Alternative Native Boreal Seed and Plant Delivery Systems for Oil Sands Reclamation

Dr. Amanda Schoonmaker[1], Dr. Jean-Marie Sobze[1], Dr. Erin Fraser[2], Eckehart Marenholtz[3], Ann Smreciu[4], Chris Powter[5] and Marshall Mckenzie[6]

[1] Northern Alberta Institute of Technology (NAIT)

[2] Alberta Environment and Sustainable Resource Development (AESRD)

[3] Chickadee Reclamation Services

[4] Wild Rose Consulting, Inc.

[5] University of Alberta

[6] Alberta Innovates – Technology Futures (AITF)

November 2014

Oil Sands Research and Information Network

The Oil Sands Research and Information Network (OSRIN) is a university-based, independent organization that compiles, interprets and analyses available knowledge about managing the environmental impacts to landscapes and water affected by oil sands mining and gets that knowledge into the hands of those who can use it to drive breakthrough improvements in regulations and practices. OSRIN is a project of the University of Alberta's School of Energy and the Environment (SEE). OSRIN was launched with a start-up grant of $4.5 million from Alberta Environment and a $250,000 grant from the Canada School of Energy and Environment Ltd.

OSRIN provides:

- **Governments** with the independent, objective, and credible information and analysis required to put appropriate regulatory and policy frameworks in place
- **Media, opinion leaders and the general public** with the facts about oil sands development, its environmental and social impacts, and landscape/water reclamation activities – so that public dialogue and policy is informed by solid evidence
- **Industry** with ready access to an integrated view of research that will help them make and execute environmental management plans – a view that crosses disciplines and organizational boundaries

OSRIN recognizes that much research has been done in these areas by a variety of players over 40 years of oil sands development. OSRIN synthesizes this collective knowledge and presents it in a form that allows others to use it to solve pressing problems.

Citation

This report may be cited as:

Schoonmaker, A., J-M. Sobze, E. Fraser, E. Marenholtz, A. Smreciu, C.B. Powter and M. Mckenzie, 2014. Alternative Native Boreal Seed and Plant Delivery Systems for Oil Sands Reclamation. Oil Sands Research and Information Network, University of Alberta, School of Energy and the Environment, Edmonton, Alberta. OSRIN Report No. TR-55. 61 pp.

Copies of this report may be obtained from OSRIN at osrin@ualberta.ca or through the OSRIN website at http://www.osrin.ualberta.ca/en/OSRINPublications.aspx or directly from the University of Alberta's Education & Research Archive at http://hdl.handle.net/10402/era.17507.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

REPORT SUMMARY

The purpose of this document is to review traditional and alternative systems of seed and nursery stock treatment and delivery for use in oil sands reclamation. *Treatment systems* are considered those activities conducted prior to delivery to the field site while *delivery systems* include those activities involved in physically deploying the seed and plant material on the reclamation site. *Traditional systems* are those currently in use by the oil sands reclamation community, while *alternative systems* are those that have potential or promise for use following additional research.

The traditional systems included the following seed treatment and/or delivery systems: natural recovery, direct placement of topsoil, nursery production, planting of nursery stock and basic seed broadcasting. Alternative systems were drawn from a variety sources including: forest industry, agriculture, horticulture, mining, and home gardening. Results of peer-reviewed and non-reviewed scientific studies were included when available; in some cases anecdotal observations and unpublished results were presented. The following twelve alternative systems were identified: enhancement of soil stockpiles, seed priming, seed nano-coating, seed pelleting, multi-species propagation, Jiffy peat pellet®, biodegradable containers, disc seed driller and air seeders, harrowing, push-seeder, hydroseeding and aerial seeding.

It was clear that for all the alternative systems examined, further testing would be required on native boreal species in order to determine the effectiveness of the individual system. The following systems were highlighted:

1. Inclusion of targeted seed treatment systems, such as seed pelleting and priming, prior to delivering seeds is suggested as a promising area of future research and high application potential for field trials.

2. Seedling delivery from containers with multiple species (multi-species production) and biodegradable containers are most likely to have merit for specialized applications. However, multi-species production requires verification both at the level of identifying appropriate species mixtures, optimizing greenhouse production and quantification of field performance. Biodegradable containers are a suitable option to further test on slow-growing species that are difficult to produce under standard greenhouse conditions in styroblocks.

3. Improving on basic seed broadcasting with the addition of a delivery system that would improve seed-soil contact is also suggested as beneficial. Harrowing is an easily deployable delivery system at small or large scales while large-scale delivery systems such as disc seeders and air seeders also had merit. The main drawbacks of these approaches are the necessity to conduct activities prior to roll back of woody materials on site, as well as any major surface site activities such as mounding or deep ripping. However, hydroseeding is also an option as it could be deployed following roll back of woody materials.

4. Aerial seeding may also have merit, for specific species (to be tested) on large reclamation areas as well as in situations with remote or difficult access.

5. Lastly, enhancement of soil stockpiles is an alternative delivery system that is closely analogous with the traditional delivery system and best practice of direct placement of topsoil. Reforestation of a soil stockpile, is in principle, a straightforward activity and could easily be implemented into broader revegetation and reclamation plans.

ACKNOWLEDGEMENTS

The Oil Sands Research and Information Network (OSRIN), School of Energy and the Environment (SEE), University of Alberta provided funding for this project. A National Science and Engineering Research Council Innovation Enhancement (NSERC IE) Grant and a Canadian Foundation for Innovation (CFI) grant provided support to A. Schoonmaker and J.M. Sobze during the preparation of this project.

The authors wish to thank Dr. Rciahrd Krygier, Canadian Forest Service, for his review of the draft report.

1 INTRODUCTION

The objective of a revegetation strategy is to ensure the establishment of desired plant species that are healthy and vigorous enough to survive and grow. The three common ways to achieve this objective are: seeding, planting and soil replacement (relying on entrained plant propagules to provide the desired plants). There are a variety of methods to enhance the potential for successful plant establishment, including treatment of seeds and nursery stock[1] prior to deployment in the field, and packaging seeds in various media to improve delivery or to provide the basic necessities for establishment (water, nutrients, soil contact).

This report summarizes[2] several methods currently used by the oil sands reclamation community as well as alternative methods that have potential to be deployed following additional research and field-demonstration to determine their effectiveness and economics. For the purposes of this report, a *delivery system* encompasses the range of activities relating to the direct or indirect treatment of seeds and nursery stock, as well as the methods for deploying seeds or nursery stock in the field.

1.1 Need for an Enhanced Delivery System

Approximately 9.24 million hectares of oil sands in the Athabasca, Cold Lake and Peace River areas are currently under lease (Alberta Energy 2014), suggesting that significant expansion is underway or planned. Only a small portion of the Athabasca oil sands will be mined; the remaining Athabasca leases and all of the Cold Lake and Peace River deposits will be extracted through in-situ technologies. The areal extent of oil sands-related disturbance will be considerably higher than other industrial activities. Thus the need for operationally feasible and cost-effective methods to apply native boreal plant propagules following industrial development is growing exponentially.

Almost all native boreal propagules are collected from the wild on public land[3]. This is a very expensive endeavour, and in many cases, insufficient to meet reclamation needs. There is an inconsistent availability of seeds and a general lack of understanding regarding the implications of repeated seed removal on the forest plant community (Oil Sands Research and Information Network 2013). As a result, it is even more critical that the available seed is used in the most effective and efficient manner.

---

[1] One could argue that production of container or bare root revegetation stock in a greenhouse is an enhanced seed treatment system, but for this report we will consider them separately.

[2] This is not intended to be an exhaustive review of all available literature. Instead it provides an overview of methods with selected references to provide context.

[3] The Oil Sands Vegetation Cooperative (OSVC) is an Environmental Priority Area-led COSIA initiative that provides coordinated efforts in native plant seed collection for use in reclamation by partnering COSIA members – http://www.cosia.ca/initiatives/land/oil-sands-vegetation-cooperative

The alternative delivery systems described in this document should be viewed as additional tools that practitioners can use. The availability of seed and objectives or constraints on site will dictate which tool, or combination of tools, best fits the situation and circumstances. Sites waiting for reclamation cover a wide range of forest ecosystem types, soil types, and moisture regimes, and they vary in age since time of disturbance. Some sites have naturally recovered whereas others require assistance to start regenerating. The complex interactions between different disturbance types, intensities and the spatial and temporal factors associated with the disturbances require a wide range of treatment and delivery systems to achieve reclamation goals.

1.2 Life Cycle of Revegetation Stock

The following sections describe the "life cycle" of a plant used for revegetation. Methods to improve revegetation success target different parts of this life cycle as outlined in Figure 1.

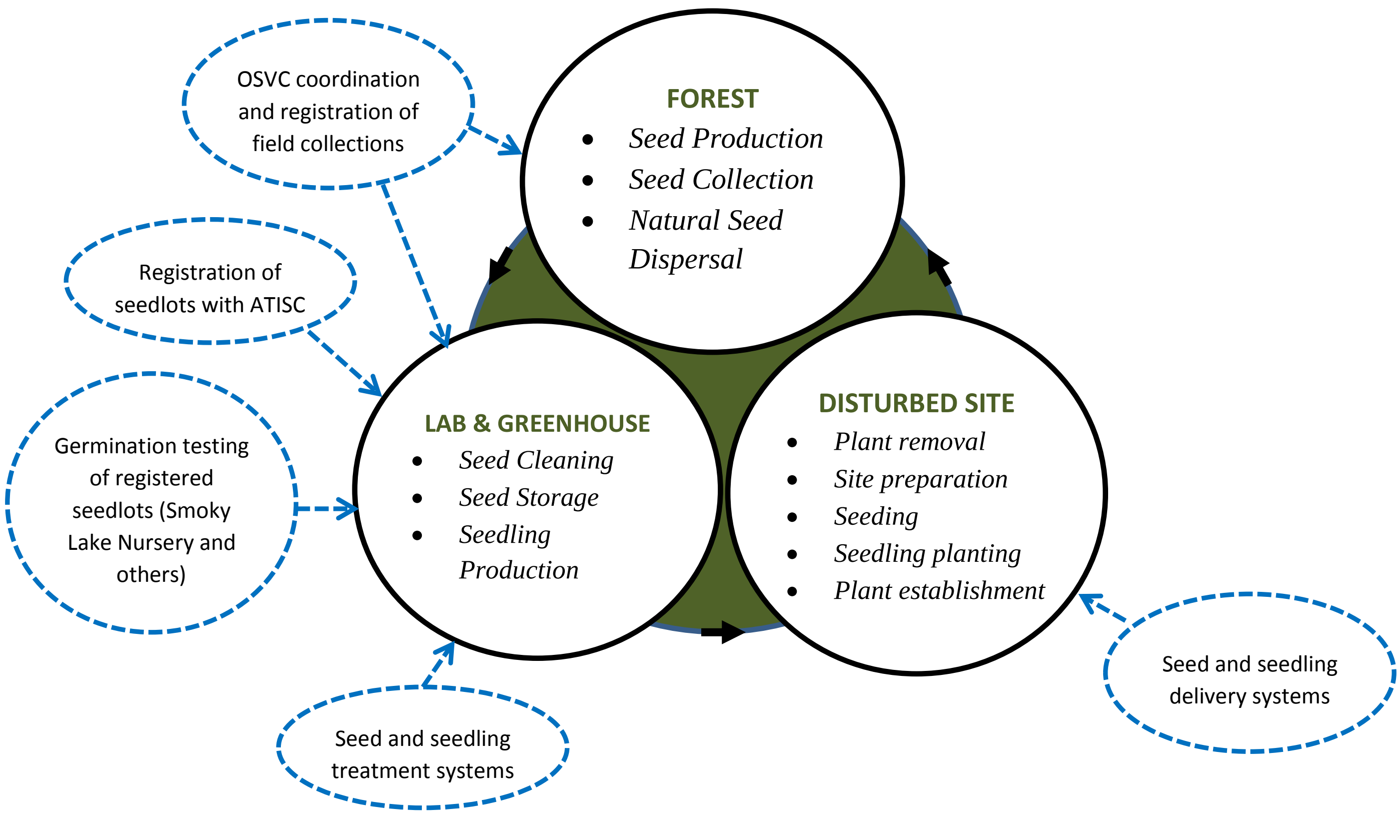

Figure 1. Life cycle of revegetation stock in context with regulatory requirements (registration and germination testing).

1.2.1 *Seed Collection*

With the exception of some conifer species that carry serotinous cones throughout the year, seed collection timing in the boreal forest is critical. Seed collection period varies from as little as a few days for species such as aspen to possibly weeks for species such as green alder or rose. However, there is little available quantitative research guiding optimal harvest time windows as species may have visibly 'ripe' seed for long periods but germination and long-term viability may peak over a much shorter period of time.

Depending on the type of plant (tree, shrub, herbaceous) and its height, seeds/fruits are collected from felled trees and shrubs, or from standing shrubs and herbaceous stems when the seeds/fruits can be accessed from the ground. Collected fruits must be kept cool as some may undergo changes in their germination responses when exposed to high temperatures in the field. Native shrub seed collection is labor-intensive as the fruits are usually picked by hand. Establishing seed orchards can reduce collection costs over the long-term, avoid donor site damage, establish phenotypic locales, and provide a more dependable seed bank over time (Oil Sands Research and Information Network 2013). At the same time, seed orchards require long-term dedicated space, would need to be established in a way that manages genetic diversity and adaptation in the composition of parent plants and would need to consider seed zone transfer rules in Alberta.

1.2.2 *Seed Cleaning and Storage*

Efforts in seed extraction/cleaning vary significantly in intensity depending on the species. Methods vary, depending on the form of the seed at maturity, fruit, capsule or cone. Fleshy seeds are usually cleaned using wet sieving or gold panning methods. Seeds in capsules can be cleaned using a strong air flow through screens of appropriate size (Smreciu et al. 2013[4]). Seeds in cones can be extracted by drying the cones and tumbling open cones to release seeds.

After cleaning, seed may either be utilized for plant propagation or field deployment or else dried and stored under frozen conditions (-18°C) until required. In Alberta, plant material harvested from Alberta public lands or destined for delivery on public lands must be registered with the Alberta Tree Improvement and Seed Centre (ATISC).

1.2.3 *Seed Stratification/Scarification*

Many temperate or boreal species exhibit some type of seed dormancy. Dormancy may be due to some characteristics of the embryo that prevent germination and/or some characteristics of structures including the seed coats (Baskin and Baskin 2001). Hard seed coats are impermeable to water and gases and require scarification, i.e., breaking the coat by chemical or mechanical process to make it permeable to water. Embryo dormancy can be broken by cold stratification and/or warm stratification, which involves moistening the seeds and storing at specific temperatures in the dark (or light) for weeks or months (Mayer and Poljakoff-Mayber 1982).

---

[4] For information on oil sands species see Smreciu, A., K. Gould and S. Wood, 2013. Boreal Plant Species for Reclamation of Athabasca Oil Sands Disturbances. OSRIN Report No. TR-44. 23 pp. plus appendices. http://hdl.handle.net/10402/era.37533

Seed stratification/ scarification requirements are species-specific and a number of different techniques are likely required when handling a range of native species.

1.2.4 *Seedling Production*

Nursery grown seedlings provide greater relative establishment success compared with many other delivery methods as the seed is effectively 'pre-developed' or provided with a head-start in the field due to the development of significant root and leaf/stem tissue[5].

Seedlings are most commonly produced as container stock of varying sizes and ages, though bareroot stock is also available. Seedlings may be produced in greenhouses or in outdoor nurseries. Landis et al. (1999) provide a comprehensive review on aspects of seedling production in a nursery setting.

Logistical problems of transporting seedlings to the deployment site and ensuring they arrive in a suitable condition for outplanting can be a challenge.

1.2.5 *Deployment on Site*

The deployment method will depend on the type of propagule – bare seed, packaged seed or nursery stock.

1.3 Plant/Seed Requirements for Successful Establishment

All plants require light, water, nutrition and air to some degree to persist. The quantity required varies by species. For shade-intolerant species, the light requirement is critical as these species typically do not tolerate significant competition or overshading by other species. Water constraints are often seen on coarse textured sites, on well-drained slopes and in compacted or massive fine-textured soils (these soils tend to alternate between anoxic and too dry). Seeds are particularly susceptible to drying if there is little or poor soil/seed contact. Seed and seedling establishment and survival may be reduced through predation and excessive competition.

Efforts to provide the necessary growing conditions, and to minimize environmental constraints, will enhance establishment, survival and growth of target species[6].

1.4 Reclamation Practices

Oil sands mine and in-situ operators target a specific ecosite during reclamation and revegetation. Oil sands operators outline their planned reclamation outcomes (ecosites) in the 'Life of Mine Closure Plans' that are submitted every 10 years. The recommended overstory

[5] Seedlings are also produced from vegetative cuttings (e.g., poplar, willow) however the focus of this report is on deployment of seed-based plant materials.

[6] This report focuses on efforts to enhance seeds and seedlings. There is a wide body of literature that addresses efforts to enhance revegetation of reclamation sites (soil, slope, aspect, microbiology, etc.).

tree species and minimum/ maximum planting densities for different site types[7] are outlined in the *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (Alberta Environment 2010). This document also provides a partial list of understory species appropriate for each ecosite ('a' through 'h'). Oil sands operators are required to reference this manual through their *Environmental Protection and Enhancement Act* (EPEA) approval conditions.

In-situ operators specify their planned reclamation outcomes in the Environmental Impact Assessment and EPEA Application that are submitted prior to construction of the project. These documents outline the expected impacts of the development during all stages of the project, including construction, operation, decommissioning and reclamation (Alberta Environment and Sustainable Resource Development 2013a). Operators are expected to comply with the Reclamation Criteria that were in place at the time of facility construction/abandonment. Under the 2010 Reclamation Criteria (Alberta Environment and Sustainable Resource Development 2013b), operators are to reclaim sites to an early seral stage of the ecosite/forest type of the surrounding undisturbed area (unless operators can justify why a 'vegetation override' is appropriate).

Traditional seed delivery systems include natural recovery, planting of nursery stock or direct seeding. However, delivery systems typically employed by oil sands mine and in-situ operators vary slightly and are described separately below.

1.4.1 *Oil Sands Mine Reclamation*

After soil placement is complete, reclaimed areas (commonly referred to as polygons) are often seeded with a cover crop of agronomic species (annual barley, oats or millet) or sometimes native grass species such as: slender wheatgrass, awned wheatgrass, Rocky Mountain fescue, fringed brome, spike trisetum, tufted hairgrass, ticklegrass, fowl bluegrass, Canada wildrye, and junegrass (Suncor Energy 2012, Syncrude Canada 2012). The goal of cover crop seeding is to stabilize exposed soil and prevent erosion, and protect seedlings by providing shade in summer and insulation in winter. Individual operators vary in their use of cover crops; some use/plan to use cover crop seeding everywhere whereas others identify high-erosion potential areas for cover crop seeding (Canadian Natural Resources Limited 2012, Shell Canada Energy 2012a,b, Suncor Energy 2012, Syncrude Canada 2012).

Natural regeneration is currently not used as a method of re-vegetation for minable oil sands reclamation. Disturbances are too large and reclamation areas are typically too far from seed sources for natural regeneration to be a reliable method of regeneration. Natural recovery could be used in the future for selected small disturbance areas near the edges of leases (adjacent to natural forest areas), near directly placed LFH sites, or for areas that were cleared but not developed.

[7] Site types are ecological classification units that are broader than ecosites. These units are intended to provide flexibility in re-vegetation treatments and acknowledge the uncertainty around edaphic position on newly reclaimed landscapes. Site types for the mineable oil sands region are: dry, moist poor, moist rich, wet rich and wet poor.

Currently, almost all reclaimed areas are planted with tree and shrub seedlings, and are typically planted one to three years after soil placement is complete (Canadian Natural Resources Limited 2012, Suncor Energy 2012, Syncrude Canada 2012) (Table 2). One operator has a policy of planting every reclaimed area to the maximum tree stocking recommended by the *Guidelines for Forest Reclamation to Forest Vegetation in the Athabasca Oil Sands Region*; other operators plant more variable densities.

Direct placement of LFH as a reclamation technique is considered an operational best-practice (Alberta Environment and Water 2012). EPEA approvals require operators to salvage upland surface soil from all disturbed areas. There is a general agreement among operators that the direct placement of these soils is preferable to stockpiling for both economic and environmental reasons (Canadian Natural Resources Limited 2012, Shell Energy 2012a,b, Suncor Energy 2012, Syncrude Canada 2012). Specific benefits of direct placement include:

- Minimizes double handling of material;
- Reduces the area required for soil stockpiles;
- Increases the rate of re-colonization of native vegetation by preserving live propagules; and
- Facilitates the recovery of natural biodiversity (Canadian Natural Resources Limited 2012, Suncor Energy 2012).

Direct placement of LFH/ surface soils is employed whenever possible for permanent oil sands reclamation; however, the amount of area that can currently be reclaimed with this material is limited because the amount of area being disturbed for development exceeds the amount of area being permanently reclaimed on an annual basis, especially on the newer mine leases. Also, the majority of sites being disturbed in the mineable oil sands area are comprised of wetland ecosites, as opposed to upland which means there will be a limited amount of LFH available for reclamation, relative to the area that will be reclaimed (Alberta Environment and Water 2012).

There is a limited amount of direct seeding currently taking place for understory species establishment (species other than cover crops). One operator is currently using two seed mixes that contain desirable woody and herbaceous understory species. Several other operators plan to use direct seeding in the future for a few species that are "easy to harvest and clean" to increase understory diversity. Much of the work in direct seeding woody species is still at the evaluation stage (Smreciu et al. 2013).

Fertilizers are commonly used as part of oil sands mine reclamation to improve plant establishment outcomes. Broad application of NPKS fertilizer often accompanies cover crop seeding and tends to enhance the establishment of the cover crop as well as potential undesirable species. Some operators may fertilize all areas where a peat/mineral mix is used as the reclamation material for four or five consecutive years, whereas others tailor fertilizer applications to the results of soil analyses. Fertilizer is not applied to areas reclaimed with upland forest soils (LFH).

Table 1. Summary of tree and shrub species currently deployed by oil sands operators.

Tree	**Shrubs**
White spruce (*Picea glauca*)	Willow (*Salix spp.*)
Jack pine (*Pinus banksiana*)	Western dogwood (*Cornus sericea*)
Black spruce *(Picea mariana*)	Buffalo berry (*Shepherdia canadensis*)
Trembling aspen (*Populus tremuloides*)	Common blueberry (*Vaccinium myrtilloides*)
Balsam poplar (*Populus balsamifera*)	Saskatoon berry (*Amelanchier alnifolia*)
Paper birch (*Betula papyrifera*)	River alder (*Alnus tenuifolia*)
Tamarack (*Larix laricina*)	Green alder (*Alnus viridis*)
	Pin cherry (*Prunus pensylvanica*)
	Choke cherry (*Prunus virginiana*)
	Red currant (*Ribes triste*)
	Beaked hazelnut (*Corylus cornuta*)
	Labrador tea (*Rhododendron groenlandicum*)
	Raspberry (*Rubus idaeus*)
	Dwarf birch (*Betula nana*)
	Shrubby cinquefoil (*Dasiphora fruticosa*)
	Bearberry (*Arctostaphylos uva-ursi*)
	Bog cranberry (*Vaccinium vitis-idaea*)
	Prickly rose (*Rosa acicularis*)
	Low bush cranberry (*Viburnum edule*)
	Snowberry (*Symphoricarpos albus*)

For more information on the characteristics of these species see OSRIN's Revegetation Species Profiles site at http://www.osrin.ualberta.ca/Resources/RevegSpeciesProfiles.aspx [8]

[8] After December 31, 2014 this information will be accessible through the Alberta Centre for Reclamation and Restoration Ecology site at http://acrre.ualberta.ca/

1.4.2 *In-Situ Disturbance Reclamation*

The reclamation of in-situ disturbances is conducted with a combination of natural recovery and assisted natural recovery (i.e., direct seeding or planting) techniques. Natural recovery allows the land to re-vegetate naturally (without planting or seeding) by conserving and replacing topsoil as well as spreading of any woody debris available on site. The Enhanced Approval Process requires natural recovery techniques for activities on native forested and peatland landscapes that have not been padded with clay. Natural recovery must be implemented on areas not required for operations within six months of the completion of drilling or within six months of construction if the site was not drilled (Alberta Energy Regulator 2013; operating condition 200.2.7). Minimally disturbed oil sands exploration (OSE) sites that are cleared, drilled and abandoned, and not located close to existing roads or other developments that could be a source of weeds or agronomic species, are often left for natural recovery.

Assisted natural recovery is permitted on native forested or peatland sites if there is high erosion potential, the site is prone to invasion by weeds or agronomic species or if the site was padded with clay (Alberta Energy Regulator 2013). After soil de-compaction has been completed, in-situ sites may be seeded with a grass/agronomic seed mix to reduce soil erosion and weed infestations. Operators generally use a "native grass seed mix", though the species contained in the mix often do not reflect the grasses found in the adjacent forest. In addition, over-seeding with aggressive species in these mixes or at high rates can reduce woody plant establishment and disrupt natural succession processes on some sites. The best practice of coarse woody debris placement has been accepted by industry; un-merchantable timber and tree tops are placed over the site for seed sources and microsite creation[9].

Depending on the reclamation objective, in-situ sites may be allowed to naturally regenerate following seeding, others will be planted with shrub and/or tree seedlings. Although species selected for planting should reflect the desired ecosite and the surrounding vegetation, they are often selected based on availability. Planting densities are generally ~ 2,000 stems per hectare, but can vary from ~ 500 to 5,000 stems per hectare, depending on the reclamation objective.

In contrast to the mineable oil sands operations, fertilizer is not commonly used in the reclamation of in-situ sites as it can promote the growth of non-desirable species.

1.5 Goals of an Enhanced Delivery System

As seed and nursery stock availability and related costs vary substantially based on the target species, the appropriate delivery method is likely to vary. A successful delivery system will be one in which the following attributes are considered:

1. *Re-vegetation success (establishment, survival and growth).* This will be driven by the physiological state of the seed or plant at the time of delivery as well as the microsite conditions on site. The greater the effort towards physiologically

[9] See 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

preparing the seed or plant and the creation of adequate conditions for establishment (reasonable access to moisture, light etc.), the greater the likelihood of revegetation success.

2. *Effectiveness of the system*. An effective system will result in the greatest relative number of established propagules per unit of effort. Native boreal seeds are relatively scarce, therefore efficient and effective use of this seed is of significant importance. When seeding, systems that further ensure adequate soil contact for initial germination of seeds are likely to improve effectiveness of the delivery system relative to others.

3. *Practicability (operational feasibility) or ease of application*. This consideration will likely counter-balance the attributes described in 1 and 2 above. Greater intervention or more highly specialized equipment and technologies, at least initially, are likely to be less practicable than traditional or simpler systems. New equipment may be required for new methods of delivery. This may range from standard agricultural equipment to new machinery. It could also include training of planting staff. The economy of scale is what truly determines practicability. If there are enough areas and enough need to warrant purchasing new equipment and train additional staff, it is practical. If it is used sparingly, rental may make more sense, but be less practical.

4. *Cost-effectiveness.* The best delivery system is not always the cheapest. A system which initially appears to cost significant dollars to implement may in fact be as cost-effective as a cheaper system once the re-vegetation success is accounted for. The entire life-cycle costs (seed collection, handling, treatment, storage, viability, and delivery), with consideration to the attributes above (1 to 3), must be considered before arriving at an assessment of the most cost-effective system.

2 TRADITIONAL DELIVERY SYSTEMS

Traditional systems can be categorized by varying degrees of intervention including: no intervention, non-targeted intervention and targeted intervention. Non-targeted intervention may be defined as a method where the objective is to regenerate a range of plant species at unspecified densities. Targeted intervention involves seed or nursery stock treatment and delivery with specific species and densities in mind during establishment. Table 2 summarizes the traditional methods according to the degree of intervention required; these are further described below.

Table 2. Summary of traditional delivery systems by degree of intervention. The letter in brackets indicates if the system is employed at the seed treatment (ST) or delivery stage (D).

No intervention	Non-targeted intervention	Targeted intervention
Natural recovery (ST/D)	Direct placement of topsoil or LFH (ST/D)	Nursery production (ST) Planting of nursery stock (D) Basic seed broadcasting (D)

2.1 Traditional System 1: Natural Recovery

Natural recovery may be considered a best-practice wherever practicable as it involves the lowest overall 'footprint' for treatment and delivery and minimal cost for industry. This approach works best where soil disturbance was minimal and therefore healthy propagule (roots and seeds) availability is maximal. In general, it becomes a less consistent mode of recovery with increasing degree and duration of soil disturbance. There is no assurance of the species composition or plant density that will be achieved with natural recovery.

Present use	Availability	Constraints	Cost considerations
Forestry operations on deciduous cutblocks; conventional oil and gas leases; minimal disturbance in-situ exploration; most linear disturbances (e.g., seismic lines, winter roads).	Wherever a seed or root propagule source exists within the topsoil or a seed source is in reasonable proximity	Inconsistent method of re-vegetation. Relies on interaction between appropriate weather (soil moisture, winter temperature impacts on root survival), seed or propagule availability, seed bed or microsite availability. Success dependent on proper preparation of soils.	No direct costs incurred provided that the method is successful (follow-up planting may be required).

2.2 Traditional System 2: Direct Placement of Topsoil (or LFH)

Replacement of salvaged soil is a fundamental step in reclamation. Direct placement of salvaged soil on land ready for reclamation is the preferred option; the alternative is to stockpile soil for later use. With the latter, there is the potential for loss of viable plant propagules due to composting within the pile.

Oil sands mines have been required to salvage upland surface soils (LFH plus a limited amount of the underlying mineral soil) since 2007 to maximize the potential return of upland forest plant species (Alberta Environment and Water 2012, Naeth et al. 2013). The intent of this revegetation approach is to quickly establish a diverse plant community using the native plant propagules contained in the forest floor (seed bank and roots/rhizomes capable of vegetative reproduction).

The benefits of using this approach include: seeds/roots contained in the forest floor are locally adapted to the area being revegetated, seed dormancy for many species will be broken through natural processes and no seed collection/cleaning/storing/growing of transplants is required. Genetic variability in a given area is also maintained. However, there is no assurance of the species composition or plant density that will be achieved.

Mackenzie and Naeth (2010) carried out an operational project in the mineable oil sands that examined the viability of forest floor direct transfer. They found greater plant species richness and a higher occurrence of native plant species in areas reclaimed with transplanted forest floor compared to areas reclaimed with a traditional peat-mineral mix reclamation substrate (Mackenzie and Naeth 2010; see also, Archibald 2014 for follow-up assessment).

Unpublished data in MacDonald et al. (2012) summarized results of a forest floor direct placement trial on a reclaimed coal mine. These data showed that more than 60% of the species growing at the donor site were recorded growing on the reclaimed site in the first year. However, only 35.5% of species found in the above-ground vegetation at the donor site emerged when the forest floor was transplanted into the greenhouse. This suggests that forest floor transfer can provide propagules for some understory species, but recently reclaimed sites are still likely to be dominated by early successional, shade-intolerant native and non-native species (MacDonald et al. 2012).

Present use	**Availability**	**Constraints**	**Costs**
Some use for permanent oil sands reclamation. Limited use operationally on oil sands sites.	Wherever areas are disturbed concurrently with reclamation.	Works best when soil salvage is being conducted concurrently with permanent reclamation. Otherwise, soil materials must be stored which eventually leads to degradation of propagules.	Transportation of material from donor site to target site may be significant depending on distances[10].

[10] Additional overall reclamation cost savings through not having to re-handle soils.

2.3 Traditional System 3: Nursery Production

Nursery grown seedlings provide greater relative establishment success compared with many other delivery methods as the seed is effectively ‘pre-developed’ or provided with a head-start in the field due to the development of significant root and leaf/stem tissue.

Where seed availability is scarce, utilization of seed in the production of seedlings is likely to be preferable to maximize the number of physical plants available for delivery as any direct seeding approach will likely have lower rates of plant establishment.

Though planting of native species has been conducted for many years on oil sands sites, quantitative assessment of nursery stock for a range of native boreal species has generally been lacking.

Improvements of stock quality for oil sands reclamation have included activities such as comparative examinations of container stock morphology in aspen (Landhäusser et al. 2012).

Present use	Availability	Constraints	Cost considerations
Widely used on in-situ and mines, and by forest industry.	Seedlings of a range of species can be produced at most commercial nurseries.	Significant lead time required (often two to three years) for species other than commercial trees.	Seed collection costs and greenhouse production are species-specific.
		Delivery of plant material to site requires greater logistical and transport considerations due to size of materials.	Storage of overwinter stock adds to cost.

2.4 Traditional System 4: Planting of Nursery Stock

Field outplanting of nursery grown container or bareroot stock has been used for decades in the forest industry. One of the priorities in planting is to ensure that each tree or shrub is planted in the best available microsite, within the limits of the spacing requirements (Mihajlovich and Wearmouth 2012). Trees and shrubs that are properly planted will be more resilient than those poorly planted as the best microsite provides moisture, nutrients, light, and warmth to the seedling.

Out-planting performance of nursery stock trials in Alberta commenced in the late 1960s (Walker and Johnson 1974) with the intention of applying results for use in the forestry industry. There is significant literature (e.g., Arnott 1992 provides a review of research in western Canada) on a variety of aspects that will influence seedling performance. Some examples include:

- ecosite characteristics (Mollard et al. 2014)
- seedling quality (Jackson et al. 2011, Palacios et al. 2009)
- season of planting (Grossnickle and Folk 2003, Palacios et al. 2009), and
- relative cost of planting (Sullivan and Amacher 2012).

However, field performance in reclamation sites is likely to exhibit some differences from forestry cutblocks in large part due to differences in the soils arising from forest harvesting vs. reclamation. Efforts within the Faster Forests program[11] will likely provide significant insight relating the actual success of large-scale planting efforts on in-situ sites.

Testing alternative seasons has also been explored through winter planting in areas with poor or remote access (Carpenter 2011, Tan and Vinge 2012); the studies have not been long enough to demonstrate the efficacy of the methods.

In-situ wellsite reclamation planting may be more costly than forest cutblock and open pit mine reclamation as it involves small crews moving to multiple sites. This requires more attention to logistics of crews and multiple seedling transportation events.

[11] The Faster Forests Program is a collaborative partnership between a number of oil sands companies including ConocoPhillips Canada, Husky Energy, MEG Energy, Nexen, Shell Canada, Statoil Canada and Suncor Energy. http://www.cosia.ca/initiatives/land/faster-forests

Present use	Availability	Constraints	Cost considerations
Widely used on in-situ sites and mines, and by forest industry.	Many reclamation and reforestation contractors have qualified tree/shrub planters.	Requires significant forward planning (often two years or more) as availability of seedlings is dependent on wild seed collections. Limited knowledge on seedling quality specifications for most boreal woody species (with the exception of commercial tree species).	Generally costly because of the manual aspect of the work. Per seedling cost is likely more expensive for in-situ operations due to travel and logistics associated with site access.

2.5 Traditional System 5: Basic Seed Broadcasting

Broadcast seeding is the most common and easiest method for seeding rough landscapes Broadcasting is conducted with hand seeders or attachments to ATVs for smaller scale disturbances. Larger equipment, more analogous to that used in the agricultural industry, tends to be a more effective means of deploying seed over large areas. In general, seed is placed in a hopper (Figure A1.1) where it is mixed to stay homogenous. As the seeder moves, a measured amount of seed falls through the bottom of the hopper onto a spinning disk that spreads the seed onto the ground. Additionally, the seed may then be packed into the soil bed by heavy wheels or rollers.

In Western Australia, establishment of *Banksia* woodland species in sand quarries was successfully conducted with surface broadcasting of seeds onto restoration sites and resulted in greater seedling abundance and richness (Rokich et al. 2002). Preliminary results from a plot-scale study on reclaimed borrow pits in the Peace River region suggest that a native boreal forb, Indian paintbrush (*Castilleja* sp.), can be successfully established by broadcasting (Schoonmaker unpublished data).

Present use	Availability	Constraints	Cost considerations
Widely used on a range of oil and gas sites (oil sands and conventional).	Equipment widely available.	Limited by the availability of seed for target species. Seed-soil contact is inconsistent leading to greater seed quantity use.	Equipment is inexpensive. Costs will depend largely on availability and cost of seed of target species.

3 ALTERNATIVE DELIVERY SYSTEMS

The following 16 alternative options describe methods that have not yet been utilized by oil sands operators (mining or in situ) or are not commonly used (may still be in the experimental stage). As described for the traditional systems, the methods may be grouped by the degree of intervention required (Table 3). Figure 2 summarizes stages where each of the traditional and alternative delivery systems is introduced.

3.1 Alternative System 1: Enhancement of Soil Stockpiles

This approach allows for many of the same principle benefits or motivations to using direct placement, however, is not constrained by coordination of soil salvage and reclamation site availability. Effectively, the principle of this approach is to revegetate soil stockpiles with forest species that have characteristics such as prolific seed production (to accumulate a seed bank in the soil) or capacity for regeneration from root materials. The planted stockpile could be left until final reclamation or routinely salvaged for the root-active soil layers and re-planted thus repeating the cycle of reforestation and salvage material use (MacKenzie 2013).

Although there are no studies presently demonstrating this technique, it would in principle, have similar outcomes as standard direct placement of topsoil or LFH from a recently disturbed area to a reclaimed area, albeit not necessarily the same diversity of species.

Present use	Availability	Constraints	Costs considerations
Not presently used.	Wherever stockpiled soil is present and could be planted with forest species.	Will still likely require supplemental planting on reclaimed areas with species that do not readily propagate from roots or seed bank prolifically.	Field costs for planting still incurred. May reduce weed management costs over time due to reduction of weeds on stockpiles.

Table 3. Summary of alternative systems by degree of intervention. The letter in brackets indicates if the system occurs at the seed treatment (ST) or deployment stage (D).

No intervention	**Non-targeted intervention**	**Targeted intervention**
N/A	A1. Enhancement of soil stockpile (ST)	A2. Seed enhancements (ST)
		Seed priming
		Mycorrhizal inoculations
		Seed nano-coating
		Seed pelleting
		A3. Seed packaging (ST)
		COSIA/CFS pucks
		Peat pucks
		A4. Seedling enhancements (ST)
		Nutrient loading
		Mycorrhizal inoculations
		A5. Seedling packaging (ST)
		Jiffy peat pellet®
		Biodegradable containers
		A6. Multi-species propagation (ST)
		Disc seed driller and air seeder
		Broadcast with harrowing
		Push-seeder
		Hydroseeding
		Aerial seeding

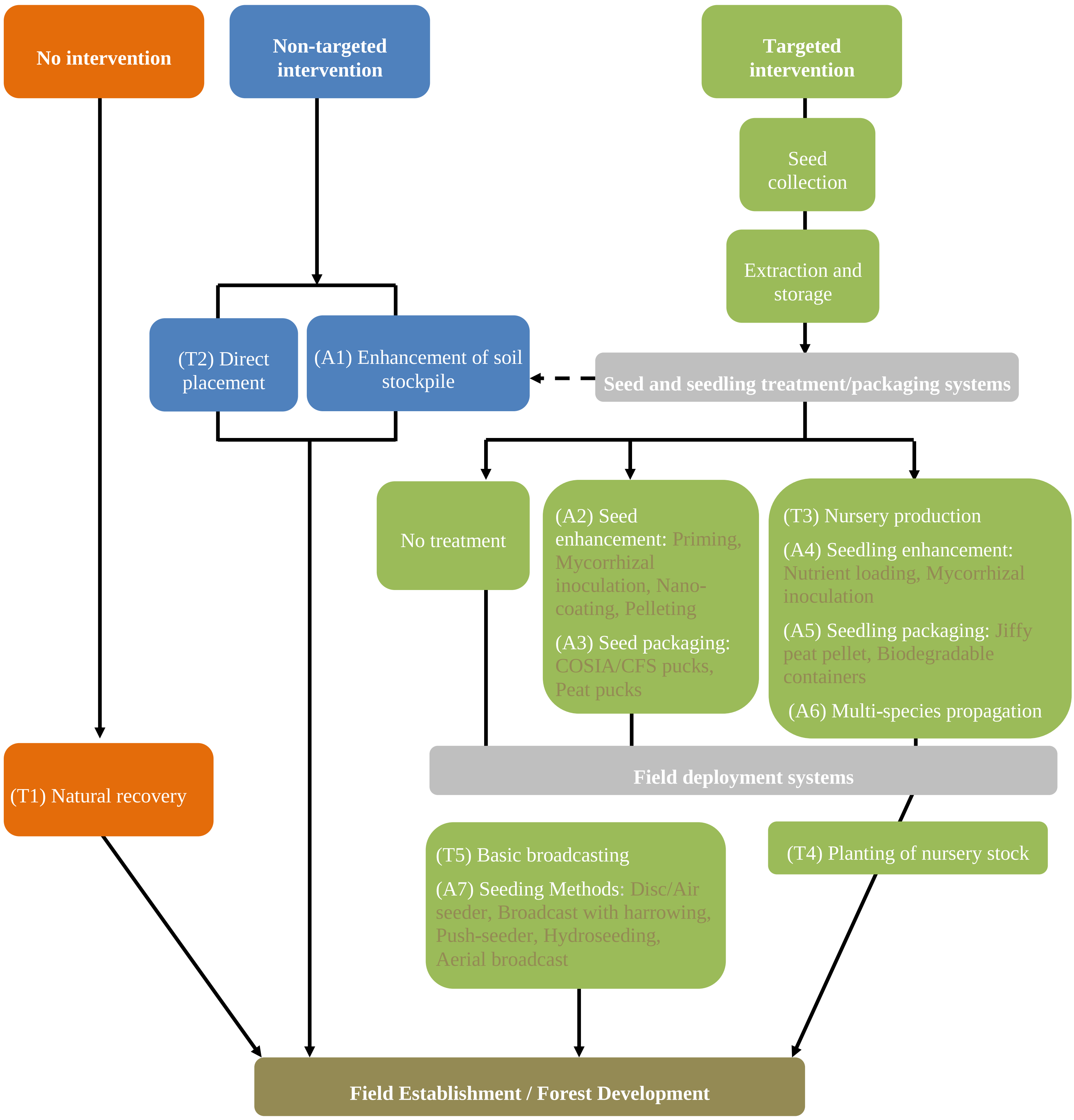

Figure 2. Diagrammatic overview of traditional (T) and alternative (A) seed delivery strategies for establishment of native vegetation on oil sands reclamation sites.

3.2 Alternative System 2: Seed Enhancements

A variety of methods are available to enhance seed quality and viability prior to seeding.

3.2.1 *Seed Priming*

Seed priming, which represents a range of seed treatment approaches to uniformly pre-hydrate the seed before field delivery, can significantly improve germination (Bodsworth and Bewley 1981) and early vigour of directly seeded species. It is well-known in the agricultural sector but has seen no applications for reclamation.

Treatments are broadly grouped into three categories depending on the mode of hydration: hydropriming, osmopriming and matripriming.

- Hydropriming is the simplest approach and simply involves limited moistening of the seeds with a known quantity of water.
- Osmopriming uses low water potential solutions such as polyethylene glycol, salts or other high molecular weight compounds.
- Matripriming uses solid materials such as peat or vermiculite.

All three approaches aim to regulate and limit the quantity of water imbibed in the seed (McDonald 2000) with the purpose of shortening the time to germination once deployed in the field and exposed to additional moisture.

Seed priming is well-studied in the horticultural industry and agricultural sector with research dating to the 1970s (e.g., Hegarty 1978). Improved crop yields through early, more vigorous establishment are typical outcomes and methodological approaches can be applied in the field, as this technique is being tested and used by farmers in developing countries (e.g., Harris et al. 1999).

Present use	**Availability**	**Constraints**	**Cost considerations**
Widely used in the agricultural and horticultural sectors.	Range of techniques available for use; however many approaches are proprietary.	Not tested for native boreal seeds or on reclamation sites.	Additional cost for seed pre-treatment but otherwise would be similar to other straight seed deployment techniques with improvements in field survival. This increased cost may be offset by reduced volume of seed required.

3.2.2 *Mycorrhizal Inoculation*

Mycorrhizae provide seedlings with enhanced access to moisture and nutrients, especially phosphorous. Commercial inocula are available and can be applied as powders or liquids[12]. Mycorrhizal inoculation of seed is intended to kick-start the colonization of roots. However it is important to note that greenhouse and field studies have shown that while there may be initial benefits in terms of growth, the plants are quickly colonized by indigenous mycorrhizae (e.g., Parkinson 1984, Danielson and Visser 1988).

Present use	**Availability**	**Constraints**	**Cost considerations**
Not used operationally at present.	Inoculants are commercially available.	Uncertain benefits.	Additional costs for materials and application.

3.2.3 *Nano-Coating Seed*

Carefully selected nanomaterials at low physiological concentrations may be beneficial in improving germination rate and growth performance of native boreal species. Application of nanotechnology as a pre-delivery, seed preparation system could improve nursery production and field establishment of native boreal species but there is no published information presently available. Similar to seed priming, this approach has seen more use and testing in the agricultural and horticultural sectors.

Nanomaterials enhance water uptake in seeds and activate enzymatic and hormonal responses during seed germination and plant growth. A number of experiments also indicate that the beneficial effects of nanomaterials on seed germination, plant growth and development are dependent on the types of nano-particles used, concentration, plant species and specific experimental conditions (Gao et al. 2011, Khodakovskaya et al. 2009). For example, hydrated C60 fullerenes were shown to increase vegetative biomass up to 2.5 fold and germination rate up to 50% in tomato (Khodakovskaya et al. 2009).

[12] See http://www.maiaustralia.com.au/more-info/articles-and-scientific-papers/84-inoculate-with-mycorrhizaeits-as-easy-as-a-b-seeds

Present use	Availability	Constraints	Cost considerations
Not used operationally at present.	Nano-materials are commercially available.	Requires extensive testing (for individual species) as the most suitable nanomaterial tends to be species specific. Need to assess and manage the level of public concern with deployment of nano-materials in the environment.	Comparable to other seed coating[13] and priming systems.

3.2.4 *Seed Pelleting*

Seed pelleting is a process by which small or irregularly-shaped seeds are coated with an inert material to increase their size and uniformity, which facilitates the seeding process. Pelleting is being used extensively in commercial vegetable production industry. The consistent sizing of the seeds allows for better flow through seeders and greenhouse seeding equipment (Taylor et al. 2001).

Introducing this technology to native boreal seed delivery systems has several potential benefits. The biggest benefit may be increasing seed size because many boreal seeds are small and light weight; for example aspen has 9,000 seeds per gram and fireweed has 16,000 seeds per gram. Pelleting can increase seed size up to 35 times or more. Seed pelleting can be combined with other seed technology to improve germination and growth. Specifically, seeds can be primed, which means that seed dormancy is broken artificially to encourage consistent, uniform germination. The material used to form the seed pellet around the seed can also trigger the seed to germinate under favorable conditions.

Seeds are pelleted using either a coating pan or a rotary coater (Figure A1.2). A combination of a wet-sprayed binder and a dry filler are tumbled with the seed mass until the desired seed pellet size and firmness are achieved (Caruso et al. 2001, Taylor et al. 2001).

This technique has been tested and utilized in agriculture. For example, Bradford and Still (2004) showed that pelleted lettuce seeds germinate more rapidly than the control seeds that were not treated. Since pelleted seeds have not been available to the reclamation industry, there is very

[13] For example, Scott et al. (1997) describe “design and development of computer-controlled, laboratory-scaled seed coating equipment and operational parameters for the coating of seeds with fine, particulate material (especially lime)”.

little evidence yet on how well they work. Very small seeds such as fireweed cannot be direct-seeded efficiently without increasing seed size. A study established at Genesee Mine in 2011 used pelleted fireweed seed and it did improve seed spread from an aerial seeder; however no results were published because the fireweed did not appear to establish from seed (Marenholtz, unpublished observations).

Present use	Availability	Constraints	Cost considerations
Agriculture sector.	Pelleting equipment is commercially available.	No information for native boreal species on reclamation sites. Development of appropriate coating treatments tends to be species specific and consequently independent testing must be done prior to operational use. Seed mixes cannot be pelleted in batch mode; each species must be pelleted and then mixed subsequently for delivery.	Equipment costs (to purchase). Pelleted seed will be bigger and heavier therefore transportation costs may increase slightly.

3.3 Alternative System 3: Seed Packaging

Packaging seeds in biodegradable containers provides a self-contained microsite that has the potential to enhance plant establishment and survival. The packages may also make targeted deployment in favourable sites possible and has the potential to allow for aerial- or land-based mechanized deployment.

3.3.1 *COSIA / CFS Pucks*

Preliminary trials are underway to evaluate alternative materials to construct pucks to compensate for some of the drawbacks of peat-only containers (e.g., desiccation and premature structural collapse). The puck is designed to hold one or more seeds of a single species or a combination of species. Selection of puck components is driven by balancing competing objectives, most notably:

- physical integrity – maintain integrity during production, transport and deployment but allow puck to disintegrate once deployed
- chemistry – additives (e.g., fertilizers, stabilizers) cannot result in an unfavourable pH and salinity
- biology – position the seeds at an appropriate depth (and perhaps with an appropriate cover) such that they stay in the puck during transport and deployment but have access to air and light to allow for germination

The basic principle of a seed puck or capsule to deliver seeds to the field has been examined in conifers including black spruce and jack pine (Adams et al. 2005 provides an overview) and is summarized below:

- Encapsulation materials have included compressed vermiculite (FMC wafer, FMC Export Corporation – referred to in Fraser and Adams 1980), compressed vermiculite and activated charcoal (Seed tablet, University of Idaho), and hydrophilic polymers (Dupont tree egg) [14].
- When the seeds are embedded in these capsules, germination is typically poor (Adams et al. 2005); however, adhering the seeds to the surface with adhesives has been shown to improve germination in the field (Adams 1995).

Present use	Availability	Constraints	Cost considerations
None (preliminary greenhouse scoping trials underway).	None.	Work underway to determine appropriate materials, mixture rates and sizes. Field work needed to determine how to deploy and ensure optimum performance.	Aiming for least-cost materials but will add to cost. Extra size and weight will add to transportation costs.

3.3.2 *Peat Pucks*

In Sweden, Anders Landstrom has been evaluating the use of peat pucks for five years to establish forest species[15]. The puck consists of peat, fertilizer and a single seed. Landstrom

[14] Recent searches for these companies and products indicate they may no longer be produced or in operation.

[15] See http://www.skogforsk.se/pagefiles/64556/shortcuts_3-11_lowres.pdf

reports improvements in germination and growth, and that the pucks are reasonably resilient if planted incorrectly (wrong side up).

Present use	Availability	Constraints	Cost considerations
None in the oil sands.	None.	Concerns regarding peat desiccation and puck integrity.	Extra size will add to transportation costs relative to conventional direct seeding.

3.4 Alternative System 4: Seedling Enhancements

Improvements of stock quality can be made by enhancing nutrient content or mycorrhizal status.

3.4.1 *Nutrient Loading*

The principle of nutrient loading is to provide the growing nursery seedling with a level of nutrition that results in luxury consumption of nutrients which will be available for additional growth following field out-planting (Timmer and Aidelbaum 1996). Schott et al. (2013) tested the potential for nutrient loading aspen (*Populus tremuloides*) and found the optimal approach was through a combination of early shoot termination and subsequent nutrient additions. Hu (2012) found that optimal nutrient loading rates varies by species (aspen, jack pine and white spruce). Field testing is required under field conditions in a reclamation setting in order to better evaluate the need for this approach.

Present use	Availability	Constraints	Cost considerations
Not used operationally at present.	Methodology is available for commercial use.	Species-specific information required to optimize treatments. Benefits are likely to be species-specific and driven by nature of field conditions for deployment.	Minor additional cost for added fertilization during nursery production. May be offset by improved field performance.

3.4.2 *Mycorrhizal Inoculation*

Mycorrhizal inoculation of seedlings has been evaluated in numerous studies in the forest industry (e.g., Owston et al. 1992). Greenhouse and field studies have shown that while there may be initial benefits in terms of growth (e.g., Ortega et al. 2003) the plants are quickly colonized by indigenous mycorrhizae (e.g., Danielson and Visser 1988, Parkinson 1984). However, as most artificial inoculation occurs with commercially available strains, there is valid concern and uncertainty regarding the implications of this practice through the introduction of non-native or aggressive strains of mycorrhizal fungi into the environment (Schwartz et al. 2003); moreover, locally adapted strains that specifically associate with target species will often perform better (Cripps and Grimme 2011).

Present use	Availability	Constraints	Cost considerations
Not used operationally at present.	Mycorrhizal inoculants are commercially available.	Uncertain or inconsistent benefits. Species-specific information required to optimize treatments.	Additional costs for materials and application.

3.5 Alternative System 5: Seedling Packaging

There are options to provide biodegradable containers for transplanting seedlings with undeveloped root system into field conditions. This may be an improved approach for species which are sensitive to root handling or have difficulty developing an extensive root system under greenhouse conditions.

3.5.1 *Jiffy Peat Pellet ®*

Jiffy Pellets®[16] can be directly placed/planted as all materials are biodegradable (Figure A1.3). This approach is different than typical greenhouse seedling propagation as the Jiffy Peat Pellet ® allows for transplant of seedlings that have not filled their plugs with roots (a requirement for styroblock container or root trainer stock to be extractable). An additional benefit is that pellets can actually be organized within standard nursery styroblocks, making them reasonable to manage in an operational nursery environment.

Anecdotally, residential users have found that the peat acidifies soil without adding nutrients, they are too small (for the plant) and dry out, tend to mold when too wet and roots may not readily spread out of pellet due to incomplete breakdown of casing that holds the pellet together (Adams et al. 2005). However, commercial nursery applications of Jiffy Peat Pellets ® (to

[16] See http://www.jiffypot.com/en/about-jiffy.html

contain root systems of nursery stock grown from stem cuttings) have been positive (Marenholtz, unpublished observations).

Present use	Availability	Constraints	Cost considerations
Used in gardening and small-scale applications.	Available online.	Seeds not included, ample water is required.	Likely similar to standard nursery stock or slightly higher.

3.5.2 *Biodegradable Containerized Seedlings*

Similar to the Jiffy Pellets®, a biodegradable pot provides a method to transplant seedlings with undeveloped root system into field conditions. However, unlike peat pellets which can be inserted into styroblocks (multi-plant units), biodegradable containerized seedlings are produced in single-plant units.

There are a number of different options in terms of specific biodegradable pots available including cardboard or newsprint (Lee Valley supplies a tool to make this type of pot) or manure (CowPots™[17]) (Figure A1.4). Wood fibre composite mats are another potential biodegradable product that could be started in the greenhouse and transplanted into the field[18].

Present use	Availability	Constraints	Cost considerations
Used by home gardeners.	Available commercially.	Untested for operational use on native species. Delivery products may limit root egress when dry.	Greenhouse and field delivery costs will be higher than standard nursery stock.

3.6 Alternative System 6: Multi-species Propagation and Planting

Greenhouse propagation in standard styroblocks typically involves a single woody species (or in some cases herbaceous species). This method proposes to grow multiple species together in the same plug for field delivery. The companion species could include a native forb (such as

[17] See http://www.cowpotscanada.com/

[18] See http://albertaventure.com/2014/03/industry-searching-for-new-tree-products/

fireweed, aster or goldenrod) and a shade tolerant woody species. As planting tends to be a more costly exercise, it would allow for more efficient delivery of plant material on site.

In a pilot project recently initiated in the greenhouse, observations indicate that at least the propagation appears to be feasible (Schoonmaker et al., unpublished observations). No other research information is available at present.

Present use	Availability	Constraints	Cost considerations
Not used.	Readily available pending research trials as all necessary infrastructure is present in the nursery sector.	Would need to test each species combination before operational delivery. Risk of herbaceous species drying out the plug during initial planting if soil conditions are too dry.	Increased cost of individual plugs, however, the per plant cost may be similar to standard propagation given consideration for the fact that multiple plants are in a single plug.

3.7 Alternative System 7: Seeding Methods

Various seeding equipment and methods have potential use for oil sands reclamation. A key drawback to the application of some of the methods listed below is current best practice approaches of creating rough surfaces and incorporation/application of coarse woody materials to enhance microtopography and seed/seedling microsites. They may find niche applications in sensitive areas where enhanced certainty of application rates and seed distribution is desired, in areas where road access is available (hydroseeding), or in remote areas (aerial seeding).

3.7.1 *Disc Seed Drills and Air Seeders*

The principle benefits of disc seed drills or air seeders are that they improve the contact between the deployed seed and the soil and that they can place seed into the soil at a specific depth. Placing larger seeds into the soil, instead of on the soil surface, ensures the seeds stay hydrated long enough to germinate. This will increase the efficiency of directly sowed seed (less seed used than in standard broadcast approaches) and improve germination results.

Disc seed drills operate by creating small trenches in the soil where rows of seed are inserted and then pressed to the soil with wheels at the rear of the seeder (Figure A1.5). However, when seeding native species, disc seed drills may require specialized hoppers and additional seed pre-treatments such as de-awning.

Air seeders utilize air to inject seeds directly into the ground (Figure A1.6). These seeders can also be used on slightly frozen soils or in windy conditions (Smreciu et al. 2002). However, rough seed beds are not conducive to this type of seeder. Nevertheless, air seeders may be appropriate for use over small areas to establish islands of vegetation.

No known testing in mining or in-situ circumstances. Disc seed drills and air seeders have been used effectively in agricultural applications for decades.

Present use	Availability	Constraints	Cost considerations
Used in agriculture; Rangeland and White Area reclamation	Equipment is commercially available.	Requires a pulling vehicle (tractor). Requires relatively level terrain (enough to keep seeder and tractor from tipping), requires a large volume of seed; linear distribution. Equipment must be utilized prior to rollback of woody debris or any final surface soil treatments such as ripping or mounding.	Equipment purchase is very costly and requires knowledgeable operators to run efficiently.

3.7.2 *Broadcast with Harrowing*

Broadcast seeding with harrowing is a random seeding method that results in a more aesthetic vegetation establishment pattern relative to conventional seedling planting (Smreciu et al. 2002). The equipment is the same as in basic broadcasting with the addition of chains, tires or diamond harrows dragged behind the seeding equipment in order to mechanically abrade the soil surface to mix the seed into the soil surface (Smreciu et al. 2002); this results in improved seed-soil contact. This approach can also accommodate several species at one time, which makes it a good option for sites where multiple species are desired.

Recent work in the oil sands has examined direct broadcast seeding in small field trials with 40 native species (Smreciu et al. 2013). Seeds were broadcast following surface scarification of the substrate to simulate harrowing. Direct seeding by this method seemed to work well for many species, especially graminoids, forbs and a few shrubs (e.g., *Bromus ciliatus, Fragaria virginiana, Solidago simplex, Rosa acicularis*), but not as successful for some small-seeded shrubs (e.g., *Vaccinium* species).

Present use	Availability	Constraints	Cost considerations
Primarily used as an agricultural tool.	Widely available (can be purchased for commercial use). Harrowing can be executed at different scales.	Requires large amount of seed which may not be available for many native species.	Low-cost method for small-scale (in-situ) operations. Equipment costs will increase for larger sized equipment. Selection of target species will also influence final costs.

3.7.3 *Push Seeder*

This apparatus is hand-pushed and delivers single seeds to specific depths. The back wheel then presses seed and soil in place (Figure A1.7). This is a targeted, effective means of placing seeds and will reduce wastage of valuable seed relative to more random seed broadcasting.

Presently, there is no known testing in mining or in-situ circumstances. However, it is simple, easy to use and adaptable and could be used for targeted areas.

Present use	Availability	Constraints	Cost considerations
Used in market gardening, relatively small scale	Equipment is available commercially by various suppliers.	Generally, models seeding more than one row are not adjustable. Not ideal for wet seeds. Labor intensive: one operator per seeder, seeds one to six rows at a time (approximately 30 cm wide row maximum). Multiple attachments may be necessary for different sized seed. Better suited for in-situ reclamation than in mines.	More cost-effective use of seed; however labor cost will increase as delivery is slower.

3.7.4 *Hydroseeding*

Hydroseeding is frequently used for revegetating reclaimed sites, typically with grasses as the intent is quick initial establishment for soil stability and erosion control. The advantage is that the mulch and tackifier components of the hydroseeding slurry act as an erosion control blanket as well as serving as a means of delivering seeds.

In addition, hydroseeding has the potential to increase the speed of site recovery by inoculating the disturbed site with beneficial forest floor components salvaged from a donor site. Hydroseeding can provide a cost-effective mechanism for transferring a part of the native forest floor seed bank and associated belowground microbial community.

There are presently no studies examining native boreal seed establishment with hydroseeding. However, other examples around the world suggest that the principle is feasible:

1. The Sonoran Institute reports success with hydroseeding freshly collected cottonwood and willow seed for riparian area restoration (Sonoran Institute 2014).
2. RST Environmental Solutions, a New Zealand-based company, advertise a product called 'Hydrobush,' which deploys native seeds using hydroseeding[19]. They advertise that they take a systematic approach that includes collecting seeds at the

[19] See http://www.rst.co.nz/hydroseeding.html

correct time, seed testing and preparation to optimize germination. Their 'Hydromoss' system can add mosses, lichens and vascular plants to a reclaimed site.

These two examples suggest that native seeds, other than grasses and legumes, can be introduced effectively using hydroseeding.

Present use	Availability	Constraints	Cost considerations
Slope stabilization in reclamation, road right-of ways	Contracting companies available throughout the province that provide this service.	Not tested for native boreal forbs and woody species. Standard equipment may be too heavy for forest soils though tracked equipment options may be feasible.	Application cost is substantially higher than conventional seed broadcasting approaches.

3.7.5 *Aerial Seeding*

Aerial broadcast seeding can be a useful tool for establishing plants on a site and is conducted with a seeder mounted on a fixed-wing aircraft or helicopter (Figure A1.8). Jack pine is the species most commonly seeded (Fleming et al. 2001) and is the species that has been shown to have the most reliable germination/ establishment (Barth 1986) in forest industry applications. Aerial seeding of grasses and fertilizer has also been utilized for mine reclamation in eastern Canada[20].

The main benefit of aerial seeding is that it is an inexpensive way to deliver a large quantity of seeds to a site; it requires few personnel to implement and large, remote areas can be seeded quickly with a wide window of delivery (much more than for standard tree planting) (Adams et al. 2005). Another benefit of this re-vegetation treatment is that areas treated with aerial seeding often have a more natural appearance than planted stands due to the random distribution of seedlings (Adams et al. 2005). However, spreading seed from aircraft is the least efficient seeding method in terms of seed use, as most seed will land on inappropriate microsites (Lieffers et al. 2003).

Site preparation is the key for successful aerial seeding; microsites where the surface organic layers have been removed for seeds to germinate will promote the greatest establishment (Adams et al. 2005, Fleming et al. 2001, Mitchell et al. 1990). A BC Ministry of Forests manual

[20] See http://www.vale.com/canada/EN/aboutvale/communities/health-safety-environment/our-environment/reclamation-and-decommissioning/reclamation-and-decommisioning-sudbury/Pages/Reclamation.aspx

recommends at least 25% (preferably >40%) mineral soil exposure for successful seeding regeneration (cited in Mitchell et al. 1990). However, the microsites that are most favourable for aerial seed germination are also very good germination and growing environments for other competitive species. If there is a high vegetation competition on a site, aerial seeding may not be the best revegetation option as germinants are very susceptible to competition and can be easily out-competed (Lieffers et al. 2003).

The most important environmental factor for successful aerial seeding is surface moisture. The surface soil must remain moist long enough for the seedling root to reach soil layers with more consistent, available moisture (Fleming et al. 2001). Establishment of seeds is best when sown in late winter to mid-June (Fleming et al. 2001). During this period, there is likely to be sufficient soil moisture for seeds to germinate, the seed will most likely experience moderate temperatures (no extreme fluctuations) and rodent populations are typically low enough that significant seed predation should not occur (Mitchell et al. 1990). The success of aerial seeding varies significantly by species. For instance, aerially seeding white spruce is not considered a wise investment as it has been shown to be a very unreliable method of regeneration for this species (Barth 1986, Greene et al. 2002). However, it has been suggested that these previous poor results could be due in part to the sowing of too little seed and performing too little scarification (Greene et al. 2002).

In general, aerial seeding is considered less expensive than planting container seedlings. Various reports suggest aerial broadcasting seeding costs 1.5 to 3.0 times less than planting for jack pine, black spruce or white spruce seedlings (Adams et al. 2005, Greene et al. 2002, Mitchell et al. 1990).

Present use	**Availability**	**Constraints**	**Cost considerations**
Primarily by the forest industry as a relatively inexpensive way to deliver conifer seeds to harvested areas.	Widely available.	Uses very large quantities of seed; young germinants are very sensitive to site moisture conditions and vegetative competition.	Significant seed quantities will drive up costs; however the speed to deploy large areas is more efficient than most other approaches.

4 SUMMARY AND FUTURE WORK

Each of the traditional and alternative seed delivery systems described above has merit in the appropriate circumstances (Table 4). Ultimately, the use of methods will be driven by: the primary objectives of the site (e.g., target plant community), availability of seeds, on site constraints or challenges, expertise of the field staff and supervisors, and the degree of financial input by individual companies.

In terms of seed treatment systems, pelleting and priming have significant promise in forest land reclamation and represent improvement over traditional systems where typically no treatment was employed other than development of seedlings. Pelleting and priming are good candidates for further development as (1) both systems have been shown to be successful in agriculture; (2) priming does not required very specialized knowledge (testing and implementation should be straightforward) and (3) the pellets consistently increase the capacity of the seeds to absorb moisture, which in turn improves their germination conditions of seeds both in the nursery setting and in the field. Seed packaging (pucks) are currently being evaluated, with an emphasis on native boreal shrubs and forbs primarily for use on in-situ sites. Utilization of these systems will provide for greater efficiencies in native boreal seed use as improved germination will require less seed to be deployed. These systems, however, require additional research to develop the best combination of techniques for individual species.

Improving on basic broadcasting with the addition of harrowing, is an easily deployable delivery system at small or large scales and due to the versatility of the method (chains attached to an ATV) can be applied across a range of site sizes and more difficult to access regions. Large-scale delivery systems such as disc seeders and air seeders have significant scalability for mineable oil sands operations and are proven techniques in the agricultural sector (which also operate at large spatial scales). Although additional research would improve the quantitative understanding of the degree of improvement, it is generally understood that methods, which improve soil-seed contact are going to improve germination outcomes.   The main drawback of both harrowing and disc or air seeders are the necessity to conduct activities prior to roll back of woody materials on site as well as any major surface site activities such as mounding or deep ripping.

Hydroseeding is a highly proprietary industry and historically very costly to implement. However, it is a proven method of providing uniform, dense coverage (at least in grasses) under a range of soil conditions, slopes and terrain due to its present use for right-of ways and slope stabilization. It is also a very speedy method to deliver seed to a site. As there are nearly unlimited combinations of materials that can be combined to create the hydroseeding slurry, it is likely worth further exploring this seed delivery system for select native boreal species.

Aerial seeding is an approach that may have merit for specific species and has applicability for large reclamation areas as well as a useful mechanism in very remote, difficult to access sites. Since it has been shown that aerial seeding success tends to be species-specific, additional testing for a range of candidate species would be warranted in order to provide better recommendations on seeding rates.

Seedling delivery from multi-species production and biodegradable containers are most likely to have merit for specialized applications. Multi-species production requires verification both at the level of identifying appropriate species mixtures, optimizing greenhouse production and quantification of field performance. Biodegradable containers are a suitable option to further test on slow-growing species that are difficult to produce under standard greenhouse conditions in styroblocks.

Enhancement of soil stockpiles is an alternative delivery system that is closely analogous with the traditional delivery system and best practice of direct placement of topsoil. As stockpile enhancement effectively involves active reforestation of the stockpile until further use, it could easily be included as part of regular revegetation activities with other reclamation sites. The range of targeted interventions of treatment and delivery systems could also be employed to achieve the primary reforestation. Consideration for the objectives of stockpile reforestation would drive the degree of intervention as well as the species composition established. Additional research would be required to identify the most suitable species mixtures and densities to meet the objectives.

What is currently missing for all of the alternative approaches presented here is the field testing and optimization of the techniques for native boreal species. The next step would include the selection of study sites for comparative testing of alternatives against traditional methods. The selection of a short-list of the most high-priority native species will be driven by the availability of seed in large enough quantities for thorough, replicated field trials.

Table 4. Summary of the revegetation success, cost, feasibility and additional work required for traditional and alternative seed treatment, packaging and delivery systems.

System	Re-vegetation success[1]	Cost[2]	Feasibility[3]		Additional work needed?
			mine	in-situ	
(T1) Natural recovery	H-L	N/A	L	M	Better understanding of physical conditions that will improve predictability and consistency of natural regeneration.
(T2) Direct placement	H	Group 1- M Group 2- M	M	L	Not required, it is understood that it is effective.
(T3) Nursery production	M-H	Group 1- L Group 2- M	H	H	Monitoring of field performance would improve species-specific recommendations for delivery. This would largely be focused on the range of shrub species with verification and transferability of known performance of tree species in forest cutblocks.
(T4) Basic broadcast	L-M	Group 1- L Group 2- H	H	H	Field testing with native boreal species required to provide better understanding and recommend appropriate rates of seeding.
(A1) Enhancement of soil stockpile	H	Group 1- L Group 2- M	H	H	Optimization of appropriate species to establish, rates and approaches required in order to recommend best practices.
<u>(A2) Seed enhancements</u>					
(A2.1) Priming seeds	Unknown	Group 1- M Group 2- M	H	H	Laboratory and field testing required for individual species.
(A2.2) Mycorrhizal inoculations	M-H	Group 1- L Group 2- M	H	H	Testing of specific species with inoculation is required under field conditions in order to evaluate actual improvement compared with traditional nursery production.

System	Re-vegetation success[1]	Cost[2]	Feasibility[3] mine	Feasibility[3] in-situ	Additional work needed?
(A2.3) Nano-coating seeds	Unknown	Group 1- M Group 2- M	H	H	Laboratory and field testing required for individual species.
(A2.4) Pelleting	M	Group 1- M Group 2- M	H	H	Coating techniques need to be tested and optimized for individual species and tested under field conditions to determine appropriate seeding rates.
(A3) Seed Packaging					
(A3.1) COSIA/CFS pucks	Unknown	Group 1- M Group 2- H	H	H	The most appropriate formulation and species composition of the puck requires testing in greenhouse and field conditions.
(A3.2) Peat pucks	Unknown	Group 1- M Group 2- H	H	H	Evaluation of puck with species native to Alberta under field conditions.
(A4) Seedling Enhancements					
(A4.1) Nutrient loading	M-H	Group 1- L Group 2- M	H	H	
(A4.2) Mycorrhizal inoculations	M-H	Group 1- L Group 2- M	H	H	
(A5) Seedling Packaging					
(A5.1) Jiffy peat pellet®	M-H	Group 1- M Group 2- M	L	M	Greenhouse and field testing required for individual species.
(A5.2) Biodegradable seedling container	M-H	Group 1- L Group 2- M	M	M	Greenhouse and field testing required for individual species.
(A6) Multi-species propagation and planting	M-H	Group 1- M Group 2- M	H	H	Method needs to be optimized both in terms of greenhouse production as well as quantification of benefit for field establishment. Companion plants need to be tested.

System	Re-vegetation success[1]	Cost[2]	Feasibility[3]		Additional work needed?
			mine	in-situ	
(A7) Seeding methods					
(A7.1) Disc seed drill and air seeding	M	Group 1- L Group 2- H	H	L	Field testing required at different spatial scales. Compatibility of this system with roll back and coarse woody debris placement needs to be evaluated.
(A7.2) Broadcast with harrowing	L-M	Group 1- L Group 2- H	M	H	Additional species specific information is required on a variety of site types as well as seeding rates and composition for all seed mixes.
(A7.3) Push-seeder	M	Group 1- M Group 2- M	L	M	Field testing required for a range of native species.
(A7.4) Hydroseeding	L-M	Group 1- H Group 2- H	H	H	Field testing with native boreal species required to provide better understanding and recommend appropriate rates of seeding. Tackifier and biofibre material trials required.
(A7.5) Aerial broadcast	L-M	Group 1- M Group 2- H	H	M	Most work has been conducted in a forestry setting to-date. Field testing with additional native boreal species under reclamation conditions is required to recommend appropriate rates of seeding.

Notes:

1. Re-vegetation success is rated as the potential for reclamation success based on the author's knowledge of existing trials and baseline understanding of plant biology. It is a relative scale with the following categories: high, moderate or low (H, M or L).
2. The costs are rated as: high, moderate or low (H, M or L) and are separated by broad plant groups as cost scaling will vary substantially by the seed types:
   a. Group 1: Easily obtainable seeds. Typically smaller seeds of wind-dispersed species (e.g., aspen, balsam poplar) or high volume producing species (e.g.,

conifers, alders or birches). Also includes grasses (some commercially available) and many native forbs (e.g., fireweed).

b. Group 2: Difficult to obtain seeds. Typically includes most species that produce fewer than 5 seeds/fruit, cone or catkin. Examples would include: low bush cranberry, western dogwood or buffaloberry.

3. Relative scale of practicability of the method categorized as the ability to deploy in the near future (even if some additional research is required): high, moderate or low (H, M or L).

5 REFERENCES

Adams, M.J., 1995. Seed treatments have potential for direct seeding. Natural Resources Canada, Canadian Forest Service, Sault St. Marie, Ontario. Frontline Technical Note 34. 4 p. http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/9170.pdf [Last accessed November 20, 2014].

Adams, M.J., A. Groot, G.W. Crook, R.L. Fleming and F.F. Foreman, 2005. Direct seeding black spruce and jack pine: A field guide for northern Ontario. Canadian Forest Service, Sault Ste. Marie, Ontario. 528 pp. http://www.cfs.nrcan.gc.ca/pubwarehouse/pdfs/26195.pdf [Last accessed November 20, 2014]

Alberta Energy, 2014. Alberta leased oil sand areas. http://www.energy.alberta.ca/LandAccess/pdfs/OSAagreeStats.pdf [Last accessed October 14, 2014].

Alberta Energy Regulator, 2013. Enhanced Approval Process: Integrated Standards and Guidelines. http://esrd.alberta.ca/forms-maps-services/enhanced-approval-process/eap-manuals-guides/documents/EAP-IntegratedStandardsGuide-Dec01-2013.pdf [Last accessed September 2, 2014].

Alberta Environment, 2010. Guidelines for reclamation to forest vegetation in the Athabasca oil sands region, 2nd Edition. Prepared by the Terrestrial Subgroup of the Reclamation Working Group of the Cumulative Environmental Management Association, Fort McMurray, Alberta. 332 pp. http://environment.gov.ab.ca/info/library/8269.pdf [Last accessed October 29, 2014].

Alberta Environment and Sustainable Resource Development, 2013a. Environmental Assessment Program: Guide to preparing environmental impact assessment reports in Alberta. Alberta Environment and Sustainable Resource Development, Edmonton, Alberta. 26 pp. http://esrd.alberta.ca/lands-forests/land-industrial/programs-and-services/environmental-assessment/documents/8127.pdf [Last accessed October 28, 2014].

Alberta Environment and Sustainable Resource Development, 2013b. 2010 Reclamation criteria for wellsites and associated facilities for forested lands (Updated July 2013). Alberta Environment and Sustainable Resource Development, Edmonton, Alberta. 81 pp. http://environment.gov.ab.ca/info/lbrary/8364.pdf [Last accessed October 28, 2014].

Alberta Environment and Water, 2012. Best management practices for conservation and reclamation materials in the mineable oil sands region of Alberta. Prepared by MacKenzie, D. for the Terrestrial Subgroup, Best Management Practices Task Group of the Reclamation Working Group of the Cumulative Environmental Management Association, Fort McMurray, Alberta. 161 pp. http://environment.gov.ab.ca/info/library/8431.pdf [Last accessed October 28, 2014].

Archibald, H.A., 2014. Early ecosystem genesis using LFH and peat cover soils in Athabasca oil sands reclamation. University of Alberta, Department of Renewable Resources, Edmonton, Alberta. M.Sc. Thesis. 344 pp. http://hdl.handle.net/10402/era.37790 [Last accessed October 28, 2014].

Arnott, J.T., 1992. Forest renewal by artificial regeneration: A review of research in western Canada. The Commonwealth Forestry Review 71(1): 40-46.

Barth, G.R., 1986. Direct seeding of white spruce *Picea glauca* (Moench) Voss: A critical review of the inherent requirements and limitations of this reforestation option. Canadian Forest Service, Prince Albert, Saskatchewan. 43 pp.

Baskin C.C. and J.M. Baskin, 2001. Seed ecology, biogeography, and evolution of dormancy and germination. University of Kentucky.

Bodsworth, S. and J.D. Bewley, 1981. Osmotic priming of seeds of crop species with polyethylene glycol as a means of enhancing early and synchronous germination at cool temperatures. Canadian Journal of Botany 59: 672-676.

Bradford K.J. and D.W. Still, 2004. Applications of hydrotime analysis in seed testing. Seed Technology 26(1): 75-85.

Canadian Natural Resources Limited, 2012. 2011 Conservation and Reclamation Annual Report for the Horizon Oil Sands. Submitted to Alberta Environment and Water April 15, 2012. 111 pp.

Carpenter, A., 2011. Winter reclamation trial progress report – 2011, Surmont 2011 OSE Program. 20 pp.

Caruso, L.V., R.C. Pearce, B. Gilkinson and L.P. Bush, 2001. Effect of seed pellet modification on spiral root formation of tobacco seedlings. Agronomy Notes 33(2): 1-3.

Cripps, C.L. and E. Grimme, 2010. Inoculation and successful colonization of whitebark pine seedlings with native mycorrhizal fungi under greenhouse conditions. IN: The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium. Keane, R.E., F.D.F. Tomback, M.P. Murray and C.M. Smith (Editors). 28-30 June 2010, Missoula, Montana. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. Proceedings RMRS-P-63. 376 pp. http://www.fs.fed.us/rm/pubs/rmrs_p063.html [Last accessed October 28, 2014].

Danielson, R.M. and S. Visser, 1988. Ectomycorrhizae of jack pine and green alder: Assessment of the need for inoculation, development of inoculation techniques and outplanting trials on oil sand tailings. Alberta Land Conservation and Reclamation Council, Reclamation Research Technical Advisory Committee, Edmonton, Alberta. Report No. RRTAC 88-5. 186 pp. http://hdl.handle.net/10402/era.22602 [Last accessed October 28, 2014].

Fleming, R., A. Groot, M. Adams, L. Van Damme and F. Foreman, 2001. Chapter 18: Direct Seeding. IN: Wagner, R.G. and S.J. Colombo (eds.). Regenerating the Canadian Forest: Principles and Practice for Ontario. Fitzhenry & Whiteside, Markham, Ontario. pp. 351-373.

Fraser, J.W. and M.J. Adams, 1980. The effect of pelleting and encapsulation on germination on some conifer seeds native to Ontario. Canadian Forest Service, Sault Ste. Marie, Ontario. Report O-X-319. 17 pp.

Gao T., J. Zhang, S.M. Zhou, M. Graham, M. Hayden and C. Roe. 2011. On stress-state dependent plasticity modeling: Significance of the hydrostatic stress, the third invariant of stress deviator and the non-associated flow rule. International Journal of Plasticity 27(2): 217-231.

Greene, D.F., D.D. Kneeshaw, C. Messier, V. Lieffers, D. Cormier, R. Doucet, K.D. Coates, A. Groot, G. Grover and C. Calogeropoulos, 2002. Modelling silvicultural alternatives for conifer regeneration in boreal mixedwood stands (aspen/ white spruce/ balsam fir). Forestry Chronicle 78(2): 281-295.

Grossnickle, S.C. and R.S. Folk, 2003. Spring versus summer spruce stocktypes of Western Canada: nursery development and field performance. Western Journal of Applied Forestry 18(4): 267-275.

Harris, D., A. Joshi, P.A. Khan, P. Gothkar and P.S. Sodhi, 1999. On-farm seed priming in semi-arid agriculture: Development and evaluation in maize, rice and chickpea in India using participatory methods. Experimental Agriculture 35(1): 15-29.

Hegarty, T.W., 1978. The physiology of seed hydration and dehydration, and the relation between water stress and the control of germination: a review. Plant Cell Environment 1(2): 101-119.

Hu, Y., 2012. Nutrient loading of aspen, jack pine and white spruce seedlings for potential out-planting in oil sands reclamation. University of Alberta, Department of Renewable Resources, Edmonton, Alberta. M.Sc. Thesis. 134 pp. http://hdl.handle.net/10402/era.28966 [Last accessed October 28, 2014].

Jackson D.P., R.K. Dumroes and J.P. Barnett, 2011. Nursery response of container Pinus palustris seedlings to nitrogen supply and subsequent effects on outplanting performance. Forest Ecology and Management 265: 1-12.

Khodakovskaya, M., E. Dervishi, M. Mahmood, Y. Xu and Z.R. Li, 2009. Carbon nanotubes are able to penetrate plant seed coat and dramatically affect seed germination and plant growth. ACS Nano 3: 3221-3227.

Landhäusser, S.M., J. Rodriguez-Alvarez, E.H. Marenholtz and V.J. Lieffers, 2012. Effect of stock type characteristics and time of planting on field performance of aspen (*Populus tremuloides* Michx.) seedlings on boreal reclamation sites. New Forests 43(5/6): 679-693.

Landis, T.D., R.W. Tinus and J.P. Barnett, 1999. The container tree nursery manual. Volume 6: Seedling propagation. USDA Forest Service, Agriculture Handbook, Washington DC. 166 pp.

Lieffers, V.J., C. Messier, P.J. Burton, J-C. Ruel and B.E. Grover, 2003. Chapter 13: Nature-based silviculture for sustaining a variety of boreal forest values. IN: Burton, P.J., C. Messier, D.W. Smith and W.L. Adamowicz (eds.). Towards Sustainable Management of the Boreal Forest. NRC Research Press, Ottawa, Ontario. pp. 481-530.

MacDonald, E., S. Quideau and S. Landhäusser, 2012. Rebuilding boreal forest ecosystems after industrial disturbance. IN: Restoration and Reclamation of Boreal Ecosystems. Vitt, D. and J. Bhatti (Editors). Published by Cambridge University Press.

MacKenzie, D.D., 2013. Oil sands mine reclamation using boreal forest surface soil (LFH) in northern Alberta. University of Alberta, Department of Renewable Resources, Edmonton, Alberta. Ph.D. Thesis. 240 pp. http://hdl.handle.net/10402/era.29371 [Last accessed October 28, 2014].

Mackenzie, D.D. and M.A. Naeth, 2010. The role of the forest soil propagule bank in assisted natural recovery after oil sands mining. Restoration Ecology 18(4): 418-427.

Mayer, A.M. and A. Poljakoff-Mayber, 1982. The germination of seeds. 3rd addition. Pergamon Press, Oxford, United Kingdom. 211 pp.

McDonald, M.B., 2000. Seed Priming. IN: Seed Technology and its Biological Basis. Black, M. and J.D. Bewley (Editors). Sheffield Academic Press Ltd., Sheffield, United Kingdom.

Mihajlovich, M. and P. Wearmouth, 2012. Planting trees on upland forested sites. Technical Note, NAIT Boreal Research Institute, Edmonton, Alberta. 6 pp. http://www.nait.ca/docs/Woody_Vegetation_Establishment_(892K_pdf).pdf [Last accessed October 28, 2014].

Mitchell, W.K., G. Dunsworth, D.G. Simpson and A. Vyse, 1990. Chapter 18: Planting and seeding. IN: Lavender, D.P., R. Parish, C.M. Johnson, G. Montgomery, A. Vyse, R.A. Willis and D. Winston (eds.). Regenerating British Columbia's Forests. UBC Press, Vancouver, British Columbia. pp. 235-253.

Mollard F.P., A. Naeth and A. Cohen-Fernandez, 2014. Impacts of mulch on prairie seedling establishment: Facilitative to inhibitory effects. Ecological Engineering 64: 377–384.

Naeth, M.A., S.R. Wilkinson, D.D. Mackenzie, H.A. Archibald and C.B. Powter, 2013. Potential of LFH Mineral Soil Mixes for Land Reclamation in Alberta. Oil Sands Research and Information Network, School of Energy and the Environment, University of Alberta, Edmonton, Alberta. OSRIN Report No. TR-35. 64 pp. http://hdl.handle.net/10402/era.31855 [Last accessed October 28, 2014].

Oil Sands Research and Information Network, 2013. Future of Shrubs in Oil Sands Reclamation Workshop. Oil Sands Research and Information Network, University of Alberta, School of Energy and the Environment, Edmonton, Alberta. OSRIN Report No. TR-43. 71 pp. http://hdl.handle.net/10402/era.17507 [Last accessed October 28, 2014].

Owston, P.W., R. Molina and G.A. Walters, 1992. Selection of planting stock, inoculation with mycorrhizal fungi, and use of direct seeding. IN: Reforestation practices in southwestern Oregon and Northern California. Hobbs, S.D., S.D. Tesch and P.W. Owston (Editors). Forest Research Laboratory, Oregon State University. 465pp.

Palacios G., R.M. Cerrillo, M.D. Campo and M. Toral, 2009. Site preparation, stock quality and planting date effect on early establishment of Holm oak (*Quercus ilex* L.) seedlings. Ecological Engineering 35(1): 38-46.

Parkinson, D. (Ed.), 1984. Mycorrhizal studies regarding the reclamation of oil sand tailings: Production and outplanting of jack pine seedlings and amounts of VA- and ectomycorrhizal inoculum in stockpiled peat. Alberta Environment, Research Management Division, Edmonton, Alberta. Report No. OF-70. 131 pp. http://hdl.handle.net/10402/era.25545 [Last accessed October 28, 2014].

Rokich, D., K.W. Dixon, K. Sivasithamparam and K.A. Meney, 2002. Smoke, mulch, and seed broadcasting effects on woodland restoration in western Australia. Restoration Ecology 10(2): 185-194.

Schott, K.M., B.D. Pinno, S.M. Landhäusser, 2013. Premature shoot growth termination allows nutrient loading of seedlings with an indeterminate growth strategy. New Forests 44(5): 635-647.

Schwartz, M.W., J.D. Hoeksema, C.A. Gehring, N.C. Johnson, J.N. Klironomos, L.K. Abbott and A. Pringle, 2006. The promise and the potential consequences of the global transport of mycorrhizal fungal inoculum. Ecology Letters (9): 501-515.

Scott, J.M., G.J. Blair and A.C. Andrews, 1997. The mechanics of coating seeds in a small rotating drum. Seed Science and Technology 25(2): 281-292.

Shell Canada Energy, 2012a. 2011 Environment Report – Jackpine Mine. Submitted to Alberta Environment and Water April 15, 2012. 426 pp.

Shell Canada Energy, 2012b. 2011 Environment Report – Muskeg River Mine. Submitted to Alberta Environment and Water April 15, 2012. 628 pp.

Smreciu A., K. Gould and S. Wood, 2013. Establishment of native boreal plant species on reclaimed oil sands mining disturbances. Prepared for Canadian Oil Sands Network for Research and Development. 45 pp. plus appendices.

Smreciu, A., H. Sinton, D. Walker and J. Bietz, 2002. Establishing native plant communities. Alberta Agriculture, Food and Rural Development and Alberta Environment and Alberta Sustainable Resource Development, Edmonton, Alberta. 93 pp.

Sonoran Institute, 2014. Colorado River delta restoration project: Hydroseeding native tree seeds. http://www.sonoraninstitute.org/component/docman/doc_view/1548-colorado-river-delta-program-restoration-project-hydroseeding-using-native-tree-seeds-10012012.html [Last accessed October 10, 2014].

Suncor Energy Inc., 2012. Reclamation progress tracking report for the year 2011. Submitted to Alberta Environment and Water April 15, 2012. 156 pp.

Sullivan J., G.S. Amacher, 2012. Optimal hardwood tree planting and forest reclamation policy on reclaimed surface mine lands in the Appalachian coal region. Resources Policy 38(1): 1-7.

Syncrude Canada Limited, 2012. 2011 annual reclamation progress tracking report – Mildred Lake and Aurora North Oil Sands Mines. Submitted to Alberta Environment and Water April 15, 2012. 126 pp.

Tan, W. and T. Vinge, 2012. Survivability and growth of winter-planted black spruce (*Picea mariana* [Mill.] B.S.P.) seedlings on a boreal fen in northwestern Alberta, Canada. Final Report to the Oil Sands Leadership Initiative. 20 pp.

Taylor, A.G., C.J. Eckenrode and R.W. Straub, 2001. Seed treatments for onions: Challenges and progress. HortScience 36(2): 199-205.

Timmer V.R. and A.S. Aidelbaum, 1996. Manual for exponential nutrient loading of seedlings to improve outplanting performance on competitive forest sites. Natural Resources Canada, Great Lakes Forestry Centre, Canadian Forest Service. Technical Report TR-25. 29 pp.

Walker N.R. and H.J. Johnson, 1974. Field performance of pine and spruce reared in the BC/CFS styroblock- Alberta. Northern Forest Research Centre, Canadian Forestry Service. Edmonton, Alberta. Information Report NOR-X-84. 14 pp.

6 GLOSSARY

6.1 Terms

Agronomic Species

A plant developed using agronomic methods (rather than a native plant).

Cover Crop

A close-growing crop used primarily for the purpose of protecting and improving the soil between periods of regular crop production or before establishment of the final vegetation on a reclaimed site.

Disturbed Site

Land on which excavation has occurred or upon which overburden has been deposited, or both.

Donor Site

A donor site is a site where seeds or other plant materials are harvested for the re-vegetation of a disturbed site.

Dormancy

A characteristic of the seed, not of the environment, the degree of which defines the conditions required to make the seed germinate or the failure of an intact viable seed to complete germination under favorable conditions.

Ecosite

(1) A subdivision of an ecosection that consists of an area of land with a particular parent material, having a homogeneous combination of soils and vegetation. A Canadian ecological land classification (ELC) system mapping unit, usually mapped at a scale of 1:50,000 to 1:10,000. Originally referred to as a “land type”.

(2) In Alberta, ecosite is defined as an area with a unique recurring combination of vegetation, soil, landform, and other environmental components.

Germination

Germination incorporates those events that commence with the uptake of water by the quiescent dry seed and terminate with the elongation of the embryonic axis.

In Situ Oil Sands

Distinguished from mineable oil sands as the deposit is too deep for surface extraction and thus bitumen is extracted in situ (underground) and brought to the surface via drilled wells. See also Mineable oil sand.

Lease:

(1) A legal document giving an operator the right to drill for or produce oil or gas;

(2) The land on which a lease has been obtained.

Mineable Oil Sand

Oil sand is a naturally occurring mixture of sand, clay or other minerals, water and bitumen, which is a heavy and extremely viscous oil that must be treated before it can be used by refineries to produce usable fuels such as gasoline and diesel. Minable oil sand is found close enough to the surface to be economically mined.

Nanomaterial

Chemical substances or materials that are manufactured and used at a very small scale.

Nanotechnology

Nanotechnology means to work at the nanoscale under controlled conditions.

Nanotechnology is the engineering and manufacturing of materials at the atomic and molecular scale.

Native plant

A species, subspecies, or lower taxon, occurring:

> a) within its historic range; or:
>
> b) in an extension of that range bounded by the dispersal potential of the "taxon" and under the condition that the extension of that "taxon" is not known to be related to, and cannot be reasonably attributable to, human activities.

Nursery Stock

Young plants grown in a nursery.

Overstory

A species that occurs within the tallest vegetation layer within a plant community. Most often trees.

Peatland

A peatland is a wetland where peat (partially decomposed organic material) has accumulated.

Pelletization

Process by which small or irregularly-shaped seeds are coated with an inert material to increase their size and to make them round and uniform, which facilitates the seeding process.

Reclamation

The process of reconverting disturbed land to its former or other productive uses.

Reforestation

The natural or artificial restocking of an area with forest trees.

Revegetation

The establishment of vegetation that replaces original ground cover following land disturbance.

Scarification

Breaking the seed coat by chemical or mechanical process to make it permeable to water.

Seed Orchards

A plantation of selected clones or progenies which are isolated or managed in order to avoid or to reduce pollination from outside sources, and managed to produce frequent, abundant and easily harvested seed crop.

Seed Zone

Geographic subdivisions of Natural Regions and Sub-regions and reflect climate, ecology and early results of coniferous tree species provenance trails. Free movement of tree seed for replanting is permitted within a seed zone.

Soil Compaction

The moving of soil particles closer together by external forces. In the compaction process, individual soil particles are packed closer together and soil aggregates are crushed, thus greatly reducing porosity. The major causes of soil compaction are:

(1) natural consolidation during soil forming processes (e.g., the weight of glaciers during the ice ages);

(2) trampling by animals and humans;

(3) natural shrinkage of soil upon drying; and,

(4) use of heavy equipment.

Soil Structure

The combination or arrangement of primary soil particles into secondary particles, units, or peds. The secondary units are characterized and classified on the basis of size, shape, and degree of distinctness into classes, types and grades.

Soil Texture

The relative proportions of sand, silt or clay contained in a soil sample.

Statification

Moistening the seeds and keep them at specific temperatures in the dark (or light) for weeks or months.

Understory

A species found in one of the lower vegetation layers within a plant community. Commonly shrub, grass or moss.

6.2 Acronyms

AER	Alberta Energy Regulator
AITF	Alberta Innovates – Technology Futures
ATISC	Alberta Tree Improvement and Seed Centre
ATV	All-Terrain Vehicle
CEMA	Cumulative Environmental Management Association
CNRL	Canadian Natural Resource Limited
COSIA	Canada's Oil Sands Innovation Alliance
EPA	Environmental Priority Area (of COSIA)
EPEA	*Environmental Protection and Enhancement Act*
ESRD	Environment and Sustainable Resource Development
GIS	Geographic Information System
LFH	Layer of dead organic matter and living organisms on the surface of the mineral soil in a forest
NAIT	Northern Alberta Institute of Technologies
NPKS	Nitrogen-Phosphorus-Potassium-Sulfate (Fertilizer)
OSE	Oil Sands Exploration
OSLI	Oil Sands Leadership Initiative
OSRIN	Oil Sands Research and Information Network
OSVC	Oil Sands Vegetation Cooperative

SEE	School of Energy and the Environment

APPENDIX 1: Examples of Seed Delivery Systems

Figure A1.1: Standard broadcast spreader, versatile spreader for rough ground and application of seeds to soil surface. Example shown is attached to a small tractor but sizes range from hand operated to ATV to tractor mounted. Source: www.landpride.com

Figure A1.2: Equipment used in pelleting process: (a) coating pan and (b) rotary coater equipment. Source: www.seedpelletingequipment.com

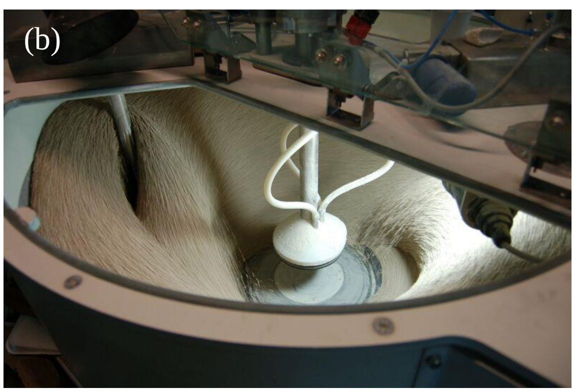

Figure A1.3: Jiffy peat pellet ® sourced: www.jiffypot.com

Figure A1.4: Examples of biodegradable pots. (a) CowPots™ biodegradable pots made from recycled cow manure. Source: www.johnnyseeds.com and (b) home-made cardboard pots. Source: www.gardentherapy.ca

Figure A1.5: Examples of equipment to enhance seed-soil contact. (a) Land-pride compact seed drill – these types of drills are suitable for reclamation because they are compact and can be carried directly on a mid-size tractor for maneuverability. The narrow width improves soil contact on uneven sites by reducing bridging across the width of the implement. Source: www.landpride.com. (b) close-up view of drill seeder wheel that creates trench for seed. (c) This seeder presses the seed into the ground. Often used for roadside reclamation planting, commonly called a 'Brillion seeder'. Source: www.landpride.com (d) second example of seed press viewed from above.

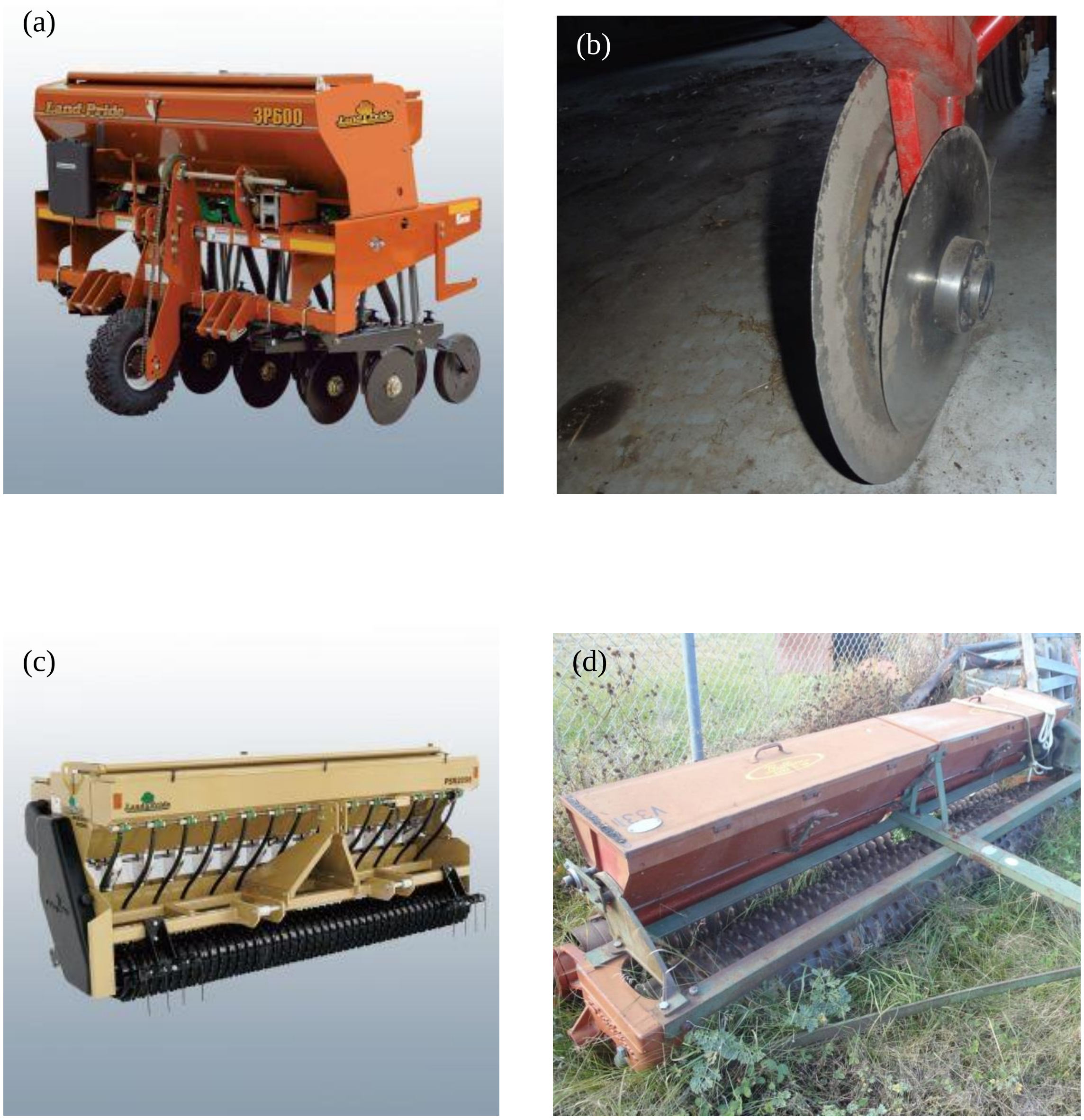

Figure A1.6: Example of an agricultural air-seeder system which plants the seeds in rows; seed stored in the tank at the rear of the implement is metered out and then carried by an air stream in tubes to the back of the cultivator shovels where the seed is injected into the soil. A row of press wheels at the back of the cultivator closes the furrows firming the soil around the seeds. Source: http://www.morris-industries.com/media/image/media/Concept-Feature.jpg

Figure A1.7: Examples of push seeders including (a) Jang JP1 Clean Seeder, capable of singulating a range of common vegetable seeds. Source: www.johnnyseeds.com and (b) an EarthWay push seeder. Source: http://earthway.com

(a)

(b)

Figure A1.8: Helicopter-mounted broadcast seeder for aerial seeding applications. Source: www.egliair.com

LIST OF OSRIN REPORTS

OSRIN reports are available on the University of Alberta's Education & Research Archive at http://hdl.handle.net/10402/era.17209. The Technical Report (TR) series documents results of OSRIN funded projects. The Staff Reports (SR) series represent work done by OSRIN staff.

OSRIN Technical Reports – http://hdl.handle.net/10402/era.17507

BGC Engineering Inc., 2010. Oil Sands Tailings Technology Review. OSRIN Report No. TR-1. 136 pp. http://hdl.handle.net/10402/era.17555

BGC Engineering Inc., 2010. Review of Reclamation Options for Oil Sands Tailings Substrates. OSRIN Report No. TR-2. 59 pp. http://hdl.handle.net/10402/era.17547

Chapman, K.J. and S.B. Das, 2010. Survey of Albertans' Value Drivers Regarding Oil Sands Development and Reclamation. OSRIN Report TR-3. 13 pp. http://hdl.handle.net/10402/era.17584

Jones, R.K. and D. Forrest, 2010. Oil Sands Mining Reclamation Challenge Dialogue – Report and Appendices. OSRIN Report No. TR-4. 258 pp. http://hdl.handle.net/10402/era.19092

Jones, R.K. and D. Forrest, 2010. Oil Sands Mining Reclamation Challenge Dialogue – Report. OSRIN Report No. TR-4A. 18 pp. http://hdl.handle.net/10402/era.19091

James, D.R. and T. Vold, 2010. Establishing a World Class Public Information and Reporting System for Ecosystems in the Oil Sands Region – Report and Appendices. OSRIN Report No. TR-5. 189 pp. http://hdl.handle.net/10402/era.19093

James, D.R. and T. Vold, 2010. Establishing a World Class Public Information and Reporting System for Ecosystems in the Oil Sands Region – Report. OSRIN Report No. TR-5A. 31 pp. http://hdl.handle.net/10402/era.19094

Lott, E.O. and R.K. Jones, 2010. Review of Four Major Environmental Effects Monitoring Programs in the Oil Sands Region. OSRIN Report No. TR-6. 114 pp. http://hdl.handle.net/10402/65.20287

Godwalt, C., P. Kotecha and C. Aumann, 2010. Oil Sands Tailings Management Project. OSRIN Report No. TR-7. 64 pp. http://hdl.handle.net/10402/era.22536

Welham, C., 2010. Oil Sands Terrestrial Habitat and Risk Modeling for Disturbance and Reclamation – Phase I Report. OSRIN Report No. TR-8. 109 pp. http://hdl.handle.net/10402/era.22567

Schneider, T., 2011. Accounting for Environmental Liabilities under International Financial Reporting Standards. OSRIN Report TR-9. 16 pp. http://hdl.handle.net/10402/era.22741

Davies, J. and B. Eaton, 2011. Community Level Physiological Profiling for Monitoring Oil Sands Impacts. OSRIN Report No. TR-10. 44 pp. http://hdl.handle.net/10402/era.22781

Hurndall, B.J., N.R. Morgenstern, A. Kupper and J. Sobkowicz, 2011. Report and Recommendations of the Task Force on Tree and Shrub Planting on Active Oil Sands Tailings Dams. OSRIN Report No. TR-11. 15 pp. http://hdl.handle.net/10402/era.22782

Gibson, J.J., S.J. Birks, M. Moncur, Y. Yi, K. Tattrie, S. Jasechko, K. Richardson, and P. Eby, 2011. Isotopic and Geochemical Tracers for Fingerprinting Process-Affected Waters in the Oil Sands Industry: A Pilot Study. OSRIN Report No. TR-12. 109 pp. http://hdl.handle.net/10402/era.23000

Oil Sands Research and Information Network, 2011. Equivalent Land Capability Workshop Summary Notes. OSRIN Report TR-13. 83 pp. http://hdl.handle.net/10402/era.23385

Kindzierski, W., J. Jin and M. Gamal El-Din, 2011. Plain Language Explanation of Human Health Risk Assessment. OSRIN Report TR-14. 37 pp. http://hdl.handle.net/10402/era.23487

Welham, C. and B. Seely, 2011. Oil Sands Terrestrial Habitat and Risk Modelling for Disturbance and Reclamation – Phase II Report. OSRIN Report No. TR-15. 93 pp. http://hdl.handle.net/10402/era.24547

Morton Sr., M., A. Mullick, J. Nelson and W. Thornton, 2011. Factors to Consider in Estimating Oil Sands Plant Decommissioning Costs. OSRIN Report No. TR-16. 62 pp. http://hdl.handle.net/10402/era.24630

Paskey, J. and G. Steward, 2012. The Alberta Oil Sands, Journalists, and Their Sources. OSRIN Report No. TR-17. 33 pp. http://hdl.handle.net/10402/era.25266

Cruz-Martinez, L. and J.E.G. Smits, 2012. Potential to Use Animals as Monitors of Ecosystem Health in the Oil Sands Region – July 2013 Update. OSRIN Report No. TR-18. 59 pp. http://hdl.handle.net/10402/era.25417

Hashisho, Z., C.C. Small and G. Morshed, 2012. Review of Technologies for the Characterization and Monitoring of VOCs, Reduced Sulphur Compounds and CH_4. OSRIN Report No. TR-19. 93 pp. http://hdl.handle.net/10402/era.25522

Kindzierski, W., J. Jin and M. Gamal El-Din, 2012. Review of Health Effects of Naphthenic Acids: Data Gaps and Implications for Understanding Human Health Risk. OSRIN Report No. TR-20. 43 pp. http://hdl.handle.net/10402/era.26060

Zhao, B., R. Currie and H. Mian, 2012. Catalogue of Analytical Methods for Naphthenic Acids Related to Oil Sands Operations. OSRIN Report No. TR-21. 65 pp. http://hdl.handle.net/10402/era.26792

Oil Sands Research and Information Network and Canadian Environmental Assessment Agency, 2012. Summary of the Oil Sands Groundwater – Surface Water Interactions Workshop. OSRIN Report No. TR-22. 125 pp. http://hdl.handle.net/10402/era.26831

Valera, E. and C.B. Powter, 2012. Implications of Changing Environmental Requirements on Oil Sands Royalties. OSRIN Report No. TR-23. 21 pp. http://hdl.handle.net/10402/era.27344

Dixon, R., M. Maier, A. Sandilya and T. Schneider, 2012. Qualifying Environmental Trusts as Financial Security for Oil Sands Reclamation Liabilities. OSRIN Report No. TR-24. 32 pp. http://hdl.handle.net/10402/era.28305

Creasey, R., 2012. Professional Judgment in Mineable Oil Sands Reclamation Certification: Workshop Summary. OSRIN Report No. TR-25. 52 pp. http://hdl.handle.net/10402/era.28331

Alberta Innovates – Technology Futures, 2012. Investigating a Knowledge Exchange Network for the Reclamation Community. OSRIN Report No. TR-26. 42 pp. http://hdl.handle.net/10402/era.28407

Dixon, R.J., J. Kenney and A.C. Sandilya, 2012. Audit Protocol for the Mine Financial Security Program. OSRIN Report No. TR-27. 27 pp. http://hdl.handle.net/10402/era.28514

Davies, J., B. Eaton and D. Humphries, 2012. Microcosm Evaluation of Community Level Physiological Profiling in Oil Sands Process Affected Water. OSRIN Report No. TR-28. 33 pp. http://hdl.handle.net/10402/era.29322

Thibault, B., 2012. Assessing Corporate Certification as Impetus for Accurate Reporting in Self-Reported Financial Estimates Underlying Alberta's Mine Financial Security Program. OSRIN Report No. TR-29. 37 pp. http://hdl.handle.net/10402/era.29361

Pyper, M.P., C.B. Powter and T. Vinge, 2013. Summary of Resiliency of Reclaimed Boreal Forest Landscapes Seminar. OSRIN Report No. TR-30. 131 pp. http://hdl.handle.net/10402/era.30360

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

Mian, H., N. Fassina, A. Mukherjee, A. Fair and C.B. Powter, 2013. Summary of 2013 Tailings Technology Development and Commercialization Workshop. OSRIN Report No. TR-32. 69 pp. http://hdl.handle.net/10402/era.31012

Howlett, M. and J. Craft, 2013. Application of Federal Legislation to Alberta's Mineable Oil Sands. OSRIN Report No. TR-33. 94 pp. http://hdl.handle.net/10402/era.31627

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

Naeth, M.A., S.R. Wilkinson, D.D. Mackenzie, H.A. Archibald and C.B. Powter, 2013. Potential of LFH Mineral Soil Mixes for Land Reclamation in Alberta. OSRIN Report No. TR-35. 64 pp. http://hdl.handle.net/10402/era.31855

Welham, C. and B. Seely, 2013. Oil Sands Terrestrial Habitat and Risk Modelling for Disturbance and Reclamation: The Impact of Climate Change on Tree Regeneration and Productivity – Phase III Report. OSRIN Report No. TR-36. 65 pp. http://hdl.handle.net/10402/era.31900

Eaton, B., T. Muhly, J. Fisher and S-L. Chai, 2013. Potential Impacts of Beaver on Oil Sands Reclamation Success – an Analysis of Available Literature. OSRIN Report No. TR-37. 65 pp. http://hdl.handle.net/10402/era.32764

Paskey, J., G. Steward and A. Williams, 2013. The Alberta Oil Sands Then and Now: An Investigation of the Economic, Environmental and Social Discourses Across Four Decades. OSRIN Report No. TR-38. 108 pp. http://hdl.handle.net/10402/era.32845

Watson, B.M. and G. Putz, 2013. Preliminary Watershed Hydrology Model for Reclaimed Oil Sands Sites. OSRIN Report No. TR-39. 193 pp. http://hdl.handle.net/10402/era.34250

Birks, S.J., Y. Yi, S. Cho, J.J. Gibson and R. Hazewinkel, 2013. Characterizing the Organic Composition of Snow and Surface Water in the Athabasca Region. OSRIN Report No. TR-40. 62 pp. http://hdl.handle.net/10402/era.36643

De Corby, R.G., 2013. Development of Silicon-Based Optofluidic Sensors for Oil Sands Environmental Monitoring. OSRIN Report No. TR-41. 19 pp. http://hdl.handle.net/10402/era.36936

Iqbal, M., T.K. Purkait, J.G.C. Veinot and G.G. Goss, 2013. Benign-by-Design: Synthesis of Engineered Silicon Nanoparticles and their Application to Oil Sands Water Contaminant Remediation. OSRIN Report No. TR-42. 30 pp. http://hdl.handle.net/10402/era.37308

Oil Sands Research and Information Network, 2013. Future of Shrubs in Oil Sands Reclamation Workshop. OSRIN Report No. TR-43. 71 pp. http://hdl.handle.net/10402/era.37440

Smreciu, A., K. Gould and S. Wood, 2013. Boreal Plant Species for Reclamation of Athabasca Oil Sands Disturbances. OSRIN Report No. TR-44. 23 pp. plus appendices. http://hdl.handle.net/10402/era.37533

Pereira, A.S. and J.W. Martin, 2014. On-Line Solid Phase Extraction – HPLC – Orbitrap Mass Spectrometry for Screening and Quantifying Targeted and Non-Targeted Analytes in Oil Sands Process-Affected Water and Natural Waters in the Athabasca Oil Sands Region. OSRIN Report No. TR-45. 33 pp. http://hdl.handle.net/10402/era.37793

Liang, J., F. Tumpa, L.P. Estrada, M. Gamal El-Din and Y. Liu, 2014. Ozone-Assisted Settling of Diluted Oil Sands Mature Fine Tailings: A Mechanistic Study. OSRIN Report No. TR-46. 43 pp. http://hdl.handle.net/10402/era.38226

Rochdi, N., J. Zhang, K. Staenz, X. Yang, D. Rolfson, J. Banting, C. King and R. Doherty, 2014. Monitoring Procedures for Wellsite, In-Situ Oil Sands and Coal Mine Reclamation in Alberta. OSRIN Report No. TR-47. 156 pp. http://hdl.handle.net/10402/era.38742

Taheriazad, L., C. Portillo-Quintero and G.A. Sanchez-Azofeifa, 2014. Application of Wireless Sensor Networks (WSNs) to Oil Sands Environmental Monitoring. OSRIN Report No. TR-48. 51 pp. http://hdl.handle.net/10402/era.38858

Marey, H.S., Z. Hashisho and L. Fu, 2014. Satellite Remote Sensing of Air Quality in the Oil Sands Region. OSRIN Report No. TR-49. 104 pp. http://hdl.handle.net/10402/era.38882

Li, C., A. Singh, N. Klamerth, K. McPhedran, P. Chelme-Ayala, M. Belosevic and M. Gamal El-Din, 2014. Synthesis of Toxicological Behavior of Oil Sands Process-Affected Water Constituents. OSRIN Report No. TR-50. 101 pp. http://hdl.handle.net/10402/era.39659

Jiang, Y. and Y. Liu, 2014. Application of Forward Osmosis Membrane Technology for Oil Sands Process-Affected Water Desalination. OSRIN Report No. TR-51. 27 pp. http://hdl.handle.net/10402/era.39855

Zhu, L., M. Yu, L. Delgado Chávez, A. Ulrich and T. Yu, 2014. Review of Bioreactor Designs Applicable to Oil Sands Process-Affected Water Treatment. OSRIN Report No. TR-52. 39 pp. http://hdl.handle.net/10402/era.39903

Oil Sands Research and Information Network, 2014. Oil Sands Rules, Tools and Capacity: Are we Ready for Upcoming Challenges? OSRIN Report No. TR-53. 120 pp. http://hdl.handle.net/10402/era.39985

Iqbal, M., T.K. Purkait, M. Aghajamali, L. Hadidi, J.G.C. Veinot, G.G. Goss and M. Gamal El-Din, 2014. Hybrid Aerogel SiNP Membranes for Photocatalytic Remediation of Oil Sands Process Water. OSRIN Report No. TR-54. 29 pp. http://hdl.handle.net/10402/era.40004

OSRIN Videos – http://hdl.handle.net/10402/era.29304

Rooney Productions, 2012. Assessment Methods for Oil Sands Reclamation Marshes. OSRIN Video No. V-1. 20 minutes. Also available on the University of Alberta You Tube Channel (recommended approach).

Rooney Productions, 2012. Assessment Methods for Oil Sands Reclamation Marshes. OSRIN Video No. V-1. Nine-part mobile device version. Also available on the University of Alberta You Tube Channel (link to Part 1 - recommended approach).

OSRIN Staff Reports – http://hdl.handle.net/10402/era.19095

OSRIN, 2010. Glossary of Terms and Acronyms used in Oil Sands Mining, Processing and Environmental Management – December 2013 Update. OSRIN Report No. SR-1. 123 pp. http://hdl.handle.net/10402/era.17544

OSRIN, 2010. OSRIN Writer's Style Guide – November 2013 Update. OSRIN Report No. SR-2. 29 pp. http://hdl.handle.net/10402/era.17545

OSRIN, 2010. OSRIN Annual Report: 2009/2010. OSRIN Report No. SR-3. 27 pp. http://hdl.handle.net/10402/era.17546

OSRIN, 2010. Guide to OSRIN Research Grants and Services Agreements - June 2011 Update. OSRIN Report No. SR-4. 21 pp. http://hdl.handle.net/10402/era.17558

OSRIN, 2011. Summary of OSRIN Projects – October 2014 Update. OSRIN Report No. SR-5. 113 pp. http://hdl.handle.net/10402/era.20529

OSRIN, 2011. OSRIN Annual Report: 2010/11. OSRIN Report No. SR-6. 34 pp. http://hdl.handle.net/10402/era.23032

OSRIN, 2011. OSRIN's Design and Implementation Strategy. OSRIN Report No. SR-7. 10 pp. http://hdl.handle.net/10402/era.23574

OSRIN, 2012. OSRIN Annual Report: 2011/12. OSRIN Report No. SR-8. 25 pp. http://hdl.handle.net/10402/era.26715

OSRIN, 2013. OSRIN Annual Report: 2012/13. OSRIN Report No. SR-9. 56 pp. http://hdl.handle.net/10402/era.31211

OSRIN, 2014. OSRIN Annual Report: 2013/14. OSRIN Report No. SR-10. 66 pp. http://hdl.handle.net/10402/era.38508