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Restoration Innovation Roadmap Phase 2:

A summary of opportunities to advance innovation for linear restoration within woodland caribou habitat

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Disclaimer

This report was developed for the purpose of exploring new and emerging technologies that may have utility in achieving restoration goals more efficiently and effectively. By including specific technologies in this report, the authors in no way imply or guarantee that these technologies will achieve the intended restoration goals. Rather, the purpose of this report was to provide a first look at innovations that could solve key challenges in linear restoration. All financial modelling presented in this report should be treated as preliminary in nature. Financial estimates were intended to provide a *"first look"* at how key technologies could benefit restoration.

Before advancing any of the ideas contained within this report to an operational stage, additional analyses and research should be conducted to further refine and quantify the potential benefits of specific technologies.

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Executive Summary

Restoration of legacy seismic lines within woodland caribou habitat has received considerable attention in the last seven years in Alberta. Restoration programs have successfully transitioned from testing techniques at an experimental scale to delivering operational scale programs of up to 350 km per year. As restoration programs shift in scale, one of the major challenges has been the cost of treatments. Programs regularly cite costs of $8,000-16,000 per km.

To help guide the identification of innovation opportunities for linear restoration, a series of organizations came together to fund a two-phase Restoration Innovation Roadmap. The first phase, funded by the Regional Industry Caribou Collaboration (RICC), focused on identifying key learnings to date to facilitate an adaptive management process. The second phase, contained within this report, was funded by Canada's Oil Sands Innovation Alliance (COSIA) and Alberta Innovates - Clean Energy. The focus of this second phase of the Restoration Innovation Roadmap was to identify a series of new technologies and techniques that could significantly increase the efficiency of restoration treatments, while maintaining or improving the ecological effectiveness.

This second phase of the Restoration Innovation Roadmap led to the identification of 23 potential technologies or techniques that could reduce the costs of restoration treatment delivery while maintaining or improving ecological effectiveness. Of these innovations, 17 were technologies and six were techniques. The innovations range from very concrete technologies like alternate excavator bucket designs that could be applied tomorrow, to forward-looking innovations such as airships which would require considerable time to develop but could transform the way in which restoration programs are delivered.

Of these 23 innovations, the authors determined their top ranked opportunities based on the ability to improve the efficiency and effectiveness of restoration programs. Five technologies or techniques that could be applied in the near term included:

1. Implementing virtual simulators to reduce training costs and increase productivity
2. Using the Hummock Transfer Technique to potentially avoid the costs of tree planting
3. Developing a multi-function machine to treat wetlands and uplands more efficiently
4. Planting shrubs within wetlands to potentially avoid the cost of site preparation
5. Adopting alternative equipment for treating uplands such as tow-behind implements or an excavator RipPlow

Three technologies that are forward-looking, but would require more research and development in order to be applied in the long term, included:

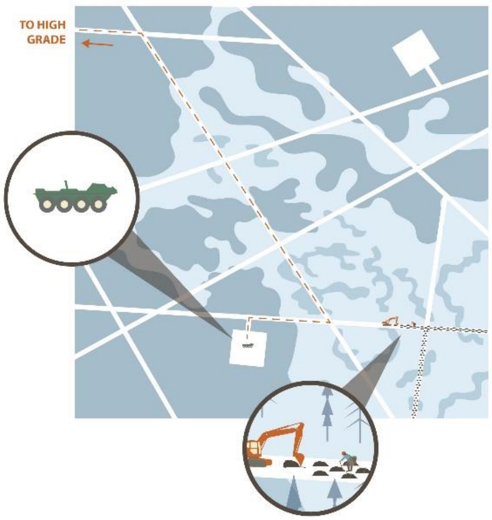
1. Airships to transport people and equipment, and to serve as a mobile camp
2. Autonomous equipment operations to facilitate increased productivity
3. The use of explosives to create surface roughness and apply woody materials

One of the key observations from this project was that there are no 'silver bullets' that promise to address all of the challenges and opportunities associated with restoration. However, some innovations,

such as the use of explosives or the planting of shrubs in wetlands without site preparation, do represent a drastic rethinking of how restoration programs are delivered.

The core observation from this study is that the cumulative impact of adopting multiple innovations could lead to a significant change in the way restoration programs could be delivered in the future. For example, adopting the use of virtual simulators to improve training for operators could increase the productivity of treatment delivery, while adopting alternative access vehicles instead of Argos could increase the time available for delivering restoration treatments. The Hummock Transfer Technique - a process by which intact peat hummocks are placed on treated lines - could eliminate the need to plant trees on difficult wetland sites. Taken together, just these three innovations could help reduce the costs of a hypothetical $12,000 per km program by between $3,272-4,202 per km (a savings of 27-35%) for wetland sites.

In addition to exploring these cumulative impacts through modelling, the changes to restoration programs can also be explored visually. The below figures show a conventional winter restoration program (left) and an alternative summer restoration program (right) that adopts many modest options identified through this Restoration Innovation Roadmap.



While the pursuit of new technologies identified in this report is exciting, organizations should not overlook the importance of project planning and project management. Many of the innovations within this document will likely fail to realize a material change in restoration costs without effective planning and project coordination.

The final step in the Restoration Innovation Roadmap project was the evaluation of opportunities to advance an innovation ecosystem for restoration. Through interviews with innovators and funders, the following opportunities emerged: creating a test site to showcase innovations, increasing communication about funding opportunities, reducing the administrative burden of funding applications, and creating an X-Prize challenge for restoration.

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Introduction

Why a Restoration Innovation Roadmap?

Restoration of linear features within woodland caribou habitat has received significant attention in the last five to seven years in Alberta. The first large scale restoration programs were initiated in 2012 (Pyper et al., 2014), and restoration has continued to gain interest and see significant application on the ground. In the last six years alone, oil sands and forestry industry partners have restored 1,200 km of linear features within the East Side Athabasca River and Cold Lake woodland caribou ranges (RICC, 2018), and across Alberta, restoration commitments from various organizations have totaled at least 7,500 km (Pyper and Broadley, 2018). The Government of Alberta, through their draft range plan, has also committed significantly to linear restoration as a range planning tool (Government of Alberta, 2017a), and has recently developed a framework to guide the treatment and evaluation of restoration success of linear features (Government of Alberta, 2017b).

Restoration of linear features has, therefore, moved from an experimental idea to one that is operational in nature. Programs are regularly being applied each year to address 75-150 km of linear features per project, and some have restored up to 350 km of linear features in a single year. While these numbers may seem small compared to the approximately 100,000 km of seismic lines that occur within woodland caribou ranges, the operational realities and accomplishments to deliver programs of this size are significant.

As restoration programs shift to larger scale programs, one of the major obstacles to success has been the cost of applying restoration treatments. Programs regularly cite costs of $8,000-16,000 per km. At the extreme ends of the range of costs, some programs cite as low as $6,000 per km, while others cite as high as $32,000 per km.

To help address some of these financial challenges with restoration, a range of supporters have recently invested in a Restoration Innovation Roadmap for linear restoration within woodland caribou habitat. Phase one of this Restoration Innovation Roadmap was funded by the Regional Industry Caribou Collaboration and focused on synthesizing what is currently known from past restoration programs and research (Pyper and Broadley, 2019). It included a detailed review of the academic literature and a review and synthesis of key operational learnings from programs delivered to date. The report also recommended a cost metric to help programs to report on costs in a more consistent way, such that comparing costs between programs becomes more standardized. This first phase of the Restoration Innovation Roadmap was intended to facilitate the adaptive management process, and ensure that key learnings from programs to date are synthesized and available for making adjustments and guiding further learning and experimentation in the field of restoration.

The second phase of the Restoration Innovation Roadmap is contained within this report. Funded by Canada's Oil Sands Innovation Alliance (COSIA) and Alberta Innovates - Clean Energy, this second phase is focused on looking forward to what opportunities might still exist in terms of innovations to achieve the goals of restoration within woodland caribou habitat. This second phase of the Restoration Innovation Roadmap project draws on the clarity and synthesis provided by phase one to develop a visionary roadmap to address the question, "what would it take to get restoration costs down to $4,000 per km while maintaining or improving ecological effectiveness?" While this target could arguably be viewed as too aggressive, an ambitious target can motivate a discussion about necessary innovations and opportunities to reduce the costs of restoration and maintain or improve its effectiveness. By setting a goal that is so aggressive as to be considered unattainable by some, this model motivates innovation that pushes far beyond the benchmark of "good enough".

Goals of the Restoration Innovation Roadmap Project

This second phase of the Restoration Innovation Roadmap project had three core goals:

1. To identify up to 30 innovations that could help improve the efficiency and effectiveness of linear restoration within woodland caribou ranges;
2. To bring together entrepreneurs and innovators to raise awareness about current experience and future opportunities in the field of restoration; and
3. To evaluate whether an innovation ecosystem currently exists for linear restoration, and what is needed in the future to further foster such an ecosystem.

References

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Approach

To complete this project, five core stages were executed by the project team:

1. Inventorying innovation ideas in the field of restoration from COSIA member companies, Alberta Innovates, and the Government of Alberta.
2. Completing a global review of available technologies that could guide innovation within the field of linear restoration.
3. Meeting with individual entrepreneurs to better understand their innovations and ideas around achieving increased efficiency in the field of linear restoration.
4. Hosting a workshop to bring together COSIA member companies, contractors currently delivering restoration, and local entrepreneurs and innovators who may have ideas that could help address key challenges faced in linear restoration. This included a pre-workshop webinar to introduce participants to the technical and logistical challenges being faced in linear restoration.
5. Evaluating each innovation based on the potential investment required, health and safety considerations, and potential to reduce the costs of delivering restoration treatments while maintaining or improving the ecological effectiveness (including cost modelling where feasible).

Inventorying innovation ideas

The first stage of phase two of the Restoration Innovation Roadmap was designed to draw on the knowledge and experience of the project Steering Committee (Appendix 1). Members of the Steering Committee were asked to share ideas they felt could be included in a list of potential future innovations in the field of linear restoration. The results of this inventory were collated and served as the first input into the selection of opportunities for the Restoration Innovation Roadmap.

Completing a global review

Next, the project team completed a high level, global scan of innovation ideas and existing technologies that might help support the goal of improving the efficiency of restoration treatments while maintaining or improving the effectiveness. This review was completed via Google Search using the following list of keywords: “amphibious harvesting equipment”, “amphibious equipment” “low ground pressure equipment”, “low ground pressure harvesting equipment”, and “harvesting equipment wetlands”. Specific countries were also added to the search terms to ensure the review focused holistically on technologies available in different locations around the globe. This review was not designed to be exhaustive. Rather, it served as an initial opportunity to identify unique technologies around the world. It also served to help the authors understand whether solutions to specific challenges, such as operating on wetlands, are similar around the world or whether distinct regional innovations have emerged to address region-specific technical challenges.

Meetings with individual entrepreneurs

Individual entrepreneurs, innovators, and manufacturers were then contacted to make them aware of the project and to meet and discuss potential opportunities for innovation. This process included meetings or phone calls with several organizations working in western Canada (Appendix 2). In some cases, these conversations included conceptual discussions about innovation opportunities. In other cases, conversations focused on understanding detailed information about equipment capabilities and specifications for inclusion in the Restoration Innovation Roadmap.

Workshop to bring entrepreneurs, innovators, and contractors together

A workshop was then held on November 4th, 2019. The workshop brought together a total of 36 entrepreneurs, innovators, contractors, and project Steering Committee representatives. The goals of the workshop included:

- Increasing awareness about linear restoration with a diverse group of contractors, entrepreneurs and innovators, and building relations and new collaborations
- Identifying key opportunities for research and innovation
- Identifying key steps required to foster more innovation around the topic of habitat restoration in Alberta
- Generating new ideas and enthusiasm for creative research and innovations around linear restoration in woodland caribou habitat that could be brought forward to COSIA

The workshop consisted of multiple small group discussions focused on the following key topics:

- Building a common understanding of challenges and opportunities in linear restoration
- Identifying the top innovation opportunities in linear restoration
- Discussing what is needed to advance an innovation ecosystem for linear restoration

The results of the workshop were used to inform the innovation opportunities showcased in this report and to inform discussion about advancing an innovation ecosystem.

Evaluating innovations

The final steps in the Restoration Innovation Roadmap project were to collate all the ideas and innovation opportunities and determine which would be included in the final Restoration Innovation Roadmap report. To determine which innovations were selected for inclusion in the final report, two key factors were considered: the scale of the potential impact on efficiency and the likelihood of the innovation realizing a step change in restoration practices. Innovations were also evaluated for their ability to achieve the ecological goals of restoration. Ecological effectiveness in the context of this project was defined as the ability to achieve the outcomes of the Provincial Restoration and Establishment Framework for Legacy Seismic Lines in Alberta (Government of Alberta, 2017).

Once the final list of innovations was determined, information about each innovation was collated into a two to four-page briefing note. These briefing notes were then further synthesized into this final report. The synthesis of each innovation focused on the following core areas:

- Why this innovation?
- Current context/where it is currently being applied

- Considerations and limitations
- Health and safety considerations
- Likelihood to reduce costs

Health and safety considerations were defined as the potential for an implemented innovation to change the expected risk profile for field personnel or environmental considerations as compared to current restoration practices. We used basic elements of the Energy Safety Canada Life Saving Rules Program and the ten base life-saving rules (LSRs) to provide a high level, preliminary assessment and contextualization of changes in health and safety risks. This assessment was chosen because it has broad acceptance and is widely used by multiple companies across the Athabasca Oil Sands region.

Likelihood to reduce costs was one of the most challenging sections to complete for each innovation. In some cases, results were available from case studies to project the potential cost savings for restoration programs. In other cases, modelling was completed to estimate the degree of potential time and cost savings for restoration programs (Appendix 3). When case studies or modelling were not viable approaches, the authors were required to draw on their professional experiences and opinions to estimate the potential impact of the innovation on costs. In all cases, readers are encouraged to see the likelihood to reduce costs as a preliminary projection that could be used to inform more detailed cost-benefit analyses, should organizations wish to pursue specific innovations.

The final step of this project was to provide an initial determination of the risk/reward for each innovation. To complete this step, each author filled out a form ranking each innovation in response to several questions. The first question was "How great is the risk that the innovation will be unsuccessful?", and was scored on a five-point scale based on the following criteria:

1 = Near certainty that the innovation will work right away
2 = The innovation will probably work in most intended situations
3 = The innovation may not work and/or will likely need some fine-tuning
4 = The innovation is unlikely to work the first time and will need repeated modification
5 = The innovation may never work, even with significant R&D

The authors' scores for each innovation were then averaged and categorized as either low risk (1-2), moderate risk (2-4), or high risk (4-5).

The second question was "How much could the innovation reduce restoration costs?", and was scored on a similar four-point scale:

1 = 0-5%
2 = 5-10%
3 = 10-25%
4 = >25%

The average scores for each innovation were then categorized as either low value (1-1.5), incremental value (1.5-2.5), moderate value (2.5-3.5), or high value (3.5-4). These evaluations were then merged to assign a risk/reward statement to each innovation. Readiness and Scale of Investment were ranked in a similar fashion.

Summary of Key Innovation Opportunities

The following table summarizes each of the key innovations showcased in this report. Preliminary assessments of risk/reward, readiness, and scale of investment are included here to help guide the assessment of each innovation opportunity.

Table 1. A summary of the key innovation opportunities captured in the Restoration Innovation Roadmap. Risk/reward rankings are based on a cumulative evaluation by the authors based on information collected during this project.

Category	Innovation	What is it?	How could it help?	Risk/Reward	Readiness	Scale of Investment*
Technologies	Virtual Simulator Training	Virtual simulators could be used to more efficiently train operators in restoration techniques.	Shorten training period, reduce time on equipment, improve productivity.	Low Risk/ Mod Reward	Immediate	Moderate
	Tree Scoop	A specially-designed implement to scoop trees or hummocks more easily than a traditional bucket, so they may be moved and placed on the line.	Reduce the cycle time of conventional mounding and facilitate efficient transfer of tree or hummock transplants. Less slumping of the mounded microsite is anticipated.	Mod Risk/ Incremental Reward	Immediate	Low
	Multi-function Machine	A dedicated all-in-one restoration machine fitted with implements that can deliver restoration treatments in wetlands and uplands.	Increase travel speed between sites and enable different implements to be used in different ecosites.	Mod Risk/ High Reward	Up to 10 years away	High
	UAVs Beyond Line-of-Sight	UAVs beyond line-of-sight could be used for rapid collection of planning and monitoring data over a large area.	Collect mapping/monitoring data over a wide project area quickly and with minimal crew costs.	Low Risk/ Mod Reward	Immediate	Minimal to Moderate
	Automated UAV Data Processing	An automated system that takes consumer-grade camera data and creates planning and	Facilitate the use of UAVs for monitoring and enable efficient	Mod Risk/ Incremental	Few years away	Low

* Scale of investment was categorized as:
- **Minimal** = no cost or little additional cost
- **Low** = thousands of dollars
- **Moderate** = tens of thousands of dollars
- **High** = hundreds of thousands of dollars
- **Very high** = millions of dollars

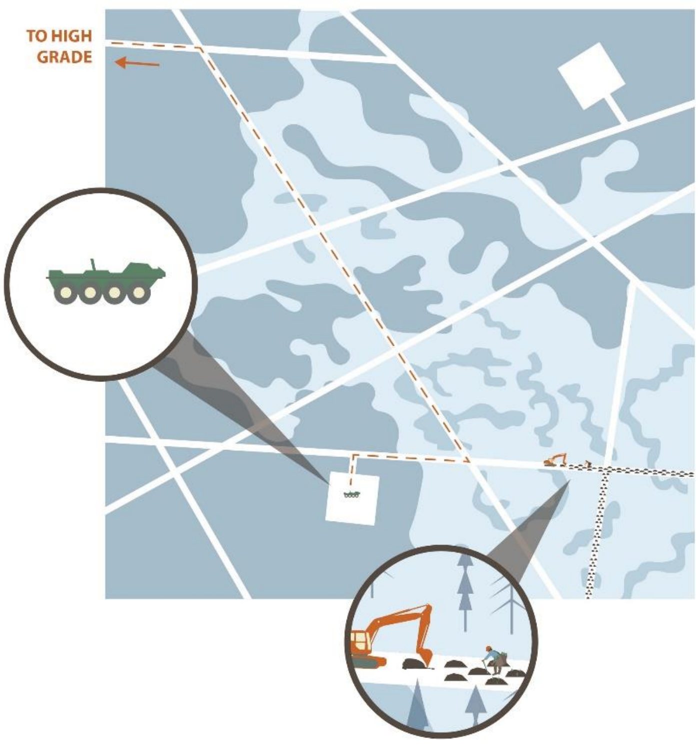
Category	Innovation	What is it?	How could it help?	Risk/Reward	Readiness	Scale of Investment*
		monitoring information.	protocols for handling and interpreting point cloud data.	Reward		
	Excavator RipPlow	An implement developed by Dave McNabb for plowing disturbed soils and rapidly creating surface topography.	Can be fitted to an excavator arm. Address compaction, competition, and site limiting factors.	Low Risk/ Mod Reward	Immediate	Moderate
	Alternative Access Vehicles	Vehicles which could offer more efficient crew mobilization compared to Argos.	Reduce commute times, increasing amount of productive hours each work day.	Low Risk/ Mod Reward	Immediate	Low to High
	Tree Planting Head - Bracke Planter	Excavator attachment which plants a seedling into an individually formed microsite.	Reduce the costs of tree planting by mounding and planting at the same time.	Mod Risk/ Incremental Reward	Immediate	High
	Teleoperation/Semi-autonomous Equipment	Control of machines outside line-of-sight by an operator in another location via a communication network.	Reduce worker travel time and facilitate transition to a 24 hour operation.	Mod Risk/ Mod Reward	Few years away	High
	Fully Autonomous Equipment	Machines which can recognize and respond to their environment, conducting site treatments without the direct control of an operator.	Reduce crew number and increase efficiency and consistency of treatments. Facilitate a 24 hour operation.	High Risk/ Mod Reward	10+ years away	Very High
	Breeding Trees	A selectively-bred, fast-growing variety of tamarack for each seed zone.	Boost survival rates and productivity of planted seedlings. Reduce frequency of re-treatment.	Low Risk/ Incremental Reward	Few years away	Moderate
	Amphibious Excavators	Specialized excavators that can travel on uplands and wetlands in non-frozen conditions.	Enable summer restoration programs and alleviate need to freeze in access roads.	Low Risk/ Mod Reward	Immediate	Low to High
	Tow-behind Implements	Rippers, disc-trenchers, mounders, and custom implements like the Shark Fin Drum for more quickly applying site preparation compared to conventional machinery.	Treat sites much faster than mounding with an excavator bucket. Produce microsites efficiently while moving machines between treatment areas.	Mod Risk/ High Reward	Few years away	Low to High
	Airships	Airships that can serve as all-in-one mobilization vehicles, remote camps, and staging locations.	Replace camp and access needs, while streamlining remote data collection.	High Risk/ Mod Reward	Up to 10 years away	Very High

Category	Innovation	What is it?	How could it help?	Risk/Reward	Readiness	Scale of Investment*
	Screw-propelled vehicles	Vehicles propelled by the rotation of flanged pontoons.	Produce microsites efficiently while moving machines between treatment areas.	High Risk/ Mod Reward	Up to 10 years away	High
	Modify and Miniaturize by Leveraging Robotics	Miniaturized remote-control or semi-autonomous tools for non-frozen ground conditions.	Reduce costs associated with mobilization, logistics, and terrain access.	High Risk/ Mod Reward	Up to 10 years away	Moderate to Very High
	Track Modification - Performance	Vehicles which could offer more efficient crew mobilization compared to Argos.	Reduce time lost to travel between sites.	Mod Risk/ Mod Reward	Few years away	High
Techniques	Hummock Transfer Technique	The process of scooping peat hummocks from a donor site adjacent to the line and placing them intact to serve as a functioning microsite.	Improve reliability of restoration in wet sites and potentially avoid the costs of tree planting.	Low Risk/ High Reward	Immediate	Minimal
	Planting Shrubs	Planting non-canopy-forming shrubs (e.g., willow, alder) on challenging wetland sites instead of trees.	Potentially eliminate the need for intensive site preparation.	Mod Risk/ High Reward	Immediate	Minimal
	24 Hour Operations	Implementing rotating shifts to enable continuous operations.	Shorten rental periods and/or get more productivity out of day rates for heavy equipment.	Mod Risk/ Incremental Reward	Immediate	Minimal
	Time-in-Motion Studies	Using productivity studies to identify opportunities for improved operator efficiency.	Identify concrete changes that can be made to increase productivity and operator efficiency in different conditions.	Low Risk/ Mod Reward	Immediate	Low
	Remote Camps	Eliminating the daily commute to the project site by having crews reside in mobile/temporary camps in the field.	Convert commuting time to work on a project.	Low Risk/ Incremental Reward	Immediate	Moderate
	Restoration via Explosives	Explosives that can deliver site treatments by creating surface roughness.	Rapid deployment of site treatment.	High Risk/ High Reward	Few years away	Moderate

Case Studies on the Cumulative Impact of Restoration Innovations

This report synthesizes 23 innovation opportunities and discusses their potential application in restoration. However, it is key to consider restoration as a system where each individual innovation may play a small, but cumulative role in helping realize improved restoration efficiency and effectiveness. To help readers visualize these linkages and assess the potential impacts on the cost of restoration, this section outlines two cases studies that could make use of multiple innovations. These case studies are presented early in the report to help users think about potential cumulative benefits of technologies and techniques summarized in later sections. One case study provides a visual representation of how restoration could evolve by implementing multiple innovations within this report. Second, a more thorough case study is presented that shows the cumulative impacts of multiple innovations on different cost factors in a restoration program.

Case study one: Visualizing changes in restoration through innovation



In this simple example, the illustrations depict three alternate realities for restoration. Figure 1 represents the most common current state of winter restoration programs: completing winter access site treatments and winter planting. In figure 2, a shift to summer operations is enabled by the use of amphibious equipment. Additional changes include planting of shrubs in wetlands and the use of new access equipment, teleoperation, tow-behind implements, and remote camps. Lastly, the final panel shows a forward-looking scenario of using fully autonomous multi-function machines, summer operations, explosives to create microsites, and airships to transport equipment and operators.

Figure 1. A visualization of current winter operations used to deliver restoration treatments.

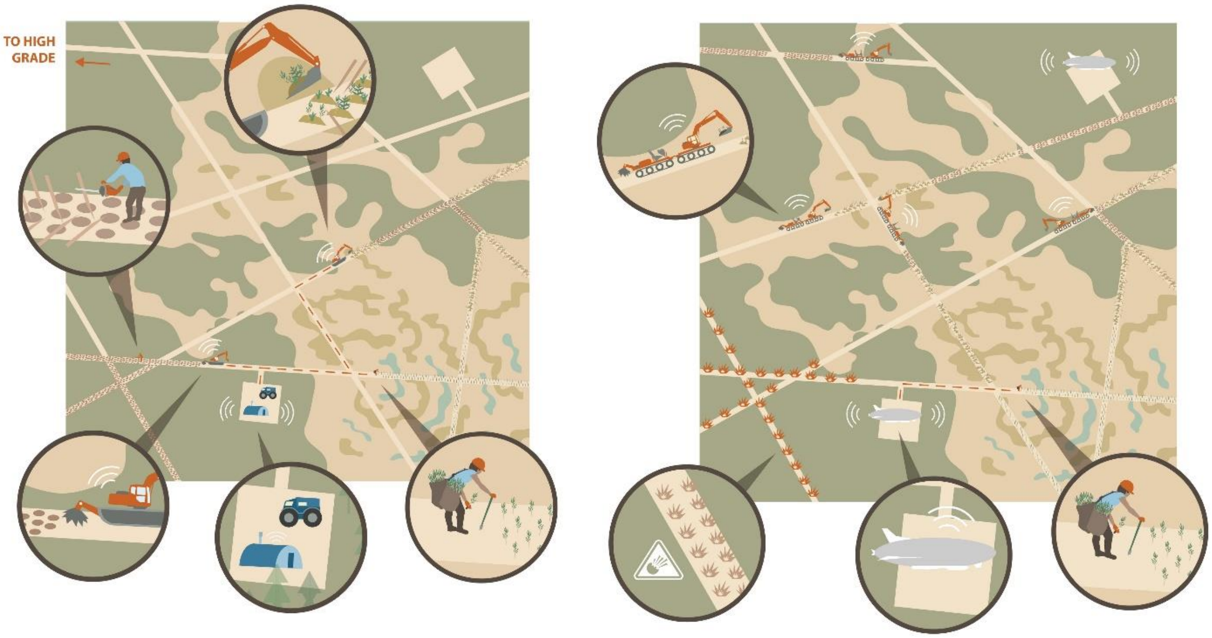


Figure 2. A visualization of changes in restoration practices that could be realized through the adoption of key technologies within the Restoration Innovation Roadmap.

Case study two: Estimating the cumulative impacts of technologies

To help quantify the potential cumulative economic benefit of innovations on a restoration program, a hypothetical case study is used here to showcase where, and by how much, specific innovations might affect the total cost of delivering an ecologically effective restoration program. For this case study, a generalized program cost has been selected and inputted into the restoration cost-reporting formula developed by Pyper and Broadley (2019). This formula assumes the following:

Cost per km = Planning (20-30%) + Implementation (65-75%) + Monitoring (3-5%)

To help explain this case study, a total cost per km of $12,000 is used for the hypothetical program. This cost is broken down into specific parts of a restoration program (i.e., planning, implementation, and monitoring) and innovations are showcased that could impact one or more of these components of a program. Individual innovations are presented and their impacts on cost are showcased. As additional innovations are then included in the hypothetical program, cost estimates are tallied to show the potential cumulative benefit of using multiple innovations.

For the case of a $12,000 per km program, we can start by assuming the following approximations for each stage of a restoration program:

$12,000 per km = Planning ($2,800) + Implementation ($8,720) + Monitoring ($480)

Planning costs generally include site inventories, site prescriptions, permitting, stakeholder meetings, and other preparatory activities. Implementation costs generally include access, treatment delivery, accommodation, tree planting, and other incidentals. Monitoring costs generally include post-treatment surveys to confirm survival of trees on treated sites and to assess whether sites are on a trajectory to achieving restoration goals.

This case study focuses on the impacts of new innovations on implementation costs to keep the example simple and clear. For this case study, the following variables are considered as part of the implementation costs. Specific allocations to access, treatment and tree planting were based on professional experience and the review completed by Pyper and Broadley (2019).

Implementation Costs ($8,720) = Access ($2,200) + Treatment ($3,720) + Tree Planting ($2,300) + Other ($500)

The first potential innovation in this case study is to change the way in which sites are accessed. Access has been noted as a significant challenge for restoration programs. Winter access requires considerable investment in construction and maintenance of ice roads, and summer access requires long, slow commute times from high grade to remote restoration areas. Argos have primarily been used to access these remote sites. However, a wide range of alternate access vehicles are available and could reduce access times to remote locations. To help evaluate the potential financial and productivity impacts of alternate access vehicles, a thorough modelling exercise was completed that included specific estimates of rental costs, access time, and operating costs over a hypothetical 24 day program for a range of access options (see modelling details in Appendix 3).

A core takeaway from this modelling exercise is that while alternate access vehicles may not directly reduce costs (in fact, they may cost more than Argos), they provide tangible benefits by facilitating faster travel, which in turn increases the amount of actual working time available for delivering restoration treatments. Thus, their impacts are indirect. Additional work time translates to cost savings by increasing the amount of line treated each day. Depending on program proximity to high grade roads, alternate access vehicles could reduce implementation costs by as much as 30% (Figure 3), while potentially costing 15% more per km. Though less tangible, workers are also likely to arrive at work sites less fatigued compared to access via Argos due to increased comfort. Based on this modelling, we can assume a shift to an alternate access vehicle could prove beneficial. Based on a 20-30% increase in productive treatment time, while accounting for 15% higher access costs, alternate access vehicles could help reduce treatment costs by $414-786 per km (i.e., ($3,720 x 0.2)-($2200 x 0.15) = $414). The relative benefit of alternate access vehicles is also increased the farther treatments are from high grade access (Figure 3). For more information on alternate access vehicles, see Appendix 4.

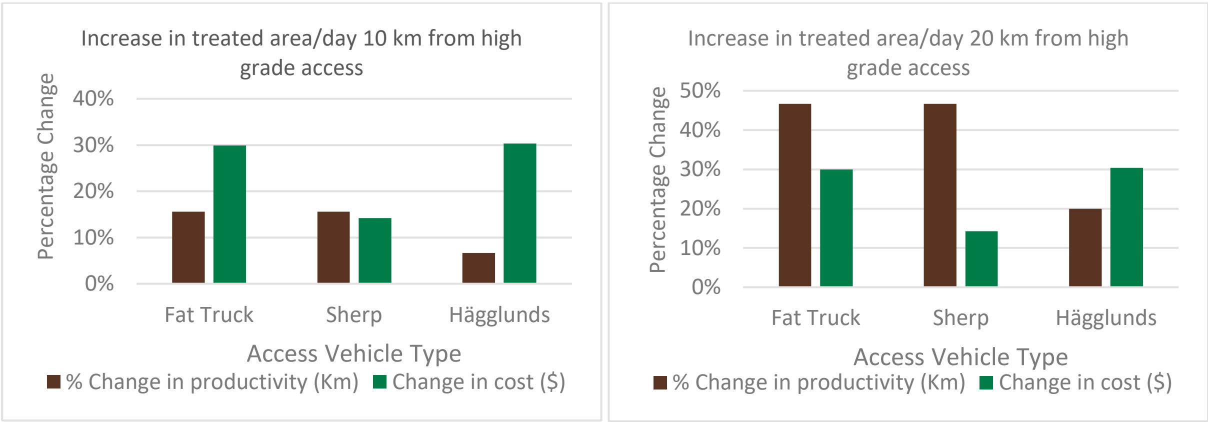


Figure 3. Results of a modelling exercise showing the projected increase in area treated per day by reducing the time required to access a site by using alternate access vehicles. This scenario was modeled for a program that is 10 km from high grade access (left) and 20 km from high grade access (right). Percentage change reflects the increase in area treated per day in comparison to a base case of using an Argo to access a site. Fat Truck, Sherp and Hagglunds are commercially available access vehicles selected for this comparison. See Appendix 3 for modelling assumptions and methods.

Next, virtual simulators have the potential to improve restoration efficiency. Virtual simulators have been shown to reduce the time required to train operators, and could result in efficiency improvements for treatment implementation of 15-30%. Applying this value to only the treatment delivery portion of the implementation costs, we could see a potential reduction in costs of $558-1,116 per km (i.e., $3,720 x 0.15 = $558).

Finally, the delivery of restoration treatments in both wetlands and uplands could be changed. In wetlands current techniques rely on creating an inverted mound, felling trees, and planting trees on the mounded microsites. However, two new methods - the Hummock Transfer Technique and tow-behind implements - may facilitate more rapid and efficient treatment options.

In wetlands, the Hummock Transfer Technique may provide an opportunity to re-establish tree, shrub, and moss cover on lines while avoiding the costs of tree planting. Use of a tree scoop may provide opportunities to do this technique efficiently and reliably within wetland sites. By potentially removing the need to plant trees on these sites, implementation costs could be reduced by $2,300 per km in our case study example.

In uplands, use of a tow-behind implement or an excavator RipPlow could transition the creation of microsites from “one at a time” to a more continuous process to increase efficiency. An excavator RipPlow may reduce the time to treat a kilometre of upland seismic line from 6-8 hours to 2.5-3 hours (approximately a 60% reduction in time). A RipPlow has not yet been tested alongside excavator mounding on an upland site, so there is uncertainty in the projected treatment times. However, if a conservative estimate of a 30-40% reduction in treatment times is used, this innovation could translate into a $1,116-1,488 reduction in treatment costs per km for upland sites ($3,720 x 0.3 = $1,116). Tow-behind implements would likely realize an even more significant change in cost per km.

Bringing the savings estimated in these case study calculations together could translate into meaningful changes in the cost of delivering restoration programs. Within wetland sites, the use of multiple innovations could realize a $3,272-4,202 reduction in restoration costs per km based on this case study. Using the same approach, within upland sites a $2,088-3,390 reduction in costs could be realized per km.

Importantly, the cost savings realized here leveraged only a few innovations to address two cost drivers (Access and Treatment) within one component (Implementation) of the broader restoration program cost formula. By leveraging additional innovations to address other Implementation needs and to address Planning and Monitoring components of a restoration program, it is likely that overall restoration costs could be further reduced.

This case study should serve to show the potential of innovative technologies and techniques to reshape the way in which restoration can be completed. While no single innovation constitutes a 'silver bullet', this case study demonstrates the potential of combining multiple innovations to realize cumulative step changes in efficiency. Additional case studies and small scale field trials could be used to test the assumptions and projections presented here, and to confirm the potential for these estimates to translate into increased efficiency and effectiveness of treatment delivery on restoration programs. It is likely that by changing the way in which we think about restoration programs, meaningful reductions in restoration costs could be realized by using new technologies and techniques.

Case study considerations

When considering these case studies, it is important to interpret them as an initial best estimate of potential cost efficiencies. Robust modelling and analysis supports the estimates presented here; however, even the best models carry uncertainty. It is also possible that transitioning from case studies to operational implementation may not result in all of the cost efficiencies being realized due to factors not considered in the modelling. As with other financial estimates in this report, readers are encouraged to view these estimates as a first cut at potential cost efficiencies that could be realized by adopting innovations.

See Appendix 3 for model assumptions and inputs.

References

Pyper, M., & Broadley, K. (2019). Restoration Innovation Roadmap Phase 1: A Synthesis of Lessons Learned to Date. Prepared for Regional Industry Caribou Collaboration (RICC). May 3, 2019.

Innovation Opportunities

Here we summarize a broad range of innovation opportunities that were selected as part of this project. Each technology is summarized by the following subsections: why this innovation, current context/where it is currently applied, considerations and limitations, health and safety, and likelihood to reduce costs. Note that dollar amounts presented are in CAD unless otherwise indicated.

Technologies

A. Virtual Simulator Training

Why this innovation?

Operators of heavy equipment are often more familiar with construction operations than restoration, making restoration work an unfamiliar challenge. Field supervisors have often commented that it can take up to three weeks for an operator to achieve optimal efficiency. Training for operators is therefore often identified as a key cost driver for restoration programs.

Virtual simulators are training tools that replicate the performance and feedback of a real machine, but in a virtual environment. Using simulators to train operators could reduce restoration costs by shortening training periods, reducing equipment costs by ensuring operators are fully trained when they begin operations, and improving the quality and speed of treatments on the ground.

Current context/where it is currently applied

The level of investment required for virtual simulators depends on the degree of customization. Devices that simulate excavators are already available at the Northern Alberta Institute of Technology (NAIT) Spruce Grove training centre. Their simulators are produced by CM Labs, based out of Montreal, and include a suite of training modules focused on more traditional construction, as well as a sandbox module (i.e., a module where the student is free to try whatever they wish) (Figure 4).

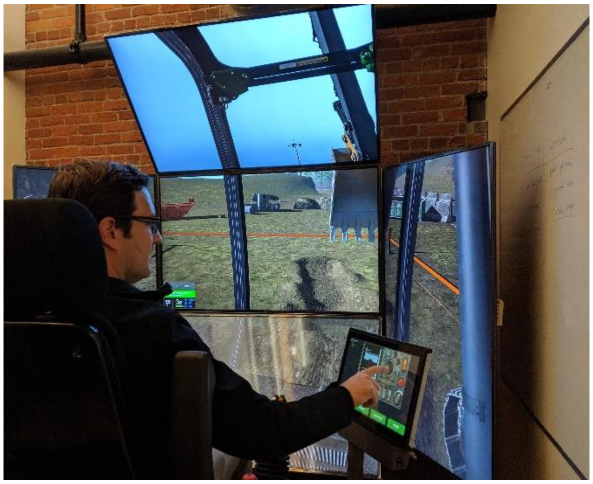


Figure 4. An excavator simulation at CM Labs.

Additional virtual simulators are available in Alberta from Woodlands Operational Learning Foundation (WOLF), and these simulators were produced by SimLog, based in Montreal.

Considerations and limitations

Representatives of CM Labs suggested that multiple options are available for developing a virtual simulator module for restoration. Adding simple modifications to an existing, basic training module could be straightforward and cost approximately $10,000. Creating a fully customized set of restoration training modules, where students would operate on a virtual linear feature and have prescribed exercises to complete, could cost up to $100,000; however, a precise cost estimate has not been determined at this stage.

Companies interested in using virtual simulators to train their operators could coordinate with NAIT or WOLF to use their simulators and avoid the costs associated with the purchase of physical hardware. One of the key advantages of using virtual simulators is that operators can be trained in restoration techniques without equipment expenses. This being said, contractors would still need to be compensated for operator training time.

Health and safety

Better training via simulators can significantly reduce a range of health and safety risks. In particular, simulator training can prepare field personnel for expected conditions and standardize operator training for restoration needs, which would help to address Line of Fire and Fit for Duty LSRs. Modules could be specifically designed to help operators identify hazards and know what to expect in difficult terrain, such as in wetlands.

Likelihood to reduce costs

How might it reduce costs?	Savings via increases in productivity (shorter cycle time), lower insurance premiums (lower incident rates), less time lost due to accidents, and less time training in real equipment.
Evidence of cost reductions?	In one case study, Conwego Enterprises saw training time reduced from six months to seven weeks and cycle times significantly reduced. The International Union of Operating Engineers Local 178 saw operators reaching required levels of proficiency in 100 hours versus 180 hours (55% reduction), with increased performance of 40%.
How much might it reduce costs?	A 15-30% increase in treatment efficiency could lead to a cost reduction of $558-1,116 per km for a hypothetical $12,000 per km program. Additional savings may be realized through classroom versus field-based training. In a simple scenario where training occurs for eight hours per day in the classroom versus 12 hours per day in the field (including travel to and from the field), training in a classroom via virtual simulator could reduce training costs by 20-25%, and is likely to reduce training time required (cost savings are realized by no equipment costs, truck fees etc.).
Scale of initial investment?	$10,000-100,000

B. Tree Scoop

Why this innovation?

Mounding treatments currently rely on the use of a conventional mounding bucket. While these buckets have proved useful to date, many operators have identified the need to try new bucket designs to improve efficiencies. With the Hummock Transfer Technique (pg. 47) being tested as a possible option for restoration, new bucket designs could result in more efficient treatment speeds and cycle times (Figure 5).

Figure 5. An example tree scoop bucket. Source: http://www.erskineattachments.com/utility-spade

Current context/where it is currently applied

Tree scoops are widely used in landscaping as attachments on compact track loaders. The basic tool is designed to scoop into the ground to aid in stump removal and tree transplanting. However, the simple design could also be adapted to an excavator for the Hummock Transfer Technique, and even potentially mounding. Sites that require two or more scoops using conventional machinery could be achieved through a single scoop using a tree scoop, depending on scoop size used and the power of the machine. The tree scoop could provide operators with a more efficient way of creating microtopography on wetland sites, while keeping moss clumps and trees intact.

Considerations and limitations

There is some uncertainty around the required excavator size and the operability of the tree scoop on an excavator. However, with a relatively minimal investment of $2,500 for a single tree scoop, plus modification costs to adapt the tree scoop to an excavator, the potential exists to more efficiently treat sites. It is also possible that the tree scoop could more efficiently facilitate tree transplants, especially of smaller trees. This tool could be a way to facilitate techniques that more quickly realize tree cover on lines. Currently available tree scoop sizes are approximately one cubic yard, therefore a larger custom tree scoop may need to be built for the unique conditions faced in restoration.

Health and safety

No material changes to health and safety risks are expected.

Likelihood to reduce costs

How might it reduce costs?	A tree scoop may be able to produce more efficient restoration in two key ways: reducing the cycle time for conventional mounding, and increasing the efficiency and effectiveness of the Hummock Transfer Technique.
Evidence of cost reductions?	No trials have been conducted with a tree scoop. However, evidence does exist to show how efficiently tree transplants can be delivered using a skid steer. A similar field trial could be used to evaluate the performance of tree scoops.
How much might it reduce costs?	The economic impact of a tree scoop may indirect by enabling the delivery of the Hummock Transfer Technique more efficiently. If the Hummock Transfer Technique could eliminate the need to plant trees, it may be possible to reduce costs by $1,500-3,500 per km within wetland sites.
Scale of initial investment?	~$2,500 per tree scoop + modification costs

C. Multi-function Machine

Why this innovation?

One of the core challenges in restoration is that different treatments, and therefore different machines, are needed depending on the location (e.g., uplands versus wetlands). Travel time between sites also represents a significant cost to programs and efficient walking times have been difficult to achieve with current amphibious equipment. A multi-function 'do it all' style machine, which could be equipped to treat both upland and wetland sites, has been discussed for some time in the context of restoration. Dave Larsen and Cenovus initiated conversations with Foremost and a concept sketch of a machine was developed (Figure 6). A multi-function machine was also identified as the highest priority innovation opportunity at the Restoration Innovation Roadmap workshop associated with this report.

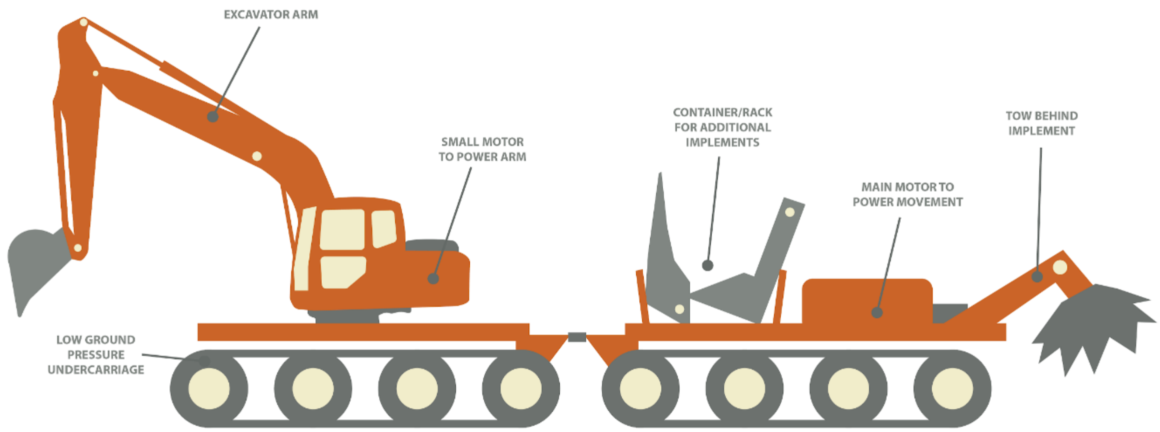


Figure 6. A conceptual rendering of a multi-function machine.

<u>Current context/where it is currently applied</u>

A multi-function machine does not currently exist, and one of the core challenges in developing such a machine would be the contrasting needs from the machine itself:

- Greater weights are required to achieve sufficient traction when mounding mesic and transitional sites, while a very low ground pressure is desired to safely operate on wetlands.
- Similarly, larger, heavier engines are needed to achieve rapid transport speeds when moving between sites, but lighter machines are desired for wetland sites.

Multiple different attachments will be required as well. An ideal scenario would see a machine light enough to traverse wetlands, while also having the speed to travel quickly between sites and the horsepower to pull a tow-behind implement. The ability to fell trees while delivering tow-behind treatments would be a coveted, though potentially unachievable goal of such a machine.

<u>Considerations and limitations</u>

The risks and costs associated with a custom-built machine are anticipated to be very high. Development will likely require an investment of at least $500,000, and more likely $1-2 million. It is also possible that such a machine may fail to deliver on the desired restoration goals. It is important to be aware that a custom-built machine will require significant leadership and intellectual energy from COSIA member companies. Staff would need to be available to guide development and ensure a custom solution meets the needs of operators.

Health and safety

Potential changes to health and safety risks could range widely depending on the nature of the machine that is developed. There could be no material change in risk expected, or there could be increased risk associated with the Line of Fire and Energy Isolation LSRs if multi-function machines were complex, pressurized, and or were comprised of a variety of interconnected parts.

Likelihood to reduce costs

How might it reduce costs?	A multi-function machine could significantly reduce costs by increasing travel speeds between sites and enabling different implements to be used in different ecosites (e.g., mounding in wetlands, tow-behind in uplands).
Evidence of cost reductions?	There is no evidence of cost reductions at this time for a multi-function machine. Field trials have shown how important faster travel speeds are for productivity, and have also highlighted the potential of tow-behind implements for use on uplands.
How much might it reduce costs?	Cost reductions are unknown at this time. Any cost reductions would be realized through increased productivity and reduced walking time for equipment.
Scale of initial investment?	$500,000-2,000,000+

D. Using UAVs Beyond Line of Sight

Why this innovation?

Surveying project areas and collecting pre-treatment inventory and post-treatment monitoring data are traditionally done via large aircraft (e.g., LiDAR) or by ground crews. Both methods are cost and labour intensive. Unmanned Aerial Vehicles (UAVs) fitted with consumer-grade cameras have the potential to collect data quickly and inexpensively (Pyper and Broadley, 2019). The data can then be used to develop 3D point clouds for evaluating tree heights, densities, canopy cover, and other relevant site characteristics. A significant limitation, however, has been the regulatory restriction that requires operators to maintain the UAV within their line of sight. Companies are now pursuing regulatory approval to fly beyond line-of-sight, which could be a significant advance for remote restoration work.

Current context/where it is currently applied

Data collection using UAVs within line-of-sight is already being trialed for various forestry applications in Alberta. Several peer-reviewed publications by the Boreal Ecosystem Recovery and Assessment (BERA) project cover potential protocols for handling and analyzing the camera data. These studies have proven the utility of consumer-grade cameras to capture data, and have acknowledged the importance of beyond line-of-sight UAVs to realizing the potential of these tools. An Alberta based company, Canadian

UAVs, is one of the first companies in Canada to be on track to receive beyond line-of-sight approval from Transport Canada.

Considerations and limitations

Implementing a UAV program is fairly low risk, as UAVs use mature technology (consumer-grade cameras) and can produce a detailed and flexible dataset in the form of 3D point clouds. If UAV service providers are able to secure beyond line-of-sight permits, a pilot program using UAVs to survey large areas could begin as soon as next year. Some current beyond line-of-sight technologies have a flying radius of approximately 14.8 km, covering an area of 688 km^2.

Health and safety

The use of UAVs could both mitigate and incur health and safety risks. By alleviating or reducing the need for ground crews to cover difficult terrain in remote areas, and by providing detailed mapping data for project planning, UAVs address risks associated with the Line of Fire LSR. However, UAVs do introduce some unique risks associated with dropped objects and aerial collision with other infrastructure, though these risks are easily mitigated. Transport Canada restricts beyond line-of-sight use to areas where the population density is less than one person per km^2, which describes the majority of restoration project areas.

Likelihood to reduce costs

How might it reduce costs?	Beyond line-of-sight operation means a single UAV could collect data over a wide project area with minimal crew costs. Ground crews would only be required to perform ground verification of plots.
Evidence of cost reductions?	Chen et al. (2017) conducted a cost analysis of a UAV monitoring program compared to traditional ground surveys for a study area with 30 sites. The data was based on their own trials using UAVs for seismic line surveys.
How much might it reduce costs?	Chen et al. (2017) estimated costs of $16,900 for a traditional vegetation height survey conducted by ground crews versus $10,463 for a UAV program (including equipment purchase, data collection, software, and data processing). In a scenario where beyond line-of-sight operation is permitted, which would eliminate most of the travel/setup time between plots, the cost savings might be much greater than this study's estimates.
Scale of initial investment?	Beyond line-of-sight technology is nearly market-ready and requires no up-front capital costs. Hourly rates or program based rates from service providers would apply.

References

Chen, S., McDermid, G., Castilla, G., & Linke, J. (2017). Measuring vegetation height in linear disturbances in the boreal forest with UAV photogrammetry. Remote Sensing, 9(12), 1257.

Pyper, M., & Broadley, K. (2019). Restoration Innovation Roadmap Phase 1: A Synthesis of Lessons Learned to Date. Prepared for Regional Industry Caribou Collaboration (RICC). May 3, 2019.

E. Automated UAV Data Processing

Why this innovation?

Remote sensing, LiDAR data, or even 3D point clouds produced from consumer-grade cameras are types of data that can require considerable technical expertise and processing time to be developed into products that can inform a restoration program. Similarly, ground based sampling or helicopter flyovers of restoration programs to collect pre-treatment planning information can add considerable time and cost to a program. Finding opportunities to increase the efficiency of pre-treatment and monitoring data collection and processing could help reduce the costs of pre-treatment site inventories, and expedite data processing for monitoring protocols.

Current context/where it is currently applied

FP SILVI is a data analysis tool produced by FPInnovations for analyzing UAV-captured photos and is currently being trialled in BC. This user-friendly software tool accepts input variables from the user (the location of the input file containing the images, what was planted, and where), processes the data, then outputs a final shapefile and a PDF report summarizing the findings at the block level (e.g., seedling height and health status, whether they are free-to-grow, etc.). Processing times are quite reasonable: with a 6-core processor, 40 hectares of data (approx. 3,000 photos) can be processed in about 20 minutes.

Considerations and limitations

The FP SILVI tool is currently limited to assessing trees 30 cm in height or greater. Paired with a beyond line-of-sight UAV, data analysis could become highly automated and efficient with the adoption of a program such as FP SILVI. Companies interested in FP SILVI would need to contact FPInnovations and negotiate the use of the tool, as it is currently only available to FPInnovations members.

Health and safety

No material changes to health and safety risks are expected.

Likelihood to reduce costs

How might it reduce costs?	By automating data processing, companies may be able to more easily shift to use of tools like beyond line-of-sight UAVs for both pre-treatment inventories and monitoring.
Evidence of cost reductions?	No case studies have been developed to date. However, reducing field time, data processing time, and time required of dedicated GIS staff should help realize cost reductions.
How much might it reduce costs?	Estimates from project case studies suggest data processing costs could be reduced by 87% on a per-hectare basis (from approximately $15 per hectare to $2 per hectare). While these

	cost changes may not materially affect the cost per kilometre for a program, having high quality data about potential advanced regeneration areas that could be skipped during treatments could prove to be of significant value. The value may therefore be indirect.
Scale of initial investment?	Investment scale is unknown at this time and would be negotiated with FPInnovations. Costs are anticipated to be low to moderate (i.e., $10,000-25,000).

F. Excavator RipPlow

Why this innovation?

The RipPlow is an implement designed to be attached to the back of a dozer and pulled through severely compacted soils. The goals of this practice are to restore hydrological function, improve porosity of the soil, and produce a variety of microsites at the surface.

Dave McNabb (Forest Soil Science Ltd.) has recently adapted the RipPlow to be attached to an excavator. While the Excavator RipPlow was designed for compacted soils, it may assist restoration recovery by creating elevated microsites, increasing moisture availability along lines, and reducing compacted soils when present (Figure 7). The Excavator RipPlow may also be able to treat uplands more efficiently than conventional site preparation (Figure 8).

Figure 7. The Excavator RipPlow attached to the arm of an excavator and being used to decommission a forestry road.

Figure 8. The Excavator RipPlow being tested on a linear disturbance similar to a seismic line at the Evergreen Learning and Innovation Centre (Alberta Innovates Demonstration Project #2470).

<u>Current context/where it is currently applied</u>

RipPlows have been tested and used on dozers for over a decade and a modified attachment for an excavator arm has been recently tested at the Evergreen Centre in a linear feature context. With a RipPlow attachment on the arm of an excavator, the operator can draw several rows of furrows rather than making mounds one-by-one. Trials with the modified excavator attachment have achieved production rates of 2.5-3 hours per km, compared to 6-8 hours per km for conventional winter mounding.

<u>Considerations and limitations</u>

Excavator RipPlows are only suited for upland sites, therefore an operator would need to carry a different implement (e.g., traditional bucket) to use for wetland sites (though swapping implements can be conducted in 10 minutes). While the RipPlow may be able to address site limiting factors for seedling growth by reducing compaction, creating surface roughness, or disrupting roots of competing trees, the furrows created are unlikely to act as movement barriers. Tree tipping or stem bending may be required to adequately reduce predator movement on linear restoration sites, which can be achieved using the RipPlow's functioning thumb to manipulate trees. Another potential consideration is that long furrows may create channeling of water on slopes; however, this drawback might be mitigated by random, short furrows angled across the slope.

<u>Health and safety</u>

No material changes to health and safety risks are expected.

Likelihood to reduce costs

How might it reduce costs?	If the technology is effective when applied to linear restoration sites, then a reduction in cost is likely given that the Excavator RipPlow should be faster than a traditional mounding bucket, and represents a relatively low up-front cost.
Evidence of cost reductions?	Alberta Innovates co-funded the development of the Excavator RipPlow and a trial was delivered to estimate production efficiency. Production rates of 2.5 hours per km were realized by a new operator during decommissioning of an in-block harvest road, compared to 6-8 hours per km for conventional winter mounding (McNabb, 2019).
How much might it reduce costs?	If a conservative estimate of a 30-40% reduction in treatment times is used, this innovation could translate into a $1,116-1,488 reduction in treatment costs per km for upland sites, based on a case study of a $12,000 per km program.
Scale of initial investment?	$24,000 per RipPlow attachment

References
McNabb, D.H. (2019). Establishing Sustainable Forests on Machine Trafficked Industrial Sites. *Submitted to Canadian Reclamation.*

G. Tree Planting Head

Why this innovation?

A tree planting head is an attachment that creates a microsite and mechanically plants a tree. Mechanical planting represents an efficient way to conduct site preparation and planting with just one piece of equipment. Employing this type of equipment could rapidly create microsites and alleviate the need for a planting crew on upland sites.

Current context/where it is currently applied

Mechanical planting has been used for forestry operations in Fennoscandia, but is more common in Finland, where contractors have found it more profitable (Errson et al., 2018).

The Bracke P11.a is an attachment which can be fitted to an excavator arm. The attachment creates a small mound and plants a seedling directly into the microsite. The Bracke planter is designed to be fitted onto a standard excavator, so no additional modifications are necessary (Figure 9). The Finnish M-Planter is a similar type of mechanized planter that has two planting heads rather than one. Similarly, Tim Van Horlick has developed a prototype of a planting head which can plant three trees at a time.

Figure 9. A Bracke P11.a planting head. Source: https://www.brackeforest.com/

Considerations and limitations

A mechanical planter is likely limited to use on upland sites in non-frozen conditions. A separate mounding bucket would be needed for wetland sites. Use of a mechanical planter would need to be paired with tree felling. A separate implement, felling crew, or adaptation of the planting head to protect it from impact may be needed to supply this function. Supplying the excavator with tree seedlings is also an important consideration, and would either require storage of seedlings on the excavator or regular transport of seedlings from a supply vehicle.

Bracke and M-Planter devices can plant about 200 seedlings per hour during normal operation (Rantala et al., 2009). Cycle times for site preparation may be longer with a mechanical planting head compared to a mounding bucket; however, the cost savings would be realized by not having to deploy and compensate a human tree planter in remote conditions.

Mechanized tree planting has been found to have relatively low cost-competitiveness compared to manual tree planting. Cost efficiency is hampered by low productivity, which originates from operator inexperience, among other reasons (Ersson et al., 2018). By comparison, however, tree planting costs on seismic lines are extremely high, and this may make a mechanized tree planting head a viable option for linear restoration.

Health and safety

No material changes to health and safety risks are expected with respect to the mechanical parts involved in mechanized planters. Because humans would not be required to plant trees at sites treated with a mechanized planter, this innovation could reduce risks associated with the Line of Fire LSR, as well as other fatigue- and repetitive injury-related risks.

Likelihood to reduce costs

How might it reduce costs?	Not only does mechanized planting potentially treat sites faster than conventional mounding practices, but it also removes the need for a human tree planter.
Evidence of cost reductions?	Time-in-motion studies conducted in Fennoscandia have estimated productivity rates for various mechanized planters, including the Bracke P11.a. Note that operation on a seismic line may be faster than the rates documented in these studies due to the absence of slash and rocks.
How much might it reduce costs?	Current estimates for tree planting on seismic lines are between $1,800-3,500 per km. Finding ways to efficiently implement mechanized tree planting could help reduce these costs to only that of the tree seedlings.
Scale of initial investment?	A Bracke P11.a planter costs $100,000-125,000.

References

Ersson, B.T., Laine, T., & Saksa, T. (2018). Mechanized Tree Planting in Sweden and Finland: Current State and Key Factors for Future Growth. *Forests, 9*: 370.

Rantala J., Harstela P., Saarinen V.M., & Tervo L. (2009). A techno-economic evaluation of Bracke and M-planter tree planting devices. *Silva Fennica, 43*(4): article id 186.

H. Alternative Access Vehicles

Why this innovation?

Although access to worksites in many western Canadian locations is difficult, access options have remained mostly unchanged for decades. When the ground is not frozen, off-road access is often accomplished via Argos. While consistently used, these vehicles can be described as reliably unreliable and slow. Beyond Argos, there are a number of tracked and wheeled, low ground pressure, and off-the-shelf or nearly off-the-shelf vehicle options that are available and used outside of western Canada in difficult-to-access, soft, and varied terrain.

Use of alternative access vehicles can improve operational efficiencies by more rapidly and reliably transporting personnel to field work sites to increase the amount of working time per day. A detailed summary of all vehicle options is presented in Appendix 4, including a detailed vehicle specifications table.

<u>Current context/where it is currently being applied</u>

A wide range of access vehicles currently exist for accessing remote sites. In addition, many are currently available for rental in Alberta and may be cost-comparable to current access vehicles such as Argos. When considering the possibility of alternative access vehicles, COSIA member companies should keep in mind that increased rate of travel, reduced worker fatigue, and the potential to transport remote camp arrangements are all current realities afforded by alternative access vehicles.

Table 2. Summary of alternative access equipment that could be used in restoration. More detailed information on each machine, including additional model options, is located in Appendix 4. Dollar amounts are presented in CAD unless otherwise indicated.

Hägglunds Cost: $20,000 per month; $50,000-70,000 purchase and refurbish Rental availability: Available  Pick up style caboose shown	**Prinoth** Cost: $12,000-15,000 per month; $350,000 USD build Rental availability: Available  Panther T6 with crew carrier shown	**All Track** Cost: $15,000-21,000 per month; $250,000-350,000 build Rental availability: Available  AT 50HD shown
Marsh Master Cost: $50,000-70,000 USD build Rental availability: By special order may be possible.  MM 2LX crew carrier shown	**Hydratrek & Land Tamer** Cost: $95,000-175,000 USD build (varies by vehicle) Rental availability: By special order.  Model D2488B shown	**Fat Truck** Cost: $17,500 per month; $165,000 build Rental availability: Available  Model 2.8C shown

Sherp Pro Cost: $14,500 per month; $110,000 USD build Rental availability: Available  Pro enclosed vehicle shown	**Sherp Ark** Cost: $300,000 USD build Rental availability: Not available  Crew carrier style caboose shown	**Vehor RX2** Cost: Starting at $4,000 build Rental availability: Not available 
Abtopoc Shaman Cost: Starting at $200,000 build Rental availability: Not available 	**Makar Burlak** Cost: Starting at $200,000 build Rental availability: Not available  Truck and sleeper styles shown	**BigBo ATV** Cost: Unknown; estimate equivalent to Sherp/Fat Truck Rental availability: Not available 

<u>Considerations and limitations</u>

Use of alternative vehicles offers opportunities not just for access, but also for multi-function customization to combine personnel transport with restoration tools or remote camping arrangements. Benefits include leveraging base platforms to streamline logistics, costs, and multiple contractors, and to move people and equipment together as a self-contained unit. Drawbacks include potentially insufficient nimbleness or responsiveness of multi-function equipment to conduct restoration treatments, or loss of logistical flexibility to shuttle personnel independently of equipment.

The main potential advantages of a shift to alternative access vehicles are extending the hours available for delivering restoration treatments and reducing worker fatigue while accessing remote sites. The following modelling analyses show the potential increases in work time available by shifting to alternative access equipment (Figure 10). While the results may appear modest, the opportunity to add 1.5-2 hours of treatment time per day could increase area covered per day by up to 30-50%.

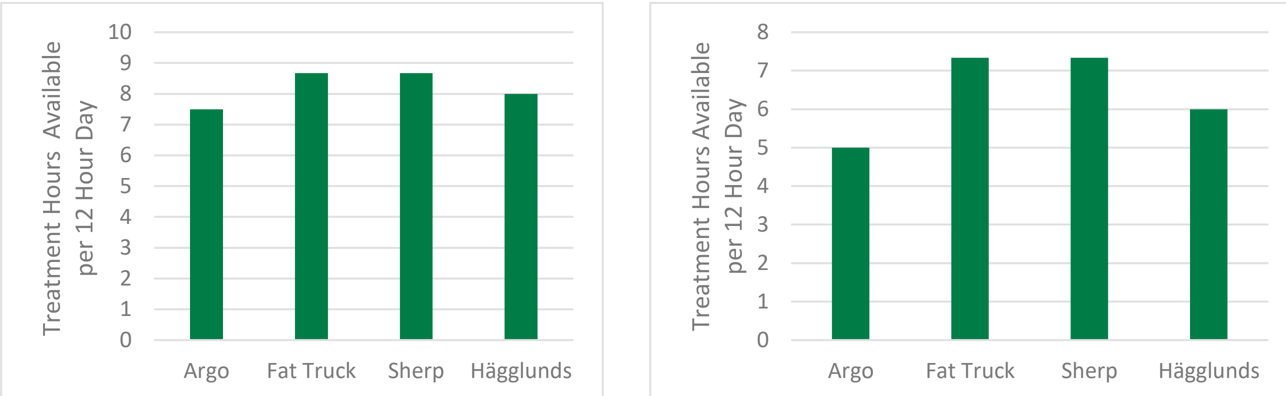


Figure 10. Results of a modelling exercise that factors in rental costs, travel speeds, and site remoteness to project what possible change in working hours per day may be realized through a shift to alternative access vehicles. Modelled for a program 10 km from high-grade (left) and 20 km from high-grade (right). See additional information in Appendix 3.

<u>Health and safety</u>

No material changes to health and safety risks are expected, though the use of alternative access vehicles could reduce risks associated with the Driving LSR to some extent.

<u>Likelihood to reduce costs</u>

How might it reduce costs?	Improved efficiency in work site access would reduce costs by increasing the amount of time per day spent on actual restoration activities.
Evidence of cost reductions?	Vehicles range in both cost and speed. We have provided extensive financial modelling based on estimated vehicle travel speed and the translation to increases in work time per day.
How much might it reduce costs?	Vehicles presented range in both cost and speed. Based on a 20-30% increase in productive treatment time, such gains could help reduce treatment costs by $744-1,116 per km based on a hypothetical $12,000 per km program.
Scale of initial investment?	No capital investments required. Most examples are available for rental.

I. Teleoperation / Semi-autonomous Equipment

<u>Why this innovation?</u>

Teleoperated equipment involves setups where a machine is controlled remotely from another location (out of line-of-sight). The operator provides inputs to the machine, observing its operation via remote cameras and monitors. Semi-autonomous systems involve an onboard artificial intelligence system automating some functions of the machine while still being controlled by the operator. Such systems could allow greater flexibility and safety of operations (e.g., allowing nighttime work to be conducted safely in a secure location). Access time and costs could also be reduced using this technology.

A smaller scale variant of teleoperation which may also prove useful in restoration is the use of remote controlled (R/C) equipment. Remote control of machines, such as excavators, could help improve worker safety when operating on less predictable terrain or conducting stream crossings. For example, when crossing a peatland a worker could stand safely to the side and would be protected in the event that the machine broke through the peat layer.

Current context/where it is currently applied

Semi and fully autonomous solutions are already being used in some industries like mining (e.g., autonomous haul truck systems) and are currently in use by COSIA member companies. Similarly, teleoperated excavators are at an advanced stage of technology readiness (Technology Readiness Level of 7-8 on a scale from 1-9) (Ha et al., 2019). In five years, teleoperated excavators are anticipated to incorporate augmented reality, GPS and laser-based localization, and ground scanning and warning sensors; in 10 years, commercial off-the-shelf platforms are expected (Ha et al., 2019).

For simple R/C, there are existing aftermarket R/C systems that can be fitted onto standard excavators, skid steers, dozers, and other machines. For instance, Bobcat and CAT both offer R/C systems for their machines.

Considerations and limitations

A key limitation of teleoperated equipment is that a high-speed communications network is necessary for teleoperated/autonomous machines to communicate. There are several options for establishing a connection between machines and the operator (e.g., 4G, LTE, wireless mesh networks in remote areas), but these may not be feasible in all remote field sites due to the lack of adequate cellular network coverage or the difficulty of sending/receiving wireless signals through dense trees. The key factor required for success is maintaining enough bandwidth to support real-time video data from the remote cameras. Installation of temporary receivers and towers can be possible through third party providers. Assuming communications infrastructure is available, a teleoperated excavator program could be developed in about a year.

Health and safety

Automation is likely to reduce a range of health and safety risks by delivering treatments without operators in machines (or in some cases without operators in the field). Such measures address Line of Fire, Energy Isolation, Driving, and Fit for Duty LSRs, and can reduce other fatigue-related risks.

Likelihood to reduce costs

How might it reduce costs?	Teleoperation could reduce costs by reducing worker travel time to remote sites, thereby increasing the time spent each day delivering restoration treatments. Teleoperation may also make 24 hour operations feasible.
Evidence of cost reductions?	There are no known financial case studies to inform projections of cost reductions.
How much might it reduce costs?	By reducing the travel time to remote sites, it is possible to increase productivity and time spent delivering treatments. Reducing access times by two hours per day could result in a 20-30% increase in productivity per day (i.e., eight hours of treatment delivery versus six hours).
Scale of initial investment?	The required investment represents a broad range. From off the shelf R/C options to custom development which may cost millions of dollars.

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J. *Fully Autonomous Equipment*

Why this innovation?

Full automation of equipment would see machines operated by a pre-set program or by artificial intelligence (AI). AI integration may enable machines to respond to their environment, identify hazards and obstacles, and change treatments according to observed conditions on the site. This form of advanced automation could help more sites to be treated faster compared to manual systems. Savings could also be realized through lower operator costs as one operator can monitor multiple machines simultaneously.

Current context/where it is currently applied

Fully autonomous haul trucks are available as commercial off-the-shelf products and are operating in some mining operations, including within some COSIA member companies. Excavators are much farther behind and are still not expected to reach commercial semi-autonomy until 2023 (Ha et al., 2019).

Considerations and limitations

To implement something similar to autonomous mining operations in a restoration setting, companies would need to engage with a provider (e.g., Autonomous Solutions Inc.) and work with them to develop a system that can respond to the unique challenges of working on restoration sites (e.g., complex deformable terrain obscured by vegetation, remote field sites, etc.) and can have the machine perform appropriate restoration tasks (e.g., creating mounds in specific configurations). Success will depend on whether an automated machine can reliably apply treatments with the accuracy needed - for example, not leaving trails at the sides of linear features when mounding.

Companies interested in engaging a provider will need to have a strong business case (i.e., a long term, high -volume, multi-phased project) to justify the devotion of personnel and resources to the development of fully autonomous excavators. Unlike autonomous haul trucks, which already exist and operate in fairly predictable conditions, development of a fully autonomous excavator would involve incremental development and could take a decade to reach a commercial level.

Health and safety

Fully autonomous equipment is likely to reduce a range of health and safety risks. However, new risks may also be introduced. Rogue machines (in the event of failure of the two-way communication and the machine's shut down safety system – something that has anecdotally happened with UAVs) may fail to stay within designated driving routes, and machines may fail to detect nearby workers on site. Appropriate use of LSRs like Work Authorization and Line of Fire could help companies to plan for and mitigate such concerns. Currently, oil sands mines have implemented autonomous haul trucks in their operations have noted improved safety as a key benefit.

Likelihood to reduce costs

How might it reduce costs?	A fully autonomous restoration program would allow multiple machines to be monitored by a single operator, reducing crew costs. Efficiencies in production (assuming the AI is effective at executing treatments) would also save costs associated with time, fuel, and maintenance. 24 hour operations may also be feasible.
Evidence of cost reductions?	Mining companies using Caterpillar's fully autonomous haul trucks have reported overall productivity increases of 20%.
How much might it reduce costs?	Mining operations using autonomous haul trucks have reported a 15% reduction in operating cost relative to manual operation (Hyder et al., 2019).
Scale of initial investment?	Millions of dollars due to the substantial research and development work needed.

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K. Breeding Trees

Why this innovation?

Research shows that recovery of woody vegetation to a minimum height of 50 cm significantly slows wolf travel along seismic lines (Dickie et al., 2017; Finnegan et al., 2018). Importantly, reduced wolf travel speeds can help to reduce encounters between caribou and these predators; however, growing trees to a height of 50 cm is a slow process. In order to reach the 50 cm movement threshold quicker and more reliably, planting more vigorous seedlings may be a key strategy. Tamarack (larch) could be a particularly promising candidate for challenging wetland sites.

Current context/where it is currently applied

Tamarack develop wide root systems with no taproot on wetland sites, and are adapted to nutrient-poor conditions. Tamarack exhibit a wide range of genetic variation, meaning there is great potential to generate fast-growing varieties through selective breeding. Breeding programs could focus on traits such as growth rate to improve tree establishment on treated sites.

Tree breeding programs are known to increase wood volume by 10-25% (Jansson et al., 2017). Several tree breeding initiatives already exist through the Alberta Government’s Forest Health and Adaptation program. Companies interested in developing a tamarack variety bred specifically for restoration might consider engaging with the Alberta Tree Improvement and Seed Centre or fRI Research, which led the Tree Species Adaptation Risk Management Project.

Considerations and limitations

Tree improvement for marketable traits (height, volume, wood quality, etc.) have been broadly cost-effective. However, tree improvement has generally focused on marketable traits and marketable species. Cost analyses for existing tree improvement programs (e.g., white spruce and lodgepole pine in Alberta - see Chang et al., 2019a) may not exactly translate to a different species (e.g., tamarack) or to a different planting scale (e.g., linear features in restoration programs versus reforestation after harvest). Genomics-assisted tree breeding is an emerging technique that could drastically reduce the cycle time of tree improvement programs, as it could shorten the progeny testing period from 17 years to two (Chang et al. 2019b).

Health and safety

No material changes to health and safety risks are expected.

Likelihood to reduce costs

How might it reduce costs?	Tree improvement of tamarack may lead to better survival rates and faster recovery on restored seismic lines. Selection for flood tolerance may reduce the need for intensive site preparation on wetland sites. Fast-growing seedlings may also make differences between restoration trials apparent sooner (i.e., shorten the time needed to observe responses), increasing the rate at which learnings can be applied.
Evidence of cost reductions?	Tree breeding is unlikely to lower costs for programs, unless higher survival or greater growth rates improve the ability to meet provincial restoration criteria.
How much might it reduce costs?	Costs may increase through a tree breeding program because of the program costs and higher costs per seedling. Benefits of a tree breeding program would be realized through increased probability of achieving restoration goals, and achieving these on shorter timelines.
Scale of initial investment?	Tree improvement programs in Alberta typically cost $50,000-70,000 per year (Schreiber and Thomas, 2017); however, these costs are distributed across the seedling crop. In a cost analysis of white spruce and lodgepole pine in Alberta (Chang et al., 2019a), the breeding and establishment costs of an unimproved seedling was estimated at 49 cents, versus 60 cents for an improved seedling and 60-93 cents for an improved seedling via genomics-assisted tree breeding. Costs may be higher given limited experience working with tamarack to date.

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L. Amphibious Excavators

Why this innovation?

Restoration work has traditionally been carried out under frozen ground conditions to ensure enough frost establishment to support equipment on wetland sites. However, expanding restoration opportunities to include the summer and fall seasons could offer several benefits to restoration operations, including a reduced need for ice road construction (Pyper and Larsen, 2016a; 2016b). Other benefits include potentially faster treatment rates, the opportunity to use smaller machines, and extended working hours (Pyper and Larsen, 2016a; 2016b). It is estimated that a summer restoration program using amphibious excavators could be delivered for 45-60% the cost of a similar winter program (Pyper and Larsen, 2016a) and a 50 km trial in the fall of 2016 confirmed these estimates.

Current context/where it is currently applied

The amphibious excavator is one tool that would allow restoration work to be performed in non-frozen conditions. Such machines use specially modified undercarriages to apply ultra-low ground pressure, meaning they do not require the same ground support as traditional excavators (Pyper and Larsen, 2016a; 2016b). COSIA member companies have performed several pilot studies to determine the viability of amphibious equipment for restoration in Alberta. A follow-up to the sites treated in the COSIA amphibious trials found that microsites created by the amphibious and low ground-pressure excavators were persisting as expected (Pyper and Larsen, 2019).

Considerations and limitations

Initial trials with a large Trax 200 machine and small Bobcat E50 machine found favourable performance with respect to mounding, stem bending, and tree transplanting, and it was estimated that the amphibious excavators could treat 0.9-1.8 km per day compared to the 0.8 km per day typical for winter programs (Pyper and Larsen, 2016a).

In a follow-up trial, an amphibious excavator and a low ground-pressure (i.e., Nodwell) excavator were tested in non-frozen conditions. Both excavators performed well at conducting restoration activities and travelling over upland and wetland sites (Pyper and Larsen, 2016b). However, the transit speed of the amphibious excavator was noted as a limitation (Pyper and Larsen, 2016b). The Nodwell excavator, while able to transit at a faster pace, exhibited a significant "wobble" during treatment delivery which could result in substantial operator fatigue and nausea (Pyper and Larsen, 2016b).

Health and safety

No material changes to health and safety risks are expected.

Likelihood to reduce costs

How might it reduce costs?	Amphibious excavators enable summer restoration programs, taking advantage of a longer season and longer working days, and alleviate the need to freeze in access roads. Treatments can also be delivered more efficiently under non-frozen conditions.
Evidence of cost reductions?	Past COSIA trials have included some cost analyses for the machines tested. Estimates for productivity were confirmed in a 50 km operational program in 2016.
How much might it reduce costs?	It is estimated that a summer restoration program using amphibious excavators could be delivered for 45-60% the cost of a similar winter program (Pyper and Larsen, 2016a). While these estimates were confirmed by a 50 km operational trial in 2016, there has been variability in costs as operational programs are tested.
Scale of initial investment?	Technology already exists. Generally a higher hourly rate is charged for specialized equipment like amphibious excavators.

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M. Tow-behind Implements

Why this innovation?

Mounding with an excavator has proven to be an effective technique for creating microsites, but the efficiency of treatments is low. Tow-behind implements offer an opportunity to create many microsites in a short amount of time. While tow-behind implements are not well suited to challenging wetland sites, incorporating tow-behind implements into a restoration program could enable quick treatment of upland areas.

Current context/where it is currently applied

Tow-behind mounders are often used in forestry, where upland microsites can benefit from the rapid application of treatments. The most common implements in forestry are a disc trencher or a mounder (Figure 11). These implements are typically attached to a large skidder and used to create microsites for planting; however, smaller customized implements could also be created. Ripper shanks on dozers or RipPlows are also often used in heavily compacted areas.

Figure 11. Examples of tow-behind-implements used in forestry to create microsites. Source: www.brackeforest.com.

Custom tow-behind implements have been developed for restoration. The Shark Fin Drum is a custom implement developed by Dave Larsen that was tested on an upland mixed pine forest with relatively rich soil conditions. It can create a large number of small microsites at a speed of 1.5 km per hour (versus ~1 km per day for traditional mounding with an excavator) (Pyper and Larsen, 2016). Despite early concerns about whether the microsites would persist, a follow-up study found strong evidence that the microsites persisted and assisted with the regeneration on the treated site (Pyper and Larsen, 2019). Monitoring plots showed that naturally regenerating trees and shrubs were strongly associated with the microsites created by the Shark Fin Drum.

While no known tow-behind implements exist for restoration work in wetlands, conversations with local entrepreneurs (Butler Equipment Ltd.) suggested they would be open to exploring how to modify existing equipment to achieve the desired mound heights within wetlands.

Considerations and limitations

Current commercially available mounders require a large skidder to tow them. These machines are too heavy to traverse non-frozen wetlands. In addition, tow-behind equipment would need to be modified to achieve efficient treatments on wetlands. This being said, the opportunity to efficiently treat uplands could be a game changer for restoration programs. Simple implements like the Shark Fin Drum have proven effective on a limited number of upland sites (Pyper and Larsen, 2019).

Tow-behind implements do not deliver tree felling treatments, so additional efforts would be required to deliver this treatment to address wold movement efficiency concerns.

Health and safety

No material changes to health and safety risks are expected. It is feasible that in some cases, tow-behind implements may introduce rotational hazards; however, such risks are regularly mitigated within existing forestry programs and are not considered to change the risk level for treatments.

Likelihood to reduce costs

How might it reduce costs?	A tow-behind implement can treat sites much faster than mounding with an excavator.
Evidence of cost reductions?	A case study led by Cenovus showed that the Shark Fin Drum (Pyper and Larsen, 2016) can treat sites at a rate of 1.5 km per hour, compared to 0.3 km per hour and 0.4 km per hour for amphibious excavators and Nodwell excavators respectively.
How much might it reduce costs?	Pyper and Larsen (2016) estimated the costs of a tow-behind implement to be $429 per km compared to $1,779 per km for an amphibious excavator. This estimate only included operator and machine costs, and did not consider mobilization, planning, planting, and other additional costs. Felling costs would also be additional to the tow-behind estimate provided here.
Scale of initial investment?	Shark Fin Drum: Minimal Adapting a Butler Mounder or Bracke Mounder would require investment in prototyping and manufacturing. This cost could be considerably higher (i.e., $50,000-250,000).

References

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N. Airships

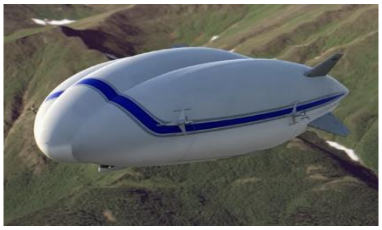
Why this innovation?

An airship is a blimp for the 21st century: it can act as a mobile cargo hauler, equipment mover, people mover, and camp. There are two main forms of airships (large carriers and small aerostats). The large capacity and heavy lift carriers are designed to facilitate and support large projects or missions in remote locations, often with limited to no road access. Smaller aerostats are designed to acquire data on monitoring and surveillance missions. Both forms are forward-looking and potentially promising for future application in restoration.

Current context/where it is currently being applied

Airships and aerostats are without question a forward-looking but potentially disruptive idea in the field of restoration. There are currently three leading manufacturers of airships which are at various stages of advanced commercialization (Table 3).

Table 3. Examples of existing airships available through leading companies.

Manufacturer	Status	Specifications
Hybrid Air Vehicles 	Hybrid Air Vehicles is currently in a prototype phase with a smaller model ship (A10) designed to accommodate passenger flight, cargo transport, and deployment of sensors, monitoring, and surveillance equipment.	Documented ship sizing is unclear, but the A10 can hold up to 16 passengers and can carry cargo up to a 10-ton payload. Expected production timing is in the early 2020s.
Lockheed Martin 	Lockheed Martin has an 85' airship called the LMH-1 in a production-ready phase. Several airships have been produced and sold to date.	The LMH-1 has an approximately 3 m x 3 m x 18 m cargo bay and can carry a 21-ton payload and 19 passengers. It is unclear when or if commercial production will commence.
Flying Whale 	Flying Whale is in the earlier stages of development, but has collaborated with Total on the Metis Project to provide logistical support for seismic exploration programs in Papua New Guinea.	Flying Whale is planning to produce the LCA60T capable of transporting 60 tons in an 80 m x 80 m x 5 m cargo bay. The LCA60T is also designed to load and unload cargo while airborne.

An airship is a helium-filled, laminated fabric hull that is powered by a rotary blade propulsion system (in a fixed position or on pivoting mounts) and uses fixed carbon and glass fiber fins for stability and righting. The ships are designed to be "lighter-than-air" and to leverage aerodynamics to accomplish long lasting flights and heavy lift capability. The ships are also designed with several on-the-fly fix-it modules to remain aloft when the fabric hull is ripped.

An aerostat is a smaller airship that is used in both self-propelled and tethered applications. Larger mobile aerostats can carry up to 6,000 lbs, remain airborne for up to a month, and operate at up to 15,000 feet above sea level. Smaller tethered aerostats or balloons can remain in place indefinitely, and payload and range of vision depends on ship size.

Considerations and limitations

The innovation opportunity for airships is expansive, but difficult to clearly identify at present. Certainly, there is an ability to use a larger airship as a mobile camp and potentially even move equipment between worksites or between the ground and the ship using large hoists or cranes. Airships need relatively little room for take-off and landing (for example, the smaller Hybrid Air Vehicle A10 requires a ~550 m clearing) and can stay aloft for five days. However, because airships are not yet in commercial production it is difficult to objectively quantify their potential as a realistic tool for restoration.

The main opportunity for aerostats is to collect large volumes of data over large areas efficiently. Feasibly, these tools could "leap frog" drones to collect data from multiple sensors simultaneously and continuously over large areas. A range of Transport Canada and restrictive permitting processes are likely for use of aerostats, depending the type and scope of an operation.

Health and safety

Any change to health and safety risk would be dependent on which type of ships were used and how those ships were used. Generally, it is likely that risks would be reduced overall related to a wide range of LSRs including Energy Isolation, Line of Fire, Driving, and Fit for Duty. Increased risks associated with the Working at Height LSR may occur. Thinking to the future, if an airship were to serve as a mobile base camp or command and control center for a restoration project, exposure risk could be significantly reduced by minimizing the amount of time and the number of tasks required for field personnel to reach a work site each day. Any increased risk could be addressed using appropriate Planning, Job Safety Analyses, and Work Authorization LSR principles.

Likelihood to reduce costs

How might it reduce costs?	Airships could reduce costs by increasing program efficiency and replacing camp and access needs. Aerostats could reduce costs by streamlining advance data collection to plan restoration needs and programs.
Evidence of cost reductions?	For both airships and aerostats, estimation of cost savings would require a complex and detailed cost-benefit analysis of current expenditures. Both technologies are somewhat disruptive in that they replace several current processes and offer value in a new way.
How much might it reduce costs?	Cost estimates are not possible at this time; however, in the short-term, use of aerostats may reduce the costs of data acquisition for planning and monitoring work.
Scale of initial investment?	The purchase cost of an airship is unclear. Straightline Aviation agreed to a purchase price of 12 LMH-1 airships for $40,000,000 USD per ship, though the sale has not been finalized or made to date.

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O. Screw-propelled Vehicles

Why this innovation?

Screw-propelled, or screw-drive vehicles (SPVs), offer an alternate means from tracked and wheeled vehicles to traverse water, soft, and varied ground conditions. Intended as soft ground and water specialists, screw-propelled vehicles attain movement by rotation of cylinders or pontoons wrapped in spiral-patterned fins and flanges (Figure 12). The cylinders are generally hollow, offering the additional benefit of excellent flotation in water and fully amphibious operations. A major potential benefit of a screw-propelled vehicle for restoration is that it has a propensity to create microsites, and even flip soil, as it moves through landscapes. This incidental perturbation of the soil could provide an efficient way of creating microsites on upland locations.

Figure 12. An example of a Russian screw-propelled vehicle. Source: Youtube/Ruptly https://youtu.be/nVOaDfGOPGs.

Current context/where it is currently being applied

SPVs are largely considered to still be experimental in nature. Current prototypes have mainly been generated from experiments without specific intended applications; however, machines are currently in use to assist with tailings dewatering and consolidation, largely in Australia.

Collectively, experiments with SPVs show some promise for application in restoration in two ways. First, a wide variety of SPVs and screw-propelled modifications to existing vehicles tested since the late 1800s show clear ability to navigate soft terrain, open water, and importantly, a mix of both. Second, while somewhat theoretical, some research is ongoing around fin and flange design and screw cylinder buoyancy to minimize ground disturbance, maximize propulsion speed, and maximize flotation in soft ground conditions for applications in robotics and space rovers (Nagaoka and Kubota, 2010; Bouchard et al., 2015; Stein et al., 2015; Calles et al., 2017). This work builds from initial research in the 1960s (e.g., Knight et al., 1965).

Considerations and limitations

While SPVs may prove beneficial for restoration, there are numerous environmental considerations and development constraints to be aware of.

It is likely that SPVs can achieve their highest value in an oil sands context if they can serve as a hybrid tool to deliver both restoration and tailings consolidation on mine sites. Even if limited to restoration, SPVs offer a unique multi-treatment potential by pairing traditional restoration tools like track hoes with tow-behind implements like RipPlows to deliver two-in-one restoration. There is also an opportunity for SPVs to increase surface roughness and microtopography on route to treatment sites. This approach could eliminate scenarios where walking machines between treatment areas requires large amounts of time but provides limited to no treatment value (i.e., dead walking).

The way in which SPVs disrupt the soil would need to be considered as well. It is possible that the microsites created by these machines would actually reduce restoration potential, rather than increase it. Specifically, it is possible that the SPVs may create undesirable soil shearing or compaction. If this were the case, SPVs should automatically be excluded from consideration in a restoration program.

Health and safety

No material changes to health and safety risks are expected.

Likelihood to reduce costs

How might it reduce costs?	SPVs may be able to reduce costs associated with restoration treatments by incidentally creating desirable microsites while driving from one location to another.
Evidence of cost reductions?	A variety of case studies are available demonstrating successful application of screw-propelled vehicles to mine tailings reclamation.
How much might it reduce costs?	If screws can be appropriately designed to create surface roughness and microtopography during movement, cost efficiencies would be akin to tow-behind implements (i.e., several to 10 km per day). If screws could deliver those efficiencies in wetlands, the potential to reduce costs is very high. If an SPV could double as a tailings reclamation tool, cost reductions would be much higher, but also more complex to measure.
Scale of initial investment?	Costs of development and rate of speed for restoration are unknown and difficult to quantify. Based on manufacture and modification costs for other heavy machinery and access vehicles showcased in this report, we estimate ~ $500,000-1,000,000 to develop and test a multi-function SPV for restoration needs.

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P. Modify and Miniaturize by Leveraging Robotics

Why this innovation?

Within the upstream oil and gas sector, there is often a notion that bigger is better when it comes to earth moving equipment. However, miniaturization offers several advantages including accessing difficult terrain and streamlining mobilization and logistics. One prime example of miniaturization improving outcomes in oil and gas is the use of heli-portable drills for remote seismic surveys.

Forward-looking programs could consider the potential of modifying and miniaturizing existing equipment while leveraging the power of robotics. By pairing smaller equipment with remote control and semi-autonomous operations, this innovation facilitates safer, more nimble, and more efficient operations.

Current context/where it is currently being applied

Within the aerospace industry, a number of companies are developing prototype robots that can efficiently move equipment and traverse complex terrain. All vehicles are designed with the intent to function semi-autonomously with long distance (in many cases interplanetary) remote-control.

Several companies also develop and produce platform- and rover-style, remote control, semi-autonomous, and programmed autonomous vehicles for military and industrial uses. Argo and MUTT offer vehicle lines including small (1.5 – 3 m long and wide) tracked and wheeled, fully amphibious carriers designed for light to moderate payloads (up to 1,500 lbs) that can be controlled by line-of-sight remote control, tethered remote control (e.g., blue-tooth connection or physical leashes), and remote teleoperations. The HDT Global Protector Robot is a unique line of modular equipment designed for a range of battlefield applications. Of particular interest to restoration are the backhoe loader package designed to assist in remote camp construction and the flail and rake packages designed to detect and destroy mines and clear travel routes. These machines are commercially available and used in a variety of applications.

Mini and micro excavators occupy a niche excavator market and serve as a good example of the potential to miniaturize equipment. While these excavators lack the breaking power and arm boom length required to dig through ice to create mounds in frozen ground conditions, they provide sufficient digging power and reach for other restoration techniques like transplanting or tipping trees. They are also much lighter than conventional excavators and capable of operations on non-frozen peatlands (Fort Nelson First Nation, personal communication).

Considerations and limitations

The end goal of a modify and miniaturize approach is to repurpose, redesign, and combine the above components for general use in restoration applications. There is no limit to a single application; rather, this innovation could be used in a variety of ways in both active restoration workflows and in supporting roles for delivering restoration. For example, a mini excavator arm boom and bucket with swivel base could be mounted with a compressor onto an amphibious robotic carrier to create a lightweight remoted-controlled mounding tool. In such a scenario, a small fleet of "restoration drones" could be deployed to replace a single standard amphibious excavator, thereby increasing restoration pace, per day efficiency, and per km efficiency. Alternatively, a robotic carrier could be tethered to a mechanized tree planter to carry equipment and larger loads of trees. In such a scenario, helicopter drops and daily returns to camp may not be necessary to maintain supply line to field crews, thereby reducing logistical and support costs of restoration programs.

Clearly, some of these potential ideas are forward-looking and not logistically possible today. However, exploration of this technology would provide opportunities to develop less sophisticated prototypes that could address current needs or provide an opportunity to conduct a fail-fast experiment.

The two primary limitations of robotics, especially for equipment miniaturization, are power delivery for operations and track maneuverability in typical peatland terrain. Smaller machines deliver less power for excavation and land moving than larger machines. While the addition of an air compressor or other power boosters can offset limitations, machine design and intended use would need to be appropriately matched. The small track sizes of machines would also mean less surface area for traversing wetlands.

Health and safety

Any change to health and safety risks would be machine dependent, though robotics could reduce a range of risks associated with several LSRs.

Likelihood to reduce costs

How might it reduce costs?	Using smaller equipment and capitalizing on robotics may facilitate a movement towards more automation in restoration.
Evidence of cost reductions?	Identifying costs of developing robotic and semi-robotic applications for restoration is difficult. However, forward-looking programs would be wise to conduct further research and 'desktop' studies to explore the potential of robotics to reduce costs by automating routine activities.
How much might it reduce costs?	Cost reductions are difficult to quantify for robotics for restoration. Case studies do exist in other industries and could be leveraged to explore a 'desktop' review of this technologies potential.
Scale of initial investment?	Variable, but could be very expensive.

Q. *Track Modification*

Why this innovation?

Vehicles and equipment capable of accessing soft ground conditions may be tracked or wheeled. Wheeled vehicles are faster, but tracked vehicles exert less ground pressure and are less apt to produce ground disturbance (e.g., rutting) or get stuck (e.g., spinning). Thus, the desire to access locations quickly is tempered by a desire to not cause extensive ground disturbance, especially in difficult locations (e.g., getting into and out of creeks). While this trade-off between access and speed is common and accepted in the world of construction and industrial applications, it is not accepted in military applications. Tracked, combat vehicles are capable of speeds up to 40 and 50 mph.

If tracked restoration vehicles could move more quickly, dead walking time would be reduced and active treatment time available could be increased.

Current context/where it is currently being applied

High speeds in tracked vehicles are achieved with in-track suspension systems, improved track links (connections between neighboring components of a track), and track tension control systems (Kim and Yi, 2005; Ryu et al., 2000; Liang and Wu, 2013; Maclaurin, 2018). The in-track suspension system functions to absorb bumps, surface roughness, and terrain unevenness to produce a smooth ride for passengers and allow for more rapid drive speeds. Snow machines are excellent examples of high performance, high speed tracked vehicles.

Although military applications are likely unconcerned with ground disturbance, the improved performance at higher speeds is directly applicable for restoration applications. Although military combat vehicles are large and heavy, they are capable of routine travel speeds of 50 mph. The CV family of vehicles from BAE Systems is a good example of this innovation.

Considerations and limitations

It is unclear how much it would cost to introduce sophisticated track suspension into excavators or other large machinery used for restoration. BAE CV vehicles cost ~$6,000,000 depending on the vehicle, but that purchase includes a lot of additional technology beyond track suspension.

In addition to unknown costs, high performance tracks weigh more than standard static construction tracks and would add weight to vehicles. During non-frozen seasons this extra weight would increase track PSI and potentially limit use, or require further modification to widen tracks to offset this increased PSI.

Health and safety

No material changes to health and safety risks are expected.

Likelihood to reduce costs

How might it reduce costs?	Increased travel speed of restoration equipment provides a clear path to reducing costs by reducing access times and travel times between sites.
Evidence of cost reductions?	If time can be spent working instead of walking equipment between sites or accessing sites, restoration costs should be reduced.
How much might it reduce costs?	Reducing access time was shown to increase potential time available for treatment delivery by as much as 30-50% per day, depending on the remoteness of the site.
Scale of initial investment?	Unknown at this time.

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Techniques

R. Hummock Transfer Technique

Why this innovation?

Trees are able to grow in very wet peatlands thanks to the elevated microsites provided by hummocks. These natural hummocks are compressed on linear features, and site treatments focus on restoring surface roughness to mimic the function of the surrounding terrain. Typical mounding techniques, however, bury living sphagnum under the mound. The inverted mounds may not be an ideal substrate for trees to grow and establish. The Hummock Transfer Technique (HTT) involves scooping a natural hummock from a donor site adjacent to the restoration site and placing it on the site.

The transferred hummocks are well developed mounds already supporting trees and shrubs. It is anticipated that living moss will help support the shape of the mound over time. The main advantage of this technique is the potential to reduce or eliminate planting costs by transplanting trees and shrubs directly onto the restored area.

Current context/where it is currently applied

Dr. Bin Xu with the NAIT Centre for Boreal Research initiated an HTT trial in 2019 on several seismic lines and winter roads. After six months, most hummocks had retained their shape and both pre-existing vegetation and planted seedlings on the hummocks grew and showed high rates of survival. Living mosses had also begun to grow out from the edge of the hummock onto the surrounding line, serving as a source for recovery of mosses on the treated line. Investigation of the donor sites also showed that when scoops are taken during partially frozen conditions, donor sites quickly re-establish moss cover due to residual moss fragments at the donor site. Thus, long-term damage to the donor areas is not anticipated at this time. Monitoring will continue to occur over the next three years.

Considerations and limitations

It is recommended to use a toothed implement to scoop the hummock, so that propagules are left behind at the donor site. Plants living on the transplanted hummocks are already adapted to local site conditions, which may give them a leg up over nursery stock and enable the ecological function of the sphagnum ground cover to be retained. Densities which balance the need for new material on seismic lines, versus reducing impacts to the adjacent donor sites should be explored.

As this technique is relatively new for application to restoration, there is some risk of failure. The performance of HTT will become more clear as the current NAIT trial progresses, but companies should consider it a good candidate for their own trials. As HTT does not address predator movement considerations, movement barriers will still need to be created by tree tipping, stem bending, or some other technique.

Health and safety

No material changes to health and safety risks are expected.

Likelihood to reduce costs

How might it reduce costs?	Use of HTT could improve the reliability of restoration on particularly wet sites, and provide a faster and more efficient treatment method. Tree planting costs may also be avoided using this technique.
Evidence of cost reductions?	The NAIT trial calculated the cost of delivery for the technique as $2,000-3,000 per km, though this did not include mobilization, planning or planting costs.
How much might it reduce costs?	In a conservative scenario, where cycle times are similar to mounding treatments and planting costs are avoided, it is reasonable to expect an immediate cost savings of $1,500-3,500 per km for wetlands, due to the avoidance of planting costs.
Scale of initial	An operational trial should be conducted to mitigate financial risks. Investment in

investment?	a tree scoop could expedite treatments; otherwise, no additional costs are expected.

References
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S. Planting Shrubs

Why this innovation?

The current restoration paradigm focuses on establishing tree cover; however, sites in nutrient-poor, saturated wetlands present significant challenges for trees. Growth rates are typically slow and trees require elevated microsites or hummocks to grow and persist. Within sites such as these wetlands, planting shrubs that may not require elevated microsites could be a viable alternative to establishing tree cover. Shrubs may also create effective movement barriers on linear features in a shorter amount of time (compared to planted conifer species) and with a greater probability of success.

Current context/where it is currently being applied

Planting shrubs has been discouraged for linear feature restoration because of concerns around creating forage for alternate prey (i.e., moose), and because they do not meet the criteria of an "acceptable tree" within the Provincial Restoration Framework (i.e., cannot reach canopy height) (Government of Alberta, 2017). However, the restoration framework was designed to allow for adaptive management, and its criteria can be adapted based on an evolving understanding of restoration. Preliminary modelling work from the Alberta Biodiversity Monitoring Institute has estimated that the added shrub browse across all human disturbance features (including forestry cutblocks) elevates black bear and white-tailed deer populations by only 6%, and seismic lines alone only account for increases of 1% and 2% of black bears and white-tailed deer, respectively (Apps et al., 2019). If a portion of linear features (i.e., those in challenging wetlands) are permitted to be restored with shrubs, the effect on alternate prey is therefore likely to be negligible.

Shrubs have not been trialled in a linear restoration program to our knowledge, but there is literature supporting their potential as good candidates for very wet sites. Shrub willows are characterized by efficient nutrient uptake, extensive fibrous root systems, tolerance of flooded, anoxic soils, and capacity for vegetative propagation (Kuzovkina and Quigley, 2004). The ability of shrub species like alder and willow to tolerate saturated ecosites may also offer a side benefit to conifer species, as high transpiration rates by these shrubs can help lower the water table in disturbed sites, creating more favourable conditions for nearby spruce seedlings (Landhausser et al., 2003).

Considerations and limitations

Given the 50 cm height threshold needed to significantly reduce wolf movement (Dickie et al., 2017), candidate shrub species should be able to reach and exceed 50 cm in height. Candidates could include shrub birches (e.g., *Betula nana*, *Betula pumila*) and willows (e.g., *Salix pedicellaris*, *Salix candida*), all of which typically reach 1-2 m in height in shrubby fens (ESRD, 2015). On restoration sites in otherwise treed wetlands, the peat has often been compressed and brought closer to the water table. Shrubby fens have a higher water table than wooded fens (~10 cm below the surface compared with ~20 cm below the surface), so species common in shrubby fen ecosites may be more tolerant of the conditions found on these types of restoration sites. Alders (*Alnus spp.*), found in shrubby and wooded swamps (ESRD, 2015), could also work well on such sites, and have a palatability rating similar to black spruce (Golder Associates, 2015).

Companies could consider trialing a shrub planting treatment in their restoration program – for example, including a standard spruce/tamarack treatment, a shrub-only treatment with no site preparation, a shrub-only treatment with site preparation, and a combination tree/shrub treatment.

Health and safety

No material changes to health and safety risks are expected. If shrubs prove tolerant of high water tables and do not need an elevated microsite, it is possible some site preparation, and associated exposure risk, can be eliminated.

Likelihood to reduce costs

How might it reduce costs?	Planting shrubs could eliminate the need for site preparation on difficult wetland sites.
Evidence of cost reductions?	No direct cost analyses or case studies are available.
How much might it reduce costs?	Planting shrubs is likely to incur higher, or at least equivalent, costs as planting trees. This is due to the costs of seed collection and establishment. However, significant cost savings could be realized if site preparation treatments are not required. If transit times are considered for crossing a wetland, excluding treatment time, costs per km could be at least 75% lower in wetlands.
Scale of initial investment?	Initial investment would be low, with a trial suggested to estimate long term costs.

References

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T. 24 Hour Operations

Why this innovation?

Restoration programs are often restricted to short work days, as travel time to and from remote sites consumes valuable daylight hours. During winter, available daylight hours are even fewer, which further limits productivity. An option companies could consider, alongside parallel operational changes to ensure a safe work environment, is moving towards 24 hour operations.

Current context/where it is currently applied

24 hour operations are common in industries such as mining, forestry, and seismic exploration. Using two or more shifts to fill a 24 hour day would allow more lines to be treated within a season and increase the productivity of machines on site. This shift could have a significant effect on the scale of restoration programs and what treatment targets are possible.

Considerations and limitations

The biggest consideration for companies interested in implementing extended operational hours would be health and safety. Logistically, a 24 hour operation would need to be located close to high grade access or make use of a teleoperation system. 24 hour operations would also require more trained operators to facilitate the necessary shift changes.

A 24 hour operation would also consume “double” of everything - two sets of field crews and supervisors, two sets of medics, two daily safety meetings, etc. While 24 hour operations can be extremely efficient to complete projects more quickly, appropriate cost-benefit analyses must be considered to ensure the desired balance between project costs and completion schedules.

Health and safety

Twenty-four hour operations require additional planning to sufficiently address health and safety risks. Although work requirements may remain the same in daylight and nighttime hours, risk profiles for the same work tasks may vary. As such, comprehensive job planning, including full and independent daylight and nighttime Job Safety Analyses would be required of 24 hour operations. Outcomes of such analyses would then require development of different work permissions and emergency response plans and would likely address a range of LSRs. While risks associated with nighttime work may vary markedly from those associated with daytime work, appropriate adherence to LSRs and detailed work planning are suitable to sufficiently mitigate identified and potential risks for restoration projects.

Likelihood to reduce costs

How might it reduce costs?	By enabling machines to operate more hours in a day, project level efficiencies could be realized.
Evidence of cost reductions?	Case studies show mixed results of 24 hour operations. In forestry, some companies tried 24 hour operations and moved away from them, while others see the value from a program efficiency perspective (Mitchell et al., 2008).
How much might it reduce costs?	Cost reductions are realized primarily via shorter rental periods and fewer line items on day rates. Some reductions in fuel costs may also be realized.
Scale of initial investment?	Minimal up-front costs, but investment is needed in appropriate health and safety planning.

References
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U. Time-in-motion Studies

Why this innovation?

Restoration programs are still in the early stages of operational scale delivery. Identifying subtle changes that can have major impacts on productivity are still strongly needed. Time-in-motion studies involve a detailed on-site review of operations. The goals of such studies are to observe operators, document down-time, and identify opportunities to improve efficiency and get better value out of the time spent delivering operations.

Time-in-motion studies can also assist cost-benefit analyses for incorporating new innovations. For example, if a winch machine substantially increases the amount of productive days a larger piece of equipment can operate in a year (i.e., by enabling operation in soft/wet conditions), it may make sense for the contractor to invest in that support equipment. Time-in-motion studies provide concrete numbers on which to base those decisions and are regularly used by FPInnovations with their forestry clientele.

Current context/where it is currently applied

Time-in-motion studies are widespread analysis tools used to assess productivity in industries including forestry.

Considerations and limitations

In a restoration context, a detailed time-in-motion study could show how different equipment compares in different ecotypes (e.g., upland versus wetland). This performance assessment would include not only productivity during normal operations, but also how much time is devoted to transit, maintenance, fixing breakdowns, and other routine operational tasks. Especially as companies explore new innovations and techniques in their restoration programs, a good understanding of where operational costs are actually going is essential.

To implement time-in-motion studies for their own programs, companies should consider engaging with a consultant experienced in conducting productivity studies.

Health and safety

No material changes to health and safety risks are expected for a time-in-motion study itself. Products from a time-in-motion studies are likely to identify areas where health and safety risks could be reduced (and productivity improved).

Likelihood to reduce costs

How might it reduce costs?	Time-in-motion studies identify concrete changes that can be made to a program to increase productivity and operator efficiency.
Evidence of cost reductions?	Studies by FPInnovations have helped identify tools and techniques that can increase operator efficiency. By making operators more aware of production performance, this can help increase productivity.
How much might it reduce costs?	Productivity improvements of up to 15% have been realized through collecting time-in-motion information and using this to inform productivity adjustments.
Scale of initial investment?	The scale of investment is limited to the costs of having a contractor observe treatments in the field, create a report, and develop recommendations.

V. Remote Camps

Why this innovation?

One of the largest expenses for restoration projects is the commuting time of field personnel between camps and field sites. One solution to this challenge is to move camps closer to the worksites. Camps could be stationary or mobile and move with crews. The goals of a remote camp are to reduce transit times and increase time spent delivering restoration treatments.

Current context/where it is currently being applied

A variety of remote-style camps are used across related industries, including mining exploration, forestry, seismic exploration, and tree planting. Within the context of a restoration project, three remote camp options are likely feasible:

1. Edge of high grade
2. Sleigh-style camps
3. Temporary bush camps

Camps located at the edge of high grade would strive to reduce transit times to and from a restoration site, while still providing quick access in the event of a serious health and safety emergency. This type of camp could be as simple as field personnel bringing their own 5th wheel trailers, or could include hauling in wellsite trailers to provide a range of desired comfort levels. Example service providers for edge of high grade camps include ATCO, National Trailer, Apex, and Vertex.

Sleigh camps are stripped down versions of wellsite trailers, which are mounted on skids. They are designed to be dragged over frozen and snow-covered ground. Sleigh-style camps can be mobilized into place during the winter months and staged for non-frozen season use, if kept stationary.

Temporary bush camps are designed to be semi-portable, but left in place for short time periods (e.g., weeks to months) while localized work is being done. These camps are often used for semi-nimble operations like core drilling and exploratory mining operations in remote locations. Camps are available in a variety of styles, from wall tent and hard-sided tent-style enclosures on platforms to flexible- and hard-sided Weatherhaven styles.

Considerations and limitations

Although hotels or oil company camps may be remote from restoration worksites and require significant commuting times, they may remain cost-effective overall. Setting up a remote camp is not a straightforward task. A variety of support functions must be considered like water supply and waste treatment, garbage removal, power, fuel, and mobilization costs. However, precedents exist in forestry and other industries for relatively simple, nimble camp systems. Depending on restoration program access times, remote camp availability, and the camp's proximity to a project area, remote camps save significant commuting times daily and increase overall working hours on a per program basis. The biggest barrier to shifting to remote camps may be psychological, as workers in the oil sands region may have become accustomed to well appointed camp accommodations.

Health and safety

Remote camps do increase health and safety risks related to emergency responses that fall outside of regular LSRs. LSRs are meant primarily to address safety concerns and risks for field personnel while on an active worksite. The biggest health and safety risk of remote camps is less complete and potentially less immediate medical attention available at remote camps compared to established camps. However, these concerns can be sufficiently addressed on a case-by-case basis. Such steps are routinely undertaken for remote camps globally.

Likelihood to reduce costs

Determining the potential impacts of remote camps on restoration costs is a complex process. However, through detailed modelling of a wide range of costs (see Appendix 3), scenarios can be developed to help begin to understand the potential impacts. As a test case, we assumed that sites would be accessed with a Sherp vehicle regardless of whether it was a remote camp or conventional accommodation. We then determined what the cumulative impact of lower access times would be on the total number of km that could be restored over a 24 day program (Figure 13). Through this modelling, it is projected that remote camps would increase the costs of accommodations (an increase of between 26-34%). However, they will produce a net increase in the number of km that can be restored per day due to less time spent traveling from camp to the work site.

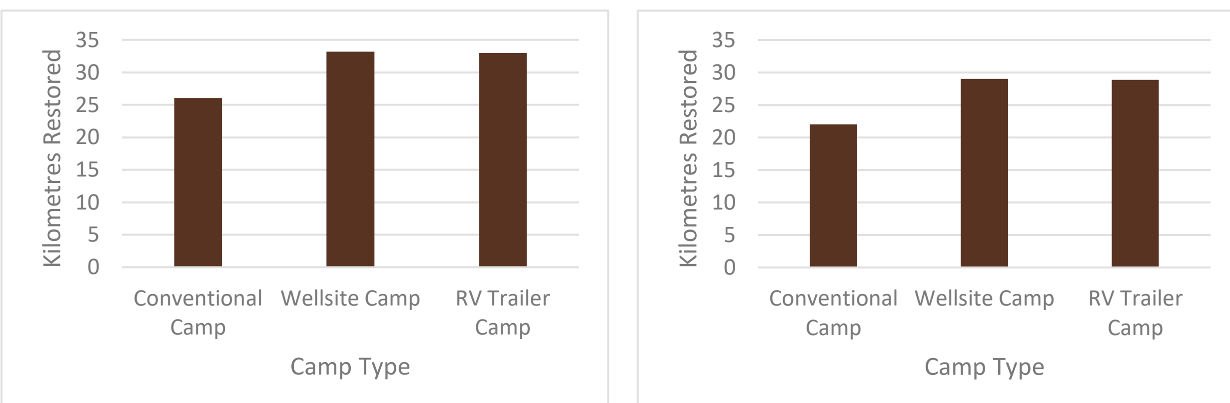

Figure 13. Modelling the potential impacts of different camp accomodations on the net productivity of a 24 day restoration program, assuming treatment productivity of one km per seven hours. Modelling results are shown for a program requiring 10 km of off high-grade access (left) and 20 km of off high-grade access (right).

How might it reduce costs?	The primary way remote camps can reduce costs is by converting commuting time to productive working time on a project.
Evidence of cost reductions?	Camp costs can vary widely depending on location, proximity to available rental pools, camp comfort, and duration of camp use. In all cases, costs are directly related to the level of comfort demanded by work crews and provided by clients. Rustic camps can be significantly more cost-effective.
How much might it reduce costs?	Remote camps are unlikely to reduce the cost of camp accomodations, but may reduce travel time and increase the working hours in a day.
Scale of initial investment?	Wellsite trailers can range from $30,000-50,000 when purchased. Rental options are also available. If using a simplified RV style camp, per diems could be offered to crews to enable them to use their own RVs (if available).

W. Restoration via Explosives

Why this innovation?

Use of explosives as a restoration tool could dramatically expedite treatment delivery and reduce costs. Rather than creating mounds one at a time on wetlands or screefs on uplands, controlled use of explosives could simply “blow lines up” and create significant surface roughness all at once. The goal would be to leverage, but modify, current uses of explosives in similar industries to create microtopography on sites and to fell trees.

Current context/where it is currently being applied

Explosives are widely used in the upstream oil and gas and mining industries to generate source energy for seismic surveys, remove overburden, and expose and free mineral deposits. Thus, product suppliers and the expertise to deploy explosives is widespread regionally.

Use of explosives to loosen and uplift hard-packed soils along pipeline right-of-ways prior to excavation is common in the midstream oil and gas sector in some areas. Explosives are also used in BC to fell dangerous trees in certain circumstances where the risk of the tree falling is deemed too high.

Figure 14. Example of explosives being used to reduce excavation time for a pipeline right-of-way (left side of image). Source: Dykon Blasting.

Currently explosives are not being used in a restoration capacity to our knowledge. However, the innovation opportunity for explosives is high if rapid and near-complete creation of surface roughness and/or rapid addition of coarse woody debris is desired.

<u>Considerations and limitations</u>

Because explosives are not currently used for restoration, little is known about the charge size, depth, or patterning required to create surface roughness in various land cover types. It is also not clear whether, or how much, loosened soil substrates may settle post treatment. Further, it is not well understood if and how blasting can be used to directionally “windthrow” large clumps of trees. In short, all components of a program would require testing.

A two-person team could drill, load, and detonate approximately 1,000 charges per day using hand tools, mini-tracked drills, or quad/Argo mounted drills in non-frozen ground conditions. Timing windows for use of explosives would be somewhat restrictive to avoid summer and fall conditions when there is a risk of fire.

Additional ecological considerations such as noise, erosion potential, and impacts to soil quality would need to be further assessed.

<u>Health and safety</u>

There are potentially large increases to health and safety risks associated with the use of explosives related to the Line of Fire LSR and risk of setting wildfire. However, with careful work planning and considerations of Work Authorization and Fit for Duty considerations, such risks can likely be mitigated and controlled. Explosions used in other industries occur deep underground and below organic layers where sparks can smolder. In contrast, explosives detonated for restoration would occur at shallow depths and could scatter sparks, which could smolder in dry organic layers. Risk of fire could therefore likely be mitigated during restoration efforts by operating during winter or wet conditions.

Explosives are regularly used, and routinely permitted by the Alberta Energy Regulator, in the seismic exploration industries and so no additional risk of heavy metal exposure to humans or the environment is anticipated. Anecdotal studies have indicated that few to no residual heavy metals occur following seismic activities which make use of black powder charges (Jesse Tigner, Personal Communication).

Likelihood to reduce costs

How might it reduce costs?	Rapid deployment of explosives and minimal time spent at each location could reduce total restoration cost.
Evidence of cost reductions?	When used in midstream operations, explosives are explicitly used to reduce excavation costs. The incorporation of explosives in the pipelining process was expressly used to reduce both excavation time and cost.
How much might it reduce costs?	Explosives would cost between $4-10 each (including cord). If approximately 1,000 explosives are drilled and detonated per day, over one km could be restored per day for the cost of two field personnel plus materials. It is feasible that restoration costs could be as low as $4,000-5,000 per km.
Scale of initial investment?	Scale of initial investment would be very low or non-existent, as the treatment method would be hired out to a third party contractor (similar to any other conventional restoration treatment).

Continual Importance of Good Project Management and Project Planning

This Restoration Innovation Roadmap report focuses exclusively on technologies and techniques that could be used to provide more efficient and effective solutions for restoration planning, implementation, and monitoring. However, it is important to note that effective project planning and project management have previously been identified as one of the most important drivers for reducing costs associated with restoration program delivery (Pyper and Broadley, 2019).

In phase one of the Restoration Innovation Roadmap project, Pyper and Broadley (2019) stated:

> "Creating more time and space for planning is critical. Restoration planning takes time and was noted by all interviewees as a key stage for reducing costs for programs. Planning reduces risks, improves the efficiency of equipment, and creates space to plan treatments to be most effective. However, restoration contracts are still often awarded with short timelines for delivery. In some cases, contracts have been awarded in November with expected delivery in January (i.e., two months later). Evaluating the feasibility of extending these timelines, and specifically targeting the award of contracts a minimum of one year prior to expected treatments is suggested. While this may be logistically challenging for funding organizations, rushed planning has been shown to lead to higher costs and less effective outcomes – both of which pose a real risk to restoration programs within woodland caribou habitat."

Effective project planning also enables selection of the highest impact locations for restoration, facilitates identification of opportunities to restore larger contiguous blocks of caribou habitat, enables the co-planning of restoration of seismic lines and abandoned well sites, and provides the opportunity to consider other factors affecting restoration such as OHV access, stakeholder access requirements and the presence of advanced regeneration.

In short, innovative restoration requires clear and carefully coordinated restoration plans. Implementing innovations contained within this report without effective project planning is likely to compromise potential gains in efficiency that would otherwise be realized by adopting these new technologies or techniques. Additional information about project planning opportunities are highlighted in phase one of this Restoration Innovation Roadmap (Pyper and Broadley, 2019).

References

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Next Steps for an Innovation Ecosystem

A final step in the project which was of key interest to COSIA member companies was to better understand whether an innovation ecosystem currently exists for linear restoration, and what advancing an innovation ecosystem could look. An innovation ecosystem is defined here as an ecosystem in which funders, innovators, and organizations implementing restoration can have constructive conversations and expedite the development of new innovations. The intent of this exploration was to better equip COSIA and Alberta Innovates - Clean Energy with clear next steps to advance an innovation ecosystem for restoration.

To complete this evaluation, a series of interviews were conducted with a total of six innovators/entrepreneurs and two funding agencies. Participants were asked a series of questions over the course of an approximately 30 minute interview. Participants at the Restoration Innovation Roadmap workshop also had the opportunity to discuss opportunities for advancing an innovation ecosystem, and these discussions are captured in this report. Individual responses to key interview questions are shared here to help both innovators and funders understand where opportunities might exist for advancing an innovation ecosystem for restoration.

Table 4. Summary of responses to interview questions about a restoration innovation ecosystem. Innovator/entrepreneur responses are in white and funder responses are in green.

What has been your experience to date with funding innovations?	How could the funding ecosystem be improved to advance opportunities in the restoration space?	What one next step could be taken to advance an innovation ecosystem for restoration?
Client has helped fund innovations through projects	Not enough awareness of current ecosystem. Good collaborations between science, funders, entrepreneurs is key	Need physical ground to trial ideas on
Some R&D work with government funding, proved to be very administratively taxing with little benefit for company	Having people who know how to access money would be helpful to aid innovation	Need to hear firm commitment from government that there is a market and a need to scale restoration
Generally it costs a lot to apply and probability of success is low. Friction costs reduce incentive to apply and reduces the quality of the output	Focus on relationships and loyalty – if a company takes the risk to buy equipment they need to know there will be work to support it	When government or companies internalize use of technologies, they stagnate the market and innovation because there is no longer a market for businesses
Requires significant effort to complete the reporting and requires an industry partner	Need to think more critically about what the site limiting factors are and how to solve	Have to focus on site limiting factors – conduct robust studies that monitor growth and survival of individual trees

What has been your experience to date with funding innovations?	How could the funding ecosystem be improved to advance opportunities in the restoration space?	What one next step could be taken to advance an innovation ecosystem for restoration?
Self-funded almost all of innovations to date	Have a remote test site to enable innovators to showcase their ideas to restoration program funders	Create a practical living laboratory where ideas can be tested and showcased
Startup funds are often available but not enough support to get ideas through the latter commercialization stages	Develop a pot of funding and find qualified talent to bring forward ideas in a successful, commercially viable manner	Bring people together that can advance new ideas in collaboration and develop a pool of funding to spark new ideas
Positive experience and have been able to find good projects. More funding could enable support for broader range of innovators. Biggest challenge is in advancing ideas through the final stages of technology readiness	Better communication between funders and partners could help ensure funding opportunities are broadly communicated	Develop a clearer ranking of innovation needs. If we could develop a list of priority innovations, get agreement on these, and deliver on the priority areas this would likely move us forward the quickest
Finding a way to clearly communicate site level constraints in restoration to guide innovators in addressing real problems has been tricky	Well-defined challenge statements, creating a challenge like an X-Prize to reward innovators, creating a test centre and raising awareness of innovation needs	Develop an X-Prize style funding arrangement where innovators are challenged to develop a conceptual design

Innovators were then asked to respond to three statements with a ranking from 1 to 5, where 1 represented strong disagreement with the statement and 5 represented strong agreement with the statement (Figure 15). The following statements were read during the interview:

1. A funding ecosystem currently exists for developing and deploying innovations in restoration.
2. An annual workshop that brings funders and entrepreneurs together to discuss developments and opportunities in the field of restoration would be valuable to me.
3. I have access to the people I need to understand operational constraints and identify opportunities for innovations.

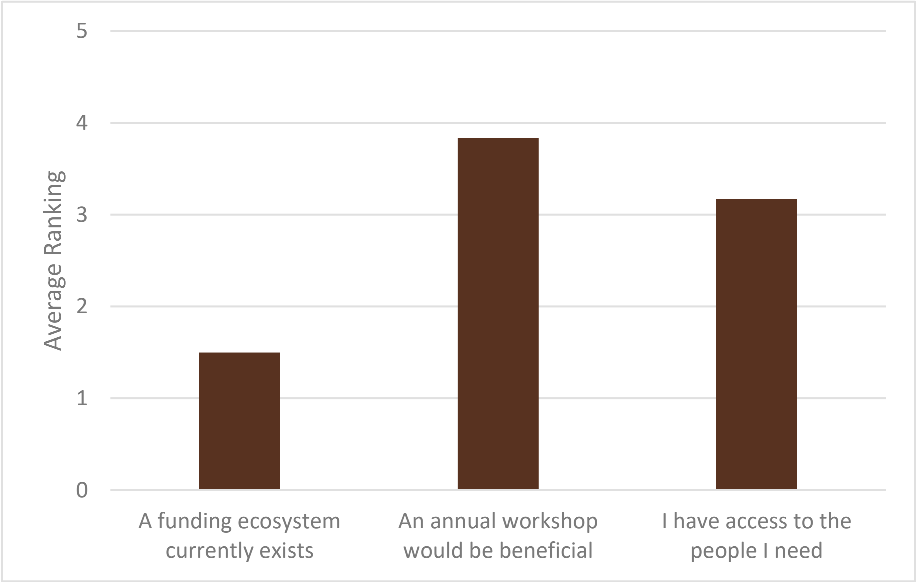

Figure 15. Average ranked responses to statements about an innovation ecosystem for restoration (1 = strongly disagree; 5 = strongly agree).

The voting results generally suggest that innovators perceive a lack of funding to move their ideas to the next stage of development. In contrast, the average vote from funding agencies in response to this question was 4.5 (Agree/Strongly Agree). This highlights a divide between the perception of funding availability of the funders themselves, and that of the innovators who would be accessing those funds.

A workshop was generally seen as a positive next step and one that could help bring together key people to better understand operational constraints and discuss opportunities to partner to advance innovation ideas on the ground. Interviewees were generally neutral on whether they felt they had access to the people they needed to understand innovation or operational constraints. Most interviewees acknowledged that if they needed to, they could find the people required to understand these constraints.

The results of the interviews and the voting exercise provide clear and concrete opportunities for advancing an innovation ecosystem for restoration. It is clear there is an appetite from the innovation community to provide solutions to challenges in restoration. It is also clear that developing a test case location where technologies could be showcased and tested could provide value to multiple innovators. Better communication of funding opportunities that are available would help increase awareness in the innovation community. However, reducing the administrative burden of these funding agreements is important to enable innovators to focus on creating new technologies and not on reporting on pre-determined metrics. A challenge opportunity, such as an X-Prize or something like an X-Prize could be a way to generate excitement and movement on a number of restoration innovation ideas.

Appendix 1: List of Steering Committee Representatives

Individual	Organization
Jack O'Neill	COSIA
Natalie Shelby-James	COSIA
Cynthia Chand	Alberta Environment and Parks
Dallas Johnson	Alberta Innovates
Michael Cody	Cenovus
Mark Boulton	Suncor
Kristen Foxcroft	Cenovus
Ted Johnson	Cenovus
Amit Saxena	Canadian Natural Resources Limited
Jon Gareau	Canadian Natural Resources Limited
Lori Neufeld	Imperial
Margaret Donnelly	Alberta-Pacific Forest Industries
Ken Byrne	FP Innovations
Matthew Pyper	Fuse Consulting
Kate Broadley	Fuse Consulting

Appendix 2: Organizations contacted as part of the project

Organization	Area of Focus
Great Excavations Ltd.	Amphibious equipment
Canadian UAVs	Beyond line-of-sight UAVs
SAIT	Research on automation and UAVs
Finning Canada	Automation and training simulators
Foremost	Equipment manufacturer
Tim Van Horlick	Mechanized tree planter manufacturer
AllTrack Inc.	Low ground-pressure access vehicles
David McNabb	Excavator RipPlow
Tree Time Services	Tree and shrub nursery
Silvana Trading	Canadian distributor for Bracke Implements
Butler Enterprises	Tow-behind mounding equipment
FPInnovations	Applied research on a wide range of innovations
Marsh Master	Access vehicles
Hydratrek & Land Tamer	Access vehicles
Prinoth	Access vehicles
Sherp	Access vehicles
Roughrider International Ltd	Access vehicles, rentals
Fat Truck	Access vehicles
Low Impact Inc	Access vehicles, rentals
ConTract Equipment Ltd	Access vehicles
Pioneer Offroad Rentals	Access vehicles, rentals
Makar Off Road	Access vehicles
Speth Drilling	Equipment miniaturization, remote control, and robotics
EnviroSize Oilfield Services Ltd	Equipment miniaturization, remote control, and robotics
Explor	Equipment miniaturization, remote control, and robotics; HSE considerations
CPTS / ATV Hire	SPVs, access vehicles
Mattracks	Track improvements and suspensions
American Track Truck	Track improvements and suspensions
Caterpillar Inc	Equipment miniaturization, remote control, and robotics
Kubota Canada Ltd	Equipment miniaturization, remote control, and robotics
Brandt	Equipment miniaturization, remote control, and robotics
National Trailer	Camps
Apex	Camps
Vertex	Camps
Matrix	Camps
CanRoss	Airships and aerostats
Raven	Airships and aerostats
Rheinmetall	Airships and aerostats
Canadian Association of Geophysical Contractors	Explosives
Orica	Explosives
Austin Powder Company	Explosives

Appendix 3: Description of modeling approach

To calculate cost and efficiency estimates in the case studies presented above, we conducted detailed financial modelling (FM) of various access vehicle and lodging alternatives. Here we present an overview of FM assumptions and inputs.

General assumptions

All FM was run for a four-person crew (to include one medic plus three workers — either two operators and one supervisor, or three operators) over a 24-day shift. A four-person crew was used because most restoration activities are currently conducted by small crews; a 24-day work shift was selected because that is the maximum number of consecutive days allowed before a rest period is required in Alberta. Capping each FM scenario at 24 days prevented the need to account for complex turn-around scenarios required to cycle through new work crews.

Access Vehicles

Vehicle types

FM compared four ground-based vehicles — Argos, Fat Trucks, Sherp Pros, and Hägglunds — and a helicopter (A-Star B2). These vehicles were selected because they a) can all accommodate the full four-person crew plus daily gear in a single trip, b) are either currently used or are new and have generated buzz and interest, and c) offer varying travel speeds around which to compare travel efficiency.

For later comparison purposes, the Argo is considered the “base case”.

Rental costs

For ground-based vehicles, we used monthly rental rates quoted from individual or from multiple (averaged) rental pools. Use of each vehicle for a 24-day shift would incur a monthly rental charge (long term rentals are typically prorated in weekly increments).

Rental costs also included mobilization and demobilization costs. Mobilization costs were calculated using quoted hourly rates per trailer type required to move each vehicle and the travel times between rental pools and programs. Travel times were estimated to the northern and southern parts of the Athabasca Oil Sands region, using Ft. McKay and Conklin as destination points, respectively. Mobilization distances and times were calculated using Google Maps to estimate travel time between rental pools and the destination points, plus one additional hour to account for off-highway travel to camps. For Ft McMurray-based rentals, a three-hour flat time was applied to mobilization costs. Mobilization costs were calculated for two round trips (i.e., four one-way trips; two trips to deliver vehicles at project start-up and two trips to retrieve vehicles at project end) and for any one-way trip over seven hours, an additional overnight cost for two drivers was added to the cost calculations to account for daily driving time-outs (i.e., one overnight on delivery and one overnight on retrieval).

For helicopters, we used averaged quoted hourly wet and dry rates from several helicopter companies in Bonnyville and Ft McMurray. Costs were calculated using three-hour minimums and no minimums (i.e., operating times only) to compare expenditures and savings.

Run costs

FM compared run costs between vehicles as the cost to travel between a camp and a restoration program. For ground-based vehicles, costs were estimated as the static rental cost described above plus vehicle fuel costs. Fuel costs were estimated using vehicle fuel efficiencies on a use-per-time basis as listed in vehicle spec sheets or estimated from discussions with experienced users, assuming $1.15 /L for gasoline and $1.25 /L for diesel. Costs were estimated at five off-road travel distances — 10 km, 15 km, 20 km, 25 km, and 50 km — representing distances between an access point on a high grade road and a restoration program location (i.e., total km of travel off of a high grade road). Fuel costs were estimated for a round trip (to the field and back to camp). An additional, static 25 L fuel cost for pickup trucks was added for calculations where crew stayed at conventional camps (two one-way, one-hour travel periods between camp and access point and back to camp).

For helicopters, costs were calculated as a "base-stationed" cost and a "camp-stationed" cost. Base-stationed costs used wet rates and a one-way flight was calculated as a flight from helibase to a camp to pick up a field crew (assuming 30 min at 125 mph travel speed to allow for a 50 mile "pickup zone"), then camp to a restoration project site to drop off the field crew (assuming 15 min at 125 mph to allow for a 20 mile "commuting zone"), and finally back to helibase (additional 30 min). Camp-stationed costs used dry rates and a one-way flight was calculated as camp to a restoration project site to drop off the field crew (assuming 15 min at 125 mph to allow for a 20 mile "commuting zone"), and then back to camp (additional 15 min). Flight costs were estimated for a round trip (to deliver crews to the field and return crews to camp). Additional helicopter related costs were applied to remote camps (see below).

Camps

We compared three different camp costs. First, use of existing camps was estimated at $200 per night per person. Second, two versions of "forward camps" were considered where camps were located at access points for restoration programs (one option for wellsite trailers and one option for travel trailers). Forward camp costs included rental and servicing costs associated with lodging, power and lighting, potable water and waste management and disposal, plus fuel. All rentals were calculated for a 26-day period to account for set-up before, and takedown after the 24-day work period. All mobilization costs for forward camps were calculated as described above (i.e., detailed transportation costs that vary by region and equipment origin).

For each camp option, two variations were considered for base- and camp-stationed helicopters. For all camp stationed options, accommodation and calculation for on-site jet fuel and two additional rooms (and associated support needs) for the helicopter pilot and engineer were included in the FM.

Cost Calculations

To understand how vehicle and camp costs propagated across restoration programs, we pooled and then annuitized costs on a per available working hour basis over a 24-day shift.

Work hours

The number of available working hours was calculated as a 12-hour workday minus commuting time between a camp and a work site, cumulatively over 24 days. A 12-hour workday was selected because that is the maximum number of work hours per day allowed in Alberta.

Commuting time was calculated for all combinations of camp locations (conventional camp or forward camp) and vehicle types (Argo, Fat Truck, Sherp Pro, Hägglunds, and A-Star B2) for each of the five off-road travel distances (10 km, 15 km, 20 km, 25 km, and 50 km) and helicopter travel times above. Average ground vehicle travel speeds were assumed as 8 kph for Argo, 15 kph for Fat Truck and Sherp, and 10 kph for Hägglunds, based on spec sheets or estimated from discussions with experienced users for pertinent ground conditions for current restoration needs (i.e., typical mixed peatland terrain in NE Alberta). Helicopter travel times were described above.

For example, if a crew stayed at a conventional camp with a one-hour, one-way travel high grade time to an access point and then used an Argo for a 10 km one-way access to a restoration work site, the total commuting time would “cost” 4.5 “commuting” hours thereby leaving 7.5 “working” hours for a 12 hour shift. Over the course of a 24-day shift, that provides a total of 180 working hours (7.5 hours /day * 24 days). If a crew stayed at a forward camp with no high grade travel time, the same 10 km access would leave 9.5 working hours per shift and 228 working hours per 24-day shift.

Cost per hour, per restoration kilometer

To calculate camp and access costs on a per hour and per restoration kilometer basis, we divided total costs by total work hours and total costs by restoration rate, respectively.

For example, in extension of the above, total camp and access costs for a 10 km Argo access program where a crew stays in an established conventional camp is $32,040.25. With an associated 180 working hours over a 24-day program, each work hour costs $178.00 (total cost / total working hours). Assuming an average rate of restoration of 1,000 m per 7 working hours, the total access and camp cost of one km of restored line is $1,246.01 ((7.5 working hours * $178.00 per hour) / 1.71 km restored in 7.5 working hours).

In 24 days, a total of 25.7 km can be restored for a total $32,040.25 in camp and access costs.

Cost comparison between vehicle types

To compare total costs between different access vehicles, we compared a percentage change in both total kilometer restored and total camp and access cost per vehicle type (for all combinations of camp type and location, vehicle, and off-road access distance).

For example, in further extension of the above, the total 10 km access costs for an Argo is $32,040.25 to restore 25.7 km of line. Total 10 km access costs for a Sherp is $36,245.00 to restore 29.7 km of line. Although we incur a 13.1% increase in cost ((Sherp cost – Argo cost) / Argo cost), we also realize a 15.6% increase in total linear kilometer restored. Thus, a higher vehicle rental cost is offset by faster travel speeds and a subsequent increase in total working hours over the course of a program.

Appendix 4: Summary of alternative access vehicles

The following section summarizes vehicles that are currently available, or could be available to support restoration work. Detailed modelling of cost comparisons are also included to showcase how each machine might benefit restoration programs by reducing access times.

Hägglunds

Hägglunds are manufactured by several partner groups under the BAE Systems banner (originally developed for use by the Swedish military and are still manufactured for that purpose). Hägglunds are a fully amphibious, tracked, and 2-component articulated vehicle designed primarily for personnel transport. The front component houses the engine and can accommodate a driver and several passengers. The rear component can be fitted with several common options including a crew carrier for additional personnel, or a pickup-style or flatbed deck for hauling equipment. A hydraulic dump is also available and after market modification of the rear component is possible for mounting various equipment directly to the track frame.

Hägglunds are reliable, but maintenance-heavy machines. For each work day, a Hägglunds will require approximately 1 hour of routine maintenance. Damage is inevitable without that routine maintenance and repairs are often costly because the machines are specialized and produced at low volume. Hägglunds are best coupled with an experienced, dedicated mechanic and an onsite mechanic shop. Remote Solutions in Fort McMurray, Alberta is experienced in onsite maintenance and service (though no longer run a Hägglunds fleet; https://www.remote-solutions.ca/). Several rental options for Hägglunds are available in Alberta and BC and rental costs are approximately $20,000 / month.

Prinoth

Prinoth is an Italian company that manufactures a wide range of rubber-tracked, moderate and low ground pressure vehicles for specialized construction and forestry applications in soft ground conditions. Most machinery is akin to the Morooka line of equipment familiar to western Canadian industrial uses (http://www.morookacarriers.com/). Prinoth will manufacture machinery in custom combinations of tools and platforms to deliver specific needs outside of their normal offerings. Though expensive, Prinoth carries a “deep bench” of regularly manufactured products to deliver versatile mix-and-match builds for specific and specialized needs likely applicable to reclamation and restoration needs beyond simply site access. A rental option for tracked personnel carriers capable of hauling up to 12 people exists in Alberta for approximately $12 – 15,000 / month. Custom builds to combine personnel transport and equipment / earthmoving tools would start at approximately $350,000 USD.

All Track (AT)

AT is a Calgary based company that makes tracked carriers in a variety of sizes. The “base” design of the AT carrier is akin to the Nodwell line of equipment familiar to remote western and Arctic Canadian oilfield and mining uses (http://www.foremost.ca/foremost-mobile-equipment/tracked-vehicles/nodwell-240/). The final build of an AT machine, including cabin needs, deck design and mounts and track requirements, is ultimately user defined and fully customizable for specific purposes and environments. AT machines have been used in wide variety of industrial and firefighting applications to transport crews and equipment and to mount equipment for localized and continued use. AT has also manufactures low-ground pressure earth and snow moving equipment (e.g., the Locust and the 20SG). A rental option for flat deck equipment carriers (2 person cabs) is available in Alberta for approximately $15 - $21,000 / month (depending on size). Custom builds to expand personnel carrying capacity and or add equipment / earth moving tools would start at approximately $200 – 350,000 (depending on size).

Marsh Master

Marsh Master is a Louisiana based company that manufactures fully amphibious personnel carriers and other vehicles to access and work in wet and marshy condition on the Gulf Coast in Texas and Louisiana. The equipment is made of aluminum to reduce overall vehicle weight and tracks are wrapped around large aluminum pontoons designed to float and to provide high clearance. In addition to personnel carriers, Marsh Master also manufactures a variety of other amphibious machines including hoes and cranes and custom mix-and-match builds are available to meet specific client needs. Equipment lacks suspension and tracks are not designed for snow so operation in frozen and snowy conditions is not advised. All machines are open air so intended for summer operations or warm climates. Rentals are not available in Canada, but new builds are fairly economical at $50 – 70,000 USD for personnel carriers.

Hydratrek & Land Tamer (HTLT)

HTLT is a Tennessee based company that makes small amphibious, tracked machines primarily to move personnel and cargo into wet and soft condition worksites. Machines are typically open air but covers and heaters can be manufactured and incorporated into custom builds. Most models are single designs to transport personnel and light equipment, but the LT 8x8 XHD can be modified to combine personnel transport and earth moving equipment. Rentals may be available to Canadian customers, but would require special ordering. New builds would range from $95 – 135,000 USD.

Modified ATVs / Buggies

The Fat Truck (Canadian), Sherp Pro (Ukrainian; Sherp North America based in Manitoba), and BigBo ATV (Russian) are all versions of the same idea and platform – a buggy-truck to navigate Siberian peatlands. All vehicles are designed to carry 4-5 passengers and some equipment. The Sherp and Fat Trucks also sell amphibious trailers. Each vehicle has slightly different packaging and each provides different comforts and interior designs. The Sherp and Fat Truck are each other's main competitors and are both new to the Canadian market. Both cater to a more comfortable ride. The BigBo ATV is still more "Old World" and a bit more ruggedized. The BigBo ATV emphasizes the amphibious capability in that it is designed as a "boat under carriage with a cap" rather than as a truck that can "go anywhere". The BigBo

ATV combines a steel bottom (boat portion of vehicle) with an aluminum top (cap portion of vehicle) to reduce overall vehicle weight. The Fat Truck and Sherp are both available from rental in Alberta at approximately $17,500 and $14,500 / month, respectively. The BigBo ATV is not available for rental in Canada; cost for purchase is currently unknown.

Large unit crossovers

The Sherp Ark (Ukrainian; Sherp North America based in Manitoba), Abtopoc Shaman (Russian), and Makar Burlak (Russian) are all versions of the same idea – large, ruggedized vehicles with optional modifications available to interior layouts. All vehicles are designed to perform in exceptionally rugged, wet, and varied terrain in remote settings. The Burlak and Ark are fully amphibious. All vehicles have available a standard option to facilitate camping and self-contained expedition-style uses. The Makar Burlak offers the most accommodating expedition interior that ultimately converts like a camper van; other models offer more spartan conversions (but Sherp offers custom builds including washrooms and kitchen). The Sherp Ark and the Makar Burlak can also convert to industrial uses to support equipment transfer or to function as mobile equipment platforms. Like a Hägglunds, the Sherp Ark is a two-component, reticulated vehicle. The rear piece can be a flat deck trailer or an enclosed carrier. The Sherp Ark offers unique steering and access options (e.g., lifting the front piece to “step over” obstacles).

Vehor RX2

The Vehor RX2 is essentially a low cost, all season, snow machine capable of amphibious travel. The Vehor ground pressure is exceptionally low at 0.46 PSI. Each machine can carry a single passenger.

Access Vehicle Pictures

Hägglunds

From L to R: crew carrier, pickup style caboose, flat deck caboose, dump bed caboose.

Prinoth

From L to R: Panther T6 with crew carrier, Trooper with Husky Transport Cabin

Marsh Master

MM 2LX crew carrier

Fat Truck & Sherp

From L to R: Fat Truck model 2.8C, Sherp Pro enclosed, Sherp Ark with crew carrier

Hydratrek & Land Tamer

From L to R: D2488B, XTB66, LT 8x8 XHD, Raft

All Track

From L to R: AT 50HD, AT 80 HD

Argo

Aurora 850 SX-R

Abtopoc (Wamah /Shaman)

Makar Off Road (Burlak)

From L to R: sleeper and truck styles

BigBo ATV

Vehor ATV

Honourable Mentions

Vityaz DT-30

CPTS / ATV Hire

From L to R: Centaur 8, Centaur 8, Swamp Master, Swamp Master

Vehicle Manufacturer	Fuel				Seats	Travel speed (max, mph) [2]		Specs (lbs. or inches, unless otherwise noted)						
Model	Tank Capacity (US Gal)	Type	Exhaust Type	Efficiency [1]		Hard Ground	In Water	Weight	Payload	Gross	Width	Length	Deck Size	Deck From Ground
Hagglunds														
BV 206 [1]	42	Diesel	Unknown	~ 150 km	6 + 10 [2]	30	2.5	Front car - 6,000; Rear car - 3,600 [3]	Front car - 1,400; Rear car - 3,600 [4]	~15,000	74	270	72 x 108 [5]	40 [5]
Prinoth														
Trooper [1]	61	Diesel	Tier 3	Several Days	2 + 9 [2]	18	Unknown	9400 [3]	3,000	12,400	101 or 118 [4]	160 [5]	N/A	N/A
Panther (T6)	46.2	Diesel	Tier 3	Several Days	2 + 10 [1]	9	Unknown	16,600	12,000	28,600	96.4 [2]	183	95 x 91 [3]	83
Marsh Master														
MM-2LX series [1]	29	Diesel	Tier 4	Several days	5-6 + 4-8 [2]	8	1	6,000	2,000	8,000	96	190	N/A	N/A
Fat Truck														
2.8C [1]	18	Diesel	Tier 4	10 - 18 hours	8	25	2	4,900	2,200	7,100	101	147	N/A	N/A
Sherp														
Pro [1]	17.7 [2]	Diesel	Tier 4	40 - 50 hours [3]	8	25	4	2,900	2,200	5,100	100	134	N/A	N/A
the Ark	118 + 150 [1]	Diesel	Tier 4	2 -3 Gal / hour	4 + Up to 22 [2]	18.6	3.7	10,500	7,500 (880 in front, 6,600 in rear)	17,100	100	380	189 x 87 [3]	~ 70 [4]
Hydratrek & Land Tamer														
D2488B	19	Diesel	Tier 4	12 hours	Up to 8	15	4	7,200	3,000 Land / 1,600 Water	Variable	94	190	N/A	N/A
XTB66	13	Diesel	Tier 4	8 hours	Up to 7	15	4	4,200	1,600 Land / 1,200 Water	Variable	84	164	N/A	N/A
LT 8x8 XHD	20	Diesel	Tier 4	10 hours	Up to 8	15	4	6,000	3,000 Land / 1,600 Water	Variable	86	188	N/A	N/A
RAFT [1]	N/A	N/A	N/A	N/A	Up to 12	N/A	N/A	1,250	2,500 Land / 1,800 Water	Variable	78	120	N/A	N/A
All Track														
AT-50HD	34	Diesel	Tier 4	At least a shift	2 [3]	14	Unknown	11,500	7,500	19,000	78 or 101 [1]	180	78 x 102	36
AT-80HD	60	Diesel	Tier 4	At least a shift	2 [3]	9	Unknown	14,500	14,000	28,500	101	240	96 x 120	43
Argo														
Aurora 850 SX-R [1]	7	Gasoline	Unknown	At least a shift	4	24 [2]	3	1680	870 Land / 570 Water	Variable	60	119	N/A	N/A
Abtopoc														
Wamah / Shaman [1]	69	Diesel	Unknown	~ 6.5 L (1.7 US Gal) / 100 km	1 + 8 [2]	44	1.2	10,600	3,300 kg "firm ground" / 2,200 kg "poor bear soil" [3]	Up to 13,900	98.5	248	N/A	N/A
Makar Off Road														
Burlak [1]	105 [2]	Diesel	Unknown	6.5 - 8 L (1.7 - 2.1 US Gal) / 100 km [3]	up to 15 [4]	31 [5]	3.7 [6]	9,200	4,480 + 9 passengers "solid ground" / 2,240 + 5 passengers " weak ground or afloat"	Up to 15,680	114	290	N/A	N/A
BigBo ATV														
BigBo [1]	24	Gasoline	Unknown	1.8 / hr	5	34	Unknown	3,080	1,550 + 5 people and personal gear (2,200 total)	5,280	99	144	N/A	N/A
Vehor ATV														
RX2 [1]	1.7	Gasoline	4 Stroke	0.5 / hr	2 [2]	28	Unknown	700	660	1,360	60	88	N/A	N/A

Vehicle Manufacturer				Ability / Gradability					What else can it do?	
Model	Track Material	Track Shape	PSI	Fording Depth (inches)	Turning Radius (inches)	Slope - up/downhill (°)	Slope - sidehill (°)	Seasonal Use	Configurable?	Multi-function?
Hagglunds										
BV 206 [1]	Rubber	Both ends sloped	1.26 empty	Fully ampibious [6]	Unknown (~ 144)	45	35	All [7]	Moderate; can function as personnel or equipment carrier [8, 9]	Moderate; can function as personnel or equipment carrier
Prinoth										
Trooper [1]	Steel or rubber [6]	Both ends rounded	0.83 or 0.68 empty [7]	N/A	0	45 [8]	37 [8]	Winter [9]	No	No, personnel only [10]
Panther (T6)	Rubber	Front rounded, rear sloped	2.19 empty / 4 loaded	40	0	31 [4]	22 [4]	All	Yes	No, personnel only
Marsh Master										
MM-2LX series [1]	Aluminum	Both ends sloped	1 loaded	Fully amphibious	Unknown	Unknown [3]	Unknown [3]	Summer	Yes; fully customizable for personel and equipment [4]	Yes
Fat Truck										
2.8C [1]	N/A	N/A [2]	1.1 empty / 1.6 loaded	Fully amphibious	0	35 [3]	22 [3]	Unfrozen [4]	No [5]	Primarily for personnel, but can tow small trailer
Sherp										
Pro [1]	N/A	N/A [4]	3 loaded	Fully amphibious	98	35	Unkn	All	No [5]	Primarily for personnel, but can tow small trailer
the Ark	N/A	N/A [5]	Not listed [6]	Fully amphibious	Not listed [7]	40	30	All	Yes; fully customizable for personel and equipment	Can function as personnel / cargo carrier, or full camping (i.e., ruggedized camper) [8]
Hydratrek & Land Tamer										
D2488B	Rubber	Both ends rounded	1.5 empty / 2.2 loaded	Fully amphibious; in water switch to jet prop	Unkown	40	40	All	Yes; customizable for layout, power, enclosures	No, personnel only
XTB66	Rubber	Both ends rounded	1.4 empty / 2.0 loaded [1]	Fully amphibious; in water switch to jet prop	Unkown	40	40	All	Yes; customizable for layout, power, enclosures	No, personnel only
LT 8x8 XHD	Rubber	Both ends rounded [1,2]	0.9 empty / 1.5 loaded [3]	Fully amphibious; in water switch to jet prop	Unkown	40	40	All	Yes; fully customizable for personel and equipment [4]	Yes
RAFT [1]	Rubber	Both ends rounded	0.5 empty / 0.9 loaded [3]	Fully amphibious	N/A	30	30	All	Yes; customizable for layout, enclosures	Moderate; seating for personnel or no seating for hauling gear/equipment
All Track										
AT-50HD	Rubber with steel crosslinks	Both ends sloped	2.0 empty / 3.4 loaded; 1.4 empty / 2.4 loaded [4]	40	0	31	22	All	Yes; fully customizable for personel and equipment	Yes, but limited person capacity if tools / equipment mounted
AT-80HD	Rubber with steel crosslinks	Both ends sloped	2.3 loaded	40	0	31	22	All	Yes; fully customizable for personel and equipment	Yes
Argo										
Aurora 850 SX-R [1]	Rubber	Both ends rounded	0.88 with 18 rubber tracks	Fully amphibious	0	30	30	All	No	Primarily for personnel, but can tow small trailer [3]
Abtopoc										
Wamah / Shaman [1]	N/A	N/A [4]	Unknown [5]	Unknown [6]	7.5 m	45	47	All	Moderate; can convert to rustic camping interior [7]	Primarily for personnel, but can convert to rustic camping interior [7]
Makar Off Road										
Burlak [1]	N/A	N/A [7]	1.71 loaded	Fully amphibious	Unknown	45	35 [8]	All	Yes; optional layouts for expedition, cargo, industrial uses [9]	Can function as personnel / cargo carrier, or full camping (i.e., ruggedized camper) [9]
BigBo ATV										
BigBo [1]	N/A	N/A [2]	N/A [3]	Fully amphibious [4]	Unknown [5]	Unknown [5]	Unknown [5]	All	No	No, personnel only
Vehor ATV										
RX2 [1]	Rubber	Both ends sloped	0.46	Amphibious [3]	0	Unknown [4]	Unknown [4]	All	No	No, personnel only

Vehicle Manufacturer	**Rental Options and Costs [1,2]**	
Model	Rental Availability	Rental Location
Hagglunds		
BV 206	Low Impact	Valleyview, AB
	Pioneer Rentals	Various; main yard in Edmonton, AB
Prinoth		
Trooper	Pioneer Rentals [1]	Various; main yard in Edmonton, AB
Panther (T6)	Pioneer Rentals	Various; main yard in Edmonton, AB
	ConTrac [1]	Edmonton
Marsh Master		
MM-2LX series	No commercial rental pools; MM can help find rentals	Various along Gulf Coast USA
Fat Truck		
2.8C	Low Impact [1]	Valleyview, AB
Sherp		
Pro	Roughriders	Fort McMurray, AB
the Ark	Roughriders [1]	Fort McMurray, AB
Hydratrek & Land Tamer		
D2488B	Various locations in US and Canada; HT / LT can help find rentals	Various locations in US and Canada
XTB66	Various locations in US and Canada; HT / LT can help find rentals	Various locations in US and Canada
LT 8x8 XHD	Various locations in US and Canada; HT / LT can help find rentals	Various locations in US and Canada
RAFT	Various locations in US and Canada; HT / LT can help find rentals	Various locations in US and Canada
All Track		
AT-50HD	Pioneer Rentals	Various; main yard in Edmonton, AB
	Green Zone Environmental	Le Crete, AB
AT-80HD	Pioneer Rentals	Various; main yard in Edmonton, AB
Argo		
Aurora 850 SX-R	Pioneer Rentals	Various; main yard in Edmonton, AB
	Argo North	Bonnyville and Plamondon, AB
Abtopoc		
Wamah / Shaman	Abtopoc [1]	Russia
Makar Off Road		
Burlak	No	None
BigBo ATV		
BigBo	No	None
Vehor ATV		
RX2	No	None