage areas were adjacent agriculture areas, although it and other non-native seed could have come from the straw. In 2010, there was a significant difference between native herbaceous cover on mature bladed (2%) and young mulched salvage treatments (7.5%). Amendments had little effect on vegetation establishment; however, coarse woody debris promoted native vegetation establishment.

In 2009, LFH mineral soil mix over overburden at the Genesee coal mine was investigated as a potential revegetation method (Fair 2011). The site was trembling aspen dominated with medium to fine textured soil and had been harvested 11 years earlier. A 15 cm salvage depth included LFH and the A horizon. A 40 cm salvage depth included LFH, A horizons and some B horizons but not Bt or C horizons. LFH comprised the upper 5 cm. It was difficult for D11 Cat dozer operators to salvage exact depths so each treatment depth varied by up to 20 cm. The relative difference was maintained with the 15 cm treatment always shallower than the 40 cm treatment. LFH mineral mix was direct placed at the same depth as salvaged in winter when the ground was frozen.

In the first growing season, 73 species established (4 grasses, 59 forbs, 10 shrubs); 49 were native. Dominant species were hemp nettle, snowberry (*Symphoricarpos albus*), american vetch, blue joint and red raspberry. Other than snowberry, the species were dominant in the upper 10 cm seed bank. Of the 73 species, 41 were in the plant community or donor site seed bank; 21 from the donor site were not found at the reclamation site, most notably bunchberry (*Cornus canadensis*). Of the remaining 32 species which naturally colonized the site, 18 were native.

The 15 cm salvage and application depth had greater cover (25% versus 20%) and species richness (69 versus 58), but was not superior to 40 cm salvage and application depth for species composition. Dominants were the same except for blue joint and white clover in the 15 cm depth and creamy peavine and wild sarsaparilla (*Aralia nudicaulis*) in the 40 cm depth. Blue joint and white clover, while not dominant in the 40 cm depth, were abundant. The 11 species missing from the 40 cm depth were a mix of annual, non-native species and perennial, native species and all were uncommon (< 10% of plots). The 15 cm depth had significantly greater cover and density of native, non-native, forbs, grasses and shrubs than the 40 cm depth. While differences in shrub cover and density between treatments was statistically significant, biologically the difference was small (both < 5% cover, 4.6 versus 3.6 plants m^{-2}).

Once LFH mineral soil mixes were placed, rough surfaces improved vegetation establishment on reclaimed mountain coal mine sites, including survival of planted trees (Cardinal River Coals 1991, 2001, Knapik and Macyk 1996). Since 2000, Cardinal River Coals has worked with rough mounding which involves dumping each load of LFH mineral soil mix in a mound with no smoothing, the next load would be dumped adjacent, but not over, the last load. This reduces compaction and creates microsites, which improve plant establishment. Tree survival was improved likely due to increased root growth with reduced compaction and increased shelter and snow accumulation in microsites which increased soil water (Macyk and Drozdowski 2008). Gregg Mine developed specialized chains and other implements which were dragged across reclamation sites. While this increased roughness and microsites for plant establishment, it may increase soil compaction.

Topsoil islands were created at the Luscar mine throughout the 1980s (Macyk and Drozdowski 2008). Topsoil was placed in strategically located islands on sites to be reclaimed at greater depth than if topsoil was widely spread across the site. Minimum depths were 30 cm with some at 50 cm. Effectiveness of this method cannot be determined as no monitoring reports or data were located. Strong (1994) assessed vegetation composition on three topsoil islands, created in 1982 and 1983. Two of the islands were seeded with a non-native mix thus vegetation was dominated by seeded species. The third was not seeded and was dominated by northern wheat grass (*Agropyron dasystachyum*) and dandelion. In general, vegetation cover was greater on topsoil islands than other reclaimed rock dumps of similar or older age.

2.3 Other Alberta Studies

In a study of seed banks from two jack pine and two white spruce stands southeast of Slave Lake, Alberta, 505 to 2,650 seeds m^{-2} were found; 47% to 78% were in the LFH but not in the 5 cm of mineral soil below (Fyles 1989). While these seed densities were higher than those in studies of other northern coniferous forests, they can be explained by the current vegetation composition and history. Thirteen species in the seed bank were identified; approximately half were in extant vegetation.

In boreal forest at the Ecosystem Management Emulating Natural Disturbance experimental area in north western Alberta, neither forest type (broadleaf or conifer) nor harvesting intensity (10%, 50%, 75% or 100% retention) affected bryophyte diaspore bank composition (Caners et al.

2009). Edaphic factors including calcium concentration, pH, sodium concentration, charcoal, potassium concentration, LFH depth and silt and spatial proximity were the most important variables. Soil samples were collected separately from LFH and mineral soil (to 5 cm). A total of 56 species germinated; most were perennial (37%) or colonist (33%); others were fugitive (1.9%), short lived (14%) and long lived (15%).

3 LFH MINERAL SOIL MIXES AS A RECLAMATION SOIL

This section of the report covers physical, chemical and microbiological properties of salvaged LFH mineral soil mixes for use in reclamation. In reclamation, LFH has been mixed with underlying mineral soil during salvaging and/or placed in an open disturbed environment and thus no longer acting in the same way as a natural soil. When LFH and upper layers of mineral soil are salvaged and used in reclamation they can create, or contribute to, a substrate with good properties for revegetation. In oil sands and coal mine regions, various mine waste materials are produced and placed on the disturbed landscape for reclamation. Oil sands mine wastes are generally void of organic matter, with high clay or sand content; mountain mines have clay, gravel and rock contents; both have low nutrients and low soil water retention; many are sodic or saline and in the oil sands may contain residual hydrocarbons (Macyk and Drozdowski 2008, Naeth and Wilkinson 2004).

Physical and chemical properties of LFH mineral soil mix is often more suitable for plants than unamended spoils and overburden after large scale mining. When LFH mineral soil mix is used as a soil rather than a plant propagule or seed source, mixing of mineral soil with LFH is less of a concern and may even be an asset. Organic LFH layers can add nutrients and increase soil water retention. The fines present in some underlying A horizons can improve soil texture, nutrient content and availability and soil water retention. Microorganisms of undisturbed forest are transported in the salvaged upland surface soil and may contribute to recovery of disturbed sites to natural forest vegetation.

3.1 Oil Sands

3.1.1 *Physical Properties*

Much of the work on LFH mineral soil mix as a soil amendment for reclamation in the boreal forest has been done in the Athabasca oil sands, starting with research by Macyk (2006a) on whether LFH and underlying sandy textured mineral soil horizons would be suitable soil capping materials. Soil physical properties varied depending on the soil unit from which material was salvaged. Macyk concluded soil texture in Ae and lower horizons was the most limiting factor for using LFH as a reclamation capping material as most were rated poor. Recommendations were thus made to salvage LFH for all sandy soil units in the Athabasca oil sands region (Macyk 2006a). LFH and H horizons of Bitumont soils > 30 cm combined were to be salvaged separately from underlying mineral soil. Although ratings for underlying sandy materials were sometimes poor due to coarse texture and low water holding capacity, the thin (5 to 10 cm) LFH of other soil units was to be salvaged with this underlying material, since it would not be operationally feasible to salvage only a 5 cm layer.

Following placement on a reclamation site, there were few differences in texture and bulk density between LFH mineral soil mixes and standard peat mineral soil mixes salvaged from adjacent sites. Differences occurred among study sites and demonstrate the variability inherent among soil units and ecosites. For example, in Suncor's Steepbank North Dump, no significant differences in texture were found between LFH mineral soil mix and the standard peat mineral soil mix control (AMEC Earth & Environmental 2007, AMEC Earth & Environmental and Golder Associates 2010b). Surface bulk density was highest in LFH mineral soil mix (1.18 g cm^{-3}) and lowest in LFH mineral soil mix combined with peat mineral soil mix (0.83 g cm^{-3}). LFH mineral soil mix and peat mineral soil mix in 0 to 20 cm depths were similar in texture, varying from sandy loam to sandy clay loam to loamy sand, at Suncor Dyke 11A South, although peat mineral soil mix had higher clay content (Suncor Energy Inc. 2008).

Brown (2010) reported in the first two growing seasons that clay content was significantly greater in peat mineral soil mix, and silt was significantly greater in LFH mineral soil mix. By the fourth growing season, there was no difference in texture (K. Forsch and M.A. Naeth unpublished). Statistical analyses of vegetation and soil properties have not been concluded, however, from preliminary data summaries, average bulk density of LFH amendment is less than peat mineral soil mix four years post-construction when comparing treatments not amended with woody debris only.

Mackenzie (2006) assessed LFH mineral soil mix and peat mineral soil mix placed at 10 and 20 cm depths on a saline-sodic overburden dump. Regardless of placement depth, peat treatments had significantly higher organic material on the surface than LFH treatments; LFH had significantly more mineral material, woody debris and moss than peat. During salvaging more mineral material was incorporated in LFH donor soil, increasing mineral soil content; woody debris was more abundant on the LFH donor site than the peat donor site. Increased mineral material may result in fewer available propagules near the surface and less organic matter, both variables related to successful plant establishment. Bulk density in the upper 7.5 cm of surface soil was significantly higher in LFH than peat; penetration resistance was significantly higher in the upper 10 cm of LFH mineral soil mix. Surface bulk density of LFH mineral soil mix (0.74 to 0.92 Mg m^{-3}) and peat mineral soil mix (0.61 to 0.66 Mg m^{-3}) was much higher than natural LFH layers (0.13 Mg m^{-3}) and upper surface horizons of peat (0.04 to 0.07 Mg m^{-3}). Thin (~10 cm) applications of LFH mineral soil mix or peat mineral soil mix resulted in significantly greater bulk densities and mineral material on the surface. Thin applications resulted in less organic matter than thick (~20 cm) applications. When applying donor soil to thin treatments the bulldozer had to lower its blade, which increased admixing of secondary mineral soil with donor soil.

3.1.2 *Chemical Properties*

Organic matter and subsoil are often added as capping material because underlying oil sands substrates are devoid of or low in nutrients and may be sodic, saline and/or contain hydrocarbons. As with soil physical properties, soil chemical properties are often highly variable among study sites.

LFH mineral soil mix and peat mineral soil mix had larger carbon pools than mature natural sites in the Athabasca oil sands region (> 70 years old) (Macyk et al. 2007). Most studies comparing LFH mineral soil mix and peat mineral soil mix, however, reported lower carbon and nitrogen in LFH mineral soil mix (AMEC Earth & Environmental 2007, Mackenzie 2012, Mackenzie and Naeth 2010, McMillan et al. 2007, Suncor Energy Inc. 2008). Samples at 0 to 20 cm from Suncor's Dyke 11A South in the second year after reclamation show that LFH mineral mix over clay had the lowest total carbon and total nitrogen of all treatments including peat mineral soil mix over clay and peat mineral soil mix alone (AMEC Earth & Environmental and Golder Associates 2010b, Suncor Energy Inc. 2008). On a tailings dyke at Syncrude with treatments of LFH mineral soil mix over secondary, LFH mineral soil mix over peat mineral soil mix over secondary, and peat mineral soil mix over secondary, LFH treatments had lower total carbon and total nitrogen than peat mineral soil mix (McMillan et al. 2007). Natural stands had twice as much organic carbon as peat mineral soil mix, which had twice as much as LFH mineral soil mix. Soils were mainly silt loam texture and sampled to a depth of 7 cm in the fifth growing season. Both cover soils had lower total carbon, total nitrogen and carbon to nitrogen ratios than natural boreal forest soils in the region.

Sandy loam and loamy sand textured reclamation soils were sampled at the Suncor Steepbank North Dump in the first through sixth growing seasons (AMEC Earth & Environmental 2007). Sampling was to 20 cm, the full depth of the cover soils. LFH mineral soil mix had lower total carbon and total nitrogen concentrations (3.5% and 0.12%, respectively) than peat mineral soil mix (3.8% and 0.18%, respectively). A 50:50 mix of LFH mineral soil and peat mineral soil had higher total carbon and total nitrogen (6.2% and 0.26%) than either of the mixes alone. Differences were greater in the first few growing seasons, which may be important for plant establishment and growth. For example, in 2000 total carbon and nitrogen in LFH mineral soil mix were 4.7% and 0.16%, respectively, in peat mineral soil mix they were 8.4% and 0.24% and in combination they were 12.4% and 0.28%. In similar textured soil at Suncor's Southeast Dump, organic matter or organic carbon did not differ between the mixes, and total nitrogen was significantly greater in peat mineral soil mix (Brown 2010).

Mackenzie and Naeth (2010) found similar results in their research comparing 10 and 20 cm applications of LFH mineral soil mix and peat mineral soil mix. LFH mineral mix was salvaged from a site with fine textured, clay loam soil. Both applications of peat mineral soil mix had more organic matter and total organic carbon than LFH mineral soil mix, with 10 cm of LFH mineral soil mix having lower amounts than the 20 cm application. Carbon nitrogen ratios of LFH mineral soil mix were lower than those of peat mineral soil mix; although there were no differences related to application depth. Peat mineral soil mix did not always have significantly more total nitrogen than LFH mineral soil mix; only the 10 cm LFH amendment had less total nitrogen, likely related to admixing with underlying subsoil. Overall application depth had less effect on peat mineral soil mix properties than LFH mineral soil mix. Thicker applications of LFH amendment were more beneficial for plant growth than thinner applications. At Syncrude Aurora mine peat mineral soil mix had greater total carbon, total nitrogen and cation exchange capacity than coarse textured LFH mineral soil mix (Mackenzie 2012). This was in contrast to

Macyk (2006a), who considered LFH the most important layer for inclusion in capping based on its high total carbon and nitrogen content and cation exchange capacity. The differences could be due to Macyk sampling natural LFH layers compared to LFH mineral soil mix and differences in nutrient status between donor site locations.

Data on available macro nutrients were only provided in a few studies. Available nutrients are of great importance as they are in a form plants can readily use. LFH mineral soil mixes from fine textured ecosites had higher available phosphorus and potassium than peat mineral soil mix at variable application depths (10 and 20 cm) (Brown and Naeth 2012, Mackenzie and Naeth 2010). LFH mineral soil mix from coarse textured ecosites at Syncrude Aurora mine had more extractable potassium and available phosphorus than standard peat mineral soil mix (Mackenzie 2012). While differences in available nutrients between LFH mineral soil mix over clay and peat mineral soil mix over clay were not significant (AMEC Earth & Environmental and Golder Associates 2010b), peat mineral soil mix had three times the available sulphate (mean of upper and lower slope positions, 110.4 versus 303.3 mg kg^{-1}) and double the available nitrogen (4.4 versus 10.0 mg kg^{-1}) (Suncor Energy Inc. 2008). Brown (2010) found peat mineral soil mix had more available sulphate than LFH mineral soil mix but by the fourth year, available sulphate was greater in LFH mineral soil mix and available potassium greater in peat mineral soil mix (K. Forsch and M.A. Naeth unpublished).

Few differences of significance to plant growth in salinity and sodicity of the two cover soils were reported. After five years at Suncor's Steepbank North Dump there were no differences in electrical conductivity or sodium adsorption ratio between LFH mineral soil mix and peat mineral soil mix (AMEC Earth & Environmental 2007). The pH was higher in peat mineral soil mix than in LFH mineral soil mix in all years with a slight increase over time in both (6.5 versus 7.5 in 2005). LFH mineral soil and peat mineral soil mix combined had similar values to LFH mineral soil mix alone. At Suncor's Dyke 11A South, sodium adsorption ratio was similar between LFH mineral soil mix (3.3) and peat mineral soil mix (3.5) (mean of upper and lower slopes); electrical conductivity was lower in peat mineral soil mix (1.4 dS m^{-2}) than LFH mineral soil mix (2.9 dS m^{-2}) (mean of upper and lower slopes) (Suncor Energy Inc. 2008). Mackenzie and Naeth (2010) found no relationship between pH and cover soil with fine textured LFH mineral soil mix. With coarse textured LFH mineral soil mix, pH and electrical conductivity were lower than in peat mineral soil mix with sand (Mackenzie 2012). McMillan et al. (2007) reported higher pH in LFH mineral soil mix from a coarse textured site (5.95) than peat mineral soil mix (5.51); both were higher than undisturbed boreal forest (5.38). Six to ten years following reclamation, Hahn (2012) found LFH mineral soil mixes and natural sites had similar pH while peat mineral soil mix pH was approximately 0.7 units higher.

Oil and grease was considerably higher in peat mineral soil mix than LFH mineral soil mix in surface soil (sample depth not provided) at Suncor's Dyke 11A South (AMEC Earth & Environmental and Golder Associates 2010a). A study at Suncor's Steepbank North Dump reported no differences between the two reclamation substrates in surface (0 to 20 cm) or subsoil (20 to 50 cm) bitumen content (AMEC Earth & Environmental and Golder Associates 2010b). Mean surface oil and grease was 1,593 mg kg^{-1} in LFH mineral soil mix and 8,660 mg kg^{-1} in peat mineral soil mix and 10,487 mg kg^{-1} and 6,410 mg kg^{-1} in clay subsoil, respectively (AMEC Earth & Environmental and Golder Associates 2010a).

The above studies assessed soil chemistry following placement on reclamation sites, most following some stockpiling (Table 1). Mackenzie (2012) compared soil properties at the donor site to those in active stockpiles of two sizes, small (4 x 15 m, 3 m high) and large (36 x 20 m, 6 m high), to provide insight into changes that occur when stockpiling. Stockpiling LFH mineral soil mixes significantly altered the forms and availability of nutrients susceptible to oxidation and reduction reactions. Oxygen decreased with depth over time. Extractable boron and nitrate decreased with increased storage time. Available ammonium and phosphate, soluble potassium, electrical conductivity and sodium adsorption ratio substantially increased in large stockpiles, but not in small stockpiles. These changes result from soil going from aerobic to anaerobic states. Rate and magnitude of change was affected by porosity, organic matter content, water content and temperature. Stockpiles that initially became most anaerobic were constructed in fall versus winter. The fine textured, large stockpile was most anaerobic. Long term impacts to nutrient availability using spread stockpiled soil are unknown.

3.1.3 *Biological Properties*

Few studies have been conducted on microbiological properties of LFH mineral soil mixes used in reclamation in the oil sands. Previous research has mostly been conducted on peat (Danielson et al. 1982, Visser et al. 1984a, b). Two studies were conducted on already established sites so longer term data could be collected in the future.

McMillan et al. (2007) investigated soil microbial properties of reclamation plots established by Lanoue and Qualizza (2000). Coarse textured, LFH mineral soil mix over secondary or peat mineral soil mix (0 to 7 cm) had higher microbial biomass nitrogen than peat mineral soil mix, although less than natural soils. Microbial biomass carbon was highly variable and numerically greater in LFH mineral soil mixes (383.0 to 413.8 versus 302.1 mg kg^{-1}). Microbial biomass typically declines following disturbance and natural soils had more microbial biomass carbon and greater net ammonification and net mineralization rates than reclaimed soils. LFH mineral soil mix had higher gross and net nitrification rates relative to natural forest soils. LFH mineral soil mix had higher microbial activity than peat mineral soil mix regardless of soil water content. At 30% water content, LFH mineral soil mix over secondary had significantly more microbial biomass carbon and higher respiration rates than LFH mineral soil over peat mineral soil mix.

In contrast to other studies, Hahn (2012) worked on established sites at Syncrude (Lanoue and Qualizza 2000, Mackenzie 2006) and Suncor (AMEC Earth & Environmental 2007) comparing microbial properties in LFH mineral soil mix and peat mineral soil mix to those of natural sites. In soil (0 to 7.5 cm) collected annually from 2004 to 2010, microbial biomass increased since reclamation on all sites, averaging 20% of that in natural soils in 2010. On a per gram of soil carbon basis, microbial biomass was greater in LFH mineral soil mix than in peat mineral soil mix. The microbial community composition of LFH mineral soil mix was more similar to that of the natural forests than the peat mineral soil mix was. Hahn suggested that lower pH in the LFH mineral soil mix and differences in vegetation species composition may explain the differences between the reclamation treatments. Natural soils had five to six times greater gravimetric water content than reclaimed sites, which varied by site rather than by treatment. In contrast to the results of McMillan et al. (2007), soil water was not the main driver of microbial communities on the reclaimed sites in the Hahn study.

A study of multiple reclaimed and natural sites in the oil sands concluded substrate rather than time since reclamation was important for microbial communities (Dimitriu et al. 2010). While LFH mineral soil ("directly placed surficial materials salvaged from adjacent areas") and peat mineral soil mixes were not directly compared, enzyme activity was greater in LFH mineral soil mix over tailings sand than peat mineral soil mix over tailings sand. Reclamation prescriptions based on tailings sand versus overburden had different effects on the microbial community. In general fungal to bacterial biomass, pH and woody debris were key factors in explaining microbial community composition, and all were greatly affected by cover soil source.

Brown (2010) compared microbial biomass carbon in LFH mineral soil mix and peat mineral soil mix in the first year after placement. LFH mineral soil mix had four times more soil microbial carbon than peat mineral soil mix. Mycorrhizal biomass, measured by root glucosamine, was greater in LFH mineral soil mix. Woody debris cover had no effect on soil microbial biomass or root glucosamine. Soil microbial carbon was considerably lower in both treatments than in older LFH mineral soil mix and peat mineral soil mix reclaimed sites (e.g., MacMillan et al. 2007) and it was anticipated that soil microbial carbon would increase with time. Root glucosamine was species dependent and may be affected by species composition at a site.

Beasse (2012) found that fresh or stockpiled LFH material had greater microbial activity based on basal respiration and a more structurally distinct microbial community based on phospholipid fatty acid analysis than fresh or stockpiled peat. Basal respiration is a good measure of organic mineralization and decomposition in soil. Fresh LFH had a greater basal respiration rate and different microbial community composition than stockpiled LFH material. Stockpiled materials had been stored for several months. Microbial activity only increased with increasing soil water content in fresh LFH. Adding stockpiled LFH material to stockpiled peat increased soil microbial activity compared to peat alone and provided a community more similar to stockpiled LFH than peat. The mixing of peat with LFH, which is in limited supply, could be an alternative to placing either alone to restore the soil microbial community of the undisturbed forest.

3.2 Coal

3.2.1 *Physical Properties*

Depth of the undisturbed LFH layer in the foothills subregion is highly variable, averaging 10 cm (5 to 30 cm) (Leskiw and Pollard 2001). Ah horizons averaged 28 cm (20 to 40 cm). At higher elevations, LFH was negligible or absent (Strong 2000). At Grande Cache, some soil units had no salvageable soil, while others had 10 to 25 cm. Thus removing the LFH layer alone or with the A horizon may be operationally difficult. Depth of soil horizons is more variable in the foothills subregion than in the oil sands region due to slope (Leskiw and Pollard 2001, Macyk 2000, 2006b) and is an important factor when considering an operationally feasible depth of salvage of LFH mineral soil mix. Approvals currently do not require more than 30 cm of cover soil unless over sodic mine spoil.

Soil assessments rate LFH mineral soil mixes used in reclamation of mountain coal mines as good based on their consistence and stoniness (Leskiw 2009). Soil texture of reclaimed soils at Cardinal River Coal was loam, while natural soils were loam to 35 cm and then clay loam below that depth (Leskiw and Pollard 2001). Upper soil layers were similar to Ah horizons of the surrounding natural soils. In another study, soil physical properties were similar to those of the reference soil (Arregoces et al. 2008).

A number of comprehensive studies have been conducted on plant community development on unreclaimed coal mines 5 to 25 years after abandonment. The consensus is that a diversity of native and non-native species establish with time, however, cover remains low without organic amendment to increase nutrient and soil water holding capacity (Baig 1992, Russell and La Roi 1985, Strong 2000). Recovery of native species following cutting and burning in the foothills is more rapid than on reclaimed coal mine sites which may be due to propagules that allow native species to re-establish vegetatively, as found in the oil sands.

3.2.2 *Chemical Properties*

LFH mineral soil mixes currently used in reclamation of mountain coal mines are rated fair to good based on soil quality criteria for reclamation (Alberta Soils Advisory Committee 1987). Recent soil assessments at the Obed Mountain mine identify pH (6.6 to 7.5) as the most limiting factor, with poor to fair rating for saturation percentage on the upper 20 cm at some sites due to high coal content (Leskiw 2009). Organic carbon was greater than 2%. High pH was likely due to less organic matter, as this thin layer is usually incorporated with mineral horizons during placement. Greatest limiting factors to soil quality at the Luscar mine in the depth to mine spoil material were pH and sodium adsorption ratio (Arregoces et al. 2006). At Cardinal River Coal, pH was also a limiting factor where it was higher than that found in natural soils (Leskiw and Pollard 2001). Chemical properties in the upper 20 cm of reclaimed soil were similar to natural soil. In a second study at Cardinal River Coal, pH and sodium adsorption ratio were limiting; both much higher than the reference soil (Arregoces et al. 2008). Macyk (2006) concluded that while pH was higher in reclaimed soil than references it was not limiting plant growth based on research since the 1970s.

Fair (2011) reported that total nitrogen and nitrates in the upper 10 cm of reclaimed soil at Genesee Mine was greater with 40 cm salvage and placement depths than with 15 cm salvage and placement depths. These results may be explained by the increased plant cover in the 15 cm salvage treatment which therefore could have increased plant uptake of nitrogen making less available to ne measured in the soil. With 15 cm depth salvage and placement, however, there was significantly greater available potassium, sulphur and zinc.

3.2.3 *Biological Properties*

There is no published research or documented operational trials on the biological properties of LFH mineral soil mixes used in the mountain coal mine reclamation programs. Thus there are no conclusions to be drawn in this area.

3.3 Other Alberta Studies

Tan and Chang (2007) did an incubation study examining effects of LFH amendment and compaction caused by typical forestry operations. The study soil was an eluviated eutric Brunisol with silt loam texture, common in the boreal forest near Edson, Alberta. The LFH layer was approximately 5 cm and composed of needle litter, deciduous foliage and partially decomposed leaf litter, followed by 10 cm of mineral soil. Research treatments consisted of two levels of mineral soil compaction (none, severe) incorporated or not incorporated with LFH mineral soil mix. They found increased soluble carbon and nitrogen with LFH amendment and in the first five months of the experiment, microbial biomass increased. Such an increase in microbial biomass could increase nutrient availability for plants. In uncompacted soil, LFH amendment increased carbon and net nitrogen mineralization and nitrification rates. When soil was amended and compacted, net nitrogen mineralization reduction by compaction was not mitigated by the amendment.

4 ANALYSIS

4.1 Current Knowledge

Current knowledge for this literature review and analysis was drawn from data collected on six research sites in the Athabasca oil sands, two research sites were located at the Genesee coal mine and several operational sites were located at mountain and foothills coal mines (Table 1). While valuable data and insight were obtained from these studies to facilitate assessment of the relative performances of LFH mineral soil mix and peat mineral soil mix and effectiveness of methods of salvaging and placing LFH mineral soil mix, most studies did not have rigorous experimental designs and monitoring regimes, and thus rigorous statistical analyses could not be conducted. This lack of rigour in experimental site set up and in data collection results in a decreased ability to make direct comparisons among studies and to make strong conclusive recommendations on how best to salvage and use LFH mineral soil mixes in reclamation. However, these studies still serve a useful purpose and were included in the review. From these studies data trends are clear, significantly adding to the current state of knowledge on LFH mineral soil mix (Table 2).

Table 2. Comparison of effects of LFH mineral soil mix and peat mineral soil mix used in land reclamation for soil enhancing properties and plant community establishment.

Response Variable	Trend		
	Increase	Decrease	No Trend
Vegetation			
Total species richness	⇧		
Total plant cover	⇧		
Total plant density			⇔
Native species richness	⇧		
Native plant cover	⇧		
Native plant density			⇔
Non-native species richness	⇧		
Non-native plant cover		⇩	
Non-native plant density			⇔
Woody species richness	⇧		
Woody plant cover	⇧		
Woody plant density	⇧		
Soil			
Mineral content			⇔
Organic matter		⇩	
Woody debris	⇧		
Bulk density	⇧		
Penetration resistance	⇧		
Hydrogen ion content (pH)		⇩	
Electrical conductivity			⇔
Sodium adsorption ratio			⇔
Total carbon		⇩	
Total nitrogen			⇔
Available nitrogen		⇩	
Available phosphorus	⇧		
Available potassium	⇧		
Available sulphur		⇩	
Microbial biomass carbon	⇧		
Microbial biomass nitrogen			⇔
Microbial basal respiration	⇧		
Mycorrhizal biomass	⇧		
Similarity microbial undisturbed community	⇧		

Arrows ⇧ = LFH mineral soil mix increases; ⇩ = LFH mineral soil mix decreases; ⇔ = no difference or inconclusive. Increase/decrease do not mean better/worse and must be interpreted based on each response variable. Due to the complexity of experimental factors within studies and the diversity among studies, arrows represent trends.
Based on field and growth chamber studies summarized in this report.

The following factors should be considered when assessing and interpreting results from individual studies that have taken place and are reported on in this document. The lack of key information in these past studies, that precludes strong conclusions, provides very useful guidance for what is needed for more statistically useful data and stronger conclusions from future studies. Future research should be designed to ensure the information gaps identified in this review are filled.

Documentation of methods. Two of the studies provided no information on the source of LFH mineral soil mix, and most provided no details on the relative proportion of LFH to underlying mineral soil horizons. Time since harvest of the donor site; exact dates of material salvage, placement and stockpiling; condition under which material was salvaged and placed; and information on stockpiling methods were absent from most of the studies. One salvage depth was generally provided, however, operationally it was not possible to salvage at a consistent depth, and measures of variability would be useful in interpretation of the data.

Replicates and controls. Experimentally, replicates allow assessment of effects and variability of ambient and uncontrollable factors on the question of interest. Without a minimum of three replicates of each treatment including controls, more rigorous, statistical data analyses cannot be conducted. Controls and references are the baseline against which treatments are compared. Studies had three replicates for some but not all treatments. Controls, while generally established, were not directly comparable to all treatments due to changes in substrate and reclamation materials and their proportions.

Other amendments and reclamation methods. The most common amendment was fertilizer in the first and sometimes second growing seasons, and the most common reclamation method was planting woody species. While these practices may enhance plant establishment and accelerate plant community development, they interfere with a clear assessment of the effect of LFH mineral soil mix or peat mineral soil mix individually on measures of reclamation success. These factors should have been included in the experimental design, not superimposed on top of the experimental design.

Measuring success. Monitoring was often conducted by different individuals in a company or by different consulting firms and institutions, and methods were altered due to changes in project resources and expertise of individuals conducting the monitoring. Measures of abundance included cover and density, for some plant species groups. Species richness was the most common measure of diversity, although various indices, which may or may not include measures of community evenness, were calculated on a project by project basis. Most lacking was a measure of species composition based on dominance and rarity and comparisons of similarity among treatments which account for plant species composition. Data on plant species composition by treatment were not provided in most studies, however, this is important for tracking plant community development over time. In many cases only common names of plant species were used, making it difficult to determine exactly which species was found, as common names vary with jurisdiction, time and individuals. In some case only the plant genus was included. When short term observations and longer term results are available, the weight should be put on the latter in data interpretation.

4.1.1 *LFH Mineral Soil Mix Versus Peat Mineral Soil Mix*

- LFH mineral soil mix composition was somewhat different in every study reviewed. Besides soil texture differences, average depth of salvage varied, ranging from 7.8 to 40 cm. Depending on the soil unit and the ecosite, this included LFH, A, B and sometimes C horizons.
- LFH mineral soil mix resulted in greater native plant species richness and abundance in the short term (up to 10 years) relative to standard peat mineral soil mix whether direct placed or stockpiled, or whether of coarse or fine texture.
- LFH mineral soil mix increased richness and abundance of native shrub species. Prickly rose and red raspberry were the most frequently occurring species in LFH mineral soil mix.
- Total plant cover was greater when LFH mineral soil mix was used as a cover soil than other cover materials.
- Half of the studies reported that LFH mineral soil mix contained the majority of plant species found in vegetation at the donor site.
- Non-native plant cover was often greater when peat mineral soil mix was used as a cover soil. Reduced native plant cover can increase the probability of undesirable plant species out competing desired plant species.
- LFH mineral soil mix resulted in establishment of a greater number and abundance of upland forest species (woody and herbaceous) than peat mineral soil mix.
- LFH mineral soil mix increased microbial biomass nitrogen and carbon and basal respiration and resulted in a soil microbial community more similar to that of natural forest soils than the microbial community achieved with peat mineral soil mix. Lower pH in LFH mineral soil mix than in peat mineral soil mix was identified as a potential driver of these microbial differences.
- Total plant cover was greater when LFH mineral soil mix was placed over peat mineral soil mix than when placed over secondary material (defined as suitable upland soil or surficial geologic material salvaged to a depth no longer considered suitable for plant growth).
- Most field studies had stockpiled LFH mineral soil mix and peat mineral soil mix in windrows for 3 to 6 months and the LFH mineral soil mix still provided increased native and woody species richness and abundance than peat mineral soil mix.
- Early studies combining LFH mineral soil mix and peat mineral soil mix found that herbaceous cover and soil total carbon and total nitrogen were higher than with either LFH mineral soil mix or peat mineral soil mix alone. However, woody species richness was reduced in these combined LFH and peat mixes, likely due to general dilution of the seed bank.

4.1.2 *Donor Sites and Soil Salvage*

- Upper soil horizons of natural forest communities on mine sites, in oil sands and mountain coal mine regions, contained an abundant and diverse source of locally common native plant species, although not all of these species were present in the extant vegetation.
- In undisturbed boreal forests, emergence from seed and vegetative propagule abundance and richness decreased with increasing burial depth.
- When salvaging coarse textured soils, salvage depth may not be as important as placement depth for successful establishment of locally common native plant communities.
- Deep salvage ($\geq$ 25 cm) resulted in a less abundant and species rich propagule bank, including native and non-native species. However, differences were not statistically significant and plant species composition and dominance were not altered.
- Landscape heterogeneity affected operational ability to salvage at constant depth and ranges in salvage depth must be accepted.

4.1.3 *Stockpiling*

- Stockpiling LFH mineral soil mix for more than 8 months significantly reduced seed and vegetative propagule viability. Fewer species lost seed viability in small stockpiles (windrows) than in large stockpiles in the short term.
- Stockpiling LFH mineral soil mix for greater than 16 months killed all vegetative propagules and most seed for most species at depths below 1 m. Most viable seed in stockpiles was located near the surface.
- Loss of seed viability for most species with seeds buried in small stockpiles was likely caused by seeds germinating in the stockpile. Lack of oxygen was postulated as one of the main causes of loss in seed viability of seeds buried in large stockpiles; however, other factors, such as bacteria, fungi, leakage, viruses, toxic concentrations of unknown compounds could also be contributing factors.
- Increased soil temperatures and concentrations of soil gases such as carbon dioxide and methane and decreased oxygen concentration in stockpiles are indicators that anaerobic decomposition was occurring. Anaerobic decomposition was more prevalent in large than small stockpiles and soil became more anaerobic with increased depth in the stockpile and over time.
- Incorporating snow into stockpiles helped maintain seed viability in the short term; however, as stockpiles thawed the increased water content killed most seeds for most species and caused greater changes to soil chemistry and soil temperature. Equipment that loaded and spread wet soil degraded soil structure more than equipment handling dry soil.

- Stockpiling up to 8 months did not significantly reduce organic matter and transformations of various nutrients into more available forms for leaching and volatilization occurred.
- Stockpiling LFH mineral soil mix with a high percentage (50%) of mulched woody debris in small stockpiles or windrows for a short period of time (< 2 months) substantially reduced native plant establishment.

4.1.4 *Placement and Amendments*

- Direct placement of LFH mineral soil mix relative to stockpiling established a more abundant and diverse, locally common, native plant community when applied in the mountain coal mine region. However, even stockpiled LFH mineral soil mix was better than direct placed peat mineral soil mix in the oil sands.
- LFH mineral soil mix provided more available potassium and phosphorous than peat or peat mineral soil mixes.
- LFH mineral soil mix had less total carbon and nitrogen than peat mineral soil mix. Combining LFH mineral soil mix and peat mineral soil mix provided a superior source of both carbon and nitrogen.
- LFH mineral soil mix placed at very thin depths (2 cm) can increase native plant establishment. However, feasibility is low using conventional placement practices (dozers) as there is much admixing of substrate and erosion potential increases relative to placing at greater depths (> 5 cm).
- Greater placement depths of LFH mineral soil mix increased plant canopy cover; however, species richness was less affected by placement depth in the short term.
- Seeds and vegetative propagules buried deeply were less likely to emerge than seeds and vegetative propagules buried at shallow or intermediate depths; vegetative propagules buried too shallowly were more prone to drying.
- Plant establishment was enhanced on rough versus smooth surfaces, such as rough mounding at some coal mines and when surface smoothing is absent in the oil sands.
- Placement of LFH mineral soil mix on substrates with existing undesirable plant species or propagule bank reduced plant establishment from propagules in LFH.
- Seed addition increased initial cover but reduced diversity in the long term if non-native or aggressive species were sown. Many non-native species used in reclamation were persistent. Seeding is necessary in mountain and foothills regions, however, short lived agronomic species should be used with LFH mineral soil mix.
- Application of woody debris increased woody plant establishment when added to LFH mineral soil mix or peat mineral soil mix. Nitrate was immobilized.

- Application of plant derived smoke water to native boreal seeds and LFH mineral soil mix enhanced germination of various boreal species including shrubs. The presence of some species on reclamation sites may be dependent on this amendment.

4.2 Predictions Based on Current Knowledge

LFH mineral soil mix reclamation research in Alberta is relatively recent; therefore data to support long term benefits of LFH mineral soil mix for reclamation are limited. However, taking into consideration the literature from undisturbed and naturally disturbed boreal forests and use of salvaged topsoil in reclamation elsewhere, there is solid evidence of the benefits of LFH mineral soil mix in reclamation. Thus principles obtained from this review can be used in combination with site specific research in Alberta to further develop our state of knowledge and to lead to refinement of current practices for the use of LFH mineral soil mixes in reclamation.

Based on this knowledge, use of LFH mineral soil mix, whether direct placed or short term stockpiled, will provide a more sustainable and diverse forest community than any other alternative revegetation or reclamation method (Table 2). Direct transport of LFH mineral soil mix would ensure seeds and vegetative propagules from pre-mined areas are present at the reclaimed areas where placed. Most species in the seed bank are currently not commercially available. Tree species that do not produce a propagule bank for re-establishment will likely need to be planted.

LFH mineral soil mix should continue to be salvaged from pre-mining sites and direct placed on sites to be reclaimed for best effect. Even if direct placement is not possible, short term stockpiling of LFH mineral soil mix is more effective than standard peat mineral soil mix for establishment of a native plant community.

Stockpiled LFH mineral soil mix can provide a better substrate than alternative reclamation materials for revegetation of upland forests (Table 2). Inherent chemical and physical properties of LFH and the Ae horizon are difficult to replace. Although fertilizer can be used to supplement some deficient nutrients (nitrogen, phosphorus, potassium, sulfur), it is costly and there are many other essential elements for plant growth that may not be feasible to supplement. For example, estimated costs to industry for phosphorus fertilizer application required with peat mineral soil mix could exceed over $50,000 per hectare (depending on market price and source material) to obtain the same phosphorus content from using a 20 cm deep cover of coarse textured LFH mineral soil mix (D.D. Mackenzie unpublished).

Conserving properties of LFH mineral soil mix is highly desirable considering that native upland boreal forests have grown on these soils for thousands of years. Salvaged LFH mineral soil mix provides a more uniform mix of organic and mineral soil creating a medium that provides better plant root to soil contact than alternative cover soils, such as peat and peat mineral soil mixes. LFH mineral soil mix placement, even if stockpiled, would not require specific or unique site preparation to improve root to soil contact. LFH provides a solid rooting medium with nutrients and organic matter that, in a natural state, can withstand frequent intense disturbances such as forest fires and droughts.

There is likely no stockpile construction method that can prevent loss of seed viability in the long term; however, viable seeds will exist near the surface because newly established plants from in situ propagules will disperse seeds on the stockpile surface and new root systems will establish. Stockpile construction that maximizes surface area will likely be the only feasible construction method for conserving local native plant seeds and vegetative propagules for future reclamation.

Data are inconclusive on optimal salvage and placement depths given limited empirical data from few experiments and long term monitoring; further research is required to maximize benefits of this limited resource. Sufficient surface soil should be salvaged to include all LFH. Operationally, salvaging only the LFH layer is not cost effective in most ecosites, and mineral soil may enhance reclamation material by improving soil physical and chemical properties such as pH. Amount of mineral soil acceptable or ideal is not known; however, salvaging more than 30 cm of LFH and mineral soil together can significantly dilute the propagule bank. Placement of 10 cm of LFH mineral soil mix is predicted to be the best minimum placement as it provides a deep enough rooting medium and sufficient water and nutrient holding capacity to facilitate plant establishment. Most seeds and vegetative propagules will not be buried too deeply to germinate or sprout and emerge. Deeper salvage and placement can be beneficial operationally by maximizing a limited resource and ecologically by increasing native vegetation and reducing erosion, at least short term. Woody species, however, are at a disadvantage in each scenario and are a priority for revegetation in the oil sands and mountain and foothills coal mine region. Therefore optimal depth ranges for both under a range of environmental conditions are required.

Placing LFH mineral soil mix in multiple locations throughout a reclaimed landscape and in locations more distant from undisturbed forest edges will likely be more beneficial in establishing a diverse reclaimed landscape. Seeds disperse short distances for most species with the exception of a few wind dispersed seeds; therefore, targeting placement areas that will allow plants established from placed LFH mineral soil mix to disperse will enhance seed dispersal on areas reclaimed without LFH mineral soil mix.

4.3 Primary Areas of Focus for Research

As with any environmental issue there are numerous gaps in our current knowledge. Our capacity, technologically and financially, to address all gaps is often not possible nor the need often warranted. Identification of essential questions and areas of research are required to efficiently direct limited resources while maximizing knowledge and application output. The following primary areas of focus have been identified based on our current state of knowledge on LFH mineral soil mixes and their potential to provide better reclamation outcomes than conventional soil salvage and placement practices.

4.3.1 *Soil Salvage*

Effects of salvage depth in different ecosites on re-establishment of in situ native plants needs to be further studied. The most rigorous research has been conducted on coarse textured ecosites and more research is required on fine textured sites, which have deeper LFH layers but higher fines content that may inhibit seed germination.

The proportion of LFH in each LFH mineral soil mix is different and may significantly alter research results and conclusions. The minimum and optimum proportions of LFH to mineral soil for use in reclamation are required. Proportion of LFH to mineral soil may be a more important factor in explaining differences in reclaimed plant communities than ecosite type or salvage depth. Thus all material used in future studies should be clearly described by its ratio of LFH to mineral soil, not just the depth of salvage.

Most research assessing salvage of upland surface soil for reclamation has been conducted using dozers; however, there are alternative salvage strategies that could be employed. For example track hoes have better depth control than dozers, and scrapers are an effective method that can be used to salvage soil materials.

Effects of time between timber harvesting and soil salvage on tree and shrub establishment after placement on reclaimed areas is not well understood. Once trees are removed, soil temperature and hydrologic regimes are altered and decomposition and soil microbial populations are reduced. This may subsequently reduce benefits of LFH mineral soil mix use for reclamation, including available nutrients, organic matter and propagule abundance and viability. This information should be consistently reported in future work. Time since clearing in the research to date has been 2 to 3 years.

4.3.2 *Soil Placement*

No research in forested regions of Alberta compared directly placed and stockpiled cover soils for physical and chemical properties of the cover soil or on plant establishment and plant growth. Viability of a variety of species is low after 8 months, however, often soil is only stockpiled for 1 to 6 months so a clearer understanding of propagule losses during this period is required.

The range of placement depths tested was 10 to 40 cm. Threshold depths for placement beyond which soil quality and revegetation benefits are lost are unknown. A placement depth at an operational scale of < 10 cm had not been tested. Shallower placements may not be operationally feasible as significant admixing with underlying substrate could occur potentially diluting the propagule bank and/or beneficial chemical properties depending on the substrate.

Shallow placement depths of LFH mineral soil mix may be effective in establishing diverse native plant communities at a similar rate as thick applications if applied as a thin layer to help inoculate land reclaimed with peat or peat mineral soil mix with or without surface treatments to enhance germination. This method would maximize use of limited LFH mineral soil mix and continue to make use of the beneficial properties of salvaged peat and peat mineral soil mix. This will be of particular importance in the mountain and foothills regions where LFH mineral soil mix is at times not salvageable or in very limited amounts.

Placing LFH mineral soil mix in patches or strips across a reclamation site to maximize the resource needs to be studied. Patches or strips will produce native and woody plants, which once established, will produce and disperse seed or spread vegetatively to adjacent areas of the site without LFH mineral soil mix. Egress from LFH mineral soil mix areas to peat mineral soil mix areas has already been documented.

4.3.3 *Sustainable Native Plant Communities*

Most handling techniques derived from research using upland surface soil for reclamation in the Athabasca oil sands region are based on results from short term (5 to 10 years) monitoring programs. Longer term monitoring will be necessary to make stronger conclusions about effects of salvage depth, application depth and substrate quality on plant community establishment.

Development of locally common native plant communities in the long term (> 10 years) is not well documented, although some current work suggests the benefits remain. Peat mineral soil mix on reclaimed sites may result in native plant communities similar to those on LFH mineral soil mixes, but require a much longer time period. Alternatively, native plant communities that develop on LFH mineral soil mixes may not be sustainable. There is a need to protect and continue monitoring established field research or demonstration sites for long term data.

Studies on the long term effects of LFH mineral soil mix and peat mineral soil mix need to be set up at an operational scale. When LFH mineral soil mix and peat mineral soil mix plots are small and adjacent to one another, species from LFH mineral soil mix may disperse into peat mineral soil mix plots, obscuring the actual trajectory of peat mineral soil mix plots had they not been exposed to adjacent LFH mineral mix plots. This has been documented in the current studies.

Information is required on species turnover and successional development on LFH mineral soil mix versus peat mineral soil mix reclaimed sites. We do not have data to show which species are maintained over the long term, which are added to the plant community from other sources such as wind and fauna, and which are not retained.

Information is needed on root development and nutrient uptake by plants grown in LFH mineral soil mix versus peat mineral soil mix. Specifically the lateral and vertical distribution of roots of various species needs to be determined.

Further research on soil microbial communities, including mycorrhizal fungi, in LFH mineral soil mix and their association with native species establishment and persistence is needed. The relative potential for establishment of non-vascular plants, an important component of diversity and driver of soil-plant interactions, is not known.

Empirical data on long term benefits of LFH mineral soil mix on a landscape level (pollinators, seed dispersal, wildlife movement) are needed. Resilience and resistance to disturbance of reclaimed land using LFH and peat mineral soil mixes and other cover soils needs to be studied.

4.4 Secondary Areas of Focus for Research

Secondary areas of focus for research depend on answers from primary areas of research and will assist in refining LFH mineral soil mix soil salvage, handling and placement to optimize results.

4.4.1 *Surface Treatments*

Short and long term effects of reducing compaction and surface smoothing and enhancing microtopography in the oil sands requires research. Rough surfaces have been beneficial to native plant establishment and planted tree survival in the mountain coal mine region.

Determining amount and quality of woody debris from harvested sites to include when salvaging LFH mineral soil mix requires research. Coarse woody debris enhanced establishment of native species including trees and shrubs and soil microbial communities. Most studies were on effects of woody debris as a surface application not incorporated into soil. If salvaged and placed with LFH mineral soil mix, fewer resources would be required to dispose of the woody debris or salvage and place it separately from LFH mineral soil. Although there is no well researched threshold for too much woody debris[4], there may be a critical value where woody debris can negatively impact soil quality, for example by nutrient retention caused by woody debris decay.

Planting desired forest tree species may be considered to meet end land use goals and enhance overall vegetation cover. Thus ability of the unique suite of native plants establishing from LFH mineral soil mixes to compete with planted trees and seeded species needs to be studied.

Applying plant derived smoke water on LFH mineral soil mix to enhance plant establishment is not well understood. Application of plant derived smoke water can suppress, enhance or have no effect on the germination of native boreal species; however, there are many knowledge gaps in factors such as smoke water concentration and type of plant material used to derive the smoke. Assessing the effect of smoke water on individual species may be a first step before applying to LFH mineral soil mix in the field or laboratory.

4.4.2 *Stockpile Design*

Effects of stockpiling reclamation materials on soil fauna need to be studied. Soil fauna have been associated with establishment of a range of native plant species. Soil disturbance and stockpile construction is a significant alteration or elimination of habitats of some soil fauna. Loss of seed viability in stockpiles is primarily due to microbial respiration and in situ germination. Stockpile construction methods that reduce microbial activity may help seeds retain viability for longer periods of time, however, replaced stockpiled soil may need inoculation with microorganisms. One method to test may be keeping stockpiled material frozen until required for placement, by salvaging LFH mineral soil mix under frozen conditions and capping with a thick layer of peat.

Stockpiling effects in the Athabasca oil sands region have only been studied for a short period of time and long term data will be required to make stronger conclusions about changes to soil quality over time. Even if propagules are not viable after a period of time, quality of LFH mineral soil mix as an amendment to enhance physical and chemical properties of the reclamation substrate are unknown.

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[4] See the following OSRIN report for general guidance – Pyper, M. and T. Vinge, 2013. A Visual Guide to Handling Woody Materials for Forested Land Reclamation. OSRIN Report No. TR-31. 10 pp. http://hdl.handle.net/10402/era.30381

Determining the exact mechanisms causing seed death for a range of species will help in developing potentially better stockpile designs that can help preserve seed viability. This may vary in different size and shape of stockpiles.

4.4.3 *Environmental and Economic Implications*

Salvaging, stockpiling and placing a second type of reclamation material has economic and environmental consequences as well as the benefits noted above. A life-cycle analysis of the benefits and costs would help determine the best approach.

4.5 Innovative Strategies

Farming the forest floor could provide propagules for revegetation, especially for sites in remote locations where purchasing native seed and seedlings is costly. The technique involves leaving residual seed and vegetative propagules on site after salvaging LFH. Propagules produce new seedlings that grow and mature to develop a new soil seed bank. The soil water regime, soil nutrient regime and type of vegetation community of the site determine how quickly a new LFH layer develops. This technique has not been validated; however, it may be a viable collection and propagation system in future. Further research is needed to determine which species have a positive and negative response to this technique to establish its effectiveness. A cost benefit analysis and impacts on soil quality should be completed before implementation on a large scale.

Methods to construct stockpiles to provide a supply of native propagules should be investigated. Periodic removal and placement (on mined land) of the upper surface layer of the stockpile could help preserve and create an additional source of propagules. Constructing stockpiles to create a propagule source involves repeated salvage of the upper surface layer of stockpiled soil, which contains the only significant source of viable propagules.

5 CONCLUSIONS

Based on a decade of research by industry and academia, an unequivocal conclusion is that LFH mineral soil mixes, relative to conventional peat mineral soil mixes, are a superior source of native propagules including shrubs, forbs and grasses and their placement on upland reclamation sites results in greater plant cover and species richness in early stages of reclamation. LFH mineral soil mixes increase richness and density of native shrubs, a functional group that is often missing or poorly represented on reclamation sites and even more difficult to re-establish than boreal tree and herbaceous species as commercial seed or plugs are not readily available and seed collection is resource intensive and subject to high variability. LFH mineral soil mix not only contains native propagules, but propagules of locally common native species in situ with their associated microorganisms, leading to communities and ecological processes more similar to natural forest in a shorter period of time compared to conventional reclamation methods.

LFH mineral soil mix provides a more sustainable cover soil for upland forest reclamation relative to alternatives, such as peat mineral soil mix. This is due to its desirable physical, chemical and biological properties that are more suited for reclaiming upland landscapes, considering the material is salvaged from pre-mined upland landscapes. Placement of LFH mineral soil mix transfers propagules of plant species adapted to local climates and disturbance regimes. The diversity of newly establishing plant species will continue to add to the existing plant propagule bank creating a forest community resilient to future natural disturbance.

Use of LFH mineral soil mix is beneficial for revegetation of disturbed sites, although there is much to learn about how to achieve optimal results. Factors such as time since harvesting, soil type and depth at the donor site, season of salvage and placement, salvage and placement depth and method, underlying substrate, and use of seed mixes and fertilizer on reclamation sites varied considerably among research projects and may influence the magnitude of results, although have not affected the overall outcome.

Knowledge of the success of direct placement versus use of short term stockpiled LFH mineral soil mixes is poor. Propagules in soil banks lose viability with time and depth and stockpiling exacerbates these factors. While direct placement has been successful, use of LFH mineral soil mix stockpiled in small windrows for 3 to 6 months has also been successful at establishing a more diverse and abundant native plant community than peat mineral soil mix. LFH mineral soil mix stockpiled for longer than 8 months will have few viable propagules. However, LFH mineral soil mix is not only a source of native propagules but a valuable source of soil organic matter, nutrients and microorganisms. Available phosphorus and potassium in LHF mineral soil mix are considerably higher than in conventional peat mineral soil mix, and not affected by stockpiling up to a year. Phosphorus is limiting in boreal systems and essential for initial plant establishment and root development and growth. The effect of stockpiling LFH mineral soil mix on soil microbial communities is unknown.

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7 GLOSSARY

7.1 Terms

Aerobic
With oxygen.

Anaerobic
Without oxygen.

A ecosite
Described by Beckingham and Archibald (1996). Nutrient poor ecosites on xeric, coarse textured soils with eolian, glaciofluvial or fluvial-eolian parent material. Vegetation includes jack pine, bearberry, bog cranberry, blueberry and lichen. Called lichen ecosites.

B ecosite
Described by Beckingham and Archibald (1996). Ecosites on subxeric to submesic, coarse textured soil with glaciofluvial parent material. Soil water and nutrients are intermediate between a and d ecosites. Vegetation includes jack pine, aspen, white spruce, blueberry, bog cranberry, Labrador tea, low bush cranberry, bunchberry, cream coloured vetchling and hairy

wild rye. Called blueberry ecosites.

Bryophyte
Terrestrial plants that do not contain vascular tissue and reproduce via spores. Includes mosses, hornworts and liverworts.

Coarse woody debris
Logs and twigs with or without foliage left on a site after it is cleared of standing trees as part of the pre mining process. See woody debris.

Cover soil
Material used as the top layer in a reclamation soil prescription.

D ecosite
Described by Beckingham and Archibald (1996). Ecosites on mesic, moderately fine to fine textured soils with till or glaciolacustrine parent material. Nutrient regime is moderate. Vegetation includes aspen, white spruce, low bush cranberry, buffaloberry, dewberry , bunchberry, wild sarsaparilla and hairy wild rye. Called low bush cranberry ecosites.

Diaspore
Plant dispersal unit that contains a reproductive unit of either seed or spore and some physical adaptation to transport it.

Donor site
Site from which soils, plant parts or other reclamation materials are salvaged prior to anthropogenic disturbance.

Ecosite
Ecological units that develop under similar environmental influences and are defined by vegetation, hydrologic and nutrient regime.

Emergent
Newly developed plant that often only contains a few leaves.

Forb
Herbaceous plant which is not a grass, sedge or rush.

Graminoid
Monocotyledonous plant from the families Gramineae, Cyperaceae and Juncacae, which include grasses, sedges and rushes.

Herb
Plant with a non woody stem.

LFH
Organic soil horizons, litter (L), fluvic (F), humic (H) developed primarily from accumulation of leaves, twigs and woody materials in various stages of decomposition, with or without a minor component of mosses. Normally associated with forested soils with imperfect drainage or drier.

LFH amendment
Term used by Alberta Environment and Sustainable Resources Development to describe LFH and mineral soil mixes used for reclamation in the oil sands.

LFH mineral soil mix
LFH layer as defined by the Canadian Society of Soil Science plus some underlying mineral soil. It can include residual coarse woody debris following logging such as slash and stumps. The definition is similar to that used by Alberta Environment (2010) for upland surface soils, however, the term LFH mineral soil mix is confined to include mineral layers in the 10 to 30 cm depth regardless of soil horizons included.

Native species
Species indigenous to a particular region, arriving by natural means, and developed over hundreds or thousands of years. Native is always in reference to a geographic area, such as native to Alberta.

Non-native species
Species introduced with human assistance to a particular region, intentionally or unintentionally. Not to be confused with invasive species, which can be native or non-native.

Propagule
Part of a plant that produces a new individual. For example, seed, rhizome, vegetative bud.

Propagule bank
Upper soil layers which contain seed and plant parts (stolons, rhizomes, vegetative fragments) and under the right conditions will produce new plants.

Receiver site
Disturbed site designated for reclamation and receipt of amendments to ameliorate soil conditions and re-establish a vegetation cover.

Ruderal species
Opportunistic or early successional species that can take advantage of the initial flush of nutrients following land disturbance thereby readily establishing and dominating the site for a period of time.

Secondary
Overburden material obtained from suitable upland soil or surficial geologic material salvaged to a depth no longer considered suitable for plant growth (Yarmuch 2003).

Seed bank
Place where seed naturally or artificially collects. For example, a soil seed bank.

Smoke water
Water amendment created when plant material is burned and the plant derived smoke funneled into a vessel containing water. Water is applied to seed or soil to enhance germination of some species.

Soil unit
Soils developed under the same environmental influences and defined by geological parent material, horizon development and depth.

Species diversity
Number, abundance and/or evenness of species on a site. Species richness is the most frequently used measure of species diversity.

Species richness
Number of different species on a site.

Subshrub
Woody species with a low, prostrate or creeping growth form.

Substrate
Base material or combination of materials that amendments are added to as part of the reclamation process.

Upland surface soils
Term used by Alberta Environment and Sustainable Resources Development to describe upper layers of soil, including LFH and mineral horizons, in a natural forest community.

Woody debris
All dead woody material in a forest ecosystem, including wood on the forest floor such as logs, fallen limbs, twigs, bark, and woody fruit; wood below ground such as dead roots and buried wood; and standing wood such as snags and stumps.

7.2 Acronyms

LFH	Litter, Fibric, Humic
OSRIN	Oil Sands Research and Information Network
SEE	School of Energy and the Environment

LIST OF OSRIN REPORTS

OSRIN reports are available on the University of Alberta's Education & Research Archive at https://era.library.ualberta.ca/public/view/community/uuid:81b7dcc7-78f7-4adf-a703-6688b82090f5. The Technical Report (TR) series documents results of OSRIN funded projects. The Staff Reports (SR) series represent work done by OSRIN staff.

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