Emissions Reductions Alberta

Final Report

Mikro-Tek Project No. B140048

Biological Plant Inoculants to Increase Carbon Sequestration in Alberta's Agricultural and Forestry Sectors

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Executive Summary

Emissions Reductions Alberta (ERA) invests in promising technologies that can be implemented within Alberta to reduce greenhouse gas emissions. In 2015 Mikro-Tek was awarded a financial contribution by ERA to demonstrate its technology's ability to increase plant growth, and by extension, increase the rate of biological carbon sequestration. The project had two components: one in the forestry sector and the other in the agricultural sector. This report summarizes the activities and outcomes of both.

At Mikro-Tek's biotech facility in Ontario, naturally-occurring soil microbes (mycorrhizal fungi) are produced and shipped to domestic and international projects as concentrated plant inoculants. When applied prior to field planting, they trigger the formation of larger, healthier root systems, enabling tree seedlings and plants to absorb additional nutrients and moisture from the soil. In exchange the host plant provides the fungal organism with carbohydrates, which it produces during photosynthesis, making this a symbiotic association that benefits both the host plant and the mycorrhizal fungus. Most plants form these mutually beneficial associations with mycorrhizae over time, but by matching the proper species and strain of mycorrhizal fungus to the host plants, and applying it early in their establishment, Mikro-Tek can maximize plant survival and growth. The application of mycorrhizal fungi is particularly effective in disturbed areas such as harvested forestry sites.

Approximately 100 million seedlings are planted annually on Crown land in Alberta under 20 different forest management agreements. By adopting new and enhanced forest management methods, it is possible to increase the productivity and carbon uptake of Alberta's forests. Mikro-Tek has developed and demonstrated the technology's ability to enhance carbon sequestration in large-scale forestry projects in Chile. The goal of the ERA project was to deploy this technology in Alberta in order to prove enhanced carbon sequestration, which is required before carbon reductions can be registered under Alberta's Offset System.

The forestry project took place over a three-year period in partnership with West Fraser Timber. In the first two years, approximately 928,000 white spruce seedlings, half of which were treated with Mikro-Tek's technology, were planted on 580 hectares in the West Fraser-managed Slave Lake Forest. Field data collected in the fall of 2018 was used to compare growth differences between the treated and not-treated trees and to model the carbon sequestration potential using provincial growth data for the region. The models showed that Mikro-Tek's technology would increase biomass growth by 16.5 tonnes per hectare over an eighty-year period, demonstrating significant promise for large scale, cost-effective GHG reductions.

Extrapolating these results to West Fraser's annual replanting in the Slave Lake Forest, which is approximately 6 million seedlings per year, an additional 10 million tonnes of CO_2e would be

sequestered over a 40-year period, which is an average of 250,000 t CO_2e per year at an average cost of $0.41/t CO_2e.

Extrapolating the field data to all of Alberta, and assuming 50% of the trees currently planted across Alberta each year are treated with Mikro-Tek's technology, it would result in additional carbon uptake of 83 million tonnes CO_2e over 40 years (>2 Mt CO_2e/year) at an average cost of $0.33/t CO_2e.

Comparing this to the current federal price on carbon of $20/t CO_2e and the 2022 legislated federal carbon price of $50/t CO_2e, Mikro-Tek's mycorrhizal technology clearly presents a cost-effective approach to GHG reduction.

Looking to the future, if Mikro-Tek's forest management technology is to be commercially implemented in Alberta, there are several steps that must be undertaken to gain the approval of this technology for the generation of GHG offsets under the Alberta Offset System. These steps, along with a summary of Mikro-Tek's actions to obtain the required approvals to date, are discussed in Section 6, "Next Steps and Recommendations".

Also included is a discussion about why this project has been a critical step in the move toward "grouped projects", which can significantly simplify and lessen the cost of implementing the carbon project management process. Two expansion scenarios are presented to assess the cost and economic benefits of Grouped Projects: one using all of West Fraser's Slave Lake Forests, and another for an Alberta-wide project.

The ERA project also assessed the possibility for similar enhanced plant growth opportunities in Alberta's agricultural sector. This report includes a discussion of the activities and outcomes of the work undertaken as the project progressed from small-scale trials, conducted in collaboration with the University of Alberta, to larger-scale field trials on private farms in southern Alberta. The results of these trials indicate that mycorrhizal inoculation of seeds does not provide a substantial growth benefit. As some of the crop yield results were negatively impacted by variability over the sites and inclement weather events, Mikro-Tek recommends that no further investigation in the agricultural sector be undertaken. Instead, future efforts should concentrate on the significant opportunity in the forestry sector.

1. Technology Background

Mikro-Tek is a privately-owned environmental biotechnology company based in Timmins, Ontario with a branch office in Santiago, Chile. It has developed a carbon sequestration technology that utilizes selected strains of naturally-occurring soil fungi that colonize the root tissue of plants and form a structure called mycorrhiza. Matching a targeted plant community with the right species and strain of mycorrhiza results in a symbiotic association that increases the host plants' efficiency in accessing moisture and nutrients from the soil (Figures 1 & 2). The result is increased plant growth and survival, a reduction in the need for chemical fertilizers, and ultimately, more carbon sequestered from the atmosphere.

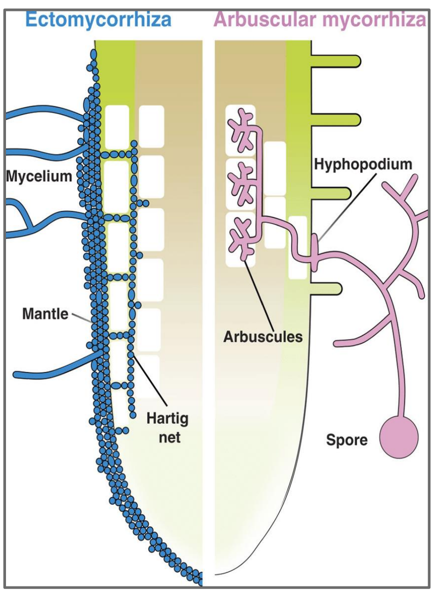


Figure 1. Root section with Ectomycorrhiza on conifer root (blue), and Arbuscular mycorrhiza on broad-leafed plant root (pink). The fungal mycelium enters the root and transfers nutrients and water from the soil into the root cells, resulting in increased plant growth. In exchange, the plant supplies the fungal organism with carbohydrates produced through photosynthesis, thereby making this a symbiotic association that benefits both the host plant and the mycorrhizal fungus.

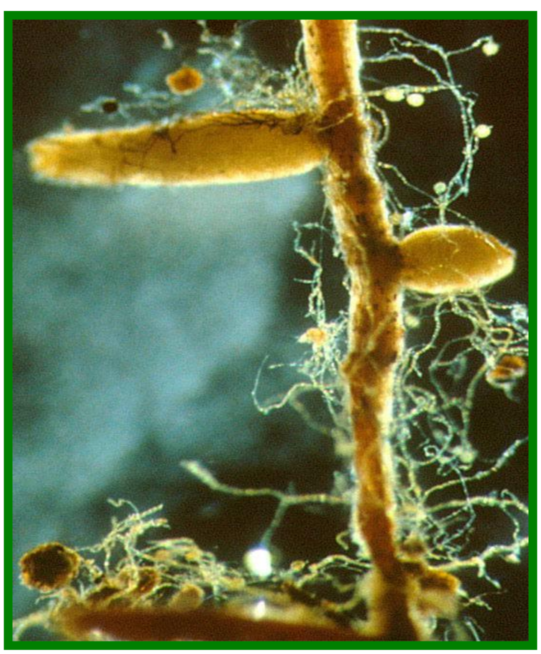


Figure 2. Magnified plant root and mycorrhizal mycelium (hyphae) and spores.

To implement the technology in the forestry sector, a liquid concentration of fungal inoculum is watered onto tree seedlings in the nursery prior to field planting. In agricultural and land reclamation projects that use broad-leafed plants, an inoculum concentrate is applied directly to the seeds at the time of planting.

This carbon sequestration technology has been successfully demonstrated in the forestry sector elsewhere in Canada, and also in Chile where large-scale afforestation projects on more than 6,500 hectares of degraded land were established in partnership with local landowners. Projects planted in 2003 and 2004 were registered in 2010 under the Clean Development Mechanism (CDM) of the Kyoto Protocol. Between 2004 and 2013 additional sites were added to make this a "grouped project", which was then registered under the Verified Carbon Standard (VCS). The projects were measured, validated and verified by independent VCS auditors and a total of 1.4 million offset credits have been registered to date, demonstrating that the technology qualifies under two of the most widely used international carbon offset registration systems. It also proves that the technology meets the stringent "additionality" requirements that qualify projects as "above business-as-usual", a prerequisite for registration of any carbon offset project.

2. Emissions Reductions Alberta (ERA) Project

The goal of Mikro-Tek's ERA project was to demonstrate and assess the mycorrhizal inoculation technology in Alberta's forestry and agricultural sectors and to determine whether the technology could be deployed to generate GHG reductions in Alberta. The project would also support the collection of site-specific field data required to register the technology for use under the Alberta Offset System (AOS). In the agricultural trials, the focus was on decreasing the use of fertilizers while increasing or maintaining biomass production. The reduction in fertilizer inputs per tonne of crop yield would reduce the overall carbon footprint of the farming operation and help the province meet its greenhouse gas (GHG) emission reduction targets. For the forestry sector, the goal was to demonstrate that the inoculation technology resulted in an increase in biomass production per hectare, compared to the standard replanting operations currently employed by the forest industry within the province.

3. Agricultural Sector

3.1 Small- Scale Agricultural Trials

The commercial use of mycorrhizal inoculants in agriculture had not been widely studied in Alberta, so the project review committee advised beginning with small-scale field trials prior to undertaking any large-scale demonstration trials.

The first small-scale trials were established in the spring of 2015 in partnership with the University of Alberta at their Breton research site 100 km southwest of Edmonton. The objective was to develop a pre-screening process to identify which crops, crop rotations, and fertilizer rates would show the best yield increases due to mycorrhizal inoculation. Despite the drought conditions that year there was a higher yield in 63 of the 84 wheat crop plots (75% of the trials) treated with mycorrhiza compared to untreated control plots. The greatest difference between treated and untreated crops was witnessed in plots where the soil had a low residual nitrogen content. Generally speaking, the more residual nitrogen in the soil, the higher the yield of the wheat, and the less significant the response was to mycorrhiza, indicating that mycorrhizal applications should be prioritized for low nitrogen soils. Dick Puurveen and Dr. Miles Dyck of the University of Alberta wrote the final report recommending that further research be done to look at the use of mycorrhiza with several rates of urea, comparing to urea treated with a nitrogen loss inhibitor.

In 2016 a second set of small-scale trials was established at the University of Alberta's Ellerslie Research Station in Edmonton and on plots near Breton. An 18-treatment experiment was conducted at the two sites, set up in a randomized control block design with four replicates for each treatment, which were averaged to determine which treatment showed the best yield. While the growing season in 2016 started off very dry, rainfall shortly after seeding maintained soil moisture with no sustained periods of soil saturation. It was hypothesized that because of the abundant rainfall, soil mineralization of organic matter provided more nutrients than anticipated, so enhanced efficiency fertilizers were not used on any of the treatments.

Canola is a crop that is not colonized by mycorrhiza and studies have shown that residual mycorrhizal populations in the soil are significantly lower after a canola rotation, so mycorrhizal inoculation would be expected to have a greater benefit for wheat grown on fields previously planted with canola. However, the University of Alberta trials had been established on wheat stubble instead of canola stubble, and testing prior to planting showed that there was no evidence that mycorrhizal populations were reduced at the initiation of the experiment. It is likely that there were sufficient residual mycorrhizae in the soil from the previous year of wheat production to mask any beneficial responses to mycorrhizal inoculation. The final results showed no improvement in grain yield in 2016 at the Ellerslie or Breton sites.

It was concluded that environmental conditions did not favour the use of enhanced efficiency fertilizers or mycorrhizal inoculation. Further, it was acknowledged that site variability is difficult to control in a field setting and it was recommended that future research should study the impact of different climatic conditions and soil types, and be undertaken on canola stubble where reduced mycorrhizal populations are known to occur.

3.2 Large-Scale Agricultural Trials

Point Forward Solutions, an agricultural management company based in Camrose, Alberta, was contracted to undertake large-scale agricultural inoculation trials in the Edmonton area in 2016 and 2017. Two 50-acre field trials were conducted in each year on wheat crops planted into canola stubble, as recommended in the small-scale studies done by the U of A. Digital zone management maps were compiled on all of the sites in order to plan the location and orientation of the inoculated test plots within the fields. The various polygon areas on the zone maps show field data such as soil conductivity, soil nutrients and topography and are used to outline the variations over the field that could have a bearing on productivity. These digital maps were used to guide the farmers' application of fertilizers, seeds and other products and to identify comparable plots on which to position mycorrhizal inoculated and control (not-inoculated) plots. See Figure 3 for a zone map example.

The mycorrhizal inoculum was shipped to the farms each spring and seeding was done directly into the stubble of the previous year's canola crop using a no-till system with a precision seeder. The inoculum was mixed into a slurry tank on the seeder and the liquid inoculum concentrate was injected directly into the soil at time of seeding. In the fall of each year a weigh wagon was used to collect yield data in the comparative strips within each respective treatment (mycorrhizal inoculated vs. not-inoculated control).

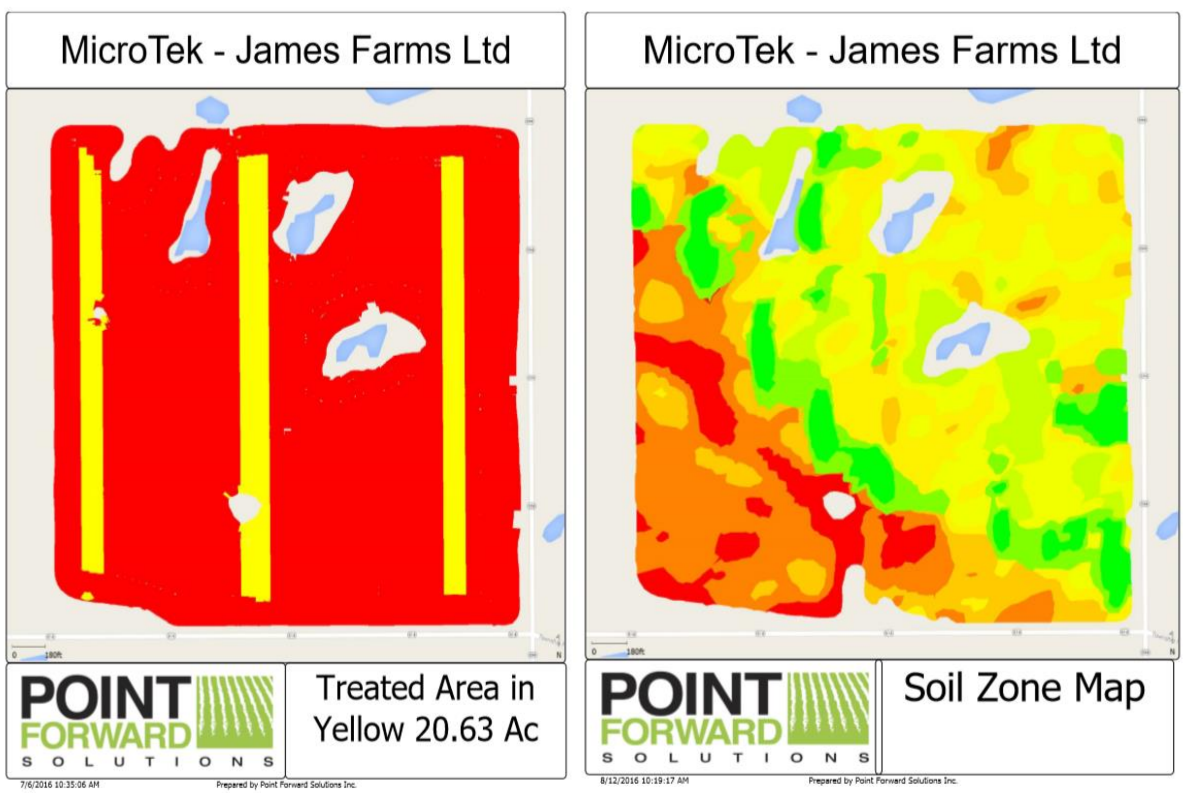


Figure 3. Digital Zone Maps showing inoculated areas (yellow) and control (red) in left map

Two additional trials were initiated near Read Deer in 2018 by Mikro-Tek personnel: one with wheat seeded into canola stubble and one on pre-established forage grasses with biochar additions to the soil. The wheat trials were designed similarly to the 2016 and 2017 large-scale trials, but the seed was pre-coated with a dry inoculum as opposed to it being applied directly to the soil as a slurry at time of seedling. The biochar additions to the forage grass trial were made to test the performance of the mycorrhizal inoculum in high carbon soils.

3.3 Agricultural Trial Results

The yield results for the large-scale wheat trials for 2016 and 2017 showed that there was no statistically significant difference between the inoculated and control treatments.

A side-by-side strip comparison method was used to collect the fall yield data for the 2018 wheat trial. The various treatment strips (inoculated and not-inoculated) were harvested on the same day to ensure that the moisture content was uniform on each. Each pass was weighed with a grain cart equipped with an electronic scale to record total yield across the entire field for each treatment. Side-by-side comparative strips were also harvested in the east and west sections because variability within the field made these more accurate than a comparison of field-to-field data. Average yield of both field areas was normal and deemed very good considering the amount of rainfall during the growing season. The inoculated treatment showed a fall yield increase of 3.3 % on the east strip and a 1.7% increase on the west strip, for an average yield increase due to mycorrhizal inoculation of 2.4 % (Figure 4).

Strip Location	Not-Inoculated (metric tonnes)	Inoculated (metric tonnes)	Difference (metric tonnes)	Increase due to Inoculation (%)
East	7.78	8.04	0.26	3.3
West	8.34	8.48	0.14	1.7

Figure 4. 2018 Wheat Trial Results

In 2018 a second set of trials was undertaken to investigate the growth response of mycorrhizal inoculation in combination with organic fertilizer on hay and feed crops. A field that had previously been treated with biochar was chosen for the trial.

Biochar is a high-carbon, fine-grained residue produced through pyrolysis by heating biomass in the absence of oxygen, which prevents full combustion. When it is used as a soil additive, research has shown that biochar can reduce the leaching and/or gas emission of fertilizers, especially nitrogen and phosphorus, resulting in increased biomass growth and reduced GHG emissions. There are also a number of published research papers[1] showing colonization of roots is increased by the presence of biochar in the soil, suggesting that this is due to the hyphal colonization of the cellulose structure of the biochar material itself. The mycorrhizal hyphae access nutrients adsorbed to the biochar and transport them back to the root of the plant via the hyphal network.

[1] "Biochar phosphorus concentration dictates mycorrhizal colonization, plant growth and soil phosphorus cycling" https://www.nature.com/articles/s41598-019-41671-7

The comparative treatment for the trial was set up using a combination of biochar, alfalfa and manure as outlined in Figure 5 below. At mid-season, a foliar sample was taken of the crop and analysed for protein content, an import component in the assessment of the quality for its use as an animal feed. In all cases the mycorrhizal additions increased the protein content of the feed with the Manure + Mycorrhizae + Biochar treatment giving the highest reading at 14%.

Treatment	Average Protein (%)	Percentage Point Increase	Percentage Increase in Total Protein
Biochar	16.8		
Biochar + Mycorrhizae	18.8	2.0	12%
Alfalfa + Biochar	15.6		
Alfalfa + Mycorrhizae + Biochar	16.4	0.8	5%
Manure + Biochar	14.7		
Manure + Mycorrhizae + Biochar	16.8	2.1	14.3%

Figure 5. Mid-season protein analysis forage crop trial

Yield results were measured just before the first mid-season cutting of the forage crop, reported in Figure 6 below:

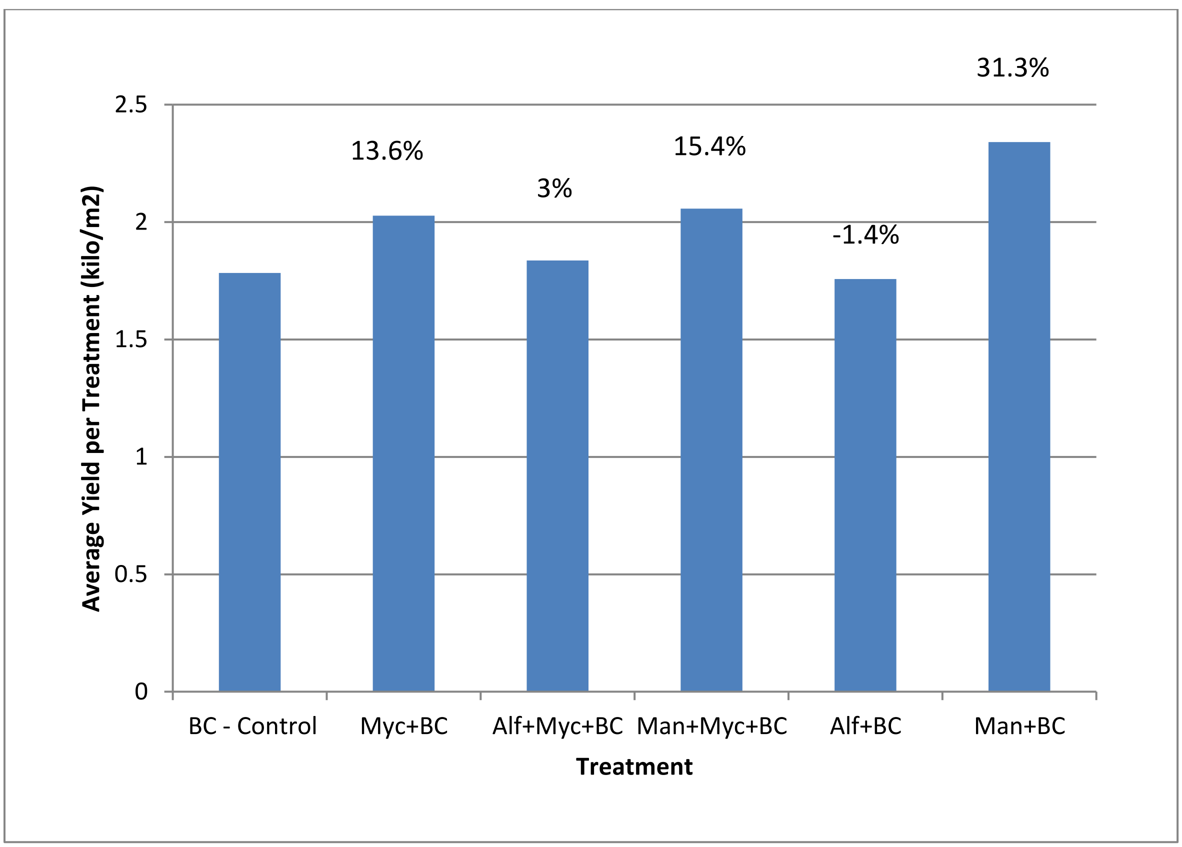


Figure 6. Mid-season yield data forage crop trial

Notes to Figure 6:

- % = percent increase in yield for treatment over control
- BC – Control = biochar control
- Myc+BC = mycorrhizae + biochar
- Alf+Myc+BC = alfalfa + mycorrhizae + biochar
- Man+Myc+BC = manure + mycorrhizae + biochar
- Alf+BC = alfalfa + biochar
- Man+BC = manure + biochar

3.4 Agricultural Trials Conclusion

The large-sale wheat trials undertaken in 2016 and 2017 did not show consistent yield increases in favour of mycorrhizal inoculation. It is hypothesized that this is due to variability over the sites and the significant impact of inclement weather events on crop yield in both years. The large-scale wheat trials undertaken in 2018 showed an average 2.4% higher yield in inoculated sites compared to not-inoculated control sites, but that slightly higher yield was not deemed sufficient to justify the additional cost of inoculation. The small-scale forage crop trial showed both a higher yield and a higher protein content for mycorrhizal inoculated crops compared to controls. As the highest yield and protein content were obtained for sites that included mycorrhizae, biochar, and manure, it is recommended that any future trials focus on additions of these supplements combined, on both forage crops and other organically produced agricultural crops.

No statistically significant changes in growth and yield results were obtained in the large-scale wheat trials using chemical fertilizers over the three-year period, so GHG assessments or economic analysis were not justified. It is therefore recommended that no additional work be undertaken on mycorrhizal inoculation of wheat or other grains at this time.

4. Forestry Sector

4.1 Tree Seedling Inoculation and Planting

Mikro-Tek partnered with West Fraser Timber to establish two reforestation test sites, where approximately 928,000 white spruce seedlings were planted on 580 hectares (ha) in the Slave Lake Forest of northern Alberta. Mycorrhizal inoculated seedlings, and an equal number of not-inoculated control seedlings, were planted in adjacent plots at each site during the 2016 and 2017 planting seasons in order to compare the difference in biomass growth. All of the reforestation seedlings were grown at private nurseries contracted by West Fraser: Coast to Coast Reforestation for 2016 seedings, and Pacific Regeneration Technology (PRT) for 2017 seedlings. The inoculum was produced at Mikro-Tek's biotech production facility in Timmins, Ontario, using their proprietary mycorrhizal strains and fermentation process (Figure 7).

Figure 7. Production of mycorrhizal inoculants

The concentrated inoculum was then shipped to the seedling nurseries each year when the seedlings were approximately 2 months old, for application by spraying the concentrated inoculum through the nurseries' irrigation systems (Figure 8).

Figure 8. Application of mycorrhizal inoculant through irrigation system at nursery

The not-inoculated control seedlings acted as the baseline, or "business as usual" scenario for the model, and the mycorrhizal inoculated seedlings provided the "additional" component that resulted in increased carbon being sequestered at the site due to increased biomass growth.

In the fall of 2018, a forest inventory was undertaken on all of the sites to collect biomass growth data (height, diameter and survival) that were used to calculate the total biomass per hectare for each treatment. (Figures 9 &10)

Figure 9. Field measurements and mapping of GPS plot locations at planting site

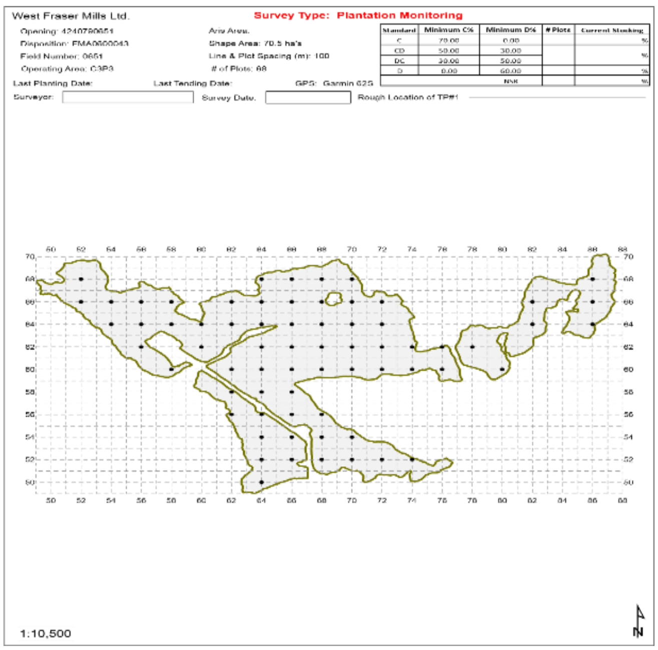


Figure 10. Plot Location map for each planted polygon

By combining seedling growth measurements with standard growth curves for white spruce growing in northern Alberta, estimates of future tree growth were calculated. These estimates showed that, over the forest rotation, the inoculated seedlings would produce approximately 16 tonnes more biomass per hectare than the not-inoculated seedlings. (Figure 11)

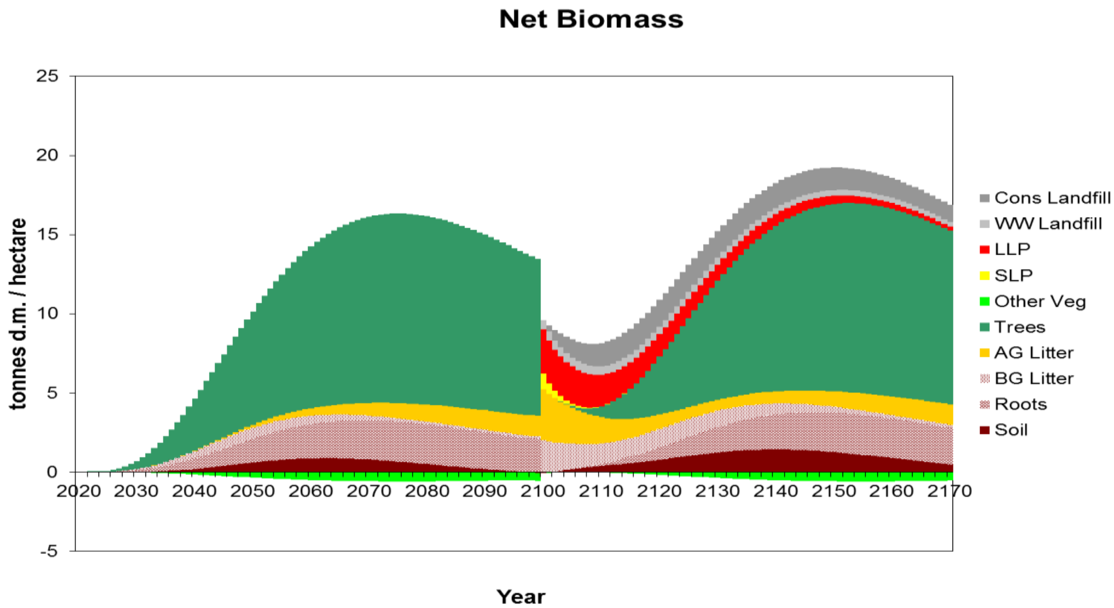


Figure 11. Net stand-level biomass per hectare

The biomass data were used to calculate the total carbon sequestered in the mycorrhizal-inoculated seedlings using internationally accepted carbon modelling techniques. These carbon models incorporate the additional carbon in the above ground tree biomass (the largest component—green section in Figure 11), and also account for carbon in roots, other vegetation, forest litter, soil, wood products and landfill. (Figure 12)

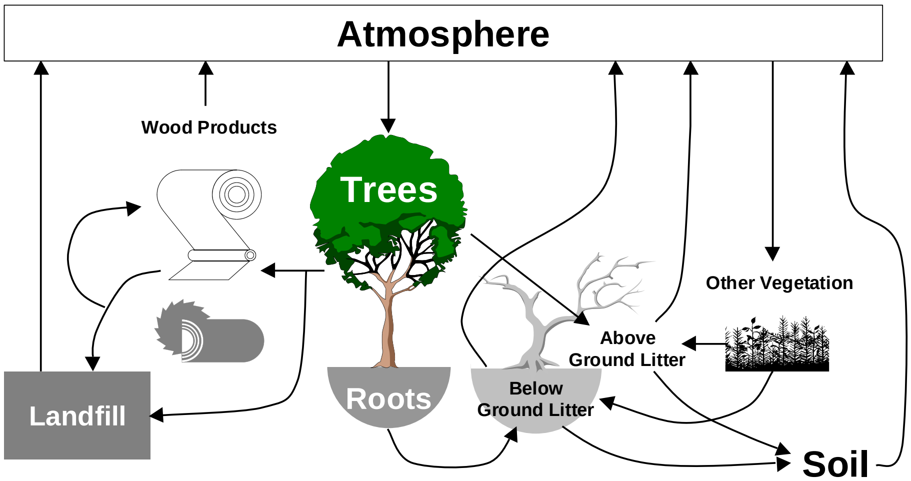


Figure 12: Carbon Flows in a Forest Ecologic/Economic System

4.2 Forestry Results

The increase in seedling survival due to inoculation at the two sites was 6.7% and 20%, and the increase in biomass volume per hectare was 9.3% and 12% respectively (Figure 13). These data were used to model increased carbon sequestration rates.

Trial Site	Species	Increased Survival	Increased Biomass Volume per unit area
North and South Wabasca	White Spruce	6.7%	9.3%
Slave Lake	White Spruce	20%	12%

Figure 13. Increased survival rates and volume due to mycorrhizal inoculation

The commercial-scale test sites provided the Alberta-specific three-year growth data required to develop the carbon models for white spruce planted on reforestation sites in the province. By matching these three-year data to Mikro-Tek's already-established growth curves from eleven-year-old sites in Ontario, the carbon sequestration potential of the sites was modelled to project an average yearly sequestration rate, and a total sequestration per rotation, under various management scenarios.

The estimates were made using a GORCAM carbon model, a published algorithm for modelling the flow of carbon and emissions from forestry projects. The optimal rotation length (time of maximum mean annual increment) is 66 years for the not-inoculated stands and 60 years with inoculation. However, the Slave Lake stands are considered mature at 60 to 130 years so, for modelling purposes, it was assumed that stands are, on average, harvested at 80 years. Figure 14 summarizes the results from the modelling. The net emissions fluctuate between a maximum immediately pre-harvest and a minimum immediately post-harvest.

Time	Biomass (t CO_2e/ha)	Non-biomass (t CO_2e/ha)	Total (t CO_2e/ha)	Annual Average (t CO_2e/ha/yr)
Pre harvest (maximum)	- 23.6	0.0	- 23.6	- 0.30
Post harvest (minimum)	- 9.4	- 6.1	- 15.5	- 0.19
Average	**- 16.5**	**- 3.0**	**- 19.6**	**- 0.25**

Figure 14. Modelled net emissions over the first rotation from inoculated stands

Finally, the affects of seedling inoculation on a forest with even age distribution were modelled (Figure 15). As shown, the majority of the emission reductions are caused by the increased growth in the first 80 years. Some additional sequestration in litter, soil and landfill, and reduction of emissions due to wood waste displacing fossil energy use occurs after this time.

Time	Biomass ($t\ CO_2e/ha$)	Non-biomass ($t\ CO_2e/ha$)	Total ($t\ CO_2e/ha$)	Annual Average ($t\ CO_2e/ha/yr$)
0 – 80 years	- 18.5	- 0.1	- 18.6	- 0.23
80 – 150 years	- 2.3	- 22.5	- 24.8	- 0.08

Figure 15. Modelled net emissions over a rotation from inoculated forests

The Alberta-specific carbon model developed in this project showed the net emissions from an inoculated forest of white spruce over a rotation to be 24.8 t CO_2e/ha, which is similar to the average of 26.6 t CO_2e/ha for three boreal species modelled in Ontario. *Ex-ante* (carbon sequestered over the rotation) and annual carbon sequestration projections outlined in this report were used to estimate the carbon sequestration potential for expanding the use of Mikro-Tek's improved forest management technology to all of West Fraser's sites in the Slave Lake area (Scenario A), and 50% of the Crown forest tenure sites in Alberta (Scenario B).

Based on the *ex-ante* carbon projections, the 580 hectares inoculated by West Fraser in 2016 and 2017 for this ERA project will sequester an additional average of 133 t CO_2e annually, for a total of 10,788 t CO_2e over the 80-year rotation of the forest as a result of mycorrhizal inoculation.

These carbon models for white spruce can now be used to establish additional projects across Alberta using a grouped project methodology as outlined below.

4.3 Forestry Conclusion

Based upon these positive study results, Mikro-Tek is recommending that the technology deployment focus for Alberta should be the forestry sector. There are currently no forestry methodologies or protocols approved for mycorrhizal inoculation use under the Alberta Offset System, so we researched similar protocols that have been approved internationally for their suitability for use in Alberta. We decided to use the Verified Carbon Standard Approved Methodology VM0034 - BC Forest Offset Methodology, as it allows for the use of improved forest management techniques and large multi-year grouped projects, as well as projects that are undertaken on Crown land where there could be multiple participants. The full VCS project design report entitled Mycorrhizal Inoculation of Reforestation Seedlings in Boreal Forests in Alberta has been completed and can be reviewed by contacting Mikro-Tek.

The models used in the project design report showed that Mikro-Tek's technology would increase biomass growth by 16.5 tonnes per hectare over an eighty-year period, demonstrating significant promise for large scale, cost-effective GHG reductions.

Extrapolating these results to West Fraser's annual replanting in the Slave Lake Forest, which is approximately 6 million seedlings per year, an additional 10 million tonnes of CO_2e would be sequestered over a 40-year period, which is an average of 250,000 t CO_2e per year with an average cost of $0.41/t CO_2e.

Extrapolating the field data to all of Alberta, and assuming 50% of the trees currently planted across Alberta each year are treated with Mikro-Tek's technology, it would result in incremental carbon uptake of 83 million tonnes CO_2e over 40 years (>2 Mt CO_2e/year) at an average cost of $0.33/t CO_2e. A detailed description of the assumptions and calculations used to make these projections is outlined in sections 5.1 and 5.2 below.

Comparing these figures to the current federal price on carbon of $20/t CO_2e and the 2022 legislated federal carbon price of $50/t CO_2e, Mikro-Tek's mycorrhizal technology clearly presents a cost-effective approach to GHG reduction.

5 Carbon Reduction Potential

A summary of the economic analysis for the deployment of the technology for GHG reductions within the province is outlined in the following two scenarios.

5.1 Slave Lake Forest

West Fraser currently plants between 5 and 7 million seedlings per year in their two Slave Lake Forest Management Areas (see Appendix A). If all these seedlings were inoculated over a 40-year period, assuming an average planting rate of 6 million seedlings per year, the project could sequester an additional 10 million t CO_2e over the 40-year period.

The cost/benefit analysis of undertaking this grouped project, which is presented in Appendix B, used the following assumptions:

- Plant 6 million inoculated seedlings per year at average planting density of 1,600 seedlings per ha.
- annual rate of emission reductions of 0.23 t CO_2e/ha/yr. (see Figure 15)
- project cost at $0.03 per seedling (inoculation cost at Net Present Value)

- total inoculation cost per 10-year monitoring period and a Monitoring, Reporting and Verification (MRV) cost of $200,000 at year ten, and an additional $100,000 increase at each ten-year monitoring event thereafter

Based upon the analysis, this project would generate approximately 190,000 carbon offsets by the tenth year at a cost of $10.54/t CO_2e. Over the entire 40-year term of the project, it would generate 10 million offsets at a cost of $0.41/t CO_2e. A project term of 40 years was used, as opposed to the 80-year rotation age, because this is the maximum term recommended for projects that use the VCS registration guidelines. At the end of the first 40-year term another project registration would need to be obtained in order to extend the project for an additional 40 years.

5.2 **Alberta-wide potential**

Alberta currently plants approximately 100 million seedlings each year on Crown land, spread over 20 different forest management agreements (see Appendix A). If just 50% of those seedlings were inoculated each year, over a 40-year period they would sequester an additional 83 million t CO_2e.

The cost/benefit analysis for this scenario, presented in Appendix C, used the following assumptions:

- Inoculation of 50% of all seedlings currently planted on Crown land in Alberta at an average planting density of 1,600 seedlings per ha.
- annual rate of emission reduction of 0.23 t CO_2e/ha/yr. (see Figure 15)
- project cost of $0.03 per seedling (inoculation cost at Net Present Value)
- a total inoculation cost per 10-year monitoring period + a Monitoring Reporting and Verification (MRV) cost of $300,000 at year ten with an additional $100,000 per monitoring period thereafter.

This analysis indicates that if Mikro-Tek’s mycorrhizal inoculation technology were deployed at 50% of the reforestation sites in the province, it would generate approximately 1.5 Mt CO_2e in carbon offsets by the tenth year at a cost of $9.67 per t$CO_2$e. After 40 years, such an approach would generate 83 million carbon offsets at a cost of $0.33/t CO_2e.

6. Next Steps and Recommendations

If Mikro-Tek's forest management technology is to be commercially implemented on reforestation sites in Alberta, the following tasks would have to be completed:

1. The Alberta Offset System would need to approve a Project Design Document outlining the forest management technology; carbon sequestration models; monitoring, reporting and verification (MVR) procedures and methodologies.
2. Project participants would have to be identified and engaged. Participants could include forest management companies holding provincial forestry licenses, First Nations groups with traditional land holdings, and/or private land owners wishing to start long-term carbon projects.
3. Official agreements would need to be secured with the various provincial agencies that have jurisdiction over natural resources on Crown land in Alberta in order to approve the establishment of projects and define the ownership of the resulting carbon offsets.

To this end Mikro-Tek has written a Project Design Document based on the trials established with West Fraser in this ERA project. In this report, two expansion scenarios have been formulated to assess the cost and economic benefits: one scenario for a Grouped Project using all of West Fraser's Slave Lake Forests and another for an Alberta-wide Grouped Project using 50% of the reforestation seedlings currently planted in Alberta.

Although these GHG projections were done using white spruce seedling growth data, Mikro-Tek did work with another research group at the University of Alberta, headed by Dr. Nadir Erbilgin and Dr. Justine Karst, who are working with mycorrhizal interactions in disturbed pine forests. Their research uses next generation advanced DNA assessments to monitor what happens to the mycorrhizal population after disturbances such as pine beetle infestation, fire, and clear-cut harvesting. In this ERA project Mikro-Tek contracted these individuals to complete the DNA assessments of some of their mycorrhizal cultures in order to identify the most appropriate strains for use with pine species in different areas throughout the province. A brief summary of their work to date is captured in this quote from Dr. Erbilgin:

"Soil fungal communities are essential parts of healthy forests as they can strongly influence soil nutritional characteristics. Particularly ectomycorrhizas can improve plant establishment and health by providing essential nutrients that plants need. However, ectomycorrhizal fungal communities change in response to disturbances including wildfire, insect outbreaks, clear-cut harvesting, and salvage harvesting. Understanding how these disturbances affect, for example, pine regeneration via changes in the fungal communities is essential as natural disturbance regime is changing due to rapid climate change. We found that some of these disturbances have much stronger effect on the fungal communities than others. In order to sustain productive pine

forests, soil fungal communities should be incorporated in pine regeneration. Our results showed that by doing so in a greenhouse, survival and establishment of pine seedlings can be significantly improved"

7. Project Financing

A downfall of undertaking forest management projects in the boreal forest is the slow growth of the trees relative to projects in more southern climates. Given that the carbon offset generation rates are directly linked to the forest growth rates, and that the majority of project costs are incurred at the start of the project, a mechanism for up-front funding for project establishment must be identified. There have been a number of reports recently on sustainable and clean technology finance that offer suggestions on how to address this issue. One report recently released by Canada's Expert Panel on Sustainable Finance entitled "Mobilizing Finance for Sustainable Growth"[2] makes a number of recommendations including Recommendation #12.3 (c):

> *"Proactively participating in negotiating the rules and technical scope of Article 6 of the Paris Agreement, and support Canadian activities that are likely to qualify. Article 6 is the part of the Paris Agreement that sets the framework for international cooperation to mitigate carbon pollution. It could set the stage for Canada to provide leading clean solutions to international markets."* Article 6 enables abatement measures taken in one country to be counted toward the achievement of another country's GHG emission targets through the process of Internationally Transferred Mitigation Outcomes, or ITMOs.

As described earlier in this report, Mikro-Tek has used its forest management technology in Chile since 2003, and has advanced afforestation projects in the country to register a total of 1.4 million offset credits under the Verified Carbon Standard (VCS). One sustainable financing option would be to use the ITMO process to provide these already-registered VCS credits to industry to address their immediate carbon offset requirements, and then supply additional offset credits from boreal projects that use the same technology in Alberta as they are registered over time under the Alberta Offset System.

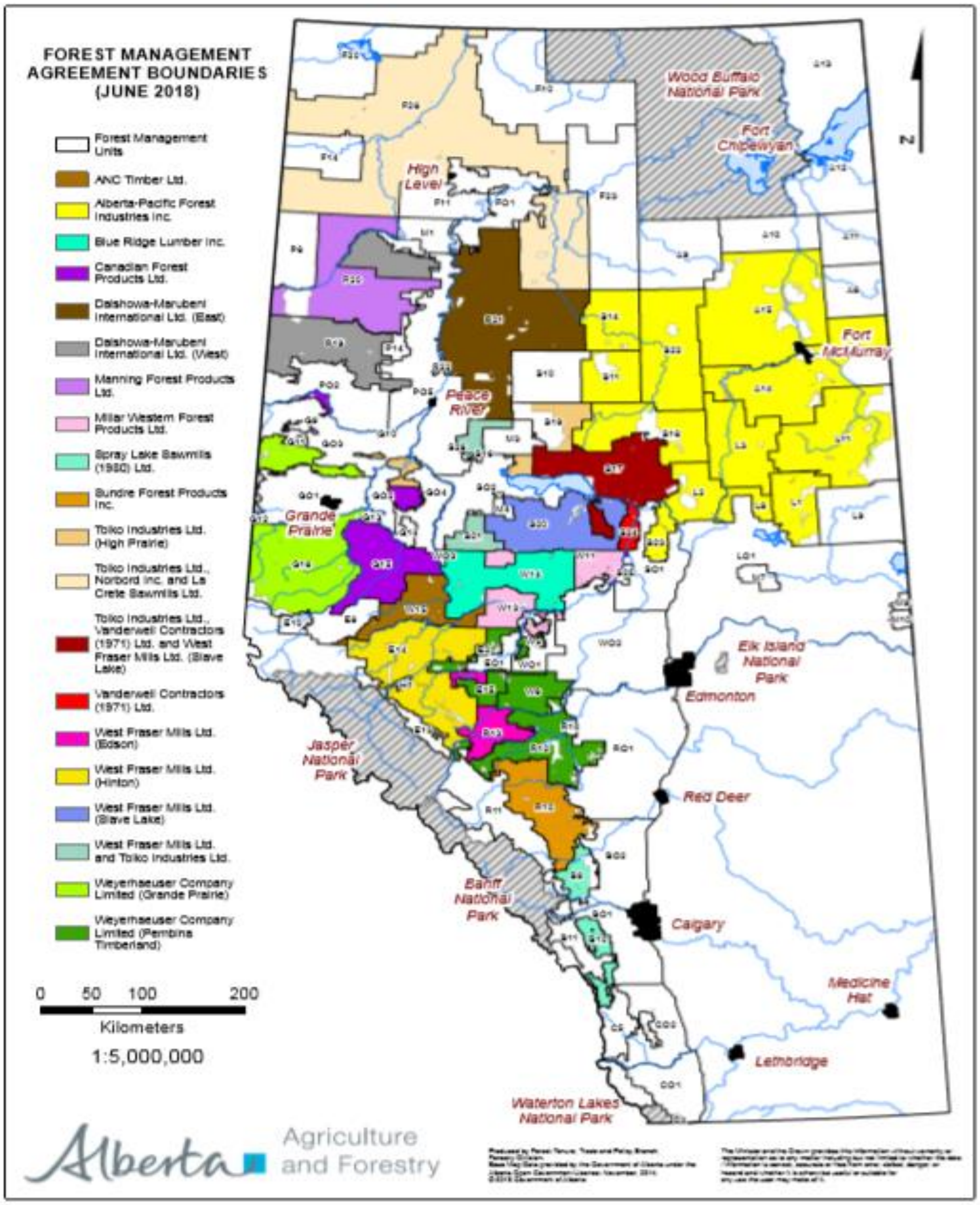
A second option for financing the upfront cost of project establishment would be to issue *ex-ante* credits, meaning 'in advance of' the offset credits being validated and verified. There are a number of offset protocols that use this system (e.g. Plan Vivo, Carbon Fix, Climate Action

[2] https://www.canada.ca/en/environment-climate-change/services/climate-change/expert-panel-sustainable-finance.html

Reserve, Ex-Act by FAO, etc.) *Ex-Ante* credits are usually issued with some type of discount to account for the delayed delivery schedule and/or the possibility of non-delivery. This non-delivery risk is handled either through deposits into a buffer (insurance) account, or a guarantee from government or insurance company. As the projects are initiated and advanced through the field monitoring and registration stages, they would be converted to *ex-post* (realized) credits and used for compliance purposes based upon registration under the Alberta Offset System.

Both of these financing options would require governmental policy directions or regulations allowing their use. Mikro-Tek continually monitors the developing carbon regulations and carbon trading markets in the provincial, federal and international sectors in order to adapt funding options accordingly. Whatever the funding model used to commercialize the technology, we are confident that cost effective offset credits can be delivered in the range of $10 /t CO_2e in the first 10 years of the project, with the cost falling far below that level as the forests reach maturity. Comparing this to the current federal price on carbon of $20/t CO_2e, which is projected to increase by $10/t CO_2e every year until 2050 when the price will be $50/t CO_2e, Mikro-Tek's mycorrhizal technology clearly presents a cost-effective approach to GHG reduction.

Appendix A. Forest Management Agreement Boundaries



APPENDIX B : A- West Fraser Timber & Mikro-Tek IFM Carbon Project - Slave Lake Alberta

Year	Seedlings Inoculated (millions)	Area Planted * (Ha)	Cumulative Areas Planted (Ha)	Estimated Annual Emission Reductions ** (tCO2)	Estimated Cumulative Emission Reductions (tCO2)	Project Implementation Cost ***	Cost per tCO2 at each 10 year MRV period ****
2021	6	3,750	3,750	863	863	$ 180,000	
2022	6	3,750	7,500	2,588	3,450	$ 180,000	
2023	6	3,750	11,250	5,175	8,625	$ 180,000	
2024	6	3,750	15,000	8,625	17,250	$ 180,000	
2025	6	3,750	18,750	12,938	30,188	$ 180,000	
2026	6	3,750	22,500	18,113	48,300	$ 180,000	
2027	6	3,750	26,250	24,150	72,450	$ 180,000	
2028	6	3,750	30,000	31,050	103,500	$ 180,000	
2029	6	3,750	33,750	38,813	142,313	$ 180,000	
2030	6	3,750	37,500	47,438	189,750	$ 180,000	$ 10.54
2031	6	3,750	41,250	56,925	246,675	$ 180,000	
2032	6	3,750	45,000	67,275	313,950	$ 180,000	
2033	6	3,750	48,750	78,488	392,438	$ 180,000	
2034	6	3,750	52,500	90,563	483,000	$ 180,000	
2035	6	3,750	56,250	103,500	586,500	$ 180,000	
2036	6	3,750	60,000	117,300	703,800	$ 180,000	
2037	6	3,750	63,750	131,963	835,763	$ 180,000	
2038	6	3,750	67,500	147,488	983,250	$ 180,000	
2039	6	3,750	71,250	163,875	1,147,125	$ 180,000	
2040	6	3,750	75,000	181,125	1,328,250	$ 180,000	$ 1.84
2041	6	3,750	78,750	199,238	1,527,488	$ 180,000	
2042	6	3,750	82,500	218,213	1,745,700	$ 180,000	
2043	6	3,750	86,250	238,050	1,983,750	$ 180,000	
2044	6	3,750	90,000	258,750	2,242,500	$ 180,000	
2045	6	3,750	93,750	280,313	2,522,813	$ 180,000	
2046	6	3,750	97,500	302,738	2,825,550	$ 180,000	
2047	6	3,750	101,250	326,025	3,151,575	$ 180,000	
2048	6	3,750	105,000	350,175	3,501,750	$ 180,000	
2049	6	3,750	108,750	375,188	3,876,938	$ 180,000	
2050	6	3,750	112,500	401,063	4,278,000	$ 180,000	$ 0.75
2051	6	3,750	116,250	427,800	4,705,800	$ 180,000	
2052	6	3,750	120,000	455,400	5,161,200	$ 180,000	
2053	6	3,750	123,750	483,863	5,645,063	$ 180,000	
2954	6	3,750	127,500	513,188	6,158,250	$ 180,000	
2055	6	3,750	131,250	543,375	6,701,625	$ 180,000	
2056	6	3,750	135,000	574,425	7,276,050	$ 180,000	
2057	6	3,750	138,750	606,338	7,882,388	$ 180,000	
2058	6	3,750	142,500	639,113	8,521,500	$ 180,000	
2059	6	3,750	146,250	672,750	9,194,250	$ 180,000	
2060	6	3,750	150,000	707,250	9,901,500	$ 180,000	$ 0.41
	240			9,901,500		$ 7,200,000	

Note * assuming planting 6 million seedling per year on West Fraser's Slave Lake Forests, with an average planting density of 1,600 seedlings per ha

Note ** using an annual rate of emission reductions @ 0.23 tCO2/ha/yr

Note *** using project cost at $0.03 per seedling (inoculation cost)

Note **** Using a total inoculation cost per 10 year monitoring period + an addtional MRV cost of $200,000 in 1st monitoring plus additional $100,000 per monitoring

APPENDIX C : B- Mikro-Tek IFM Carbon Project - Alberta

Year	Seedlings Inoculated (millions)	Area Planted * (Ha)	Cumulative Areas Planted (Ha)	Estimated Annual Emission Reductions ** (tCO2)	Estimated Cumulative Emission Reductions (tCO2)	Project Implementation Cost ***	Cost per tCO2 at each 10 year MRV period ****
2021	50	31,400	31,400	7,222	7,222	$ 1,507,200	
2022	50	31,400	62,800	21,666	28,888	$ 1,507,200	
2023	50	31,400	94,200	43,332	72,220	$ 1,507,200	
2024	50	31,400	125,600	72,220	144,440	$ 1,507,200	
2025	50	31,400	157,000	108,330	252,770	$ 1,507,200	
2026	50	31,400	188,400	151,662	404,432	$ 1,507,200	
2027	50	31,400	219,800	202,216	606,648	$ 1,507,200	
2028	50	31,400	251,200	259,992	866,640	$ 1,507,200	
2029	50	31,400	282,600	324,990	1,191,630	$ 1,507,200	
2030	50	31,400	314,000	397,210	1,588,840	$ 1,507,200	$ 9.67
2031	50	31,400	345,400	476,652	2,065,492	$ 1,507,200	
2032	50	31,400	376,800	563,316	2,628,808	$ 1,507,200	
2033	50	31,400	408,200	657,202	3,286,010	$ 1,507,200	
2034	50	31,400	439,600	758,310	4,044,320	$ 1,507,200	
2035	50	31,400	471,000	866,640	4,910,960	$ 1,507,200	
2036	50	31,400	502,400	982,192	5,893,152	$ 1,507,200	
2037	50	31,400	533,800	1,104,966	6,998,118	$ 1,507,200	
2038	50	31,400	565,200	1,234,962	8,233,080	$ 1,507,200	
2039	50	31,400	596,600	1,372,180	9,605,260	$ 1,507,200	
2040	50	31,400	628,000	1,516,620	11,121,880	$ 1,507,200	$ 1.62
2041	50	31,400	659,400	1,668,282	12,790,162	$ 1,507,200	
2042	50	31,400	690,800	1,827,166	14,617,328	$ 1,507,200	
2043	50	31,400	722,200	1,993,272	16,610,600	$ 1,507,200	
2044	50	31,400	753,600	2,166,600	18,777,200	$ 1,507,200	
2045	50	31,400	785,000	2,347,150	21,124,350	$ 1,507,200	
2046	50	31,400	816,400	2,534,922	23,659,272	$ 1,507,200	
2047	50	31,400	847,800	2,729,916	26,389,188	$ 1,507,200	
2048	50	31,400	879,200	2,932,132	29,321,320	$ 1,507,200	
2049	50	31,400	910,600	3,141,570	32,462,890	$ 1,507,200	
2050	50	31,400	942,000	3,358,230	35,821,120	$ 1,507,200	$ 0.63
2051	50	31,400	973,400	3,582,112	39,403,232	$ 1,507,200	
2052	50	31,400	1,004,800	3,813,216	43,216,448	$ 1,507,200	
2053	50	31,400	1,036,200	4,051,542	47,267,990	$ 1,507,200	
2954	50	31,400	1,067,600	4,297,090	51,565,080	$ 1,507,200	
2055	50	31,400	1,099,000	4,549,860	56,114,940	$ 1,507,200	
2056	50	31,400	1,130,400	4,809,852	60,924,792	$ 1,507,200	
2057	50	31,400	1,161,800	5,077,066	66,001,858	$ 1,507,200	
2058	50	31,400	1,193,200	5,351,502	71,353,360	$ 1,507,200	
2059	50	31,400	1,224,600	5,633,160	76,986,520	$ 1,507,200	
2060	50	31,400	1,256,000	5,922,040	82,908,560	$ 1,507,200	$ 0.33
	2,010			82,908,560		$ 60,288,000	

Note * assuming inoculating 50% of seedlings currently being planted on Crown land in Alberta, at average planting density of 1,600 seedlings per ha

Note ** using an annual rate of emission reductions @ 0.23 tCO2/ha/yr

Note *** using project cost of $0.03 per seedling (inoculation cost)

Note **** using a total inoculation cost per 10 year monitoring period + an addtional MRV cost of $300,000 in 1st monitoring + an additional $100,000 per monitoring