Cattail Biomass in a Watershed-Based Bioeconomy:

Commercial-scale harvesting and processing for nutrient capture, biocarbon and high-value bioproducts

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IISD REPORT
March 2014

International Institute for Sustainable Development
Institut international du développement durable

Published by the International Institute for Sustainable Development.

International Institute for Sustainable Development

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Acknowledgements

Our thanks are extended to our many partners on IISD's Lake Winnipeg Bioeconomy Project, who have contributed to advancing these concepts from the research stage to commercial- and watershed-scale application. These partners include: The Prairie Agricultural Machinery Institute (PAMI) for their dedicated work in the cattail harvesting project, harvesting logistics, and contributions to this report; MacDon Industries Ltd. for their invaluable support providing both harvesting equipment and expert advice; La Salle Redboine Conservation District for their partnership and support; and Manitoba Hydro for its partnership, financial support, and belief in the project concepts. We also thank our partners at Biovalco Innovative Products for their contributions to the processing and utilization of harvested cattail biomass for densified biocarbon and solid fuel; they also ran combustion trials in commercial applications of their Blue Flame Stoker biomass boilers. Other contributors to this report are the University of Manitoba and Titan Energy.

Funding for this project was provided by Manitoba Liquor and Lotteries Corporation, Manitoba Hydro, the Province of Manitoba, and Environment Canada through the Lake Winnipeg Basin Stewardship fund.

Executive Summary

One of the fundamental insights underlying the International Institute for Sustainable Development's (IISD's) "Lake Winnipeg Bioeconomy Project" is that phosphorus, the nutrient responsible for fouling Lake Winnipeg and other aquatic ecosystems, is also a scarce and valuable natural resource that is critical to agricultural production and global food security. IISD research introduced the concept of harvesting "ecological biomass"—primarily a large aquatic plant species cattail (Typha spp.)—for watershed nutrient management and biomass for the biomass industry. Harvesting the cattail removes the nutrients (i.e., phosphorus) that are taken up during growth and stored within the harvested biomass. This biomass can then be utilized as a solid fuel for bioenergy, biocarbon, and higher-value biofuels and bioproducts.

IISD has since expanded and generalized the concept at a watershed scale through the "Lake Winnipeg Bioeconomy Project" and this component project, "Cattail Biomass for Integrated Watershed Management and Biocarbon." This project moves the research from the pilot scale to the commercial harvest of cattail and other ecological biomass species on marginal agricultural land, in stormwater ditches, and from shallow water retention storage sites—areas that naturally concentrate nutrients from runoff water. Two years of commercial pilot harvests were conducted at Pelly's Lake near Holland Manitoba in the LaSalle Redboine Conservation District. IISDs research has proven innovative watershed management solutions for multiple environmental and economic co-benefits while addressing the difficult challenge of reducing non-point nutrient loading to Lake Winnipeg.

Cattail harvest research in 2013 focused on optimizing methods and techniques for cutting and baling cattails at Pelly's Lake, a natural wetland area with controlled drainage. Cattails were cut while still green using a MacDon rotary disc mower, typically used for cutting forage crops. The MacDon mower cut the heavy stand of green cattails effectively, regardless of vegetation height or density. Cattails dried down significantly faster because the conditioning rolls crimp the cattails' leaves. The cattails cut with the MacDon rotary disc mower produced a superior windrow, compared to straight cutting, allowing a large square baler to be used in 2013. Square bales, with a rectangular end face, offer greater options for stacking and help maximize transport efficiencies compared to round bales. Previous attempts to use a large square baler on cattail windrows were unsuccessful due to the height and width of the cattail windrows. The rotary disc header weighed more than the previous (2012) straight cut header but had sufficient flotation to cut cattails in the wetland area without issue. Tire pressures were lowered to reduce the impact on the wetland. The rotary disc cutter bar with conditioning rolls is a preferred cutting method for harvesting cattails where conditions permit.

Cattail yields were lower at Pelly's Lake compared to the 2012 harvest. This can be attributed to trampling by cattle in the cattail harvest research area, increased undergrowth of grasses in competition with cattails and variation in growth. Cattails were harvested as much as 18 days earlier than in the previous (2012) season, with similar average concentrations of phosphorous in the cattails.

IISD carried out tests to assess the potential of cattail as a biomass feedstock for biocarbon production. A comparison of cattail biocarbon was conducted to wheat straw biocarbon, evaluating energy content and various parameters from production. Several tonnes of cattail biomass were shipped to Titan Energy in Craik, Saskatchewan to be converted into biocarbon, or biochar. A general comparison of the lab analysis of the cattail biocarbon to the wheat straw biocarbon shows the following:

1. Organic carbon content was similar.
2. Heating value of cattail biocarbon was significantly higher at 31.41 megajoules (MJ)/kilogram (kg) compared to wheat straw biocarbon of 23.75 MJ/kg.
3. Cation exchange capacity was approximately double in the wheat straw biochar.
4. Available phosphorus was approximately 18 times less in the wheat straw biochar.
5. Available potassium was approximately 7 times more in the wheat straw biochar.
6. PAH levels were similar (and low compared to International Biochar Initiative [IBI] standards).
7. Heavy metal levels were similar (and low compared to IBI standards).

A general comparison of the lab analysis to values given in Tables 1 and 2 of the IBI standards (IBI, 2013) shows that the cattail biochar and wheat straw biochar should be adequate for soil applications.

Cattail ash from solid fuel combustion trials in Blue Flame Stokers and cattail biochar was analyzed for agricultural nutrients nitrogen (N), phosphorus (P) and potassium (K). The total nutrient content and the concentration of nutrients available to plants were determined by standard soil and manure testing procedures.

The data presented in this report represents the preliminary findings of nutrient studies on cattail ash and biochar. The study completed analysis of total N, P, and K and assessed plant-available portions of these nutrients. In addition, minor nutrients and heavy metal content were determined to ensure these concentrations would not limit land application. Research yet to be completed consists of experiments using biochar as an activated carbon medium to purify water and using cattail ash to raise liquid manure pH to remove phosphorus. Preliminary tests of cattail of biocarbon as an activated carbon have yielded excellent results, and it performs well as an activated carbon for water filtration.

Using cattail ash as an agricultural fertilizer would supply soil with potassium and phosphorus. The tests conducted in this study indicate the majority of the total potassium would be available for plant usage at neutral soil pH. The majority of the phosphorus however, is insoluble at neutral pH and may not be available to growing plants. Further long-term soil incubation tests could be conducted to verify plant availability of cattail ash phosphorus. If cattail ash is washed with water to leach out soluble compounds, potassium is the only nutrient that is present in the filtrate, removing approximately 70 per cent of the soluble K and 30 per cent of the total K. Acidifying the ash has the effect of increasing the solubility of potassium so that total soluble K increases from 46 per cent to 81 per cent of TK when the pH is lowered to 6.7. Analysis for heavy metals and other nutrients concluded that no metals are present in cattail ash at a concentration that would prohibit its use as a fertilizer according to the Canadian Council of Ministers of the Environment (CCME) guidelines.

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1.0 Introduction

Manitoba Hydro is conducting a series of demonstration projects as part of the Corporation's "Power Smart Bioenergy Optimization Program" to showcase potentially cost-effective clean and renewable energy technologies capable of converting biomass and by-products into useful energy. The primary objective of the current biocarbon demonstration project being supported by the Clean Energy Fund (CEF) is demonstrating how a carbon-rich substance called biocarbon can be produced from biomass material through a slow pyrolysis or carbonization process. The initial focus was on the use of wood chips as a feedstock, but there was potential to evaluate alternate biomass sources that offer a means to lower the cost for producing biocarbon. Additionally, beyond the application of biocarbon as an alternative to fossil coal for energy production, biocarbon has excellent potential to improve soil fertility and offer carbon sequestration and storage in agricultural soils.

The purpose of this project add-on was to address the need to diversify the portfolio of biomass feedstocks for biocarbon production beyond woody biomass material, and evaluate the use of cattail (Typha spp.) as a biomass feedstock to produce biocarbon and displace fossil fuel energy in Manitoba. Cattail is a large emergent plant found in wetlands and water-logged areas across North America, and can produce considerable biomass within a single growing season with zero input costs. The energy potential of cattail was studied in the 1970s by the United States Department of Energy, and more recently in Manitoba by IISD, the University of Manitoba, and Ducks Unlimited Canada.

In its ongoing research programs, IISD has demonstrated that cattail is a viable feedstock for use in bioenergy technologies, while harvesting the biomass provides major environmental and economic co-benefits—particularly water quality improvement and nutrient cycling. As they grow, cattails take up nutrients from the sediment, incorporating these components into their plant biomass. Phosphorus is an essential nutrient for plant growth and agriculture, but it is also the nutrient fouling Lake Winnipeg and causing algal blooms. IISD's previous research demonstrated that harvesting the cattail plants removes the bound nutrients (e.g., phosphorus) and prevents them from being released back into the water, as occurs when the plants decompose. Harvesting cattail removes captured phosphorus and reduces loading to Lake Winnipeg, while providing a biomass feedstock, ability to recover phosphorus and habitat restoration. Research on harvesting methods is a necessary step to realizing these benefits and to move towards commercial-scale application. The Cattail Biocarbon add-on project builds upon previous research by IISD to explore commercial scale harvesting and higher-value end-uses of harvested cattail biomass.

This project directly enhances the current Clean Energy Fund project by diversifying the portfolio of biomass feedstocks for biocarbon production beyond woody biomass material. It will introduce a new novel biomass feedstock for biocarbon with major environmental co-benefits by combining alternative bioenergy production with nutrient capture and removal. Most importantly the project will demonstrate practical technology for accessing novel, low-cost bioenergy feedstocks.

2.0 Project Background

2.1 IISD's Lake Winnipeg Bioeconomy Project

One of the fundamental insights underlying IISD's Lake Winnipeg Bioeconomy project is that phosphorus, the nutrient responsible for fouling Lake Winnipeg and other aquatic ecosystems, is also a scarce and valuable natural resource that is critical to agricultural production and global food security. The "Netley-Libau Nutrient-Bioenergy Project" introduced the concept of harvesting "ecological biomass" for multiple environmental and economic co-benefits—in this case primarily a large aquatic plant species cattail (*Typha* spp.). IISD's research showed how harvesting the cattail removes the nutrients (e.g., phosphorus) that are taken up during growth and stored within the harvested biomass. This biomass can then be used as a solid fuel for bioenergy, biocarbon, and higher-value biofuels and bioproducts. In addition, other market revenues are produced, particularly carbon offsets when displacing fossil fuel use for energy, and water quality nutrient credits through the removal of phosphorus and nitrogen from the watershed. Processing the biomass for nutrient extraction, bioenergy, carbon offsets and/or biomaterial end uses creates a very low-cost or potentially profitable method for nutrient management.

IISD has since expanded and generalized the concept at a watershed scale through the "Lake Winnipeg Bioeconomy Project" and this component project "Cattail Biomass for Integrated Watershed Management and Biocarbon". This project moves the research from the pilot scale to commercially harvest cattail and other ecological biomass species on marginal agricultural land, in stormwater ditches, and from shallow water retention storage sites—areas that naturally concentrate nutrients from runoff water. Two years of commercial pilot harvests were conducted at Pelly's Lake near Holland, Manitoba in the LaSalle Redboine Conservation District. IISD's research has proven innovative watershed management solutions for multiple environmental and economic co-benefits, to addresses the difficult challenge of reducing non-point nutrient loading to Lake Winnipeg.

Both the Netley-Libau Nutrient-Bioenergy research and Lake Winnipeg Bioeconomy Project are important proofs of concept, how Lake Winnipeg nutrient management together with surface water management and novel ecological biomass feedstock harvesting, offers a multitude of environmental and economic benefits, while creating economic opportunities. It also adds value to marginal agricultural land, providing additional revenue for landowners from otherwise unproductive farmland.

2.2 Cattail Biomass: A novel sustainable feedstock

Cattail is a large and aggressive emergent aquatic plant that typically dominates wet and low-lying areas. It is found in stormwater ditches, on marginal agricultural land, and in large dense patches in wetland areas throughout North America. Cattail takes up considerable phosphorus and nitrogen during the growing season, and harvesting the biomass was shown to remove 20 to 60 kilograms (kg) of captured phosphorus and up to 160 kg of captured nitrogen per hectare. With an average yield of 15 to 20 dry metric tonnes per hectare (T DM/ha), a heating value of 17 to 20 megajoules per kg (MJ/kg), and with very good densification and high-quality fibre properties, cattails are suitable for a variety of biofuel and biomaterial products.

Sustainable cattail harvesting was found to provide six main benefits:

1) Biomass for bioenergy, biocarbon, and bioproducts
2) Nutrient capture (phosphorus) and reduction of loading to aquatic environments
3) Improved habitat condition
4) Fossil fuel displacement and GHG mitigation
5) Phosphorus recovery
6) Flood mitigation when integrated with water retention/storage such as Pelly's Lake.

2.3 Integration With Surface Water Management

One of the main co-benefits of harvesting novel plant species, or ecological biomass, in Manitoba, is to capture and reduce the amount of nutrients entering waterways, thus reducing nutrient loading to Lake Winnipeg. Surface water retention sites can be linked directly to nutrient management through harvesting of wetland plants (ecological biomass) from these retention sites in the late summer or early fall. Water retention storage sites concentrate nutrients from non-point sources on the agricultural landscape, and cattails will in turn take-up these nutrients (up to 20 kg P/ha) to produce up to 20 tonnes of biomass per hectare. Processing the biomass for nutrient extraction, bioenergy, carbon offsets and/or biomaterial end-uses creates a very low-cost or potentially profitable method for nutrient management (MB Surface Water Management Strategy, 2014).

Pelly's Lake (a natural feature near Holland, Manitoba) and the North Ottawa Project (an engineered storage site in the U.S. portion of the Red River Basin) are good examples. Retention storage sites are a major element of integrated flood protection for U.S. cities in the Red River Basin such as Fargo and Grand Forks, North Dakota. Although these sites were not originally designed for nutrient capture, they still perform this function—and consequently many retention cells are full of cattail. In partnership with the Red River Basin Commission, IISD will demonstrate nutrient harvest from the North Ottawa project in 2014. The Government of Manitoba has also integrated nutrient harvesting with retention storage in its new Surface Water Management Strategy.

2.4 Economics and Market Demand

The economic viability of nutrient management via ecological biomass harvesting depends on developing markets for these biomass products and on the design of the surface water management sites, their internal drainage, and their water release strategy. Where appropriate, water storage and release strategies should encourage biomass production, which can be harvested to permanently remove phosphorus from the system (MB Surface Water Management Strategy, 2014).

In addition to relatively high nutrient capture rates, cattails also have high energy density, very good densification properties, and excellent fibre properties. IISD is currently exploring multiple product pathways for value addition, including: densified solid fuels for bioenergy, ethanol, anaerobic methane production, gasification for syngas and combined heat and power, fibres and building materials, and—as a component of this project—phosphorus capture from ash for fertilizer and biocarbon for coal replacement and agricultural soil enhancement.

Ecological biomass harvesting links multiple environmental and economic policy objectives of direct interest to the Province of Manitoba:

- Lake Winnipeg nutrient management through the Lake Friendly Accord.
- Flood mitigation through the Surface Water Management Plan.
- Biomass as a coal replacement as per the Manitoba coal ban for space heating.
- Greenhouse gas mitigation (through the climate change plan).
- Water technology and clean technology development.

Expanding IISDs Bioeconomy Project concepts serves the interest of business and industry in Western Canada as it demonstrates an innovative and entrepreneurial approach to resolving major water and environmental issues and involves key sectors of the western economy such as agriculture, manufacturing and value-added processing. IISD's success will expand Western Canadian market opportunities in key cleantech areas such as value-added biofuels and biomaterials.

IISD's concept of harvesting novel ecological biomass (cattail) to combine watershed nutrient management with biomass for biofuels and bioproducts has garnered international recognition, including the Sustainia100 award as one of the world's 100 best sustainable development projects. It has also been recognized in two Manitoba throne speeches and a budget speech, and has received provincial recognition awards. In 2013 the Winnipeg Chamber of Commerce awarded IISD the Spirit of Winnipeg award for its leadership in demonstrating that Western Canada is capable of deep innovation to solve some of our most challenging environmental issues, attracting new investment to do so and developing new markets for cleantech products.

3.0 Project Description

3.1 Commercial-scale Harvesting and Processing of Cattail Biomass

Cattails are extremely resilient, fast growing, and competitive. Under suitable soil moisture, nutrient availability and climatic conditions, they produce dense homogenous patches and very large quantities of biomass each growing season. Cattails prefer higher-moisture soil than typical agricultural forage or seed crops and will thrive on marginal agricultural land. Therefore, do not compete with prime agricultural land for food production, but rather can provide additional revenue for landowners from otherwise unproductive marginal farmland. Cattails have the potential to be a high-yielding, novel, sustainable and renewable biomass crop each year, if they can be managed effectively. However, the high-moisture soil presents challenges for agricultural equipment that rely on a firm soil bed.

In 2012, IISD with the collaboration of the Prairie Agricultural Machinery Institute (PAMI, which has over 30 years of experience evaluating and developing machinery through analytical and physical testing methods) and the La Salle Redboine Conservation District in Manitoba, evaluated the use of commercially available agricultural equipment to demonstrate that cattails can be harvested economically on a large scale. A pilot-scale commercial harvest of cattail was conducted at Pelly's Lake, Manitoba, using conventional agricultural equipment—a watershed-scale proof-of-concept of the Lake Winnipeg Bioeconomy Project. A MacDon windrower swather unit, typically used for oilseed cutting, was deployed to minimize vehicle weight. The low weight was intended to improve flotation and therefore minimize impact on the wetland area. Approximately 300 tonnes of cattail biomass was successfully harvested with conventional agriculture equipment, capturing a total of 230 kg of phosphorus. Full results of this harvest are documented in an IISD PAMI report by Grosshans and Greiger (2013). A second-year harvest was conducted in 2013, which is detailed in this report.

Commercial-scale feasibility of harvesting cattail was possible due to three key attributes of this species:

1) High density
2) Ability to absorb phosphorus
3) Demonstrated suitability as a feedstock for solid fuel, biocarbon, biogas, ethanol, and high-value biomaterial.

From current ongoing resource assessments, IISD estimates the cattail resource in Manitoba is between 3 to 10 Mt/year, a resource large enough to support multiple commercial biomass operations and have a significant impact on Lake Winnipeg water quality.

3.2 Project Objectives

As part of the "Cattail Biomass for Integrated Watershed Management and Biocarbon" project, harvested cattail biomass was tested for various end-products and high value uses. Cattail was evaluated for use as a solid fuel and densified as a pure and hybrid fuel product. Tests were conducted on the carbonization of cattail biomass into biocarbon, identifying harvesting, storage, and moisture issues. Several tonnes of harvested biomass were converted to biocarbon and tested for energy, soil amendment, manure management and water filtration properties. Ash produced during demonstration burns of the biocarbon in solid fuel burners will also be analyzed to determine fates of elements and recovery of captured phosphorus from cattail biocarbon ash.

Working with researchers at the University of Manitoba, greenhouse growth trials will be conducted on fertilizer value of the ash post-combustion, and potential phosphorus recovery. These enhancements are anticipated to more clearly define the options for producing biocarbon in a cost-effective manner and identify potential markets for non-energy grade biocarbon.

The key objectives of this research are as follows:

1) Carry out large-scale harvest of cattail biomass for use as a novel and innovative alternative biomass for solid fuel and biocarbon, combined with nutrient capture.
2) Modify and test conventional agricultural equipment to harvest suitable quantities of cattail for demonstration trials.
3) Evaluate harvesting logistics, transport, drying, and storage options.
4) Trial the shredding, processing, and densification of cattail as a solid fuel.
5) Trial the use of cattail as a sustainable source of biomass for the production of biocarbon.
6) Examine soil conditioning and soil fertility characteristics of biocarbon and ash from combustion.

3.3 Locations

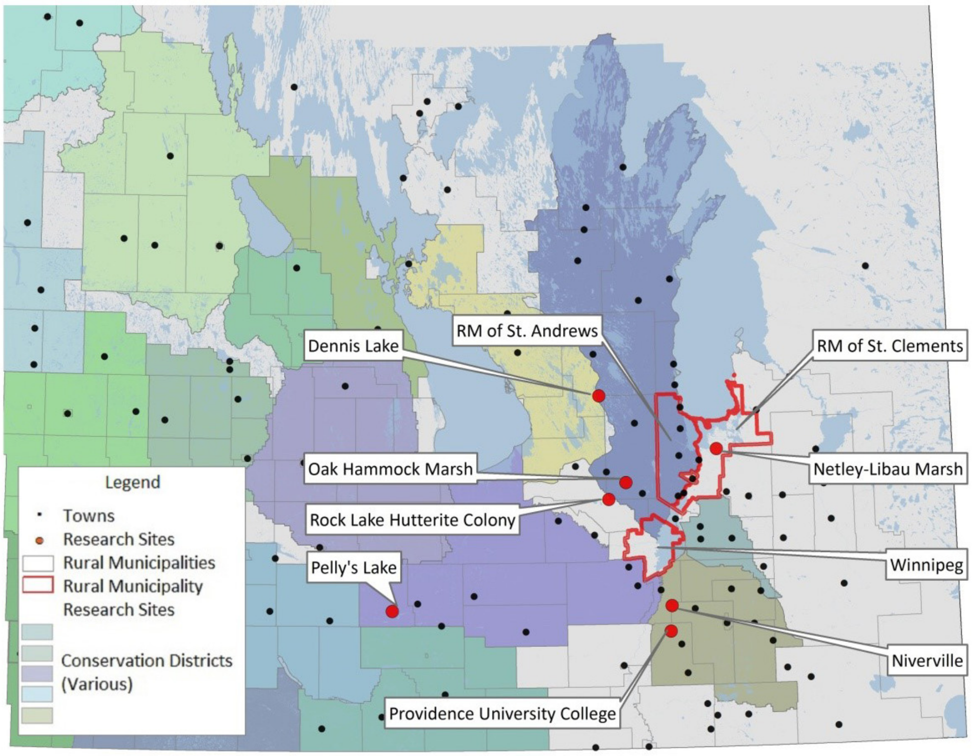

FIGURE 1. CATTAIL RESEARCH SITES.

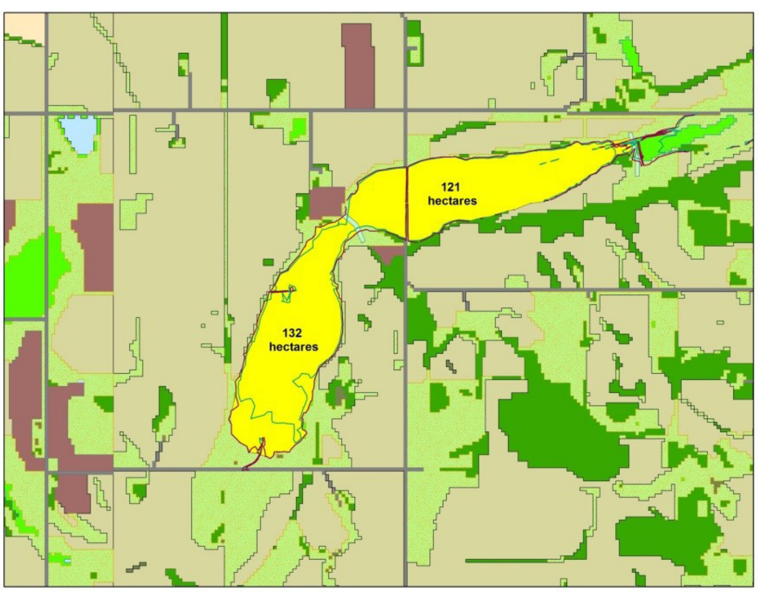

FIGURE 2. THE PELLY'S LAKE RETENTION SITE IN SOUTHWEST MANITOBA.

4.0 Project Results and Outcomes

4.1 Commercial-Scale Harvesting: Year 2 of harvest at Pelly's Lake, Manitoba

The research in 2012 highlighted both the potential and challenges of harvesting cattails in ditches and wetland areas. The focus of this research is the potential of cattails as a biomass crop and nutrient management tool, to show that improving the harvest methods would open up options for producers and end users. Although specialty "wet agriculture" harvesting equipment is available in Europe, a potentially more cost-effective alternative at this stage of market development is to use or adapt existing equipment currently used in markets with a profit stream. Efforts in 2013 focused on utilizing equipment designed for harvesting forage crops for use in cattails growing in wetland areas.

High yields from 2012 demonstrated that, while harvesting large quantities of cattails on a commercial scale is possible with current available equipment in Manitoba, the growing conditions present challenges that need to be overcome for wide-scale acceptance. Results of this report focus on year 2 of harvest with the goal of increasing the efficiencies of the harvesting process.

In the fall of 2013, IISD and its partners PAMI, MacDon, and the LaSalle Redboine Conservation District successfully conducted a second year of cattail harvesting at the Pelly's Lake site in Manitoba. The goals for harvesting in 2013 were 1) to assess cattail regrowth and potential impacts from harvesting conducted in 2012, and 2) to test and compare conventional agricultural equipment for commercial-scale cattail harvesting and baling—ultimately to improve harvesting and baling efficiency over the first year of harvest in 2012. The following sections detail the harvest areas, methods and equipment used and additional project activities.

4.1.1 Equipment and Harvesting Efficiency

MacDon R85 rotary disc mower

The windrower used in 2012 successfully cut the cattails; however, windrow volume was very large and a swath roller was required to pack and shape the windrow prior to baling. To improve on the swath formation, a MacDon R85 rotary disc mower with steel conditioning rolls was used in 2013. The same tractor unit that was used in 2012 was used this year but with a rotary disc header attached. The 4.9-metre (16-foot) rotary disc mower header weighs approximately 470 kg (1,036 lb) more than the 6.1-metre (20-foot) header used in 2012, but has the advantage of producing a thinner and narrower swath. It also crimps the cattails along the length of the stem to reduce the drying time of cattails cut while green. One of the goals was to determine if the additional weight would be detrimental to performance in wetland areas.

Cattail was cut and swathed with each unit green in September, with full moisture content of near 75 per cent, and allowed to dry for baling. Cattail was also cut and swathed when drier in October, with moisture content near 40–50 per cent, and allowed to dry for a week or more for baling.

FIGURE 3. MACDON ROTARY DISC CUTTER IN GREEN CATTAIL (LEFT) AND DRIER CATTAIL (RIGHT).

The R85 features rotary cutters with improved capacity over conventional sickle cutters by allowing faster travel speeds through the field. The reduced number of blades and absence of sickle guards decreases maintenance and is less susceptible to damage in rough terrain. Rotary cutters perform well in forage crops such as alfalfa or large-stemmed biomass crops and were expected to perform well in cattails. The rotary cutters are shown in Figure 4.

FIGURE 4. ROTARY CUTTING DISCS AND CONDITIONING ROLLERS ON THE MACDON R85 ROTARY DISC MOWER

Controlling moisture by conditioning a forage crop prior to baling has become a standard practice in the forage industry. The R85 mower was equipped with opposing corrugated metal conditioning rollers as shown in Figure 4. The conditioning rollers pull the crop through the mower while producing multiple fractures in the forage leaves and stems. These fractures help release moisture from inside the stems/leaves and decreases drying time prior to baling. The fractures due to conditioning cattails are shown in Figure 5.

FIGURE 5. (LEFT) CRIMP MARKS LEFT BY CONDITIONER ROLLERS, AND (RIGHT) MASSEY FERGUSON MODEL 200 SWATHER

Swather comparison

A conventional swather was used in a small portion of the marsh for comparison purposes. This was done to gauge the effectiveness of the mower with respect to the rotary disc mower with conditioning rolls compared to the previous swathing method used in 2012. The swather used in 2013 was a Massey Ferguson model 200 equipped with a pickup reel and is shown in Figure 5.

Harvesting Efficiencies

The MacDon M205 with R85 Rotary Disc Mower completed nearly 25 hectares in roughly 12 hours of cutting. The ground speed was limited to between 4—9 km/h to minimize the risk of damage to either the cutting head or tractor. The mower was capable of cutting the cattails at a much higher ground speed. The mower was equipped with a GPS tracking device. The GPS information was used to calculate harvest area. A map of the mower's movements in Pelly's Lake is shown in red in Figure 6.

Only portions south of the drainage ditch were harvested. An area near the ditch in the middle of the marsh was left uncut for the demonstrations to be performed at a later date. The swathed area, shown in purple, was not baled but used for comparison purposes only.

Comparison between the two units is as follows:

- Improved efficiency of harvesting and swathing with rotary disc cutter.
- Rotary disc cutter with 16′ header, compared to windrower swather with 20′ header, resulted in swaths narrower and not as tall—better for baling.
- Rotary disc cutter with crimping rollers bent and crimped cattail and placed in swath for drying—drew the moisture out faster, reduced moisture content more efficiently (before baling, moisture content from rotary disc cutter was 5–12 per cent compared to 10–20 per cent from swather.

FIGURE 6. GPS TRACE OF THE MOWER WHILE CUTTING CATTAILS AT PELLY'S LAKE.

4.1.2 Baling

The cattails were baled using a Massey Ferguson (Hesston) 2190 large square baler, which produces 1.2 m x 1.3 m x 2.4 m (4 ft x 4 ft x 8 ft) bales with an average weight of 1,500 lbs each. The square baling method has the advantage of preferred shape and density for handling and transportation, i.e., improved logistics for moving, stacking, storage, and transportation. The baler was driven by a CaseIH Magnum 275 tractor with mechanical front wheel drive (MFWD) equipped with duals on both the rear and front axles. The baling equipment is shown in Figure 7. Minimal issues were encountered in 2013 with baling, compared to 2012, with minimal material left on the field. In 2012, the swaths were so large with such excess material, the square baler could not handle the material, and round bales were produced resulting in almost 25 per cent of the material left on the site.

FIGURE 7. (LEFT) CASEIH MAGNUM 275 TRACTOR WITH MASSEY FERGUSON (HESSTON) 2190 SQUARE BALER. (RIGHT) LARGE SQUARE BALES PRODUCED FROM SWATHED CATTAIL (EACH WEIGHING APPROXIMATELY 1,500 LBS).

4.1.3 Challenges

Similar to the 2012 harvest, the soft terrain caused minor problems with the baler pickup. The soft soil lowered the pickup height and caused the unintended collection of undergrowth, soil, and previous cattail trash. Adjustments were made to the pickup height to eliminate the collection of unwanted product. The cattail stalks also caused the knotter to malfunction occasionally and the cattail flower fluff began to cover the radiator grill (Figure 8). Despite these challenges, the baling step of the harvest process was much more successful than 2012. The success of the square baling can be attributed to the MacDon rotary disc mower. The cattails cut with the rotary disc mower could be picked up and baled with a large square baler due to formation of the windrow and conditioning rolls crimping the cattails. The crimping allowed the long cattail stems to bend easier and feed into the baler throat.

FIGURE 8. (LEFT) CATTAIL SEED FLUFF ON RADIATOR GRILL. (RIGHT) TRAMPLED AREA FROM LIVESTOCK.

The perimeter of Pelly's Lake also served as pasture for livestock with the animals allowed access to the marsh. Forages (grasses) have become established as undergrowth among some areas of the marsh and are attractive to the animals for feed. This has caused much of the cattails to be trampled by the animals prior to harvest. The difficulty of harvesting cattails that have been trampled from livestock is shown in Figure 8.

4.1.4 Yields and Harvest Conditions

In general, improved efficiency of harvesting logistics in 2013 resulted in decreased costs, delays and issues, and increased collected yields of material. Greater yields were recorded from the second year of harvest, partly due to removal of dead material in year 1 of harvest. This resulted in a greater uptake of phosphorus due to harvesting earlier in the season when cattail was green

Livestock in the area, however, caused impacts by trampling the cattail. The effect of sharing the marsh with livestock prevented the harvest of some of the cattails. Most of the trampled cattails passed below the rotary cutters of the mower and were not harvested. In these areas, the limited amount of cut cattails was insufficient for the mower to efficiently produce a windrow. In addition, once the cattails were cut, it allowed additional access to the grass undergrowth and additional trampling by the cattle. Consequently, biomass yields were much lower in the areas where livestock had been present.

There are a few ways to measure harvest yield. The most useful are the total mass of cattails harvested or mass per hectare. It is also important to measure yield by bale count so that handling and storage costs and methods can be determined. The results of the harvest in terms of yield are given in Table 1.

TABLE 1. CATTAIL HARVEST YIELD

TEST SEASON	BALES	AREA		*TOTAL MASS – WET BASIS		AVERAGE MASS PER AREA	
		(HA)	(ACRE)	(KG)	(LB)	(KG/HA)	(LB/ACRE)
2013	168	24.9	61.4	108,819	239,904	4,378	3,906
2012	575	54.1	133.7	329,431	726,270	6,089	5,433

**The total mass of bales at Pelly's Lake was calculated based on a bale count and a three to four bale average mass from the balers used.*

The yield from the 2013 harvest in terms of mass per hectare was approximately two-thirds the yield of 2012. Livestock trampling of cattail had a significant impact reducing yields, as did the removal of significant accumulated dead cattail material from the site in 2012 harvest, which would have increased total mass of bales in 2012. The grass undergrowth likely contributed to the reduced yield in addition to the pressure from cattle grazing. Grass is competitive with cattails and needs to be controlled through soil moisture. Excess soil moisture will drown out grass and at the same time maximize the growth potential of cattails. Installation of water control structures in 2014 at the Pelly's Lake site will allow management of water levels. Holding back water longer in the spring will drown out the grasses and potentially provide improved conditions for cattail growth and improved future yields.

Harvest Conditions

The cattails were cut between September 13 and 26, 2013. This was as much as 18 days earlier than the previous harvest of 2012. The mowed windrows were baled October 9 and 10, 2013. The initial climate was a near-normal year in terms of precipitation. The yearly precipitation is shown in Table 2.

TABLE 2. 2012 AND 2013 PRECIPITATION TO SEPTEMBER 30.

WEATHER STATION LOCATION	YEAR ENDING SEPT 30, 2013	YEAR ENDING SEPT 30, 2012	TEN YEAR AVERAGE 1997 TO 2006
	PRECIPITATION (MM)	PRECIPITATION (MM)	PRECIPITATION (MM)
Holland, MB	440	304	514

Retrieved from National Climate Data and Information Archive, 2013.

There was concern that a normal year of precipitation would create accessibility issues that were not present in 2012. However, the drainage provisions at Pelly's Lake allowed for access to all areas that were harvested the previous year. The increase in precipitation leading up to the 2013 harvest did not prevent access to the cattails.

Controlling soil moisture will be one of the keys to moving cattails from a novel biomass research initiative to a commercial biomass crop. The cattails require high soil moisture for growth, yet commercially available agricultural equipment require a lower soil moisture to operate effectively. The Pelly's Lake wetland is an ideal scenario with a water control structure upstream and central drainage.

4.2 Research-scale Harvesting: Year 4 of harvest at Netley-Libau Marsh site

Cattail was harvested from IISDs Netley-Libau research site along an edge area of cattail approximately 50 feet from open water marsh. This site was harvested for the fourth year, and harvesting and equipment impacts were evaluated. A 12′ haybine equipped with crimping rollers was used to cut and swath the cattail for drying, pulled behind a light duty tractor. Excellent, dry weather conditions allowed for improved efficiency of harvesting, minimal impact from harvesting equipment, efficient drying for baling, and improved yield of harvest compared to previous years. Round bales were produced, which can be collected with a smaller, lighter unit, and utilized for livestock bedding.

4.3 Nutrient and Moisture Analysis

Nutrient and moisture analysis data were collected prior to harvesting (when plants were at peak growth), during harvesting, and for a period following harvest to examine nutrient capture as well as nutrient and moisture loss.

The samples of cattails were sent to two third-party labs for analysis of chemical properties: Central Labs in Winnipeg, Manitoba, and Agvise Labs in North Dakota. The Agvise Labs have been analyzing cattail samples as part of IISD's research for the past decade; they are also the lab facility used by the University of Manitoba for agronomy and soil samples.

This project is part of more comprehensive research using cattail harvesting for nutrient removal from water bodies in Manitoba. The nutrients of concern are phosphorus (P), nitrogen (N) and potassium (K). The results are reported from the lab in mg/kg as received, and mg/kg dry matter. In Table 3, the cattail nutrient values have been converted to a percentage of dry matter. Based on nutrient analysis of collected cattail samples, the total phosphorus removed from the Pelly's Lake system in 160 large square bales was estimated to be almost 120 kg of phosphorus. The majority of this phosphorus would still be present in the ash post-combustion.

TABLE 3. CATTAIL NUTRIENT PROFILE – DRY BASIS.

TEST SEASON	SAMPLE DESCRIPTION	MOISTURE CONTENT (%)	PHOSPHORUS (% DRY WEIGHT)	NITROGEN (% DRY WEIGHT)	POTASSIUM (% DRY WEIGHT)
2013	Agvise Labs				
	Standing cattail 1	72	.09	1.36	0.50
	Standing cattail 2	70	.09	1.13	0.44
	Standing cattail 3	72	.09	1.24	0.55
	Swathed 1	62	.07	0.99	0.36
	Swathed 2	63	.09	1.16	0.42
	Swathed 3	65	.11	1.53	0.64
	AVERAGE	67.3	.09	1.24	0.49
	Central Labs				
	PL-ST-130913-1	63.47	0.11	1.33	0.50
	PL-ST-130913-2	62.43	0.07	1.10	0.32
	PL-ST-130913-3	61.59	0.05	0.79	0.31
	PL-ST-130916-1	66.18	0.08	1.02	0.35
	PL-ST-130916-2	69.73	0.10	1.24	0.44
	PL-ST-130916-3	63.46	0.07	0.98	0.34
	2013 Average	64.48	0.08	1.08	0.38
2012	Bale Pelly I	37.24	0.09	1.33	0.34
	Bale Pelly II	32.85	0.09	1.27	0.33
	Bale Pelly III	29.49	0.08	1.10	0.62
	2012 Average	33.19	0.09	1.23	0.43

4.3.1 Moisture Analysis

Samples were obtained from standing cattails on September 13 and 16, 2013. Samples were also selected from swaths and conditioned windrows on September 16, 17 and 18. From these samples, a drying trend was established for days 0, 3, 4, and 5 for cattails cut on September 13 and days 0, 1, and 2 for those cut on September 16. The drying trends, along with precipitation, are shown in Figure 9. The moisture analysis shows the superior drying performance of the conditioned windrows (green) compared to the swaths (red). The swaths were nearly two times as moist as the conditioned cattails after four days. The drying trend was interrupted by precipitation (blue) in the form of rain on September 18, 2013.

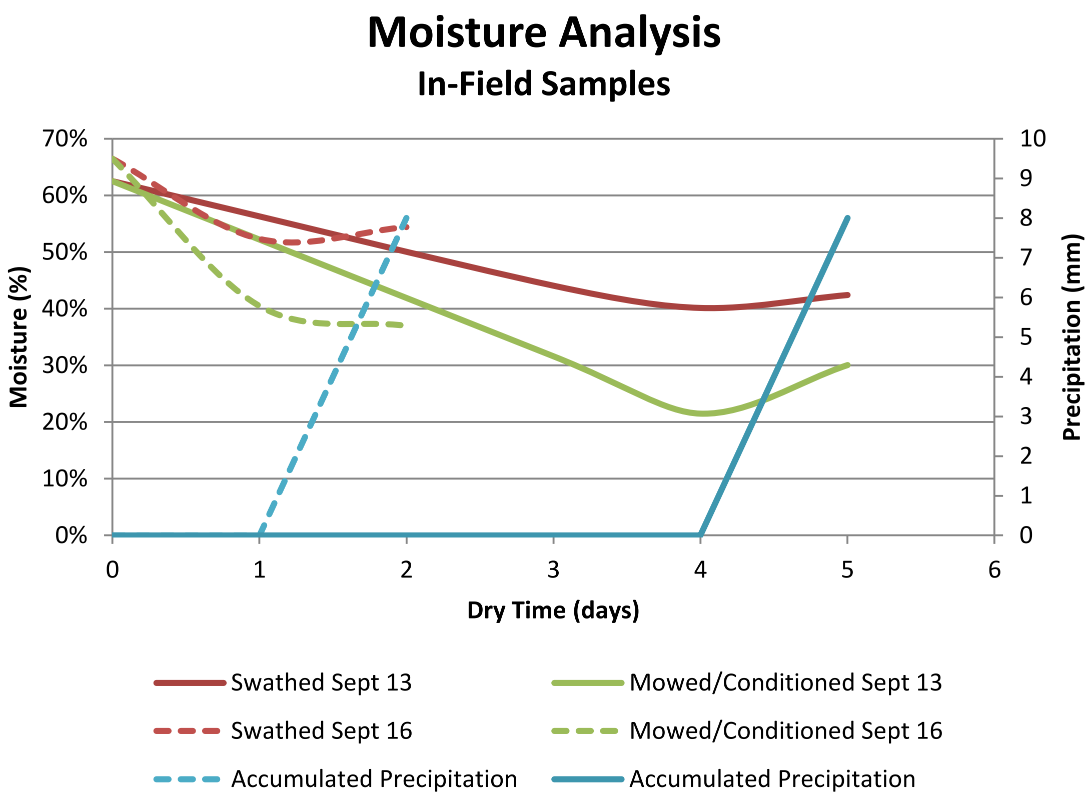

FIGURE 9. DRYING PERFORMANCE COMPARED BETWEEN SWATHED AND MOWED/CONDITIONED CATTAILS.

Source: Author figure.

4.4 Biomass Processing and High-value Products

4.4.1 Solid fuel

Processing

Harvested and baled cattail was processed and evaluated for various end uses. Solid fuel is the lowest-value use of the material, but also the most readily available and cheapest for larger-demand use. Cattail bales were shredded with hammermill tub grinders and evaluated as loose shredded biomass for feedstock for combustion, and in several densified fuel products:

- Mixed hybrid fuel cubes (50:50 mix of wheat straw and cattail)
- Pure cattail fuel pellets
- Mixed hybrid fuel pellets (50:50 mix of cattail and native prairie grasses)

Several different product formulations of the densified straw/cattail hybrid cubes were tested during densification trials, mixed hybrid cubes of 50:50 mix were identified as the best mixture, and as a result several tonnes of hybrid cubes were produced for combustion testing. Mixed native grasses and cattail were also tested for densification by IISD, and a 50:50 product mix was used for comparison to the hybrid straw/cattail cubes.

Combustion

Products of varying grades produced through densification trials were stored in large tote bags, and shipped to Sturgeon Creek Hutterite colony for combustion trials. Biovalco and IISD carried out combustion trials with the hybrid biofuel cubes produced during densification trials at the Sturgeon Creek Hutterite Colony in cooperation with the Sturgeon Creek boiler system personnel.

Combustion trials were carried out over a four-hour period in a 2-million British thermal unit (BTU) capacity Blue Flame Stoker boiler system, under "real-life" conditions, to produce hot water heat for the colony buildings. Three different product formulations were tested at the Sturgeon Creek Colony:

- Loose shredded cattail
- Hybrid cube—50:50 mix of wheat straw and cattail
- Hybrid cubes/loose co-fed with woodchips

Ash was collected following the day-long combustion trial.

The Blue Flame Stoker boiler was first fired up with wood chips for several hours using the same woodchip feedstock used in Sturgeon Creek Colony's primary boiler system, to heat the boiler up to operating temperature. The hybrid fuel cubes produced excellent heat value and had excellent combustion properties. Approximately 1.6 million BTUS of heat energy was produced, almost equivalent to the woodchip feedstock typically used in the boiler system. Operating and outgoing water temperature was between 166 and 172, with incoming water temperature approximately 149. No significant issues were encountered during combustion, once operating parameters were adjusted for the hybrid fuel cubes, including speed of feeding. Ash content, as would be expected, is slightly higher than woodchips, with clinkers accumulating in the ash box requiring occasional additional operation of the auger system to remove ash buildup, but no issues encountered with ash removal from the boiler system and to affect combustion. Loose cattail material was also tested for combustion, and required a much faster feed rate and grate speed for proper combustion, to reduce ash buildup, and to produce equivalent heat production. Combustion properties of loose cattail were excellent.

Several totes of loose and hybrid cube material was tested for combustion and co-fed with woodchips in Sturgeon Creek Colony's primary boiler during the week following the day-long combustion testing by Biovalco and IISD. No issues were encountered with the hybrid cubes or the loose material, and it was found to be a suitable material to be co-fed with the woodchip feedstock typically used in the colony stoker boiler.

Two different product formulations of fuel pellets were also recently produced by IISD and their partners at PAMI for comparison to the hybrid straw/cattail cubes, and to further explore densification properties. These fuel pellets are currently being tested (2014).

- Cattail pellets
- Hybrid pellets – 50:50 mix of native grasses and cattail

4.4.2 Biocarbon From Cattail

IISD carried out tests to assess the potential of cattail as a biomass feedstock for biocarbon production. Cattail biocarbon was compared with wheat straw biocarbon, evaluating energy content and various parameters from production. Several tonnes of cattail biomass were shipped to Titan Energy in Craik, Saskatchewan to be converted into biocarbon, or biochar. In conjunction with PAMI Humboldt research station, cattail biocarbon was compared to other biocarbon for flowability, and equipment handling for commercial-scale land applications.

Cattail Biocarbon

1. Initial grinding of the cattail bales proved to be more difficult than anticipated, but was straightforward once the grinder settings were adequate.
2. Overall, pyrolysis of the ground cattail went well. The material had a minor tendency to ball up and jam the feeder compared to wood chips, but this is not uncommon for a more fibrous material. The texture and look of the char was good. There was a mixture of larger (1 cm) particles, smaller particles, and powder. The biochar was relatively lightweight and dry, with a low "smoky" odour.
3. Once the pyrolysis plant was up to temperature, Titan processed for approximately eight hours, then ramped the plant down.
4. The quantity of the syngas generated as compared to wood was less, indicating that perhaps more biochar was produced than with a similar quantity of wood.

Approximately 15 bales of cattail were ground, and approximately five bales were pyrolysed. Approximately two to three bales worth of good quality biochar were produced during the eight-hour test, resulting in about 400 kg of good quality biochar. Average bale weight was approximately 600 kg x three bales = 1800 kg of biomass = 400 kg biochar, a ratio of approximately 4.5:1, which is reported typical for biocarbon production.

Wheat Straw Biocarbon

1. Grinding of the wheat straw bales was straightforward. Titan had some previous experience with wheat straw.
2. Pyrolysis of the ground wheat straw went well overall, and flowed easier than the ground cattail. The texture and look of the char was good. There was a mixture of larger (15 mm) particles, smaller particles, and some powder. The biochar was relatively lightweight and dry, with a low "smoky" odour.
3. Once the pyrolysis plant was up to temperature, Titan processed for approximately eight hours, then ramped the plant down.

Approximately 16 bales of wheat straw were ground and processed, and approximately 500 kg of good quality biochar was produced during the eight-hour test.

Lab Analysis

Laboratory analysis from Contango Strategies limited includes chemical analysis, polycyclic aromatics, elemental analysis, and some physical properties. A comparison of the cattail biochar properties to International Biochar Initiative (IBI) biochar standards can be made by viewing the document "Standardized Product Definition and Product Testing Guidelines for Biochar That is Used in Soil" (IBI, 2013).

A general comparison of the lab analysis to values given in Tables 1 and 2 of the IBI standards shows that the cattail biochar and wheat straw biochar should be adequate for soil applications.

TABLE 4. CHEMICAL ANALYSIS OF CATTAIL AND WHEAT STRAW BIOCARBON

	UNITS	CATTAIL-BIOCHAR	WHEAT STRAW BIOCHAR	RDL
Elements				
Cation exchange capacity	cmol+/Kg	40	74	10
Nutrients				
Available (NH4F) Nitrogen (N)	mg/kg	ND (1)	ND (1)	10
Available (NH4F) Phosphorus (P)	mg/kg	140	8.2	5.0
Available (NH4OAc) Potassium (K)	mg/kg	3,500	25,000	10
Soluble Parameters				
Soluble Conductivity	dS/m	4.4		0.02
Sodium Adsorption Ratio	N/A	55	9.1	0.10
Soluble Calcium (Ca)	mg/L	8.8	15	1.5
Soluble Magnesium (Mg)	mg/L	2.2	ND	1.0
Soluble Sodium (Na)	mg/L	710	130	2.5
Soluble Potassium (K)	mg/L	840	1,800	1.3
Saturation %	%	620 (2)	790	N/A
Soluble Sulphate (SO4)	mg/L	730	850	5.0
Physical Properties				
Moisture	%	ND	0.40	0.30

ND = Not detected

RDL = Reportable Detection Limit

EDL = Estimated Detection Limit

(1) Detection limits raised due to sample matrix.

(2) Less than 20 g of sample used due to organic content.

TABLE 5. SEMIVOLATILE ORGANICS BY GC-MS ANALYSIS OF CATTAIL AND WHEAT STRAW BIOCARBON

	UNITS	CATTAIL-BIOCHAR	WHEAT STRAW BIOCHAR	RDL
Polycyclic Aromatics				
Acenaphthene	mg/kg	0.16	0.063	0.025
Benzo[a]pyrene equivalency	mg/kg	ND	ND	0.10
Acenaphthylene	mg/kg	0.13	0.14	0.025
Acridine	mg/kg	ND	ND	0.049
Anthracene	mg/kg	0.073	0.048	0.020
Benzo(a)anthracene	mg/kg	0.043	ND	0.025
Benzo(b&j)fluoranthene	mg/kg	0.065	0.028	0.025
Benzo(k)fluoranthene	mg/kg	ND	ND	0.025
Benzo(g,h,i)perylene	mg/kg	ND	ND	0.025
Benzo(c)phenanthrene	mg/kg	ND	ND	0.025
Benzo(a)pyrene	mg/kg	0.045	ND	0.025
Benzo[e]pyrene	mg/kg	0.047	ND	0.025
Chrysene	mg/kg	0.060	ND	0.025
Dibenz(a,h)anthracene	mg/kg	ND	ND	0.025
Fluoranthene	mg/kg	0.23	0.14	0.025
Fluorene	mg/kg	0.17	0.051	0.025
Indeno(1,2,3-cd)pyrene	mg/kg	ND	ND	0.025
2-Methylnaphthalene	mg/kg	0.40	0.22	0.025
Naphthalene	mg/kg	0.57	0.38	0.025
Phenanthrene	mg/kg	0.40	0.27	0.025
Perylene	mg/kg	ND	ND	0.025
Pyrene	mg/kg	0.25	0.15	0.025
Quinoline	mg/kg	0.15	0.053	0.049
Surrogate Recovery (%)				
D10-ANTHRACENE (sur.)	%	88	60	
D12-BENZO(A)PYRENE (sur.)	%	50	13 (1)	
D8-ACENAPHTHYLENE (sur.)	%	98	78	
TERPHENYL-D14 (sur.)	%	98	62	

ND = Not detected
RDL = Reportable Detection Limit
EDL = Estimated Detection Limit

TABLE 6. ELEMENTAL ANALYSIS OF CATTAIL BIOCARBON BY ATOMIC SPECTROSCOPY

	UNITS	CATTAIL-BIOCHAR	WHEAT STRAW BIOCHAR	RDL
Elements				
Total Aluminum (Al)	mg/kg	3,200	1,400	20
Total Boron (B)	mg/kg	14	11	4.0
Total Calcium (Ca)	mg/kg	30,000	15,000	100
Total Iron (Fe)	mg/kg	5,800 (1)	3,700	20
Total Lithium (Li)	mg/kg	ND	ND	20
Total Magnesium (Mg)	mg/kg	5,300	2,100	40
Total Manganese (Mn)	mg/kg	440	110	20
Total Phosphorus (P)	mg/kg	1,600	1,000	40
Total Potassium (K)	mg/kg	7,600	28,000	50
Total Sodium (Na)	mg/kg	7,900	1,800	100
Total Strontium (Sr)	mg/kg	110	83	20
Total Sulphur (S)	mg/kg	2,100	5,300	40
Total Antimony (Sb)	mg/kg	ND	ND	2.0
Total Arsenic (As)	mg/kg	ND	2.8	2.0
Total Barium (Ba)	mg/kg	50	73	20
Total Beryllium (Be)	mg/kg	ND	ND	0.80
Total Cadmium (Cd)	mg/kg	ND	ND	0.20
Total Chromium (Cr)	mg/kg	9.7	2.3	2.0
Total Cobalt (Co)	mg/kg	ND	ND	2.0
Total Copper (Cu)	mg/kg	30	22	10
Total Lead (Pb)	mg/kg	2.2	2.7	2.0
Total Molybdenum (Mo)	mg/kg	1.7	0.83	0.80
Total Nickel (Ni)	mg/kg	5.4	ND	2.0
Total Selenium (Se)	mg/kg	ND	ND	1.0
Total Silver (Ag)	mg/kg	ND	ND	2.0
Total Thallium (Tl)	mg/kg	ND	ND	0.60
Total Tin (Sn)	mg/kg	ND	ND	2.0
Total Uranium (U)	mg/kg	ND	ND	2.0
Total Vanadium (V)	mg/kg	9.2	2.6	2.0
Total Zinc (Zn)	mg/kg	49	39	20

ND = Not detected

RDL = Reportable Detection Limit

EDL = Estimated Detection Limit

(1) Duplicate exceeds acceptance criteria due to sample matrix. Reanalysis yields similar results

TABLE 7. PHYSICAL AND ENERGY PROPERTIES OF CATTAIL BIOCARBON AND WHEAT STRAW BIOCARBON BY ATOMIC SPECTROSCOPY

	AS RECEIVED BASIS HEAT VALUE (MJ/KG)	RDL	TOTAL ORGANIC CARBON (C) (%)	RDL
Physical Properties				
Cattail Biocarbon	31.410	0.001	64*	0.40
Wheat Straw Biocarbon	23.750	0.001	63*	0.40

RDL = Reportable Detection Limit

EDL = Estimated Detection Limit

** Detection limits raised due to dilution to bring analyte within the calibrated range*

Comparison of cattail biocarbon to wheat straw biocarbon

A general comparison of the lab analysis of the cattail biocarbon to the wheat straw biocarbon shows the following:

1. Organic carbon content was similar.
2. Heating value of cattail biocarbon was significantly higher at 31.41 MJ/kg compared to wheat straw biocarbon of 23.75 MJ/kg.
3. Cation exchange capacity was approximately double in the wheat straw biochar.
4. Available phosphorus was approximately 18 times less in the wheat straw biochar.
5. Available potassium was approximately 7 times more in the wheat straw biochar.
6. PAH levels were similar (and low compared to IBI standards).
7. Heavy metal levels were similar (and low compared to IBI standards).

Combustion

Compressed fuel briquettes were produced from wood biocarbon as part of the Manitoba Hydro Biocarbon demonstration project. The cattail biocarbon (approximately 300 kg), is currently being tested for combustion and heat production at Providence College in Otterburne, Manitoba. Comparison will be made to combustion testing of wood biocarbon briquettes and compressed cattail cubes as a solid fuel.

4.5 Cattail Ash and Biochar Nutrient Assessment

Cattail ash and cattail biochar were analyzed for the agricultural nutrients nitrogen (N), phosphorus (P) and potassium (K). The total nutrient content and the concentration of nutrients available to plants were determined by standard soil and manure testing procedures. To investigate the potential of hydroxide collection from water extraction of cattail ash, an experiment was conducted to remove soluble compounds by mixing ash with deionized water and filtering the solution. As well, some micronutrients and the potentially harmful heavy metals of ash were measured to assess contamination risk to soil or crops under normal agronomic application rates. Analysis includes:

- Analysis of total phosphorus (TP), nitrogen (TN) and potassium (TK) content of biomass ash and biochar samples.
- Determination of plant-available (soluble) phosphorus and nitrogen.

- Establishing appropriate land application rates of the biomass ash and biochar products to alkaline or acidic soils as potential fertilizers.
- Assessing potential release of the bound phosphorus through mild acidification.
- Assessment of the biomass ash for pH adjustments/addition to manure and potential improvements for P capture.
- Preliminary assessment of the biochar as filtration media for assessment of its "activated carbon/filtration" properties.

4.5.1 Nutrients in Cattail Ash

Cattail ash was found to have no ammonia nitrogen and only trace amounts of organic nitrogen and nitrate (Table 8). Phosphorus was less than 1 per cent of the total mass and occurred in insoluble forms not available to plants. Potassium, however, made up almost 4 per cent of the total mass, of which approximately half was plant-available. When the ash was "washed" with deionized water, only potassium was found in the filtrate solution. The different amounts recorded as Total K and Soluble K of the filtrate is likely the result of instrument response to the different analysis procedures used to derive each parameter. Total and soluble K should be the same in the filtrate, but are either slightly over- or under-reported for each parameter.

Biochar had 1 per cent total nitrogen, likely in the form of organic nitrogen due to the lack of either ammonia or nitrate (Table 8). Total phosphorus was 0.4 per cent, of which very little was measured as soluble P. Total potassium was almost 1 per cent of total mass of which less than 25 per cent was soluble.

TABLE 8. MACRO NUTRIENT CONTENT OF CATTAIL ASH, ASH FILTRATE AND CATTAIL BIOCHAR. SOLUBLE P AND K ARE PLANT-AVAILABLE AND MEASUREMENTS BELOW DETECTION LIMIT ARE LISTED AS BDL.

	TKN %	NH4 MG/KG	NO3-N MG/KG	TOTAL P MG/KG	SOLUBLE P MG/KG	TOTAL K MG/KG	SOLUBLE K MG/KG
ash	0.0554	BDL	8.36	8,530	BDL	39,400	15,800
	0.0501	BDL	7.38	8,800	BDL	43,300	18,000
	0.0589	BDL	BDL	8,390	13.8	35,800	20,500
mean	0.055	0	8	8,573	4.6	39,500	18,100
stdev	0.004	0	1	208	0	3,751	2352
filtrate	BDL	BDL	BDL	BDL	BDL	11,875	13,110
	BDL	BDL	BDL	BDL	BDL	12,600	13,500
	0.001	BDL	BDL	BDL	BDL	12,198	12,412
mean	0	0	0	0	0	12,224	13,007
stdev	0	0	0	0	0	363	551
char	0.874	BDL	BDL	4,020	22.1	10,300	2,390
	0.999	BDL	5.93	4,100	30.5	9,820	2,320
	0.854	BDL	6.45	3,950	21.9	9,680	2,190
mean	1	0	6	4,023	25	9,933	2,300
stdev	0	0	0	75	5	325	101

4.5.2 Nutrient Release from Mild Acidification of Cattail Ash

If cattail ash were to be applied to neutral or mildly acidic soils (pH 7.5 to 6.5), a change in available nutrients might be expected since the starting pH of the ash is 12.4 and reduced pH from exposure to soil may release chemically bound nutrients. A test of this theory was carried out by gradual acidification of wet ash to different pH endpoints: the plant-available nutrients in each treatment were then measured (Table 9). Results indicated no measureable increase in soluble nitrogen forms and trace evidence of soluble P. Ash pH of 7.4 had 2 mg/kg soluble P and ash pH of 6.7 was 28 mg/kg, but ash with higher pH had no detectable soluble P at all. However, potassium increased in solubility considerably, from 46 per cent of total K being soluble at pH 12.4 to 81 per cent soluble at pH 6.7 (Figure 10). This indicates a majority of total K is plant-available at near-neutral pH.

TABLE 9. SOLUBLE NUTRIENTS IN CATTAIL ASH AT VARIOUS PH ENDPOINTS.

pH	TNK MG/KG	TOTAL P MG/KG	INSOLUBLE K	SOLUBLE K
12.42	548	8,573	21,400	18,100
7.91	350	8,370	12,000	26,800
7.69	367	8,180	12,600	24,900
7.4	439	8,260	14,200	27,500
6.71	386	8,090	6,700	29,500

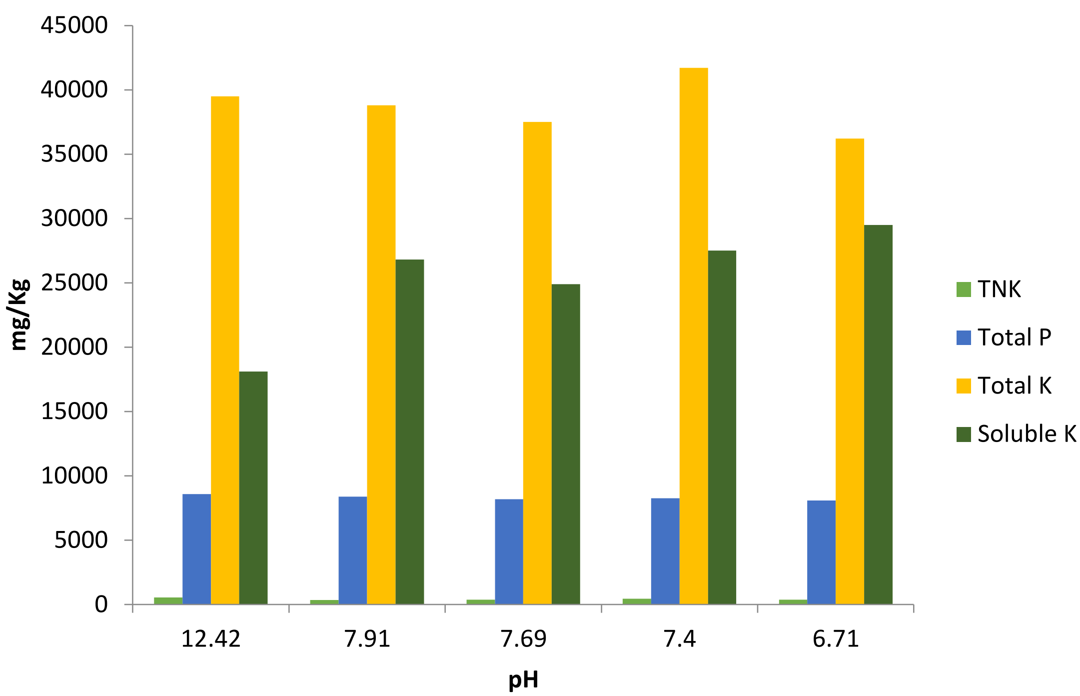

FIGURE 10. TOTAL AND SOLUBLE NUTRIENTS AT DIFFERENT PH ENDPOINTS. SOLUBLE P WAS TOO LOW TO REGISTER ON THIS CHART.

Source: Author figure.

4.5.3 Cattail Ash Land Application Rates

This analysis of cattail ash has shown that plant-available K exists in concentrations that warrant application to agricultural lands to meet the K requirements. K fertilizer is applied at different rates depending on soil assessment of the available (exchangeable) K and varies from 70 to 14 kg K/ha (equivalent to 100 to 20 lb K2O/acre), representing quantities for K deficient soils or a maintenance level to replace K removed with each harvest (Table 10). Application to land at these rates would require 3.9 to 0.8 tonnes of ash per hectare. At these application rates a significant amount of TP would also be applied to the soil, matching normal P2O5 rates for many crops (17 to 55 kg P2O5/ha, depending on the soil test P and the crop). However, the TP in cattail ash has been determined by these tests to be insoluble and not available to plants. Actual TP that eventually becomes available to plants under the wide range of environmental conditions found in soil is yet to be determined.

TABLE 10. CATTAIL ASH APPLICATION RATES TO AGRICULTURAL SOILS.

K APPLICATION RATE (KG/HA)	K CONTENT OF CATTAIL ASH (KG/T)	ACTUAL ASH APPLICATION (T/HA)	TP IN CATTAIL ASH (KG/T)	TP APPLIED WITH K APPLICATION RATE (KG/HA)	P2O5 EQUIVALENT (KG/HA)
70	18.1	3.9	8.6	33	77
14	18.1	0.8	8.6	7	15

4.5.4 Heavy Metal and Other Nutrient Content of Cattail Ash

Analysis of 10 potentially harmful heavy metals was conducted on cattail ash and filtrate of washed ash. Comparison between cattail ash metal content and the allowable limits in Class A and Class B compost as established by the Canadian Council of Ministers of the Environment (CCME, 2005) shows cattail ash was found to be below the allowable limit for all metals (Table 11). Heavy metals are not a concern at the ash application rates outlined in Table 3 because they are similar to the rates of application for compost or biosolids. Investigation into other nutrients and potentially limiting application rates for sodium was also conducted, revealing ash to be about 15 per cent Ca and 4 per cent Mg. These minerals already are major components of agricultural soils and addition of new amounts would not harm the soil structure or function (Racz & Fitzgerald 2007). Sodium levels were found to be below 0.05 per cent (Table 12).

TABLE 11. HEAVY METALS IN CATTAIL ASH AND ALLOWABLE LIMITS IN CANADA. ALL FIGURES ARE IN MG/KG.

MG/KG	As	Cd	Co	Cr	Cu	Mo	Ni	Pb	Se	Zn
Cattail ash	1	2	7	22	15	7	18	7	0	62
Class A limit	13	3	34	210	400	5	62	150	2	700
Class B limit	75	20	150	1,060	757	20	180	500	14	1850

TABLE 12. OTHER NUTRIENTS FOUND IN CATTAIL ASH. ALL FIGURES ARE IN MG/KG.

MG/KG	Ca	Fe	Co	Cr	Cu
Cattail ash	151,667	12,667	42,433	4,490	3,840

4.5.5 Conclusions and Lab Analysis Yet to Be Completed

The data presented in this report represents the preliminary findings of nutrient studies on cattail ash and biochar. The study completed analysis of total N, P, and K as well as assessing plant-available portions of these nutrients. In addition, minor nutrients and heavy metal content was determined to ensure these concentrations would not limit land application. Research yet to be completed consists of experiments using biochar as an activated carbon medium to purify water and using cattail ash to raise liquid manure pH to remove phosphorus. Preliminary tests of cattail of biocarbon as an activated carbon have yielded excellent results, and it performs well as an activated carbon for water filtration.

Using cattail ash as an agricultural fertilizer would supply soil with potassium and phosphorus. The tests conducted in this study indicate the majority of the total potassium would be available for plant usage at neutral soil pH. The majority of the phosphorus however, is insoluble at neutral pH and may not be available to growing plants. Further, long-term soil incubation tests could be conducted to verify plant availability of cattail ash phosphorus. If cattail ash is washed with water to leach out soluble compounds, potassium is the only nutrient that is present in the filtrate, removing approximately 70 per cent of the soluble K and 30 per cent of the total K. Acidifying the ash has the effect of increasing the solubility of potassium so that total soluble K increases from 46 per cent to 81 per cent of TK when the pH is lowered to 6.7. Analysis for heavy metals and other nutrients concluded that no metals are present in cattail ash at a concentration that would prohibit its use as a fertilizer according to the CCME guidelines.

4.6 Cattail Biomass Resource Assessment

From initial resource assessments of biomass availability in southern Manitoba, IISD had estimated the cattail resource is between 3 to 8 Mt/year, a resource large enough to support multiple commercial biomass operations and have a significant impact on Lake Winnipeg water quality.

Nevertheless, currently available land-use classification data within Manitoba from the Manitoba Land Initiative is based on the analysis of LANDSAT Thematic Mapper (TM) imagery from various years ranging from 1989 to 2006. Spectral signatures are divided into 16 classes including a "Marsh/Fens" class. Significant uncertainties exist when estimating cattail abundance using this dataset given the presence of other macrophyte species (e.g., sedges, reeds, bulrushes, grasses etc.) within grid cells classified as "Marsh/Fen." Given these significant uncertainties in estimating cattail abundance with this land-use classification data, IISD performed a new analysis of LANDSAT Thematic Mapper (TM) imagery from three years of images (2009, 2010, and 2011) during the growing season focusing on just the cattail spectral signature. Similar estimates of cattail resource were found, with a new conservative estimate of 2 to 6 MT/year.

TABLE 13. TOTAL CATTAIL AREA COVERAGE ESTIMATES AND ABOVEGROUND BIOMASS ESTIMATES FOR SOUTHERN MANITOBA USING BOTH METHODOLOGIES.

	LAND USE COVER CATTAIL ESTIMATE	NEW LANDSAT CATTAIL ESTIMATE	CONSERVATIVE CATTAIL ESTIMATE
Total Areal Cattail Coverage in MB (hectares)	367,000	424,000	269,000
Total Cattail Aboveground Biomass Assuming 10 t/ha (megatonnes)	3.7	4.4	2.7
Total Cattail Aboveground Biomass Assuming 20 t/ha (megatonnes)	7.4	8.5	5.4

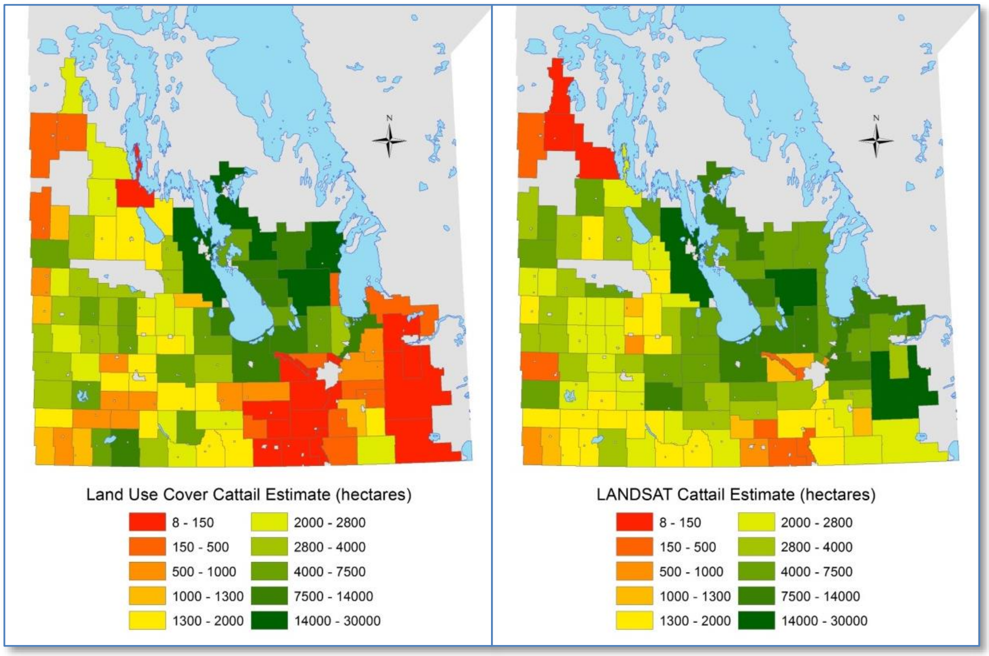

FIGURE 11. (LEFT) LAND-USE COVER CATTAIL AREAL COVERAGE ESTIMATE ACROSS SOUTHERN MANITOBA BY MUNICIPALITY. VALUES ARE IN HECTARES. (RIGHT) NEW LANDSAT CATTAIL AREAL COVERAGE ESTIMATE ACROSS SOUTHERN MANITOBA BY MUNICIPALITY. VALUES ARE IN HECTARES. *Source: Author figure.*

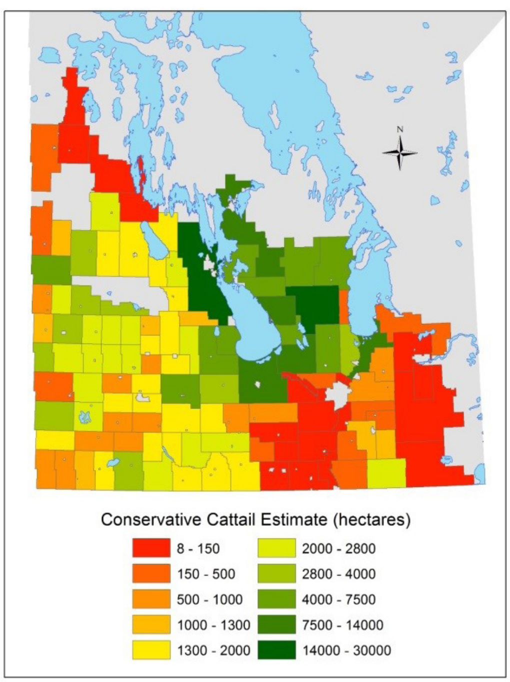

FIGURE 12. CONSERVATIVE CATTAIL AREAL COVERAGE ESTIMATE ACROSS SOUTHERN MANITOBA BY MUNICIPALITY. CONSERVATIVE CATTAIL AREAL COVERAGE ESTIMATE FOR EACH MUNICIPALITY WAS THE LOWER ESTIMATE OF THE TWO METHODS FOR ESTIMATING CATTAIL COVERAGE. VALUES ARE IN HECTARES. *Source: Author figure.*

There are substantial differences in cattail areal coverage between the two methodologies in some regions of southern Manitoba. Specifically, municipalities in eastern Manitoba have greater cattail areal coverage according to the new LANDSAT estimate than the land use classification estimate. There are two possible reasons for this difference: 1) the misclassification of minerotrophic wetlands as ombrotrophic wetlands in eastern Manitoba within the land-use cover data (i.e., classifying a marsh/fen as a bog or possibly something else), or 2) the misclassification of non-cattail dominated wetlands as cattail-dominated wetlands in eastern Manitoba within the new LANDSAT data. Overall, the new LANDSAT cattail areal coverage estimate for southern Manitoba is about 16 per cent higher than the cattail areal coverage estimate from the land use classification data.

A conservative estimate of total cattail areal coverage within Manitoba is 269,000 hectares using the lower estimate of the two methodologies for each Manitoba municipality. Assuming a lower-bound cattail biomass yield of 10 tonnes per hectare results in a provincial total of 2.7 megatonnes. Assuming an upper-bound cattail biomass yield of 20 tonnes per hectare results in a provincial total of 5.4 megatonnes.

6.0 Carbon Market and Path to Certification

IISD is currently working on an assessment and reporting on the current state of carbon markets in Canada and demand for carbon offset credits. The progress that has been found in some cases is very encouraging—particularly as Manitoba establishes the current carbon tax system and moves towards the coal ban, allowing a transition time until it is enforced. This assessment is available in two separate IISD reports.

Over the past year, there has been a maturing of the state of carbon markets and carbon offsetting in North America. This is the result of several key developments including:

- The official launch of a fully linked Western Climate Initiative carbon trading system, with an increasing number of approved offset methodologies.
- The potential for stronger Alberta regulations for the oil and gas sector, which should significantly strengthen the potential (and price) for offsets in that jurisdiction.
- Reforming of the Regional Greenhouse Gas Initiative (RGGI) carbon market, which tightened the compliance cap and buoyed prices in North America's "other" regional carbon market.
- Completion of the B.C. Carbon Tax Review, which ensured that carbon pricing would remain in place in the province for the foreseeable future.
- The folding into the B.C. climate action secretariat of the Pacific Carbon Trust, ending the crown corporation, but for the most part retaining the commitment to offsetting within public sector enterprises.
- Renewed interest in offsets and carbon trading in other provincial jurisdictions in Canada.
- Positive signs to allowing both subnational equivalency (letting provinces choose their own path) to federal regulations in both the United States and Canada, as well as an openness to compliance flexibility in meeting these regulations (opening the door just a crack to national offset schemes).

7.0 Communication

IISD continues to promote the Lake Winnipeg Bioeconomy project and its component research on cattail biomass harvesting, and research on higher-value uses of the harvested biomass, including biochar. Presentations have been given at several workshops and conferences since October, including an invited keynote speaker address and a luncheon presentation.

Several communication pieces on the cattail biomass harvesting project have been released over the past several months, including involvement in a demonstration project video produced by Manitoba Hydro. Fort Whyte Alive has requested the use of IISD-produced videos as part of their educational and interactive programming at FortWhyte Alive nature centre, which includes a component on cattail biochar. IISD research and materials will also be showcased at the new Manitoba Museum Lake Winnipeg Watershed interactive display.

As a result of IISDs ongoing research, cattail biomass harvesting has been integrated with the Government of Manitoba's new Surface Water Management Strategy. Storing water on the land for flood control has the added benefit of reducing not only flood waters, but nutrient loading by capturing dissolved and suspended nutrients. The retained water is also a source for slow release later in the season for irrigation or during drought. IISD is collaborating with the RRBC and partners in the United States to deliver surface water management, ecological biomass harvesting, and nutrient management concepts to water retention projects in Minnesota and North Dakota. Although the original objective of these water retention projects was to reduce flooding to the city of Fargo, North Dakota, they additionally retain and hold nutrients. As a secondary benefit, many retention cells are full of cattail, increasing nutrient capture and storage capacity of these impoundments, while producing valuable biomass feedstock that can be harvested for nutrient capture, additional revenue, and higher value processing such as biochar.

In addition, IISD's ecological biomass harvesting for nutrient capture has been adopted in watershed planning in southern Manitoba by Conservation Districts and Rural Municipalities as a process to reduce phosphorus loading to Lake Winnipeg and a sustainable source of renewable biomass.

IISDs Lake Winnipeg Bioeconomy and cattail harvesting concepts are also included in several collaborative projects by other research organizations: University of Manitoba as a component of distributed storage, Red River College and Native Plant solutions on floating wetlands, University of Manitoba and Native Plant Solutions cattail harvesting in Niverville's decommissioned wastewater lagoon, and the University of Greifswald and the Alfried Krupp Wissenschaftskolleg in Germany as a component of peatland restoration (paludiculture) and the economic use of aquatic plants.

IISD is also collaborating with several private business and Yes Winnipeg on developing novel ecological biomass harvesting for bioproducts as a commercial practice at a watershed scale.

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International Institute for Sustainable Development | Institut international du développement durable

Published by the International Institute for Sustainable Development.

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