

## **Agricultural Bioproducts Innovation Program**

### **FINAL NETWORK REPORT**

**ABIP Network Name:** Natural Fibres for the Green Economy Network - NAFGEN  
**ABIP Number:** 201  
**Network Lead:** Les Rankin, Flax Canada 2015 Inc.

## **Part 1. Executive Summary**

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### *Summary of Achievements*

**The original vision of the NAFGEN** included: a dramatic and significant increase in the flax acreage of Canada by 2015 and that flax would be grown for both seed and fibre in two natural fibre clusters: Western Canada, involving the provinces of Alberta, Saskatchewan, and Manitoba, and Eastern Canada, involving Ontario and Quebec.

This vision was against a historic backdrop of crop revenues being derived almost entirely from seed production and with the fibre component from about 10% of the crop finding industrial application. The balance of the residue was worked into the land, or in some unfortunate circumstances, burned in the fields.

Similarly, at the beginning of NAFGEN, the Canadian hemp industry was in its 10<sup>th</sup> year of commercial growth and had developed into a \$20 million dollar industry. Most of the commercial growth to date had been driven by the vigorous seed sector, fuelled by demand in the health food and body care products sector. NAFGEN's vision included laying the ground work for establishing value-added hemp fibre based processors and related industries. This is a critical step in fully realizing hemp's potential as a dual use crop with environmental, economic and social benefits. To capitalize on this, it was apparent that Industrial hemp should be developed and introduced as a viable crop option across Canada and would represent a further crop option for farmers and a viable option for more marginal agricultural land.



From the onset, NAFGEN adopted a collaborative, outcomes-based philosophy with a whole crop utilization strategy grounded in creating value at three different steps in the value chain:

- 1) the farm gate value for Canadian farmers realized from bast fibre crops (flax and hemp);
- 2) new high quality employment opportunities in rural regions;
- 3) new opportunities in the Canadian manufacturing sector.

The origination of a number of manufacturing sites (biorefineries) would be made possible, with the development of the technical components required. Biomaterials produced to include micro and nano-fibre reinforced injection molded parts, and engineered mats and woven fabrics and could be targeted at both the domestic and international marketplaces.

Flax and hemp straw processing generates potentially high value residue. Shives represent 65% of the biomass after decortication and are rich in chemical precursors including hemicellulose, cellulose, lignin, waxes and extractives. Effective research and development means that chemicals will be efficiently, cleanly and cost-effectively separated from the non-fibre portions of flax straw and hemp stalks for conversion into higher value biochemicals, such as lignins, ferulic acid and vanillin, and carbohydrates, with the goal of generating sustainable biochemicals that will replace petroleum derived products.

These natural fibre biorefineries would generate a significant portion of their process energy from residue biomass. The entire Canadian natural fibres value chain will operate with a minimum environmental footprint, based on rigorous life cycle analysis, and with systems in place for end-of-life use of natural fibre-based materials.

To support that vision, the mission of NAFGEN, to meet the objective of getting products to the market place, was to recruit Canada's substantial natural fibres-relevant research capacity and corporate leadership to work in a multidisciplinary network, featuring aligned research agendas and robust materials and information flow in order to tackle the issues and challenges across the entire natural fibres value chain in an integrated fashion, to achieve the targets outlined in the vision above.

Challenges and barriers that were to be directly addressed over the life of the ABIP included:

- Breeding,
- straw management,
- enhanced agronomic information for the production of natural fibres,
- under-developed bioresource engineering,
- current issues in the reliability of fibre crops (availability of natural fibre feedstocks),
- issues in the grading of fibres,
- the need for novel conversion technologies,
- the need for the integration of suites of conversion technologies in natural fibre-based biorefinery models,
- the need for the development of new products (materials, chemicals, energy/fuels),



- the need to identify, engage, and cultivate the corporate partners needed to both commercialize Canadian natural fibre-based bioproducts and to gain acceptance in the receptor markets for these products,
- the need for whole system design and analysis,
- and the need for market analysis / business case development.

The NAFGEN explicitly includes the transfer of intellectual property (IP) and innovation to the network's many commercial participants and the wider receptor community, as well as the transmission of agronomic, bioresource engineering and other information to Canada's natural fibre producers (current and potential) as part of its mission.

### **Resource Summary**

In a number of instances NAFGEN commercial members were able to utilize this funding to enhance projects that were primarily financed with their own corporate resources geared to producing products aimed at commercialization. What was network capacity during the Network operational timeframe is now an opportunity for the various entities to work independently or with others. Eligibility for future programs will of course depend on what those programs are and their stated criteria for participation.

### **Benefits to Canada**

The Natural Fibres for a Green Economy Network actively engaged in addressing the scientific and technological issues that challenged the biofibre industry development. These include the need for:

- Optimized plant breeding for total crop utilization;
- Better straw management to exploit unused material;
- Bioresource engineering to develop and improve technical processes;
- Grading systems and processes to accurately quantify the fibre properties;
- Novel conversion technologies for the processing of flax and hemp fibre into intermediate and end products and integration of conversion technologies into biorefinery models.

This positions Canada as a North American leader in this key area of biomaterials processing in contrast, for example, to the USA approach with its narrower focus on bioenergy.

### **Follow-on Activities**

The network as such no longer has priority activities with its closing as of March 31, 2011. Post March 31, 2011, individual former NAFGEN members will establish their own priorities and



direction based on a number of factors specific to each party's resources and goals. As NAFGEN will cease to exist as of March 31, 2011, there will be no ongoing strategy for managing research or commercialization processes and resources as a Network. However, with the mutual awareness and collaboration that was experienced during NAFGEN it is reasonable to anticipate that some future strategic alliances will develop.

## **Lessons Learned**

- The strength of the network lies in its structure and the scope and diversity of its membership.
- Weakness of the network centred in the lack of commitment of some researchers to meet deadlines for semi-annual and annual reports and for filing expense claims making sharing of research information among participants impossible to provide in a timely fashion.
- The role of Lead Recipient under this program was both difficult and costly. The program was launched without many of the tools such as financial reporting formats and definitions of allowable overhead expenses in place. If another identical program was to be launched now Flax Canada might well not wish to participate as a Lead Recipient.
- It would be advisable for networks to recognize that, within the administrative requirements, there are limitations to the number of members that a network can contain in order to function to the level required. This is especially critical where there is a significant number of members from a cross section including Industry, academia, NGO and AAFC. The expectations and research history and practices of these various members are so varied that they may not play well together as team members.
- A budget allowance adequate for the Lead Recipient to wrap up the network reporting requirements is required, even if it falls into the next fiscal year. Currently the research either has to be cut off early or the Lead Recipient has to find financing from another source to wrap up the program.



## **Part 2. Summary of Report for Public Release**

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Under Agriculture and Agri-Food Canada's Agriculture Bioproducts Innovation Program (ABIP), the Natural Fibres for the Green Economy Network (NAFGEN) was formed with Flax Canada 2015 Inc. serving as the Lead Recipient. The Network's role was to assemble and align a significant portion of Canada's relevant innovative capacity to tackle the issues and challenges in developing a Canadian natural fibres value chain. That chain encompassed plant breeding and harvesting research through to the development and delivery of bioproducts to market.

NAFGEN participants included several Federal Government departments, a number of universities, corporate members and associations spread over seven provinces. From the onset, NAFGEN adopted a collaborative, outcomes-based philosophy with a whole crop utilization strategy grounded in creating value at three different steps in the value chain:

- 3) the farm gate value for Canadian farmers realized from bast fibre crops (flax and hemp);
- 4) new high quality employment opportunities in rural regions;
- 3) new opportunities in the Canadian manufacturing sector.

Challenges and opportunities directly addressed over the life of the NAFGEN included flax and hemp breeding, straw management, agronomic information for the production of natural fibres, bioresource engineering, availability and reliability of natural fibre feed stocks, as well as grading of fibres and novel conversion technologies. Also included were integration of suites of conversion technologies in natural fibre-based biorefinery models and the development of new products (materials, chemicals, energy/fuels). Corporate partners within NAFGEN were challenged to commercialize Canadian natural fibre-based bioproducts and to gain acceptance in the receptor markets for these products recognizing the need for whole system design and analysis based on sound principles of sustainability. This represented the largest and most comprehensive approach to natural fibre utilization and development ever undertaken in North America. The activities of NAFGEN have had a profound effect on the quality and quantity of research and technical tools for further development and utilization and commercialization of Canadian natural flax and hemp fibres.

In the event there are post-program questions to be addressed in this area, please contact Will Hill, President of the Flax Council of Canada.



## **Part 3. Network Performance Summary**

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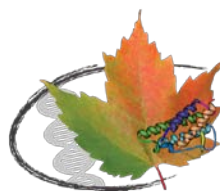
### **Activity and Schedule Performance Summary**

*This is attached as Annex 3 to the Final Report*

### **Cumulative Results from Performance Management Report**

### **Cost Performance Summary**

### **Participation and Collaboration Summary**



## **Agricultural Bioproducts Innovation Program**

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## **Part 3. Network Performance Summary**

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Supporting documentation includes:

- Activity and Schedule Summaries, which describe individual Sub-Activity results and outputs relative to workplan milestones and schedule.

### **Activity and Schedule Performance Summary**

Each Sub-Activity identified in the work plan should be discussed (300–500 words per project). Briefly describe the Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes. Clearly identify significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.

<b>Platform 1A</b>	<b>Feedstock – Flax</b>	<b>Project 1</b>	Genetic Characterization and Genetic Improvement of Fibre Yield in Flax
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Scott Duguid (204) 822-4471 x 7232 Agriculture and Agri-Food Canada	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose
- Brief methods description (reflect workplan milestones)
- Concluding statements that show the Sub-Activity met workplan deliverables.

**Project 1: Genetic Characterization and Genetic Improvement of Fibre Yield in Flax**

**Overview / Proposed Approach:** This project entails the identification and characterization of genes and genetic mechanisms involved in the production of fibre yield in flax, along with related NIR analytic tools, and the use of this knowledge to breed flax with higher fibre yields. Sub projects include: 1) flax germplasm development, 2) Coop testing, 3) development of NIR technology for determination of fibre quality, and 4) genetic map and QLT analysis

**Goals and Objectives:**

Long Term Objectives

- To breed flax with higher fibre yield (25%);
- To improve flax fibre yield by reducing the GxE interaction;
- To develop NIR analytical tools for monitoring fibre quality at all stages of the breeding program and for use throughout the industry; and
- To identify and characterize genes and genetic mechanisms involved in the production of fibre yield in flax.

Short Term Objectives

- To evaluate germplasm from world collection(s) of common flax and related species for fibre content;
- To identify high fibre parents, lines and breeding populations;
- To develop flax population(s) and characterize them at the phenotypic and genotypic levels for agronomic and straw characteristics;
- To develop NIR diagnostic tools to assist in achieving long term breeding objectives; and
- To develop molecular tools to assist in achieving long term breeding objectives



### **Project 1 -1- Phenotypic and Genotypic Characterization of the World Flax Collection and Related Linum Species for Fibre in Two Different Agro-ecological Locations in Western Canada**

Trials were established and conducted in Morden, Manitoba and Saskatoon, Saskatchewan in 2009 and 2010. Morphological and agronomic data was collected over the course of the field season and the fibre samples collected. Additionally, plants were established in greenhouses at the Cereal Research Centre in Winnipeg and leaf tissues were sampled and DNA was subsequently extracted. Straw samples were prepared and evaluated on NIR for cell wall content, fibre and shive content, cellulose, lignin and straw moisture content. The collection comprises 424 lines. Significant variation was found between the germplasm within the core collection of the world collection for cell wall content, fibre content, shive content, cellulose and lignin. A total of 241 of 248 EST-SSRs have been assessed on 40 of the 424 lines and 12 markers were done on all 424 lines. Simple sequence repeat (SSR) marker development and assessment from various sources resulted in the identification of a total of 1170 polymorphic markers by far the largest (in fact the only substantial) collection of molecular markers in the world. Polymorphism assessment of 477 SSR markers was completed on 24 of the 408 lines of the flax core collection. A total of 201 markers have been completed on the remaining 384 lines. Scoring and independent verification are complete. Preliminary data analysis for population structure was performed using the STRUCTURE software (Hubisz et al 2009) to determine the number of subpopulations. This clustering analysis was confirmed by Neighbor-Joining grouping and Principal Component Analysis. All three methods confirmed a population structure of 2 coinciding mainly with fibre and oilseed flax types. This genotypic data will be merged with the phenotypic data for fibre composition and fibre content as measured from the field trials to identify genes and/or quantitative trait loci responsible for fibre traits. Based on the amount of phenotypic variation within the world collection for the various traits examined, the genotypic markers that are being developed and the capacity to measure fibre content, shive content, cellulose, lignin and straw moisture efficiently using an NIR it should be possible to breed for improved varieties of flax.

### **Project 1-2 – Phenotypic Characterization of the Flax Cooperative Trials in Three Different Agro-ecological Locations in Western Canada**

Trials were established and conducted in Morden, Manitoba, Saskatoon, Saskatchewan, Vegreville, Alberta in 2009 and 2010. The trial consisted of 30 entries in 2009 and 31 entries in the trial in 2010. Two checks were included in the trial those being CDC Bethune and Flanders in each of the years. Samples from 2009 and 2010 were analyzed for fiber, shive, cellulose, lignin, cell walls and moisture on the NIR. Significant variation was found between the germplasm within the core collection for cell wall content, fibre content, shive content, cellulose and lignin. A significant environment and genotype x environment interaction was observed. A report has been prepared of the 2010 results and will be included in the minutes of the 2011 Prairie Recommending Oilseed Committee.

### **Project 1-3 - Phenotypic and Genotypic Characterization of World Flax Collection in Different Agro-ecological Locations in Western Canada**

Trials involving 254 recombinant inbred lines and 2 parental inbred lines representing the CDC Bethune x Macbeth population were established and conducted in Morden, Manitoba and Saskatoon, Saskatchewan in 2009 and 2010. Morphological and agronomic data was collected over the course of the two field seasons including collecting straw samples for the determination of cell wall content, fibre and shive content, cellulose, lignin and straw moisture content. Significant variation was found between the germplasm within the core collection for cell wall content, fibre content, shive content, cellulose and lignin. Transgressive segregants were observed within the mapping population for the various traits. Additionally, plants were established in greenhouses at the Cereal Research Centre in Winnipeg and leaf tissues were sampled and DNA was subsequently extracted. SSR markers were mapped on the CDC Bethune/Macbeth recombinant inbred line population which currently comprised 264 markers spanning 1604 cM in 20 linkage groups. This genotypic data will be merged with the phenotypic data for fibre composition and fibre content as measured from the field trials to identify genes and/or quantitative trait loci responsible for fibre traits. QTLs identified in this segregating population will also serve to validate the putative QTLs identified by association mapping of the core collection. Based on the amount of phenotypic variation within the mapping population for the various traits examined, the genotypic markers that are being developed and the capacity to measure fibre content, shive content, cellulose, lignin and straw moisture efficiently using an NIR it should be possible to breed for improved varieties of flax.

### **Conclusion**

Based on the amount of phenotypic variation within the world collection and mapping population as well as that observed within potential cultivars within the cooperative trials, the genotypic markers that are being developed and the capacity to measure fibre content, shive content, cellulose, lignin and straw moisture efficiently using an NIR it should be possible to breed for improved varieties of flax.

### **Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance
- May include challenges and/or barriers to work and solutions

<b>Platform 1A</b>	<b>Feedstock – Flax</b>	<b>Project 2</b>	Development of Crop Production Practices to Enhance Flax Fibre Production
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Scott Duguid (204) 822-4471 x 7232 Agriculture and Agri-Food Canada	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose
- Brief methods description (reflect workplan milestones)
- Concluding statements that show the Sub-Activity met workplan deliverables.

**Project 2: Development of Crop Production Practices to Enhance Flax Fibre Production**

**Overview / Proposed Approach:** This project addresses the gap in defined agronomic practices for producers to grow consistent quality fibres for processors. Sub projects include: 1) effect of seeding date and seeding rate on fibre yield of flax, 2) effect of nitrogen and fungicide on fibre yield of flax, 3) impact of early season management on biomass and seed yields, and 4) effect of time of swathing and desiccation on retting, fibre yield.

**Goals and Objectives:**

Long Term Objectives

- To develop crop management systems to improve fibre yield.

Short Term Objectives

- To investigate the interaction of seeding date, seeding rate and cultivar on fibre yield;
- To investigate the interaction of nitrogen fertilizer and fungicide on fibre yield;
- To examine the impact of environmental conditions (temperature), water use efficiency on fibre production;
- To investigate the effect of desiccation on fibre yield in flax; and
- To determine the impact of flax straw management options on retting success in various climatic areas.

### **Project 2-1 Effect of seeding rate cultivar and planting date on flax seed and fiber yield**

This trial was planted at four sites in each year but data is only available for Brandon, Saskatoon and Morden due to weed and water problems at Melfort. We planted 3 cultivars at 40, 60, 80, 100 and 120 kg/ha in mid May and early June. Plant density increased linearly with seeding rate with little impact of cultivar. There were significant differences between sites and seeding dates but no definite trend at all sites. When average over all sites each year seeding yields declined as seeding rates increased at both early and late seeding dates. Seed yields over all treatments were in the 1800 kg/ha in 2009 and 1300 kg/ha in 2010. Early seeding gave higher seed yields compared to late seeding in both years. In 2010 this was due in part to increased lodging with late seeding and high seeding rates. There was an overall trend to smaller stems at higher seeding rates with some sites showing smaller stems at early seeding rates. There was a significant cultivar impact on fiber content with Prairie Grande having 3% more fiber than the other cultivars. Fiber content was lower in 2010 than 2009 and in 2009 early planting had higher fiber contents. In 2009 fiber yield was greater at late seeding but there was no difference in 2010. There as about a 10% increase in fiber yield as seeding rates increased with a variable impact of seeding date.

### **Project 2-2 Effect of nitrogen rate and fungicide treatment.**

In this trial we planted flax at 80 kg/ha with 0x, 1/3x, 2/3, 1x and 1 1/3x of soil test recommendations. Seed yields were increased by fungicide application and this was influence by site year with fungicide decreasing disease. Fiber yield followed the same trend as seed yield with increasing fiber yield with increasing nitrogen application. This increase in fiber yield was due in large part to the increase in stem size as nitrogen rate increased. In 2009 there was fungicide application did not increase fiber yield at any nitrogen rate. Conversely in 2010 fiber yields were significantly improved when fungicide were applied to crops that had received 100% or more of the recommended nitrogen rate.

### **Project 2-3 Site specific impacts on seed and fiber yield**

In many areas there as a fair bit of topography we determined the variation with the field in fiber yield and attempted to determine if we could use net vegetation index to predict fiber yield prior to flowering. We found that fiber content was no correlated with fiber yield but seed yield, harvest index and biomass were highly correlated with fiber yield (0.84, 0.85, 0.82 respectively). This data indicates the high fiber yield areas of a field are well predicted by seed yield maps created with a combine equipped with a yield monitor. We will be looking at previous data sets to determine if we can do a better job of identifying agroclimatic conditions which result in higher fiber content. There seems to be relatively small amounts of fiber in the bottom portion of the plants. In the most seasons of this trial the knolls had the lowest yields with the second lowest being the south slopes and the highest the north slopes. There was a 26% difference in fiber yield between the North slope and the knoll positions.

**Project 2-4 Impact of glyphosate, Reglone and swath at varying stages of maturity on seed and fiber yield and the level of retting.**

Flax was treated with glyphosate, diquat or swathed at 25, 50, 75 and 100% brown bolls. Seed and fiber yields were determined when all the plots were ready for harvest and samples placed on the soil surface of periods of up to 7 weeks in the fall. The level of retting was determined on individual stems and the fiber content measured on these samples. Across and sites fiber content increased about 2 percentage points in 4 weeks and tended to level off. Fiber content in the straw started at the same level and increased more quickly when diquat was applied rather than glyphosate but the difference was less than 1 percentage point and tended to be similar later. We were not able to detect differences in retting rate using the fried test and conclude that fall retting is very difficult except in sites like Morden where temperatures and moisture levels are greater

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance
- May include challenges and/or barriers to work and solutions

<b>Platform 1B</b>	<b>Feedstock – Hemp</b>	<b>Project 1</b>	Best management practices for hemp fibre production and the development of breeding and genetic resources for the production of elite fibre cultivars for Canada
		<b>Project 2</b>	Development of genetic resources for the production of elite fibre cultivars for Canada
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	John Vidmar (780) 632-8244 Alberta Innovates – Technology Futures	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose
  1. The development of fibre feedstock resources for the emerging biofibre industries for Canada
  2. The development of genetic/genomic tools for improved industrial hemp cultivar breeding
- Brief methods description (reflect workplan milestones)
  1. For the first objective a Pan Canadian field trial was established to assess the growth performance of industrial hemp. The field trials were run for two years at three difference locations across Canada: Vegreville (Alberta), Dauphin (Manitoba), and Tavistok (Ontario).

Year1 (2008) – the influence of four different levels of nitrogen on different hemp varieties (five or six) was assessed.

Year2 (2009) – two different experiments were performed. The first one assessed the influence of different hemp varieties on the biomass production. The second one looked at the influence of the different nitrogen sources on the biomass characteristics.

The biomass characteristics measured include: fresh stalks yield, seed yield, dry stalk yield, the amount of bast and core yielded. The fibre characteristics were determined using either chemical analysis or NIR (near infra-red) spectrometry and include the proportion of lignin, cellulose, hemicellulose etc. in both bast and core samples.

2. The second objective targeted the development of genetic/genomic tools for improved industrial hemp cultivar breeding and included the following milestones:
  - The development of 100 microsatellite (SSR) markers
  - The development of 50 single nucleotide polymorphism (SNP) markers
  - Association of molecular markers with biomass, fibre quantity and chemical composition

For the development of SSRs a genomic library enriched in microsatellites was constructed. The library was sequenced. The genomic DNA sequences were then checked to identify microsatellites and to eliminate any duplicated sequences. Once unique DNA sequences containing SSRs were identified, primers were designed to amplify in PCR the various SSRs. The primers were initially tested under two standard PCR conditions using genomic DNA extracted from two different hemp varieties. Optimization of the PCR conditions was then undertaken for those primers that showed faint amplification band. Once a set of PCR condition were established the primers were tested with genomic DNA extracted from 11 different hemp varieties.

- Concluding statements that show the Sub-Activity met workplan deliverables.

From the SSR sequences, 416 unique sequences were identified and 416 primers sets were designed and tested in PCR reactions. In the initial phase all the primers were tested with genomic DNA isolated from two different hemp varieties. From the primer tested, 248 primer sets amplified various PCR products of expected sizes. Out of the 248 primers, 144 primer sets were tested on genomic DNA extracted from 11 hemp varieties: 58 amplified various PCR products for all the 11 genomic DNA samples with 49 primers sets yielded highly polymorphic bands.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

The association of molecular markers with fibre characteristics was not undertaken. Due to seed availability there were no proper replicates of the trials across the different provinces. Moreover there were not enough varieties plated to undertake association of molecular markers with fibre characteristics. To deals with this issue we have undertaken an added project the genomic resequencing of an number of hemp cultivars for the identification of 1000 of Molecular Marker (SNP)s.

- May include challenges and/or barriers to work and solutions

N/A

<b>Platform 2</b>	<b>Bioresource Engineering</b>	<b>Project 1</b>	The evaluation and development of systems and equipment for harvesting, retting and storing flax to improve the quality, quantity, and value of natural fibres and co-products in flax production.
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Mark Stumborg (306) 778-7261 AAFC – Research Branch	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose
  - To evaluate and develop harvest systems that maintain or improve harvested seed quality and yield while improving the opportunity to harvest and rett flax straw;
  - To evaluate and develop retting treatments that enhance the value and improve the process suitability for high value natural fibre;
  - To evaluate and develop improved field biomass processing and collection systems;
  - To share the qualitative and quantitative results from this Platform's field activities with AAFC's Prairie Farm Rehabilitation Administration (PFRA) to develop a complete inventory of biomass opportunities in Canada - Geographic Information System (GIS) Interface; and
  - To provide material of various degrees of processing, retting, and from various harvest systems for evaluation by the rest of the Network.
  
- Brief methods description (reflect workplan milestones)
  - Stripper header technology was chosen as the fundamental alteration to conventional harvesting systems. The use of this header removed the combine from impacting straw quality, as the header removed the seeds from the standing plant, leaving the standing straw to be managed without combine damage. Seed loss comparisons between the stripper and conventional header in other crop types were essential to determine overall header viability as the header is a significant investment and must be suited to more than one crop type or producers will not be able to afford to shift from conventional practices.
  - Small plots comparing different crop types were established in Indian Head, SK and Swift Current, SK to provide 2 significantly different soil types, growing conditions, and yield potential.
  - The material other than grain to grain (MOG:G) data from the plots was supplied to the GIS activity to improve the Web based Biomass Inventory Mapping and Analysis



- Tool (BIMAT) now under construction by AAFC-AESB and The National Land and Water Information System (NLWIS).
- Large scale demonstration activities using the stripper header provided by SaskFlax were conducted to develop spring retted materials for further processing by Schweitzer-Mauduit (SWM). This facilitated the comparison of stripped versus rotary harvested material to determine straw yield differential, process suitability using the SWM process, and final fibre cleanliness. SWM completed the following evaluations:
    - decortication of stripper/swather/macerator, draper/rotary combine, auger/header/conventional combine, and stripper/swather flax straw. Decorticated materials were transferred to Platform #3 for processing & evaluation.
    - Seeded 20 acres Flanders high fibre variety as a winter crop in South Carolina and evaluated the fibre content and retting progress.
    - Purchased 100 tons of well retted flax straw during a spring baling program.
    - June 2009 NAFGEN trial – purchased and decorticated 140 tons flax, 49 tons hemp
    - May 2010 NAFGEN trial – purchased and decorticated 140 tons flax, 67 tons hemp
    - June 2010 Hemp Trial – purchased and decorticated 202 tons hemp
    - August 2010 Spring Hemp Trial – purchased and decorticated 70 tons hemp
    - December 2010 NAFGEN Trial – purchased and decorticated 417 tons flax, 391 tons hemp
    - Stripper Header Trial – 110 acres. This material will be harvested, collected, and decorticated after the project termination using SWM resources.
    - Hemp Hurd screening trial to remove dust – forwarded 5 tons to building project
  - In addition, a macerator was included as part of the system to evaluate its ability to enhance straw retting.
  - Retting trials of plot treatments with 3 x 3 cutting / packing treatments, standing, and rolled flax material were evaluated in Swift Current, Indian Head, and Brandon. A macerator was included within the experimental design to determine its value as a retting enhancement operation. Materials from the retting sites were baled and provided to Biolin Research for detailed fibre and processing evaluation.
  - The MOG:G data from the small plot evaluation project was calculated based on the collection of grain and chaff weights by weighing each material by weigh wagons upon unloading (grain) and by collecting the chaff during plot harvest. The straw weights were determined via baling. The stripped plots were swathed and then baled and compared to baled conventionally harvested plots. Calculations of overall material yields were prorated for the plots based on header width (14' for the stripper header, and 20' for the conventional header). Plot harvest speed was determined by the conventional header /combine capacity and then prorated by header width for the stripper header.

- Concluding statements that show the Sub-Activity met workplan deliverables.
  - Stripper header harvesting demonstrated grain loss characteristics that were similar to a conventional header. However, tradeoffs exist as with other harvest systems. Operation of the stripper header was very crop and condition dependent, requiring modifications to the header and to header manual recommendations to improve operation consistency. Use of the header also required significant combine setting change. Once properly adjusted and operated, flax seed loss at the header was somewhat higher but was offset by a lower combine loss due to improved seed/chaff separation and lower sieve losses. Flax that was embrittled by excess maturity or desiccation appeared to exhibit higher harvest seed loss. One advantage however was the ability of the stripper header to remove flax seeds from flax where the straw still was green. This allowed flax to be harvested in mid-August with minimal seed loss, high seed quality, and improved flax straw retention in the field. By using the stripper header harvest system, farmers were able to separate seed and straw harvesting. Standing stripped straw left standing over winter produced maximum retting conditions, improving overall straw value for processors and producers at minimal economic cost.
  - Production scale testing of spring baled winter retted flax produced cleaner, lower shive content, improved fibre length & strength fibre than traditionally baled fall straw. The same can also be said for the snow retted hemp.
  - Process improvements occurred from spring retted straw materially improving production rates, yields, improved shive content level and quality of fibre. This improved marketability of fibre for higher value applications.
  - The inclusion of hemp straw testing has lead to the purchase of 600 tons of straw. Hemp fibre and hurd was made available for further evaluation. Improved prospects for hemp straw commercialization now exist.
  - The use of the mascerator, while not showing improvements in retting success, showed promise as a bale densification device. Six foot round bales of untreated straw weighed ~1350 lbs (670 kg) while 6' bales of mascerated straw weighed 2250 lbs (1020 kg). This represents approximately 50% improvement in bale density, allowing road transport to achieve or exceed legal load limits, reducing transportation cost and increasing potential straw sourcing radius.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance
  - The plan to grow 20 acres of high fibre content flax variety Flanders in South Carolina was not completed and only 11 acres were planted in 2010. This was intended as a winter crop but it could not be established in the first year due to wet weather at seeding.

- There remains 110 acres of flax left standing over winter that will be harvested for seed with the stripper header and then the straw will be swathed, baled, and sent for processing at SWM this spring. The delayed seeding and wet harvest weather caused this item to be delayed. Both projects will be completed after the program has ended by the company.
  - The 2010 small plot work was largely destroyed during spring flooding and delayed maturity. Arrangements have been made to conduct repeat plot work in 2011 using other funding sources.
  - The transfer of GIS data has occurred but its inclusion in the BIMAT functions has been delayed during the AAFC – AESB proposal process. Progress is anticipated in FY 2011-12.
  - The original concept of moving fibre from plot and demonstration scale activities was only partially successful due to the funding and time limitations imposed by the ABIP process.
  - The equipment development concepts were partially successful due to the funding and time limitations imposed by the ABIP process.
  - The energy requirements of the 2 harvest systems were not determined due to a companion project failure and lack of time during the 2010 harvest.
- May include challenges and/or barriers to work and solutions

<b>Platform 3</b>	<b>Processing of Hemp and Flax</b>	<b>Project 1</b>	Engineering of the flax straw primary processing line, investigation of various components of a pilot-plant operation
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Alvin Ulrich (306) 668-0130 Biolin Research Inc.	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose
  - To investigate the operation of different components of the processing line in order to better understand:
    - How to reduce operating costs
    - How to improve the efficiency of the new generation of bast-fibre processing lines
  - To utilize the CFC for producing the necessary fibres, shives and dust expected by the other platforms.
  - To establish more business contacts with producers and potential receptors of products

Long term objectives:

- Deliver a set of (near) optimal operating conditions for the pilot plant processing line
- Increase the production capacity of the CFC pilot plant by approximately 20%
- Produce fibres of improved qualities and properties
- Develop guidelines that will increase the networking and business activities between the producers (farmers) and the manufacturers of fibre-based materials

Short term objectives:

- Install a straw bale opener for at least one other kind of flax straw bale
- Carry out processing trials on a variety of straw types
- Supply “draft” grades of fibre and shive to other platforms and potential users
- Improve the CFC pilot plant main fibre cleaning line to the point that fibre has 10-15% impurities, within the same number of times processed as it now takes to clean fibre to the point that it has 20-25% impurities
- Reduce airborne dust within the CFC pilot plant by 25%
- Study and develop a cost-effective method of condition or properly dry straw before processing

- Brief methods description (reflect workplan milestones)

Between July 2008 and March 2009, Biolin modified existing equipment to improve its cost-effectiveness. Biolin performed a series of straw processing trials and fibre and shive produced by Biolin was supplied to other platforms and potential users.

Between April 2009 and March 2010, Biolin installed a new bale opener, fibre re-cleaner, and dust removal system in the pilot plant. Biolin further modified existing equipment to improve cost-effectiveness. Further straw processing trials were performed and fibre and shive produced by Biolin was supplied to other platforms and potential users.

Between April 2010 and March 2011, Biolin installed a straw conditioning system. Fibre and shive produced by Biolin was supplied to other platforms and potential users.

Biolin received a shipment of new processing equipment in December 2010 and had it assembled in January 2011. Since then we have been doing test runs using different types of straw and have produced a variety of fibers. The new equipment has been integrated successfully with the previous improvements that were made to our old line (e.g. the dust removal system), and has been able to produce fibers with less than 10% shive from retted straw. We have already been able to send clients samples of fiber cleaned with our new system.

- Concluding statements that show the Sub-Activity met workplan deliverables.

We worked with Platform II participants to get a range of straw types and processed it in several ways to get different types of fiber. We were also able to supply different types of fiber and shive to participants in other platforms. In addition, we have sent numerous samples of fiber and shive to potential users. Some of these have continued to buy product from us and/or to proceed to much larger scale trials. Our new processing equipment has allowed us to produce much cleaner fiber (<10% shive) at a much faster rate with the same or less labour and with a great deal less dust.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

We have had no significant changes to our milestones. The biggest challenge we faced as a small company was the very slow rate at which our expenses were reimbursed. Since we do not know how long it will be before we get re-imbursed, we have to hold onto as much cash as we can. This has, and still is, putting a severe constraint on the cash we have available for other activities. To some extent we were able to negotiate further bank loans but after waiting much longer than expected for NAFGEN reimbursements, the banks are reluctant to advance us additional funds.

- May include challenges and/or barriers to work and solutions

<b>Platform 3</b>	<b>Processing of Hemp and Flax</b>	<b>Project 2</b>	Development of Economical Clean Fibre Decortication and Separation Processes
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Joe Hogue (204) 331-2226 Schweitzer-Mauduit International	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

Long Term Objectives:

To produce and test pilot scale batches of clean fibres at a reasonable throughput to meet market technical requirements and demands economical;

To utilize the information to generate business models that would support implementation of large-scale decortication and cleaning processes;

Short Term Objectives

To assess alternate decortication processes in order to determine those most suitable for interfacing with the facilities and markets compatible with SWM's long term focus and operations;

To review those techniques being researched in other Platform 3 projects to determine their suitability and potential synergies in terms of joint development;

Confirm market approach and end-market applications

To prepare a standard that the material must meet to be able to be compatible with end market requirements;

To prepare a business model and assess the different methods available and determine their economic viability.

To prepare a plan to test out the selected processes to confirm their capabilities and/or define what development activities need to be implemented.

- Brief methods description (reflect workplan milestones)

Cotton Quality Lab – Clemson, SC – different methods to clean the fiber & reduce shive including the use of cotton cleaning equipment

NuMax Technology – FireBall treatment, provided raw materials to project

June 2009 NAFGEN trial – purchased and decorticated 140 tons flax, 49 tons hemp

May 2010 NAFGEN trial – purchased and decorticated 140 tons flax, 67 tons hemp

June 2010 Hemp Trial – purchased and decorticated 202 tons hemp

August 2010 Spring Hemp Trial – purchased and decorticated 70 tons hemp  
December 2010 NAFGEN Trial – purchased and decorticated 417 tons flax, 391 tons hemp

- Concluding statements that show the Sub-Activity met workplan deliverables.

Long term object to implement large scale fibre cleaning processes met. SWM INTL announced \$1.8 funding for fibre upgrading and flax shive separations facility, construction of which to be completed March 31, 2011.

Networking research established within platform #3. Relationships developed with NRC Biotechnology Research Institute and Industrial Materials Institute for supply of flax and hemp fibres. Contact established with Lanapole Fibre regarding shared interest in possible hemp fibre decortication. Entering into further biomaterial commercialisation projects with the Composite Innovation Centre.

Confirmation of market approach and end-market application lead to company creation of trademarked FlaxStalk brand of flax and hemp biomaterials. [www.FlaxStalk.ca](http://www.FlaxStalk.ca) Sales of which are expected to reach \$2.2 million annually and provide bioproducts needed for the new bioeconomy.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

The 1,500 lbs of cleaned flax fibre transferred to platform #4 fell short of the 6,000 lbs goal required for their matt making activities.

Suitable mechanical fibre cleaning technology capable of producing technical grade fibres still not identified.

- May include challenges and/or barriers to work and solutions

Fibre processing technology as used for other natural fibres such as linen flax, kenaf and cotton in the US, Europe and India still little understood.

At present, unable to provide or fill the need for spinable flax or hemp fibre for industrial textile applications. A textile grade of fibre would dramatically increase the value proposition for fibres.

Working with research institutes and several companies on enzymatic processes capable of producing technical fibres.

<b>Platform 3</b>	<b>Processing of Hemp and Flax</b>	<b>Project 3</b>	Bioscouring of flax and hemp fibres to improve cleanliness and fineness.
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Dr. Denis Rho (514) 496-6354 NRC: National Research Council. BRI: Biotechnology Research Institute.	

**This document will also combine the information relative to:**

<b>Platform 3</b>	<b>Processing of Hemp and Flax</b>	<b>Project 6</b>	Fibre studies and Fibre characterization.
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Dr. Denis Rho (514) 496-6354 NRC: National Research Council. BRI: Biotechnology Research Institute.	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

**The project 3** aims at developing a biotechnology based on the utilization of engineered enzymes (e.g. pectinases and cutinases) at BRI\_NRC (IPSO 11927) for the production of high quality bast fibres from flax or hemp straws (stems). Different bioreactors (configuration and size) and different operating conditions were tested to demonstrate the feasibility of such bioprocess. The parameters used to measure the efficiency of the biotreatment include: fibre fineness, fibre cleanliness, and fibre strength, modulus and length. Also, the project aims at collaborating with researchers within NAFGEN from different organizations with fibre samples of known qualities/properties for them to produce prototypes of biocomposites for different industrial applications. The project 6, which is an integral part of the PL3 platform, aims at using enabling analytical instruments to characterize different physical properties of the raw and processed fibres.

In brief, the objectives of the project 3 were: (a) to develop a processing line (small-scale for production of kg-level of fibres) for the primary transformation of flax and hemp straws to produce fibres ready to be processed further using the BRI enzymes; (b) investigate the performance of the biotreatment process; and (c) provide the necessary data to conduct a preliminary life cycle assessment (LCA) of the bioprocess.

Throughout this 2.5-year project, the optimization of our biotreatment protocol was done using two different BRI engineered enzymes, which are a pectate lyase and a cutinase.



Since these two enzymes are not commercially available, thus they had to be produced using BRI's 150-L or 750-L bioreactors and had to be purified using specific protocols that were already proven for their efficiency to recover the proteins of interest. As a result of several production / purification runs, we can conclude that we are now capable of producing the BRI pectate lyase (commonly named Linase) at a level never attained before, that is 96 MU in a volume of 40 L (after concentration and purification), which is twice the productivity level usually attained.

Knowing that bast fibres represents cellulosic fibres grouped into packages of 30 to 50 individual fibres, thus the key objective of the BRI biotreatment process is to free those so-called ultimate fibres from their pre-existing conditions. Results of our experiments successfully showed that with time the use of the pectate lyase release them effectively. However, the results obtained using the cutinase, which was targeting at residual wax components present onto some parts of the fibre bundles, were not as conclusive. Despite this fact, in the end, the ultimate result of our investigation, which also refer to those obtained while exploring the impact of different complementary processing strategies (not detailed herein), is that the cellulosic fibres of known qualities and properties can be obtained using our biotreatment process.

Although most optimization experiments were conducted in lab-scale vessels, at one point, the usage of a 200-L bioreactor design and fabricated in Canada (but purchased using NRC funding), prove to be useful for the production of kg-level of flax and hemp enzyme-treated fibres. The outcomes of those production experiments include: fibres were produced for the production of vinyl-ester biocomposites (in collaboration with CIC, PL4) and of polypropylene biocomposites (in collaboration with IMI, PL4); flow sheet mass balance was prepared; and mechanization of the process at the next scale was investigate in some details.

**In brief, the main objective of the project 6** was to characterize key physical and chemical properties of the cellulosic fibres, originating either from our biotreatment process or from other NAFGEN collaborators, using different analytical instruments and or methods. The key instruments used include: a scanning electron micrograph (SEM), an optical microscope (OM), an atomic force microscope (AFM), a Raman microscope equipped with different laser sources, a Fibreshape - image analysis software used to determine fibre fineness, a strength tester, and a Fourier-Transformed InfraRed spectrograph (FTIR) as well as Near InfraRed (NIR) and Tappi methods to measure the cellulose, hemicellulose, and lignin contents.

Those above-mentioned methods and or instruments were developed (tested and validate) and used to characterize enzyme-treated fibres before and after treatment. Most of these methods proved to be useful since they provided informative results, however the following instruments Raman microscopy, AFM and FTIR did not generate significant results. The former (i.e the 'good' methods) allowed us to describe in some details the resulting fibres; for example, several valid NIR calibration curves were developed to determine with reasonable accuracy the fibre cleanliness or the cellulose content or the

shvie content. On the other hand, the latter method (i.e. the ‘not so good’ method) provided limited information. This fact should not be regarded as a negative output of this project; these test methods can’t be regarded as routine analysis as they were chosen to explore the morphology and the topology of natural fibres based on their known potential from other experimental field. For example, (1) AFM is known for its potential to identify micro-structures but fails at doing so since the cellulosic fibres used throughout our experiments were too big (mm in length) and too heterogeneous by nature; (2) our Raman-microscope was equipped with three different laser sources to detect the signature of different biochemicals typically found in plant cell walls, but sample preparation and spectral analysis was very tedious and the full development of such method was behind the scope of this project.

- Brief methods description (reflect workplan milestones)

In brief, enzymes (pectate lyase and cutinase) were produced to conduct our biotreatment. Key operating parameters were identified. Enzyme-treated fibres were produced and fully characterized using different test methods.

Different straw/fibre processing strategies were investigated using specialized equipments (one of them was acquired through this program), thus different fibres were produced. This activity allowed us to further develop our grading system, which is an essential tool for describing the fibres (the product) for a given industrial application targeted by the process under investigation.

Preliminary search on industrial scale equipments were identified for future scale-up activities.

We attended at different NAFGEN meetings to exchange our results within the network, but also we attended at ASTM’s meeting to develop a standard test method using an image analysis software for the measurement of average fibre diameter from grab-fibre samples. Three teams (J. Foulk from USDA, A. Ulrich from Biolin Research Inc., and D. Rho from NRC\_BRI) are currently working together on this topic.

- Concluding statements that show the Sub-Activity met workplan deliverables.

Two enzymes (pectate lyase and cutinase) engineered at BRI\_NRC were produced in large-scale bioreactors (150 L and 750 L) using an improved production method, consequently the production level was increased by a 2-fold factor. Moreover, the pectate lyase was purified using a one-step procedure.

The pectate lyase (Linase) was effectively used to process flax or hemp fibre bundles to obtain the so-called ultimate fibres. These fibres were used to produce biocomposites with two different types of resins (i.e. polypropylene and vinylester).

The conditions to operate the bioreactor and the necessary processing steps to further clean and open the fibres were investigated in details at the laboratory scale.

A fast and reliable method (Fibreshape image analysis software) was successfully developed for the measurement of the average fibre diameter of grab fibre samples.

SEM and other microscopy techniques were used to provide key evidences of the fibre morphology once the fibre treatment was completed. These tools are essential to observe the presence of some defects and or some micro structures that may impact the performance of the resulting biocomposites.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

Not applicable, since all researchers involved within Platform 3- Project 3 and Project 6 achieved their respective milestones as outlined in their workplan.

- May include challenges and/or barriers to work and solutions

<b>Platform 3</b>	<b>Processing of Hemp and Flax</b>	<b>Project 4</b>	Industrial Hemp: a new crop to support the biorefinery concept.
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Daniel Babineau (450) 836-0990 Lanaupôle Fibres	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

*(English translation listed below.)*

- Sub-Activity objective or purpose
- Brief methods description (reflect workplan milestones)
- Concluding statements that show the Sub-Activity met workplan deliverables.

Lanaupôle Fibres, supporté par la région de Lanaudière (Québec), a comme mission de développer la filière des fibres naturelles et le secteur des bioproduits au Québec et dans l'Est du Canada. Les différentes activités réalisées dans le cadre du présent projet ont pour objectif de valider certains aspects techniques et scientifiques pour faire la mise en place de l'infrastructure permettant le développement d'une filière agro-industrielle en lien avec le concept de bioraffinerie végétale. La méthodologie déployée consiste à la réalisation d'un plan de travail axé sur la recherche, l'expérimentation et la validation de différents concepts et équipements industriels associés à la transformation de la paille dont le chanvre industriel. Ceci dans un premier volet afin de comprendre et connaître par la réalisation de différentes analyses et caractérisation les principaux paramètres permettant de faire la sélection, la conception et la mise en place d'équipements de traitement de la biomasse (unité d'expérimentation régionale). Dans un second volet de travailler en partenariat avec les acteurs locaux (Coop de production Lanaufibres, SADC, CLD, MRC De D'Autray, Ville de Lavaltrie, Municipalités, Ministères provinciaux et fédéraux, Centres de recherches du CNRC, Universités, CCTT, entreprises et autres, etc.) et hors-Québec (Partenaires PIBA, CHTA, EIHA, Instituts de recherche Canadien et Européen, entreprises) afin de valider les marchés potentiels, de développer des projets de recherche et développement pour la production de matière première, la transformation et la production de biens finis. Et finalement trouver certains des intervenants permettant le financement et la mise en place des assises d'une infrastructure expérimentale régionale dans Lanaudière.

Les principaux jalons réalisés ont consisté à :

- 1) Concevoir et réaliser différents essais de recherche industrielle avec des équipements pour le décorticage de bale de chanvre en champs et en usine dans des installations existantes (Québec et Europe). Les principaux équipements étudiés sont des

modèles de récolteuses en champs (coupeuse, moissonneuse, faux, ensileuse), différents systèmes pour décortiquer les bales de chanvre (crusher, roller breaker, blade cutter, hammer mill), les équipements pour nettoyer les fibres et les chènevottes (fiber and shive cleaner, baler, etc).

2) Valider la qualité du matériel obtenu lors des différents essais et tests par la réalisation d'analyses dans différents laboratoires (CNRC-IBR, CNRC-IMI, Biolin, Europe, et autres). Des analyses technico-économiques des concepts expérimentés et selon les cas, réaliser certaines caractérisations des produits obtenus. Cette étape a permis la familiarisation avec les critères de qualité pour établir les paramètres d'éventuelle fiches de caractérisation des pailles et des fibres avec les producteurs.

3) Élaborer un plan conceptuel d'une usine expérimentale. Des partenariats avec des experts et chercheurs dans le secteur de la préparation des fibres ont été établis. Des essais de validation afin de faire la conception d'une ligne de défibrage ont été réalisés. Ce jalon concorde avec la recherche de fonds et financement ainsi que l'obtention de certains fonds du milieu. Ainsi, la sélection, la conception et la commande pour la fabrication et mise en place de certains équipements dans le hall expérimentale de Lanaupôle Fibres à Lavaltrie a pu être effectuée. Les fonds obtenus ont servis aux travaux pour l'aménagement d'un hall expérimentale (Ville de Lavaltrie) et l'achat d'équipements (PIBA, Pacte rural MRC et autres).

4) Travailler à l'amélioration des connaissances des techniques de production et des procédés de transformation industriels et à la formation d'un personnel qualifié. Différentes activités, visites, échanges ont eu cours afin de valider le fonctionnement des équipements de différents manufacturiers locaux et européen. Des ententes de partenariat avec des centres de recherche pour la mise en place d'équipements et le développement d'activités de recherche industrielle sur le site de Lanaupôle Fibres à Lavaltrie près de Joliette (Québec) ont été convenues. Les équipements de préparation de la paille mis en place à Lavaltrie sont en phases de démarrage et certains tests sont en cours. Nous n'avons pas eu le temps d'expérimenter suffisamment les équipements afin de permettre de produire suffisamment de résultats obtenus via une analyse de la performance. Les résultats des essais à venir permettront de finaliser le choix de certains équipements de la ligne de défibrage des pailles pour orienter les projets de R&D.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

La finalisation de l'étape de mise en route des équipements permettra de poursuivre le travail afin d'améliorer les connaissances des techniques de production. Cet aspect est donc en lien avec la poursuite des activités pour l'élaboration de protocole de production et transformation qui sont à réaliser dans les prochains mois. La réalisation de cette étape permettra d'adapter le programme de formation pour avoir un personnel qualifié.

Plusieurs défis sont à relever afin de poursuivre la mise en place de l'infrastructure permettant le développement d'une filière agro-industrielle en lien avec le concept de bioraffinerie végétale (bioproduits). Parmi ces défis, le développement d'une chaîne d'approvisionnement considérant la nature des matériaux brutes (paille), des produits de transformation obtenus (fibres), l'adaptation de procédés de post transformation et les critères de qualité des produits finis (marché) à base de fibre naturelle est à faire.

- May include challenges and/or barriers to work and solutions

### ***English Translation:***

#### **Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

Lanaupôle Fibres, supported by the region of Lanaudière (Quebec) has the mission to develop the sector of natural fibres and bioproducts industry in Quebec and eastern Canada. The various activities carried out under this project aim to validate certain technical and scientific aspects to the development of infrastructure for the development of agro-industrial link with the concept of bio-refinery plant. The methodology deployed is to achieve a work plan focused on research, experimentation and validation of various concepts and industrial equipment associated with the processing of straw with industrial hemp. This in a first step to understanding and awareness by conducting various tests and characterization of key parameters to make the selection, design and installation of equipment for biomass processing (regional experimentation unit). In a second part to work in partnership with local actors (Coop production Lanaufibres, SADC, CLD, MRC Autray, Ville de Lavaltrie, Municipalities, Provincial and Federal NRC Research Centres, Universities, CCTT, companies and others, etc..) and outside Quebec (Partners ABIP, CHTA, EIHA, research institutes Canadian and European markets, companies) to validate potential markets, develop research and development for the production of raw material, processing and production of finished goods. And finally find some keyplayers for the financing and establishment of the foundations of an regional experimental infrastructure in Lanaudière.

Major milestones achieved included the following:

- 1) Design and conduct various research trials with industrial equipment for hemp bale processing in fields and factory in existing facilities (Quebec and Europe). The main equipment of the models studied are pickers in fields (cutter, reaper, scythe, silage), different systems to dissect the bales of hemp (crusher, roller breaker, blade cutter, hammer mill), equipment for cleaning fibres and shives (fibre and shive cleaner, baler, etc.).
- 2) Validate the quality of material obtained during the various trials and tests by conducting tests in different laboratories (NRC-BRI, NRC-IMI, Biolin, Europe, and others). Techno-economic analysis of the concepts tested and where appropriate, make

some characterizations of the products obtained. This step allowed familiarization with the quality criteria to establish the parameters of possible forms of characterization of straws and fibers with producers.

3) Develop a conceptual design of an experimental plant. Partnerships with experts and researchers in the field of fiber preparation were established. Validation tests in order to design a line of grinding were conducted. This milestone is consistent with research funding and financing and the obtaining of certain funds of the medium. Thus, the selection, design and control the manufacture and installation of certain equipment in the Lanaupôle Fibres experimental hall at Lavaltrie has been made. The funds raised were used to work for the development of an experimental hall (City of Lavaltrie) and the purchase of equipment (ABIP Rural Pact MRC and others).

4) Work to improve knowledge of production techniques and processes of industrial transformation and training of qualified personnel. Various activities, visits, exchanges were underway to validate the operation of equipment from different manufacturers local and European level. Partnership agreements with research centers for the development of equipment and development of industrial research at the site of Lanaupôle Fibre at Lavaltrie near Joliette (Quebec) were agreed. The preparation equipment set up straw Lavaltrie are start-up and some tests are underway. We have not had time to experiment enough to allow equipment to produce sufficient results obtained through analysis of performance. The test results will come to finalize the choice of certain equipment in the straw processing line to guide R & D.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

The completion of the step of setting up of equipment will continue to work to improve the knowledge of production techniques. This aspect is related to the pursuit of activities for protocol development and production process are to achieve in the coming months. Achieving this step will bring the training program for qualified personnel.

Several challenges must be overcome to continue the development of infrastructure for the development of agro-industrial link with the concept of bio-refinery plant (bioproducts). Among these challenges, developing a supply chain given the nature of raw material (straw), the transformation products (fibre), adaptation of post processing methods and quality criteria for finished products (market) based on natural fiber is to be done.

<b>Platform 3</b>	<b>Processing of Hemp and Flax</b>	<b>Project 5</b>	Electro-technologies for the processing of flax and hemp straw.
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Dr. G.S.V. Raghavan (514) 398-8731 McGill University	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

The added value and cost effectiveness of drying flax fibre and straw using an efficient microwave drying method were studied and the physical properties of the product (strength and colour) were compared to conventionally dried material.

Microwave-assisted drying of flax straw and fibre at controlled temperatures. This involves drying flax fibre and straw by using microwave energy, combined with convective air and to compare the tensile strength and colour changes of the different samples.

Specifics:

- To establish an optimum product processing temperature for flax fibre and straw.
- To compare microwave-convective drying with hot air drying at the same temperatures.
- To study the tensile and colour profile of flax fibre and straw after various drying processes.

- Brief methods description (reflect workplan milestones)

The material and methods used for the study are discussed in this section.

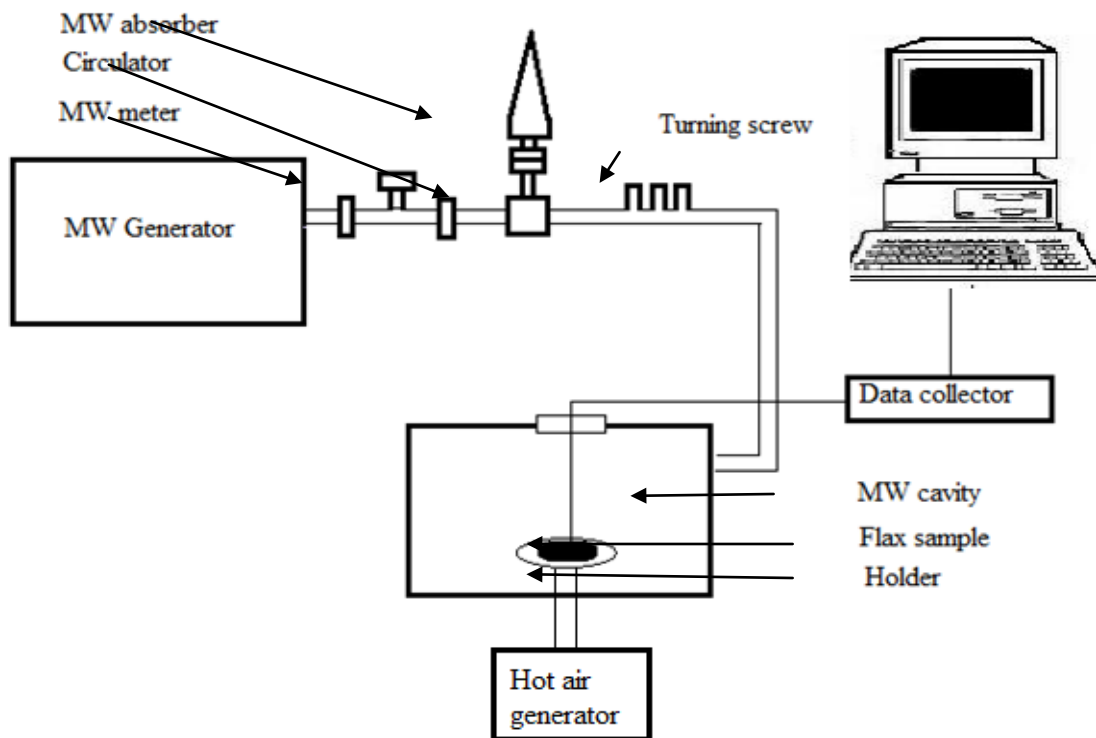
The flax straw used in all experiments was grown in a McGill University greenhouse under controlled conditions. The flax seeds of brown variety from local suppliers in Montreal were sown in pots of 24 cm diameter with a volume of 0.006 m<sup>3</sup>. The number of seeds in the pots was limited to a maximum of eight and the pots were filled with soil and organic manure mix. The flax plants were harvested after 100 days and kept in the green house for 2 weeks for drying. The moisture content of the flax stems was 3.93% w.b.

Flax fibres used for microwave drying were purchased from a local market in Humboldt, Saskatchewan, Canada. The fibre had a moisture content of 4.22% w.b.



## Microwave Apparatus

The drying of flax fibre and flax straw was performed by using a microwave apparatus designed in the post harvest technology lab, Macdonald Campus, McGill University (Figure 4.1). The microwave generator operated at 2450 MHz with a variable power from 0 to 750 kW. The temperature of the flax was measured with the help of an optical fibre probe (Nortech EMI-TS series, Quebec City, Canada). The temperature probes were connected to an Agilent 34970A data acquisition unit and that unit was connected to a computer (Dev et al., 2007). An adjustable hot air supply was attached to the microwave oven to pass hot air through the microwave oven to remove the moisture generated by the samples.



**Figure 1.** Diagram of microwave drying apparatus (Adopted from Dev et al., 2007).

## Experimental design

The flax fibre or straw was dried by either microwave-convective drying method or a hot air drying method, each operating at 40°C, 60°C or 80° C. The drying characteristics were recorded and analysed. Three replicates of each test were conducted. The tensile strength, elastic modulus and colour of the dried material were tested for all materials and each set of processing conditions.

### **Microwave drying of flax fibre**

Samples of flax fibre (25 g) bearing an initial moisture content of 4.2% w.b. were kept in a glass jar of volume 0.002 m<sup>3</sup> filled with tap water at room temperature for 48 hours. The samples were taken out and the excess water was removed by using a manually-operated centrifugal rotator (salad spinner). Initial moisture content was 60% w.b.. The drying temperatures were set at 40°C, 60°C and 80°C. Air flow of 40°C, 60°C and 80°C from an air blower was ensured in the microwave oven for the removal of moisture from the samples during the experiment. Throughout drying experiments the microwave reflectance was controlled manually with tuners. The sample temperature, microwave reflectance and sample mass were recorded by the computer at intervals of 30 seconds. The maximum incident power and the maximum reflected power were kept at 100 W and 80 W respectively for all the experiments. The drying was conducted until the material reached a final moisture content of 9% w.b.. Three replicates were done for each test.

### **Microwave drying of flax straw**

Flax straw was cut into 0.15 m lengths. The middle part of the plant stem was chosen for the experiment to ensure uniformity in carrying out drying tests. Flax straw samples (25 g) were placed in a jar full of water for 48 hours at room temperature to ensure fully wet conditions. The wetted samples (68-70% w.b.) had their surface water removed using a manually-operated centrifugal rotator (salad spinner). The samples were then weighed, and transferred to the microwave apparatus. The microwave drying was done at a temperature of 40°C, 60°C or 80°C. While drying, the microwave reflectance was manually controlled using tuners. The temperature, reflectance and mass were recorded by the computer at intervals of 30 seconds. The maximum incident power and the maximum reflected power were kept at 100 W and 80 W respectively for all the experiments. The drying was conducted till it reached a final moisture content of 9 % (wet basis). Three replicates of each test were done.

### **Hot air drying of flax straw and flax fibre**

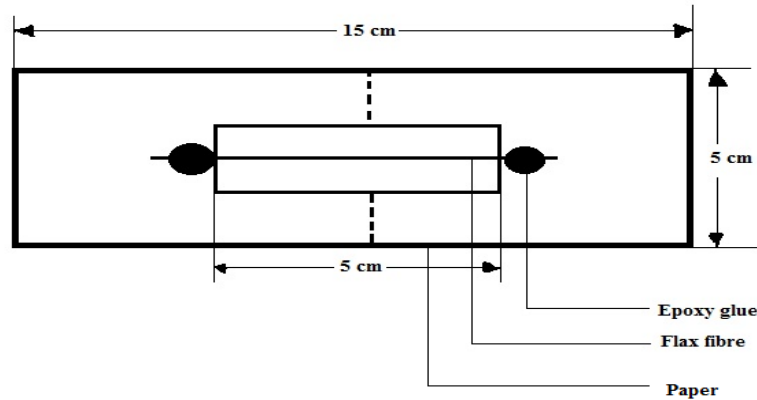
The same procedure for the sample preparation as per microwave drying was followed. The experiments were done with different temperatures of convective air at 40°C, 60°C and 80°C without microwave incidence inside the same microwave apparatus, with the microwaves off. The mass and product temperature were noted at 30 second intervals.

### **Tensile strength of flax fibre and straw**

Tensile strength of flax fibre and straw were measured with a tensile testing machine (Instron – 4502, Instron Corporation, USA) controlled by a computer software (Instron series IX, version 8.25). The samples were fixed with two clamps attached to the crosshead and platform, and crosshead set to move at a speed of 10 mm per minute. The flax fibre and straw, obtained under different drying conditions, were tested for their tensile strength and compared (Yuan et al., 2001).

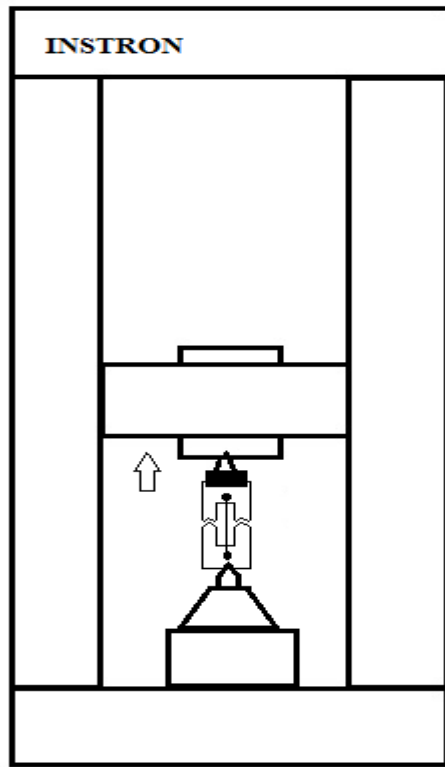
## Tensile strength of flax fibre

Five samples of flax fibres were randomly selected from the dried samples and each tested three times. For the tensile strength test (Figure 4.2), the desired length of the fibre was 75 mm, with a gauge length of 50 mm.



**Figure 2.** Flax fibre for tensile test

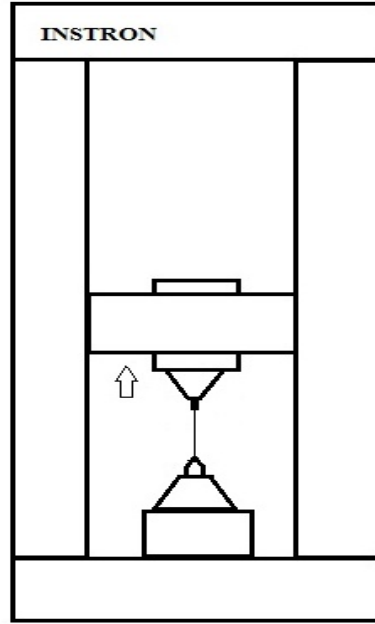
The fibre was fixed on a 50 mm × 10 mm sheet of paper with epoxy, so as to maintain the fibre in a straight and extended position (Figure 2). The flax fibre attached to the paper was mounted on the tensile test machine (Figure 3), the top end being attached to the machine with the help of a high-grip clip and the other end being connected to the chuck at the bottom. After mounting on the machine, the edges of the paper were carefully cut away and force applied in tension until the fibre broke into two. The force and displacement were recorded on an attached computer. Five sets of experiments were done, each with three replicates. The experiments were repeated for both the microwave and hot air dried samples and the results compared.



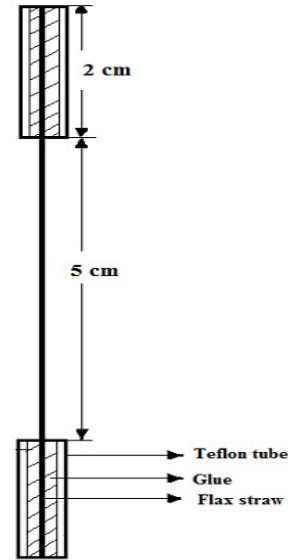
**Figure 3.** The tensile strength test of flax fibre

The tensile test of flax straw was conducted using the Instron tensile test machine only (no paper strip). Dried flax stems were taken and cut into 90 mm lengths and both the ends were inserted into small teflon tubes 20 mm in length and 3 mm in inner diameter and 5 mm in outer diameter. The flax straws were fixed in the tube with the help of a glue gun and allowed to set before conducting the experiments. The gauge length was 5 cm for all the samples. The samples prepared for the tensile strength test of flax straw is shown in Figure 4.

The prepared samples were mounted on the Instron tensile test machine (Figure 5) and the tension force applied until the sample broke into two. The force and displacement were recorded in the computer attached to the tensile strength machine. Five sets of experiments were done for each of the three replicates. The experiments were repeated for both the microwave and hot air dried samples and the results compared.



**Figure 4.** Flax stem sample



**Figure 5.** Tensile test of flax stem

The tensile strength of the flax fibre and straw were calculated using the equation:

$$\sigma_t = \frac{F_{\max}}{A}$$

where,

$\sigma_t$  is the tensile strength in  $\text{N mm}^{-2}$ ,

$F_{\max}$  is the maximum force applied (N), and

$A$  is the cross sectional area of the fibre ( $\text{mm}^2$ )

The modulus of elasticity ( $E$ ) was then calculated as:

$$E = \frac{\sigma_t}{\varepsilon}$$

where,

$\varepsilon$  is the tensile strain which is a dimensionless ratio of change in length and original length .

## Colorimetric test of flax fibre and straw

Changes in the colour of flax fibres and straw after microwave or hot air drying with respect non-dried samples were compared. Colour was assessed within the CIE 1976 L\*, a\*, b\* colour space (CIE, 2007) using a tristimulus colorimeter (Minolta Co. Ltd., Japan). Colour values, expressed as L\* (whiteness or brightness/darkness), a\* (redness/greenness) and b\* (yellowness/blueness) were determined for all samples.

Forty millimeter thick flax fibre or straw samples were placed on a table, and the L\*, a\*, b\* values measured by pressing the measuring head on the top of the samples. Three replicates of each sample were measured. Non-treated flax fibre and straw samples were taken as standards and colour change after the drying of the flax fibre and straw was calculated with respect to the standards. Colour difference values of  $\Delta L^*$ ,  $\Delta a^*$  and  $\Delta b^*$  were calculated by subtracting the respective standard colour values from the measured values for each set of dried experimental samples.

The target colours in this experiment are L, a, and b of the non dried flax fibre and straw. The total colour difference  $\Delta E$  is measured as (Minolta, 1991):

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

- Concluding statements that show the Sub-Activity met workplan deliverables.

The microwave-convective drying of flax fibre and straw was conducted at 40°C, 60°C and 80°C, and results were analysed and compared with hot air convective drying. At the drying temperatures of 40°C, 60°C and 80°C microwave convective drying took 30.8%, 54.8% and 48.5 % less time, respectively, than hot air drying. Among the microwave-convective drying conditions tested, drying at 80°C method proved to be the most suitable in terms of drying time.

The color change of the flax fibre and straw were studied in comparison with the initial untreated samples and microwave convective drying tended to result in greater colour change than did hot air convective drying. There was a significant difference in the color change between microwave-convective and convective drying of flax fibre. But in the case of flax straw, there was no significant difference in the colour change between microwave and hot air convective dried samples.

Tensile properties of microwave-convective and hot air dried flax fibre and straw were studied and compared with an initial non-dried sample. The tensile strength and modulus of elasticity increased with an increase in the temperature for both flax fibre and straw, but the tensile strength and modulus of elasticity of hot air dried flax fibre and straw were higher than that of microwave dried samples. The modulus of elasticity was found to decreasing with an increase in diameter of both flax fibre and straw.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

The studies on microwave assisted enzyme retting is not yet completed and still in progress.

- May include challenges and/or barriers to work and solutions

The early winding up of the project resulting in incomplete researches. So, ABIP could allow the organization for extending their works by giving some extra funds to perform the rest of the work.

**Under Platform 3, Project 6 report is listed with Project 3.**



<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 1A</b>	Micro and Nano Fibre Reinforced Extruded and Injection Molded Products
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Mohini Sain (416) 946-3191 University of Toronto	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose
- Brief methods description (reflect workplan milestones)
- Concluding statements that show the Sub-Activity met workplan deliverables.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance
- May include challenges and/or barriers to work and solutions

Our main objective of the project was to develop novel nanocomposites from Hemp fibre. The proposed work statement submitted with milestones were somewhat changed due to the change in the funding formula and also due to the reduction of actual time period of the project, which was originally set for 4 years.

In the early stages of the project we developed the chemical technology that relates to performance hemp fibre production for composite applications. This research resulted in lower chemical consumption and lower energy requirement.

One of the initial challenges associated with this project was the supply of nanofibre for carrying out composite manufacturing research. ABIP/NAFGEN funding was critical to purchase a high productivity grinder and that helped to produce the nanofibre in larger batches. It was a significant milestone of the project. Following are other specific milestones that were achieved:

- Developing a method to extract nanofibre from hemp stalk;
- Developing a process to pilot scale production of hemp nanofibre
- Drying technology of nanofibres

- Dispersion of nanofibres in solid/film/liquid phase

Our results on composite manufacturing indicated that aqueous phase resin can form a nearly transparent composite that has very high strength performance. These results are now being used to develop a nanopaper lab machine and the manufacturing of a lab-scale nanopaper unit is now complete. This will allow the making of sheet which is more or less the size of writing grade A4 paper.

Solid phase dispersion of nanofibre faced significant challenges in terms of reinforcement. On the other hand, laminated polycarbonate engineered composite developed have shown improvement of strength and rigidity of the polycarbonate. This project will be further explored for commercial prototype manufacturing. We are looking for additional funds for prototyping and have found an industrial partner from Europe.

<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 1B</b>	Micro and Nano Fibre Reinforced Extruded and Injection Molded Products
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Minh-Tan TON-THAT (450) 641-5138 National Research Council Canada - IMI	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

Polymer reinforced composites with flax fibres and petroleum based (polypropylene –PP) and biobased (polylactide – PLA) thermoplastics improved physical properties have been successfully developed. Flax fibres in both forms, the micro and nano-fibres, and nanoclays were also utilized to explore the possible advantages.

- Brief methods description (reflect workplan milestones)

Investigations were conducted on fibre preparation, formulation, melt compounding, and moulding processes to control the fibre distribution and the fibre-matrix interface thus the performance. Experiment was first carried on the batch process then to the continuous process (twin-screw extruder) using the semi-industrial equipment. In formulations with cellulose nanofibres and nanoclays the nanoparticles were first dispersed in the matrix prior to mixing with fibres. Different characterization techniques were developed to evaluate the quality of fibres and the fibre matrix-interface such as the Improved Single Fibre Tensile Test, the Surface Tension and the Single Fibre Pull-out Test. The developed composites were characterized using different techniques to understand the quality of dispersion of fibre and nanoparticles, the orientation in injection-molded specimens, the morphology, the interface, the rheology, the mechanical properties, the fire resistance, the biodegradability, the recycling ability.

- Concluding statements that show the Sub-Activity met workplan deliverables.

The cost-effectiveness of flax straw was briefly evaluated for the production of thermoplastic composites using the meting compounding process. It has been found that flax straw can be used without retting for low cost composite products. The developed PP-flax composites using IMI's proprietary formulation provides superior mechanical properties. The use of nanoclays (but not the nanofibres) in the formulation improves significantly to the mechanical properties of the PLA-flax composites that leads to a declaration of the invention. Both the PP-flax and PLA-flax composites appear to have a great recycling ability as the mechanical properties have not been deteriorate after 5 times of processing by injection molding, however, study on the recycling on post-consumer products is recommended. It has also been found that PLA-flax composites are

biodegradable under specific conditions. Finally the prototypes of the developed PP-flax and PLA-flax composites were also made.

Collaboration with the industrial partners, Schweitzer-Mauduit Canada and TTS, was also exploited in the development of cleaned flax fibres and flax mat-PP composites at the research level.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

N/A

- May include challenges and/or barriers to work and solutions

N/A

<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 1C</b>	Micro and Nano Fibre Reinforced Extruded and Injection Molded Products
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Satya Panigrahi Contact Kevin Rogers at (306) 966-2207 on Dr. Panigrahi's behalf. University of Saskatchewan	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

Our objective is to develop an integrated, multidisciplinary approach to R & D in economic value chains linking agriculture in Saskatchewan and Canada to develop new, unique flax fiber based commercially viable injection molding process and products for various applications that can be manufactured in Canada.

- Brief methods description (reflect workplan milestones)

The components of each value chain consist of , flax fiber, flax nano fibre, fiber modification process engineering, raw material development for injection molding industries, industrial scale product development, testing and economic analysis. Each value chain links with industry and research partner positioned to assist with the testing and market analysis of new flax fibre based biocomposite for their industries which include electronics, construction, automotive, commodity, engineering industries.

- Concluding statements that show the Sub-Activity met workplan deliverables.

We have completed the research work according to our NAFGEN plan. Extrusion and injection processing parameters of the flax fiber and nano fiber based biocomposite with polyethylene as matrices have been studied in details and optimized. Flax fiber-reinforced biocomposites were developed for two industries using extrusion and injection molding in this study. We have successfully demonstrated injection molded biocomposite products in conferences, workshops, trade mission in North America and Asia. The factors that influence the processing and the biocomposite properties were investigated. Research activities that have been conducted to fulfill the research objectives of this project. Apart from the objectives of this project, we have also studied (1) Modification of the flax fibre and nano flax fiber by chemical pre-treatment, (2) Studied the processing parameters of twin screw extruders and their utilization for the production of biocomposite, (3). Determined the influence of fiber content on biocomposite properties, (4) Determined of how injection molding parameters influence product quality, (5) Studied biocomposite rheology during injection molding etc..

Two new industries are developed with this research. Four graduate students have completed their MSc thesis. Several peer reviewed journal publications, peer reviewed conference proceedings, conference proceedings, poster presentations were made in Canada and abroad. One fiber processing pilot plant and one biocomposite pilot plant are developed at the University of Saskatchewan and technical tours conducted for NAFGEN network members and industries. These pilot plant are going to work as an incubator so that entrepreneurs, researchers and farmers can utilize this facilities in Saskatchewan.

We have developed an excellent technical and industrial network through ABIP – NAFGEN. We are very pleased with the CIC, and Flax 2015 and research service of the University of Saskatchewan and their staffs for their continuous support and guidance during the life time of this project.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

We met all according to the outline of the project.

- May include challenges and/or barriers to work and solutions

Some of the work is delayed but we are able to complete it.

<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 2A</b>	Engineered Mats for Composite Parts
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Stephen Meatherall (204) 262-3400 Composites Innovation Centre	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

Prior to the ABIP program, few attempts had been made to employ natural fibres in commercial thermoset applications, either for existing or new products. This was primarily due to the lack of availability of these materials to the commercial sector and the lack of knowledge required to correctly utilize these materials in an industrial setting. Project 4.2A was therefore established not only as a technology development initiative, but also as a technology transfer and marketing campaign for natural fibre composites. The primary objectives of this project included producing a nonwoven natural fibre composite mat in a commercial quantity and form, testing the materials to produce relevant information for the composite designer and fabricator, to produce at least one commercial prototype, investigate the economic feasibility of a nonwoven mat manufacturer supplying to the composite manufacturing market and the development a natural fibre composite material property database for public access.

- Brief methods description (reflect workplan milestones)

The commercial scale mat manufacturing activity commenced with small scale prototyping performed by the University of Philadelphia followed by extensive testing performed in-house at the CIC. Once the desired mat design and fibre specification criteria were established, ~2,500 kilograms of local Manitoba flax (supplied by SWM International) and high quality kenaf fibre were sourced to produce two commercial forms of natural fibre nonwoven composite mat. Subsequently, a comprehensive test program was performed on the composite processed material including mechanical, permeability, fire retardance/flame spread and accelerated weathering. The matting produced was made available free of charge to industry as well academic and research firms for research, testing, prototyping and process development purposes. CIC financial accounting staff were utilized to perform the business feasibility study of natural fibre composite mat manufacturer operating in Manitoba. Equipment and facility quotes were sourced and operating costs and other variables were estimated. From this, a return on investment, cost, volume & profit, income statement and sensitivity analysis were generated. Finally, a software development firm was engaged to assist in the development of the natural fibre composite property database. Once the requirements of the database were defined, iterative versions of the database were created until satisfactory functionality of the database was obtained.

- Concluding statements that show the Sub-Activity met workplan deliverables.

The natural fibre matting produced demonstrated a permeability of approximately 60% that of the equivalent glass infusion medium indicating that larger parts and parts with complex geometry could be infused. The mechanical properties of the natural fibre composites ranged from 35 – 65% that of the comparable glass reinforced composites. However, the natural fibre/glass hybrid composite outperformed the glass reinforced composite. To date, the kenaf and flax nonwoven composite mats produced in this initiative have been supplied to over two dozen composite industry fabricators, academic institutes and research firms. Commercial applications have included a bus sidewall (Motor Coach Industries), a tractor hood (Buhler Versatile), canoe (Hellman Canoes), skateboard (Rayne Longboards) and a CIC designed gazebo roof shelter. At this point, the market demand has rapidly outgrown the supply of these materials and the immediate requirement for a natural fibre nonwoven composite mat manufacturer is essential to satisfy this rapidly growing demand. The mat manufacturing economic feasibility study showed that a business supplying natural fibre reinforcement to the composite industry could operate as a profitable entity. However as the sensitivity analysis showed that the success or failure of the business is greatly dependent on the cost of the raw materials (fibre) and the end-market sales price. Finally, the database developed is currently being finalized and populated by the CIC and once satisfied, the CIC will publish the database to the internet.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance
- May include challenges and/or barriers to work and solutions



<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 2B</b>	Engineered Mats for Composite Parts
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Tamrat Tekle (780) 465-1532 Tekle Technical Services Inc.	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

The overall objective of this project is to develop natural fibre mats of relatively consistent physical properties suited for thermo set moulding (compression and/or vacuum) applications to replace current fibre glass applications.

- Brief methods description (reflect workplan milestones)

The brief methods include scaling up test set-up of lab fibre-feeder/opener; an engineered fibre mat pilot plant; Optimizing processing parameters for consistent mat configurations including fibre length, mat-laying process variables as well as operation conditions.

- Concluding statements that show the Sub-Activity met workplan deliverables.

The potential of natural fibre-based mats as a replacement for glass fibre re-enforcement in several applications in the emerging green economy is growing fast. In this study, an engineered fibre mat pilot plant equipped with air-lay forming and needle punch system has been designed and built. The optimum fibre length is in the range of 0.5mm to 100 mm depends on the type of fibre mat. Engineered fibre mats with different fibre configurations were developed including thermoset/thermoplastic mats for thermal compression moulding applications; bast fibre mats for resin infusion/impregnation applications; as well as erosion control and thermal insulation mats. The commercial applications of natural fibre mats as replacement for fibre glass mats for composites were also investigated. An automotive package-tray/ load-floor was developed by using thermoset fibre mats, as well as a truck canopy using bast fibre mats and resin infusion processing was successfully fabricated. Automotive applications based on the fibre mat composites are already being tested by car part manufacturers.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance  
N/A
- May include challenges and/or barriers to work and solutions  
N/A

<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 3A</b>	Development of a reliable fibre to resin interface for natural fibre composite as building materials
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Gilles Brunette (418) 659-2647 x 3801 FPIInnovations	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose
  - Development of strong fibres to resin matrix using different thermo-mechanical and chemical pre-treatments of natural fibres (hemp and wood)
  - Improvement of the bond quality of fibre/polymer composites through the interface modification; and
  - Process optimization for maximizing strength property of fibre/polymer matrix with the pre-treated fibres and modified interface

- Brief methods description (reflect workplan milestones)

Fibres were processed through FPIInnovations MDF pilot plant (Quebec, Canada) using the process that is similar to the process of wood fibre for medium density fibreboard. Both hemp fibre and wood fibre were produced respectively. The fibres were produced with or without coupling agent (Epolence C-26, Maleated polyethylene from Westlake Chemical Corporation). The loading of the coupling agent is 1.5 and 3.0% respectively.

The compounding of high density polyethylene (HDPE, Dow TM 12450N Health grade) with fibres of different loadings was done using either the internal mixer or the extruder with specially designed feeding system for uniform feeding of the fibre and polymer.

The composites were made with injection moulder into the standard test specimens and tests were carried out for bending strength and water absorption. The morphology of typical specimens with different composition of fibre and PE and process conditions was observed microscopically.

- Concluding statements that show the Sub-Activity met workplan deliverables.

In general, the compounding made with internal mixer had better uniformity than using the extruder and resulted with better properties in the composites.

Water absorption of the composites was reduced with introducing of the coupling agent, increasing fibre pre-treatment temperature and improving the uniformity of compounding.

The overall average retaining bending strength (MOR) after 3 weeks of water soaking was about 73.5% while overall retaining stiffness (MOE) was about 50%.

In comparison, the composite made with hemp flour without thermo pre-treatment and coupling agent had the retaining MOR and MOE of 75% and 47.9% respectively.

The hemp flour/PE composite without pre-treatment and coupling agent performed well in terms of water absorption and bending strength and similar to the best of the samples made with coupling agent and thermally treated wood fibre.

Two papers were generated and published in the Proceedings of 10<sup>th</sup> Pacific Rim Bio-Based Composites Symposium.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

Original planned experimental work on the enzymatic pre-treatment of natural fibre was not carried out due to the constraint of the budget.

- May include challenges and/or barriers to work and solutions

N/A

<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 3B</b>	Modification And Characterization Of Natural Fibre For Mat-Formed Fibre Matrix Composite
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Y. H. Chui (506) 453-4942 University of New Brunswick	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

To investigate the effect of alkaline-, enzyme- and heat-treatment on fibre properties and ultimately on composite properties.

- Brief methods description (reflect workplan milestones)

Three treatment methods were employed on flax fibres, namely: alkaline, enzyme and steam-heat treatment. Varying conditions e.g. chemical and enzyme concentration, pH, temperature and reaction time were employed for each treatment method. For alkaline treatment, sodium hydroxide was used. The enzyme used in enzyme treatment was laccase from *Rhus vernificera*. The effects of varying treatment methods on the morphology, crystallinity index, thermal stability, wettability and tensile strength of fibres were investigated.

UNB submitted flax fibres to Tekle Technical Services (TTS) for mat manufacture. Mats from Composites Innovation Centre (CIC) and those prepared by TTS were treated using alkaline solution and enzyme. Two treatment conditions from both alkaline and enzyme treatments were used, or a total of four treatment conditions. These treated mats were sent to CIC for making vinyl ester resin bonded composites. Due to the initial budgetary constraints, CIC was able to make composites only from CIC-treated mats. These composites were tested by CIC for tensile and flexural properties. The fractured test specimens were evaluated by UNB using Scanning Electron Microscopy (SEM).

With the additional funding, CIC is now able to make composites from UNB-treated mats. The mechanical properties of these composites will be tested and evaluated by UNB.

- Concluding statements that show the Sub-Activity met workplan deliverables.

It was found that enzyme treatment is the best approach to enhance the properties of flax fibre than alkaline and steam-heat treatments. CIC composites made with alkaline and enzyme treated mats gave 40% higher tensile strength, and around 28 % higher tensile modulus compared to untreated fibres. A 30% increase in flexural strength and 10% increase in flexural modulus were obtained from alkaline-treated mats. No significant

improvement on flexural properties was observed for the other three treatment conditions. SEM results indicate alkaline and enzyme treatment of flax fibre improved the bonding capacity between flax fibre and resin matrix. Thermal Gravimetric Analysis (TGA) was also conducted on the different composites to determine their thermal stability. It is theorised that if the fibres are bonded well into the resin, it will be more thermally stable than those where fibres acted only as fillers. This test is not completed yet.

One paper was submitted to a peer-reviewed journal, and another paper is being reviewed internally for submission to another peer-reviewed journal.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

It was initially planned that UNB would make the composites from different treated mats. Instead, we collaborated with CIC, who already has a good set-up for making composites from flax fibres. We requested raw fibre mats from CIC, treated them and returned the treated mats to CIC who produced composites using these treated mats. With this collaboration, both UNB and CIC were able to expand the scope of their projects without any significant increase in resources. With this arrangement UNB was able to investigate deeper into effects of various treatment methods on both fibre and composite properties, while CIC was able to extend their work to include composites made with treated fibres. We believe we met our objectives based on the results discussed above. Please note that we did not use the CIC fibres in investigating the initial work on investigating the effects of treatments on fibre properties. Nevertheless the results still show that treatment of mats gave significant improvements on mechanical properties, particularly on the tensile strength and modulus of composites. This points to the general applicability of the developed treatment method. Further validation tests on composites made with UNB fibres are being conducted.

- May include challenges and/or barriers to work and solutions

It would have been a much more productive collaboration with CIC if there was a better communication between the two research groups in the projects and that the additional funding was available earlier.

<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 3C</b>	Development of a Reliable Fibre to Resin Interface for Natural Fibre Composite as Building Materials
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Sean McKay (204) 262-3400 Composites Innovation Centre	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

This project investigated and developed optimal natural fibre surface preparations to be coupled with optimal natural fibre surface and/or resin manipulation for improved interfacial adhesion and therefore biocomposite properties.

- Brief methods description (reflect workplan milestones)

In the first year of the project we defined which test methods and protocols would best assess the behaviour/performance of the natural fibres and composites analyzed, which resins and fibre combinations would be considered, and composite processing strategies which would be most representative of large scale manufacturing and repeatable.

In the second year of the project we performed a multitude of different natural fibre pre-treatments, natural fibre surface treatments, resin modifications in the preparation of biocomposite specimens for mechanical testing and environmental stability.

In the final year of the project we evaluated all of the results to find the most optimal combination of natural fibre pre-treatment, surface treatment, and resin manipulation to enhance interfacial properties and biocomposite durability properties.

- Concluding statements that show the Sub-Activity met workplan deliverables.

The most prominent finding which is beneficial for industry's adoption of this technology to potentially replace traditionally used fibreglass in composite applications was that resin manipulation proved more effective than actual fibre surface treatments in obtaining optimal mechanical properties of the biocomposites produced. This interfacial manipulation strategy not only proved most successful in improving mechanical properties but was also the most affordable to implement because it requires less fibre handling, lower cost of chemicals used and associated disposal, and improved composite manufacturing efficiency and quality. Several conference proceedings and journal articles have been published, are currently under review, or have been recently submitted to disseminate the knowledge gained from this project.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

N.A.

- May include challenges and/or barriers to work and solutions

N.A.

<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 4A</b>	Green LEED™ Compatible Building Products
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Tamrat Tekle (780) 465-1532 Tekle Technical Services Inc.	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

This project involves the scaling up of a fibre-cement family of products/technology to develop commercial green LEED™ compatible building blocks for application in sound insulation by using agricultural residues.

- Brief methods description (reflect workplan milestones)

The brief methods include developing a standard test set-up/procedure based on hydration temperature measurement, for standard evaluation of the compatibility between natural fibre and ordinary Portland cement. Optimizing processing parameters by using design of experimental (DOE); Designing and fabricating commercial standard size temporary moulds and fabrication of fibre-cement blocks for testing, fabrication of fibre cement blocks in limited commercial moulds.

- Concluding statements that show the Sub-Activity met workplan deliverables.

Cement-bonded fibre composites are self-insulated, including thermal and sound insulation, resistant to rotting, rodents, insects, and they are fire proof, waterproof, weather resistant. A large quantity of agricultural waste is generated worldwide annually. The agricultural wastes, such as hemp hurds, flax shives and wheat straw, provide an ideal alternative to light weight aggregates for cement composites. However, there are technical challenges in mixing high content of lignocellulosic materials with cement due to high pH cement-curing environment, which causes such natural Fibres to retard or even inhibit the curing of cement. In this study, a system was developed to accelerate the setting time of Fibre cement composites. The effects of Fibre type, Fibre content, water/cement ratio on the compression strength and thermal conductivity were investigated. The results from this study indicated that wood fibre had better compatibility to cement than flax, while hemp hurd was the worst one. To improve the compatibility between hemp hurd and cement, a fractional experiment design was used to study the effect of five chemical additives on the compatibility and strength of hemp hurd-cement composites. The hydration time could be reduced by 33 hours from around 36 to 3 hours by the established accelerating system. It also works very well with other natural fibres, such as flax shives, wheat straw and wood barks. The compressive strengths of all tested fibre-cement composites with 35 % natural fibres were met the



requirements of ASTM 332 standard. The thermal conductivity of composite panels was tested according to the standard of ASTM C177. The oven-dry density of the panels was varying from 450-850 kg/m<sup>3</sup> (28-53lbs/ft<sup>3</sup>). The thermal conductivity was in the range of 0.080-0.160 W/m·K. The thermal resistance R-value (per inch) was 0.88-1.80 ft<sup>2</sup>·F·hr/BTU. The potential commercial products generated from this project are light-weight semi-structural and thermal and acoustic insulating fibre-cement blocks, wall material, ceiling tile, flooring, shingle and siding panels. The technology is ready for scaling up and a decision was made to pursue commercialization, first through a well set-up, pre-commercial pilot manufacturing activity.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance  
N/A
- May include challenges and/or barriers to work and solutions

It was difficult to set-up a test run in an existing commercial block-making plant. We were given extra funding towards the end of the project, which we supplemented to set-up a pilot manufacturing line with limited commercial size block manufacturing capability. This will enable the pre-commercialization of fibre-cement building blocks.

<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 4B</b>	Green LEED™Compatible Building Products. Structural And Thermal Performance Of NF Building Products
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Colin MacDougall (613) 533-2469 Queen's University	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

#### **Activity 4.4B.1 Design and testing of columns**

- Sub-Activity objective or purpose

Establishing the structural strength of columns constructed using waste straw bales and plaster.

- Brief methods description (reflect workplan milestones)

Full-scale columns constructed and tested to failure using standard members.

- Concluding statements that show the Sub-Activity met workplan deliverables.

Columns met required structural strength for building code purposes. This design was used to construct a sustainable performing arts building. Sustainable builders obtaining their college degree, learned about using these columns (Fleming College). Refereed conference paper presented at conference in Bath, England.

#### **Activity 4.4B.2, 4.4B.4, 4.4B.6 Hot-box testing and elevated temperature tests**

- Sub-Activity objective or purpose

Determining the performance of hempcrete at low temperatures typical of Canadian environments.

- Brief methods description (reflect workplan milestones)

Thermal testing of hempcrete in a standard hot-box while being subjected to temperatures down to -20 degrees C.

- Concluding statements that show the Sub-Activity met workplan deliverables

Hot box constructed and hempcrete tested. Refereed conference paper will be presented at conference in China in September 2011, journal paper to be submitted in 2011. Work resulted in development of relationship with company interested in patenting a new hempcrete formulation.

#### **Activity 4.4B.3, 4.4B.5 Industry Interaction**

- Sub-Activity objective or purpose:

Presenting research results to relevant industry members.

- Brief methods description (should reflect workplan milestones)

Attending conferences, contacting relevant industry members.

- Concluding statements that show the Sub-Activity met workplan deliverables

Test results used by structural consulting company (Blackwell Bowick) as part of their due diligence in approving a project using these proposed columns. Have initiated a Natural Building Engineering Group with engineers from several companies that meets regularly by teleconference.

#### **Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

N/A

- May include challenges and/or barriers to work and solutions

N/A

<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 5A</b>	Development Of New Bioproducts - Natural Fibre Agriculture Part Development
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Dr. John Wolodko (780) 450-5407 Alberta Innovates – Technology Futures (formerly the Alberta Research Council)	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

The objective of this project is to evaluate the potential of utilizing bast fibres in conjunction with synthetic thermosetting resins in the production of fibre reinforced polymer (FRP) components. The ultimate goal will be to demonstrate the technical and commercial viability of utilizing natural bast fibres as a replacement for conventional glass fibres systems in low-cost fabrication applications. The main benefit will be to develop viable materials and processes which can be directly incorporated into existing manufacturing operations with minimal capital expenditure and risk. This study targets fabrication processes which are used extensively worldwide, and will have a significant impact if successful

- Brief methods description (reflect workplan milestones)

Work plan focused on the following tasks:

1. Literature Survey & Equipment Procurement – research available literature and equipment for both spray-up and wet lay mat manufacturing of natural fibre systems for composite applications.
2. Wet Lay Mat Development & Hand Lay-up Trials – develop lab-scale wet lay mat manufacturing apparatus and trial wet laid mat processing at larger scale with available industrial paper making processes. Trial mats were used to fabricate composite laminates using hand lay-up, compression molding and resin transfer molding processes.
3. Spray-up Development & Trials– develop new spray-up method for natural fibre composites. Examine pre-mixed versus blown system.
4. Laminate Testing – Screening (short-term) – test mechanical properties of test plates manufactured using a variety of methods.
5. Laminate Testing – Long-term – test manufactured laminates for long-term durability
6. Full Scale Prototype – develop full scale prototype (if process methods are successful and scalable)
7. Economic Assessment – assess market potential and commercialization partners

8. Other Experimental Studies (added scope):
    - Mechanical and thermal cure analysis of bast fibre reinforced unsaturated polyester (UP) composite laminates – to determine how manufacturing (cure) rates are affected by using natural fibre systems
    - Fibre geometry characterization – to determine processed fibre geometries used in composite plates (fibre geometry affects properties)
- Concluding statements that show the Sub-Activity met workplan deliverables.
    1. Literature Survey & Equipment Procurement – background work was successfully completed – there was no commercially available spray-up systems for natural fibres (market potential); a number of processes were available for wet lay manufacturing (papermaking), but it was unclear whether these would be applicable for composite mat manufacturing.
    2. Wet Lay Mat Development & Hand Lay-up Trials – For the wet lay mats, a lab-scale mat forming technique was developed in-house to manufacture small mat sheets (approximately 600 mm in diameter) via a sheet forming method. This novel method will allow the future study the various parameters associated with mat formation including effect of fibre length, fibre pre-processing (e.g. mechanical versus chemical pulping), dispersants, fibre treatment and mat compression (effect on loft and permeability). Composite laminates were fabricated using the above mat preforms along with a general purpose unsaturated polyester resin. The test plates were manufactured using conventional hand lay-up techniques followed by consolidation and curing in a heated press (compression molding). Mats produced using the lab-scale process showed good permeability characteristics.
 

Wet laid mat preforms were also manufactured using a pilot-scale (commercial) Fourdrinier (single wire) papermaking machine. One main issue that was found from this preliminary work was that the pilot-scale wet lay process used produced a mat with poor wet-out properties (i.e. difficult for resin to penetrate preform structure). This is quite different from the dry laid natural fibre preform mats previously tested as well as the mat preforms produced using the in-house system.

Composite laminates were successfully fabricated using wet laid mats using hand lay-up, as well as compression molding and resin transfer molding (RTM) techniques for comparison (see property assessment below).
    3. Spray-up Development & Trials – A prototype spray-up system which is capable of handling, opening and dispensing natural fibres into a resin stream was successfully developed. The system is composed of a fibre opener (pinned rollers), a centrifugal fan to move and dispense the fibre, and a resin dispensing system to mix, meter and spray the resin on to the part along with the fibres. Initial trials were performed with both hemp and flax bast fibres. Challenges that have been noted are fibre agglomeration (i.e. clumping), and fibre spring-back on the part. Due to the curved and kinked nature of natural fibres, there is a tendency

for fibres to agglomerate particularly when they are moved in an air stream. The spring-back is also caused by the curvature in the fibre, and results in a noted increase in voids (air pockets) and reduction in consolidation (both of which are detrimental to laminate properties). Hybridization with glass fibres also adds a complication to laminate development. The E-glass fibres tend to be wet out by the UP resin very quickly leaving the hemp fibres without enough resin. This coupled with the fibre spring-back and fibre curvature still results in an increase in voids and a reduction in tensile properties.

In addition to conventional fibre spray up methods, a system for spraying pre-mixed fibre and resin mixtures was tested. Initial trials used water thickened with Guar Gum to 750 cps as an alternative to an unsaturated polyester resin of the same viscosity (this eliminated the danger of the resin curing in the equipment while these trials were attempted). In addition to the spray trial with simulated fibre-resin mixtures, lab tests were also conducted to determine the effect of fibre loading on resin viscosity changes. In both cases, the maximum fibre loading that could be sprayed was found to be approximately 2% (by weight). For composite applications, this is considered to be very low, and will not impart any structural reinforcement to a part. The main problems encountered with the pre-mix approach was two-fold: 1). the spray trials showed that at higher loadings, the longer bast fibres tend to bridge across the pump inlet, blocking flow (plugging), and 2) resin-fibre mixtures greater than 2% showed significant increases in viscosity (could not be measured by available equipment). As a result of these findings, the pre-mix approach was not considered any further.

4. Laminate Testing – Screening (short-term) – Mechanical testing of laminates made using both laminating processes hand lay-up, compression molding and resin transfer molding) and spray-up was performed. Overall, natural fibre composites showed fair tensile modulus properties compared to synthetic glass-fiber composites (approximately 30%-60% of glass fibre composites), but showed poor tensile and impact strengths relative to glass fibre composites (less than 20% of glass-fibre composites).

Overall, composites fabricated using hand lay-up showed the poorest mechanical properties versus compression molding and RTM. This was attributed to lack of part consolidation resulting in a decrease in final volume fraction of fibres and air voids.

For the spray-up trials, test specimens produced demonstrated very poor properties (less than unreinforced resins) due to lack of consolidation (fibre springback) and trapped air voids. In an effort to improve properties, a hybrid laminate (natural fibres and glass) plate was also manufactured and tested. This hybrid laminate contained a 50/50 mixture of decorticated hemp bast fibre and chopped E-glass fibre which was found to improve properties.

5. Laminate Testing – Long-term – Long-term durability testing was originally planned in the original proposal but was eliminated when project funding was reduced – this task was not initiated.
6. Full Scale Prototype – This task was also not completed due to the difficulties encountered with both pilot-scale wet laid mat forming and prototype spray-up processes. Both of these were not sufficiently ready for pre-commercial or commercial demonstration with an industry partner at this time.
7. Economic Assessment – an economic and market assessment for natural fibre composites made from both mat and spray-up technologies was completed and showed that there is a growing market for “green” products. Potential commercialization partners were identified. Challenges that are faced for commercialization include required improvement in composite properties, reduction in moisture absorption of these materials, and development of a natural fibre supply chain in Canada and North America.

8. Other Experimental Studies (added scope):

- Mechanical and thermal cure analysis of bast fibre reinforced unsaturated polyester (UP) composite laminates:

This work was conducted to investigate the impact of natural fibres on the cure rate of thermosetting polymer resins at room temperature. Since most of parts fabricated using low-cost manufacturing processes are air cured at room temperature, it is necessary to determine what factors affect cure times (and, ultimately, manufacturing cycle times). From the literature, there seems to be a contradiction on whether the addition of natural fibres actually accelerate or decelerate resin cure times. This work was intended to address this issue in a systematic manner. Tests were conducted using differential scanning calorimetry (DSC) to measure the degree of cure for a unsaturated polyester resin system with and without decorticated hemp and with fibres having different levels of moisture. The main outcome from these experiments suggests that natural fibres are beneficial for increasing manufacturing cycle times, however, special care must be made to reduce the moisture content of natural fibre mat preforms prior to molding. Furthermore, modification of the fibre to increase its hydrophobicity would be beneficial. The economic impact of drying fibres may be significant.

- Fibre geometry characterization – to determine processed fibre geometries used in composite plates (fibre geometry affects properties)

In order to characterize the geometry of bast fibres, a specialized fibre analysis procedure previously developed at AITF was used to quantify fibre length and average diameter. The main benefit of this system is that faster statistical characterization (with larger population sizes) can be performed relative to conventional microscopy methods. The system uses custom image analysis software, previously developed at AITF, to rapidly analyze a prepared plate of

bast fibres which have been sampled and manually separated. The analysis routines is especially geared towards measurement of fibre length and average diameter for curved or kinked fibres (common for bast fibres). The routines also allow for the elimination of hurd/shive particles fibre crossover in the statistical analysis (significantly speeding up the analysis process). This system was used to characterize the fibre distributions of the fibre feedstocks used in the composite mat and spray-up processes.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

Full scale prototypes with industrial partners was not completed due to the difficulties encountered with both pilot-scale wet laid mat forming and prototype spray-up processes. Both of these technologies require further development prior to deployment with a partner company (technologies not sufficiently ready for pre-commercial or commercial demonstration with an industry partner at this time). In addition, long-term durability testing needs to be performed in future work. This task was planned in the original proposal to ABIP but was eliminated when project funding was reduced (task was not initiated).

- May include challenges and/or barriers to work and solutions

Two extra work tasks were performed in this project to better understand cure rate effects of natural fibre composites (important for ensuring adequate manufacturing cycle times), and to characterize the fibre geometry of materials used in the manufacturing processes. See results in previous section.



**Under Platform 4 there is no Project 5B.**

<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 5C</b>	Development of New Bioproducts - Natural Fibre Agriculture Part Development
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Mark Townsley (204) 262-3400 Composites Innovation Centre Manitoba Inc.	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

The objective of this project is to validate nature fibre composite components for the mass transportation industry.

- Brief methods description (reflect workplan milestones)

The mass transportation industry partner was Motor Coach Industries Limited (MCI) with demonstration part, the battery door and right and left hand sidewall panels, selected from a J4500 model coach. The project consisted of producing prototype parts and small scale representing panels that were subjected to testing. The results were used to determine the viability of using the nature fibre to the bus component application.

Key attributes were identified with regards to material performance of existing materials (primarily polyester/vinyl ester resin and fibreglass laminates) and qualification programs were defined for hemp mat, hybrid hemp/glass and polyester/vinyl ester alternatives. Test regimes that were deemed critical in attaining the qualification of biofibres for their eventual replacement of fibreglass laminates consisted of the following: coefficient of thermal expansion(CTE), surface flammability (ASTM E162), bi-thermal sandwich panel deflection, sandwich panel flexural strength, laminate mechanical properties (tension, flexure and in-plane shear) and thermal expansion fatigue performance. Baseline fibreglass reinforced laminate were included for comparison purposes. Processing methods for producing the laminates were developed and test laminates and sandwich panels were fabricated, specimens prepared, conditioned and tested.

- Concluding statements that show the Sub-Activity met workplan deliverables.

Following were concluded from the test results:

- The hemp only fibre laminate illustrated a comparable CTE with the baseline laminate
- The hybrid fibreglass and hemp fibre laminates displayed CTEs lower than the baseline

- The hemp only sandwich panel was found to be very flammable, displayed the maximum displacement in bi-thermal testing and featured a brittle tensile failure in bending
- The hybrid fibre sandwich panels were found to be more flammable than the baseline, but less flammable than the hemp only fibre panel. They produced less bi-thermal displacement than the baseline. All hybrid fibre sandwich panels failed in combined interface and core shear failure modes during the flexural testing. The baseline sample consisting of fibreglass only reinforcement produced the highest load carrying capacity

A pair of the MCI J4500 side walls were successfully manufactured using the vacuum resin infusion method. A thermal expansion fatigue was performed on the side wall panels. All test coupons passed the fatigue criterion of 30,000 cycles without any major failure observed.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

There were no changes that affected the overall outcome of this project.

- May include challenges and/or barriers to work and solutions

There were no primary hurdles or barriers that affected the overall outcome of this project.

<b>Platform 4</b>	<b>Materials and Manufacturing</b>	<b>Project 6A</b>	Natural Fibre Quality Assessment
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Mercedes Alcock (204) 262-3400 Composites Innovation Centre	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

The Sub-Activity, 6A, had the objective of continuing the work on linking fibre properties to composite performance as started in the National Biofibres Initiative that was run previous to ABIP.

- Brief methods description (reflect workplan milestones)
  - Fibre materials were collected and distributed to partners
  - Fibres were treated using enzyme process developed by Platform 3
  - Composite panels were made and tested
  - Data was analysed and compared to data collected from a previous project
- Concluding statements that show the Sub-Activity met workplan deliverables.
  - The enzyme process utilized successfully reduced the fibre diameter, wax and pectin contents of the fibres
  - The changes to the fibres did not produce measurable improvements in the composites, possibly due to the fibre changes being of less impact than a weak interfacial bond between the fibres and the matrix

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

Work has not been published yet, but efforts to publish will be ongoing, even after March 2011 deadline.

- May include challenges and/or barriers to work and solutions

Issues with lagging funding approvals interfered with the completion of the project in a timely fashion. Additional delays were incurred due to project partner's technical staff leaving before the completed report could be written.

<b>Platform 5</b>	<b>Primary Fractionation and Transformation</b>	<b>Project 1</b>	Cost-competitive green technologies for the extraction, fractionation and transformation of shive/straw from flax and hemp into distinctive materials and into bio-platform molecules for further bioconversion
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Giuseppe Mazza (250) 494-6376 AAFC, Summerland	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

New S&T information on "Green" extraction, purification and conversion processes for the production of polysaccharides, polyphenols and wax-based biochemicals (Mazza et al.).

Pilot scale pressurized low polarity water extractor(s) for processing of 100 kg-quantities of feedstock (Mazza et al.)

- Brief methods description (reflect workplan milestones)

Perform pressurized low polarity water (PLPW) extraction and fractionation of biochemicals such as lignins, ferulic acid and vanillin, and carbohydrates from flax straw and shive fractions and implement advanced analytical techniques to determine the concentrations of selected biochemicals (Mazza et al.);

Investigate lignin and hemicellulose as platform chemicals for bio-phenolics and xylose derivatives (Mazza et al.);

Conduct chemical modification to improve functional properties for specific applications, such as adhesive, UV stabiliser and colouring agent, biopolymer additive, surfactant, radical technology, durability enhancement, and as a source of guaiacol, vanillin, acetovanillone, dehydrodivanillin and other high value chemicals (Mazza et al.)

- Concluding statements that show the Sub-Activity met workplan deliverables.

Research Outcomes: Technologies, Products & Knowledge

- Optimized PLPW processing conditions for the fractionation of flax shives and production of hemicelluloses, lignin, and cellulose;
- Optimized supercritical carbon dioxide extraction of wax from flax straw;

- Developed process for the isolation and characterization of lignins from flax shives using PAE;
- Developed process for the extraction and purification of ferulic acid from flax shives by alkaline hydrolysis and pressurized solvents;
- Created new knowledge on extraction of lignin from flax shives by ionic liquids;
- Created new knowledge on the pretreatment of biomass with ionic liquids.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

Demonstrate that flax shives and straw are potential new sources of

Lignins

Hemicelluloses

Cellulose

Waxes

(For details see list publications by Mazza et al.)

- May include challenges and/or barriers to work and solutions

All worked very well.

<b>Platform 6</b>	<b>Further Processing and Bioconversion</b>	<b>Project 1</b>	Production Of 2,3-Butanediol, Acetoin And Ethanol From The Hemicellulose/Pentosans Stream
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Denis Groleau (514) 496-6186 Bioprocess Centre, NRC-BRI	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

Add commercial value to the 5 carbon sugars (mostly xylose) expected from biorefineries handling natural fibres by converting, *via* bacterial fermentation, the 5 carbon sugars into important chemical feedstocks such as: 2,3-butanediol (priority 1), ethanol (priority 2) and acetoin (priority 3). Our emphasis has been on 2,3-butanediol, a 4C-diol that can be used either as chemical feedstock or as bio-fuel.

- Brief methods description (reflect workplan milestones)

A literature search was conducted in order to identify which bacteria appeared the most promising for converting 5C-sugars into 2,3-butanediol. Two *Paenibacillus* (*Bacillus*) *polymyxa* strains were finally selected. Initial work in shake flasks using glucose (6C-sugar for comparison purposes) or various 5C-sugars, tested individually, showed variable results: Good results with glucose, “interesting” results with xylose, and variable results with the other 5C-sugars. Further work carried out in small-scale bioreactors (12-20L) showed that converting glucose (6C-sugar) into 2,3-butanediol was easy. In the process, we identified fermentation parameters yielding either an enriched 2,3-butanediol + ethanol stream or an enriched acetoin stream (containing significantly lower concentrations of 2,3-butanediol and of ethanol). However, similar bioreactor work using highly pure xylose ended up being much more problematic. It became obvious that xylose is a much more “difficult” substrate than glucose for producing 2,3-butanediol. After a long period of unsuccessful results, it became increasingly obvious that efficient conversion of xylose into 2,3-butanediol requires rather “capricious” aeration conditions, of the microaerophilic type. Later on, we realized that the conversion of xylose into 2,3-butanediol required monitoring and control of the RQ (RQ: respiratory quotient or coefficient). A RQ value above 1, preferably around 1.5, is required for significant conversion of xylose into 2,3-butanediol. In the last 4-6 months, several fermentation runs have yielded 2,3-butanediol concentrations in the 20-30 g/L range, which is quite acceptable at the present stage of the project.

- Concluding statements that show the Sub-Activity met workplan deliverables.

A solid proof-of-concept for the conversion of highly pure xylose into 2,3-butanediol has been produced (with some production of ethanol). 2,3-butanediol is a rather “forgotten” chemical feedstock that seems to generate increasing interest (as potential bio-fuel and as chemical feedstock). Recent literature indicates that 2,3-butanediol could be turned into butanol (a more volatile bio-fuel).

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

Little work was done on the testing of real 5C-sugars streams derived from natural fibres due to the difficulties experienced with the conversion of pure xylose into 2,3-butanediol. Only preliminary work was conducted. Also, we now have 20-25L of 2,3-butanediol-rich fermentation liquor waiting for Dr. Kumar to use for his 2,3-butanediol recovery work.

- May include challenges and/or barriers to work and solutions

We are ready for testing our fermentation conditions on realistic 5C-sugars streams obtained from the processing of natural fibres. However, serious testing (in bioreactors) will require significant quantities of such 5C-sugars streams, with a quality (sugar concentration, absence of inhibitors, etc) that will permit efficient conversion into 2,3-butanediol. We are not sure that such 5C-sugars streams can be obtained in the short-term.



<b>Platform 6</b>	<b>Further Processing and Bioconversion</b>	<b>Project 2</b>	Recovery of 2,3-butanediol and of Associated Products
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Ashwani Kumar (613) 998-0498 National Research Council of Canada	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose
  - To develop a membrane-based separation scheme for recovering 2,3-butanediol from a biological reactor process stream;
  - To develop (possibly) processes that can also recovery some associated important products such as acetoin and ethanol; and
  - To develop recovery processes, which are cost-effective and can be scaled-up.
- Brief methods description (reflect workplan milestones)
  - Complete a comprehensive literature survey of the state-of-the-art of 2,3, butanediol separation; and identify membranes for experimental studies;
  - Adapt analytical procedures for determining the concentration of 2,3, butanediol, water, acetoin and ethanol;
  - Evaluate suitable ultrafiltration, nanofiltration and extraction techniques for pre-treating simulated liquids containing 2,3, butanediol and water and
  - Identify suitable membranes for recovering 2,3, butanediol and other chemicals from fermentation broth.
  - Perform preliminary experiments to determine the effects of process variables on separation;
  - Evaluate a series of pervaporation membranes for selective removal of organics from the simulated and actual clear liquids.
  - Develop an energy efficient separation scheme for recovering 2,3,-butanediol from broth in the laboratory;
  - Evaluate the selected process on-site with a pilot scale biochemical reactor; and
  - Generate of Intellectual Property that will possibly lead to filing of a patent.
- Concluding statements that show the Sub-Activity met workplan deliverables.

The sub-activity met most of the major work plan objectives. We were able to show the feasibility of using a membrane-based process for recovering butanediol from the product stream coming from a biochemical reactor.

The research work mainly focused on the development of a mixed matrix membrane using poly dimethyl siloxane and molecular sieves and subsequent development of a

process involving solvent extraction and pervaporative membrane process for recovering butanediol. It was shown that a two step membrane process could be used to recover butanediol of high purity exceeding 98%. We also compared our process with membrane distillation and showed that our process was more energy efficient.

We worked closely with our colleagues at Biotechnology Research Institute and successfully tested the process on the samples produced in biochemical reactor.

The following peer-reviewed publications resulted from this work (Authors Shao and Kumar):

*Can J. Chemical Eng.*, Accepted Sept. 2010.

*J. Membrane Sci.*, 339 (2009) 143-150

*J. Membrane Sci.*, 329 (2009)160-168

Others

*Chemical Engineering and Processing-Process Intensification*, under review.

Presented at the 8<sup>th</sup> World Congress of Chemical Engineering (WCCE8), August 23-27, 2009, Montreal, Canada

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

We did not evaluate the selected separation process scheme on-site with a pilot scale biochemical reactor. The work resulted in several publications but no Intellectual Property relating to this process was generated, which would have led to a patent filing.

- May include challenges and/or barriers to work and solutions

One of the biggest challenges in this project was lack of resources for this sub-activity.

<b>Platform 6</b>	<b>Further Processing and Bioconversion</b>	<b>Project 3</b>	Hemicellulose-Degrading Enzymes
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Peter Lau (514) 496-6325 NRC-BRI	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

This sub-activity was carried out to investigate the use of xylanases (hemicellulases) from fungal origin for the degradation of hemicellulose fractions obtained from different feedstock (e.g. wheat and triticale bran, flax shives etc.). Several fungi from diverse sources were screened for their ability to produce hemicellulases, enzymes that allow the degradation of hemicellulose to sugar monomers, the source of a value chain. The best performing enzymes were to be isolated, characterized and expressed in a simple surrogate production host viz. *E. coli* in order to avoid the cumbersome cultivation of the original fungal system.

- Brief methods description (reflect workplan milestones)

Ten new fungal strains were screened for wheat-bran induced xylanase activity. A *Rhizopus* strain which showed the highest requisite enzyme activity was chosen for investigation. At first fermentation was optimized to produce the highest level of xylanase. The xylanase-containing culture supernatant was subjected to protein purification which revealed the existence of two different xylanases. Both xylanases were purified by column chromatography (purification protocol was developed for each protein) to electrophoretic homogeneity. The N-terminal and/or internal amino acid sequences were then determined to facilitate cloning of the respective genes. The purified enzymes were characterized by determination of their molecular and kinetic parameters.

- Concluding statements that show the Sub-Activity met workplan deliverables.

According to the workplan, we successfully identified, isolated and cloned two new xylanase-encoding genes from a fungal origin which was shown to be effective in degrading hemicellulose from wheat, triticale, flax and hemp biomass fractions to produce monomeric sugars (xylose). We worked interactively with theme 5 which supplied one of the “field” substrates instead of model substrates. New knowledge was gained and added to the repertoire and important families of hemicellulases. A manuscript describing the new enzymes and their applications is in preparation for possible publication as a way to attract partnership or collaboration.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

All milestones outlined in the project plan have been met.

- May include challenges and/or barriers to work and solutions

A hurdle to overcome was when a hired person left before the term ended. A low budget caused the division of tasks instead of a dedicated input. Also the relative short term of the project created a sense of uncertainty.

**Under Platform 6 there is no Project 4.**

<b>Platform 6</b>	<b>Further Processing and Bioconversion</b>	<b>Project 5</b>	Enabling analytical tools to analyze and quantify processes related to above projects
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Jalal Hawari (514) 496-6267 BRI, National Research Council Canada	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose  
Our role was to develop enabling analytical techniques to support the project lead by Robert Lortie.
- Brief methods description (reflect workplan milestones)  
We developed HPLC, LC/MS and SPME/GC/MS tools to analyze butanediol to help advance the project.
- Concluding statements that show the Sub-Activity met workplan deliverables.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance
- May include challenges and/or barriers to work and solutions

N/A

<b>Platform 7</b>	<b>Bast Biorefineries: Sustainable Systems Design</b>	<b>Project 1</b>	System Design Options for a Sustainable New Hemp Industry (Quebec Case)
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	René Pigeon  (613) 943-8840 NRCan, CanmetENERGY, Bioenergy Group	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

The goal of developing system design options, or pathways, for a new hemp industry in Lanaudière had to be adapted halfway while that of raising sustainability was adapted accordingly. After having worked, in the initial phase (2008-2010), chiefly to develop system design options and receptors that can convert intermediate hemp products (fibre, hurd...) into fibre-enhanced products, the rare availability of stakeholders (Lanaupôle Fibres and Lanaufibres) for collaboration led NRCan to steer its work, in the final phase (2010-2011), towards designing and experimenting pathways that valorize processing wastes (dust, husk) into biofuels and a soil amendment for growing hemp: biochar. These pathways raise the sustainability of hemp growing & processing through lowering the impact of fertilization on water bodies and of carbon balance on climate change. They can also be adopted by the flax industry. Their design drew more broadly from NRCan's expertise in energy-related processes.

- Brief methods description (reflect workplan milestones)

The design & evaluation of pathways to valorize processing wastes into biofuels & soil amendments involved studying literature on bioenergy processes, scaling mass & energy balances of flowsheets to the same capacity, and conducting lab & field experiments for 4 selected options; this led to recommend two pathways for further study by eastern and western fibre industries. Flowsheets were designed by regularly asking oneself: How many processing steps are worth adding to a given chain in order to valorize residues into a valuable by-product? Questions raised with Dr Rho of Platform 3 improved our understanding of processing.

In order to perform the field trial of biochar, NRCan hired one agronomist expert in biochar, Dr Julie Major, who remains available (along with researchers of U. Laval and McGill) to advice growers on combinations of fertilizers and soil amendments suited to specific crops, soil & growing conditions.

- Concluding statements that show the Sub-Activity met workplan deliverables.

The initial search for data and industry receptors has revealed potential partners for designing fibre products – e.g.: Camoplast for non-structural automotive panels; JB Martin inc. for weaved-fibre products; Holcim for light concrete along with two labs dedicated to concrete at NRCan and NRC – who will be available to collaborate with Lanaupôle fibres on a confidential basis when Lanaupôle is ready to consider these options. Notes discussing the industrial infrastructure of the region and the criteria for selecting target products & markets were delivered to Lanaupôle.

In the final phase, the techno-economic evaluation of 3 biofuel pathways – Dry Pellet vs. Torrefied Pellet vs. Pyrolytic Liquid – concludes that the mid-level of plant complexity brought by torrefaction delivers the lowest cost per GJ of heat or electricity in the safest & most efficient way, thus the "bio-coal" dub given to Torrefied Pellet by electric utilities. However, knowing that the fibre industry of a given region can supply only a small amount of residues to a biofuel plant built to an adequate scale, it may be preferable to valorize fibre residues as soil amendments. Of the 4 amendments considered, turning fibre residues, or non-merchant wood, into biochar by slow pyrolysis likely is more gainful than burying the residue as is or as ash in the soil.

Combining biochar with suitable fertilizers – say, low-cost liquid manure or an N-fixating microbe – may offer the best crop management system for growing hemp sustainably, because porous biochar 1- lowers input cost while avoiding chronic over-fertilization and the ensuing pollution of water bodies, 2- improves drought resistance, and 3- avoids drawing from fossil natural gas to make N-fertilizers while sequestering C underground as biochar, at a lower cost than CO<sub>2</sub> capture & storage, enough to turn the GHG balance of a fibre crop "from C-positive to C-negative". Laboratory characterization of the biochar tried with hemp is helping NRCan to design test methods for measuring agronomic properties – porosity, labile matter, labile C / N,... – which could be included in the product standard being drafted by the International Biochar Initiative.

While the information presented at *FiberLinks* on Torrefied Pellet and Biochar arose enquiries from flax growers and the SK Ministry of Agriculture, the work done under Project 7.1 with the support by ABIP-NAFGEN has introduced researchers & managers in CanmetENERGY, OERD and the Canadian Forestry Service to the possibility that using biomass in a pyrolytic form for amending soil be more valuable than selling it as a biofuel. Also, it likely has enhanced NRCan's willingness to collaborate with AAFC on making and using biochar in order to raise the sustainability of Canadian crops regarding fertilization and carbon balance.



**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

2008-2010: Lanaupôle fibres, Lanaufibres and their conseils administratifs were unavailable to hold regular meetings with NRCan. Lanaupôle lacked time for interacting with NRCan about the search for data and partners for growing hemp and designing fibre products. It is planning to validate the preliminary information delivered in biannual reports after termination of NAFGEN, e.g., whether its fertilisation plans meet the limits in allowable fertilization rates set to avert polluting water bodies.

2010-2011: Search in the literature for data that allow running a fair comparison and a valid techno-economic evaluation of the 3 biofuel pathways proved challenging. The delivery of pellet and biochar samples by Lanaupôle at Christmas 2010 to NRCan for characterization meant that laboratories could only deliver results late for interpretation. The initial phase and final (revised) phase were thus achieved behind schedule. The project was completed on budget.

- May include challenges and/or barriers to work and solutions

In response to concerns raised by the Lead, our Manager and Lanaupôle about health risks posed by the presence of polyaromatic hydrocarbons in char, the Project Investigator submitted a review of literature & enquiries which reassured the enquirers of the harmlessness of amending soil with biochar as well as a plead to NRCan's Environmental Assessment Group which issued a Preliminary Environmental Assessment declaring that the change proposed to the project of amending soil with biochar does not require any environmental assessment under the Canadian Environmental Assessment Act.

Several sources of biochar were found before one agreed to deliver the material in time for sowing. Our trial confirmed the hypothesis that chars made by fast pyrolysis offer poor agronomic properties, contrary to biochars made through slower pyrolysis.

<b>Platform 7</b>	<b>Best Biorefineries: Sustainable Systems Design</b>	<b>Project 2</b>	Sustainability as a Driver for Innovation in the Flax Industry (Saskatchewan Case Study)
	<b>Principal Investigator:</b> <b>Phone:</b> <b>Organization:</b>	Maria Wellisch  (613) 996-6195  Natural Resources Canada, CanmetENERGY	

**Sub-Activity objective/purpose, methods, results, and conclusions relative to expected outcomes.**

- Sub-Activity objective or purpose

The objective of this project was to engage stakeholders from different parts of the oilseed flax value chain to develop new flax value chains - for both the seed and straw components - through the sustainability lens.

- Brief methods description (reflect workplan milestones)

A two-phased approach was followed. The goal of the first phase was to define what sustainable development meant for the flax industry. This was done by applying The Natural Step framework, which involved participant sustainability education followed by a facilitated exercise of backcasting from sustainability principles. The main outputs included the articulation of six sustainability goals for the flax industry, and a preliminary list of actions for the first stages of the value chain that would help achieve the sustainability goals.

The primary aim of the second phase was to use the sustainability goals (developed in the first phase) as a lens for the development of new flax value chains. As the focus of NAFGEN was to derive more value from flax straw, focus was placed on the development of the straw value chains. Through group discussions, interviews and farm visits, actions that were underway and planned were reviewed with stakeholders who represented the breeding, agronomy, crop production, primary and secondary processing stages of the value chain. A process to incorporate sustainability into decision-making was thereby developed.

- Concluding statements that show the Sub-Activity met workplan deliverables.

This project was very timely in that the public interest in sustainability, sustainable agriculture, green products and green washing was at an all-time high throughout this period (2008-2011).

The first phase was completed on time and on budget. Based on feedback from the participants, The Natural Step was shown to be an efficient and effective process, producing useful results in a short period of time. The success factors were determined to

include: 1) having a dedicated, industry champion; 2) the serious commitment of the participants; 3) the availability of a practical, tested sustainability planning tool that is based on sound theory; and 4) an interesting and engaging program design. Phase 1 results were presented at 3 conferences, and were written up in 2 papers that have been published in conference proceedings.

Progress was also made in the second or “implementation” phase, albeit at a slower pace than originally anticipated. The sustainability vision and strategic goals were translated, distributed to all NAFGEN participants and at agricultural meetings, and posted on the SaskFlax website. A sustainability screening template was tested for evaluating actions in the breeding, agronomy, crop production and primary processing stages of the value chain. Over 40 actions have been reviewed for their alignment with sustainability principles and goals, and recommendations have been made regarding “next steps”. The screening template was distributed to all participants at the FiberLinks workshop, and can be downloaded from the SaskFlax website.

In conclusion, this project continued to connect the various members of the flax industry community and provided this community with a common language for discussing sustainability, and a decision-making tool for evaluating their decisions and actions. The flax industry is now poised to take the next steps in developing processes and products that will contribute to a more sustainable world. While the results are specific to the flax industry, the approach followed in Phase 1 can be adopted by the developers of any new agricultural value chain.

**Significant and approved changes to the Sub-Activity schedule or milestones if they affected the overall outcome of a Sub-Activity.**

- Significant milestones or deliverables that were not met with explanation for variance

The outbreak of the Triffid crisis in 2009 coincided with the start of Phase 2. The importance and urgency of this issue meant that many of the participants did not have the time to be actively involved in Phase 2. The year 2010 presented an additional challenge in that farmers experienced very difficult seeding, growing and harvesting conditions due to extreme wet weather. The two events combined slowed down the progress made in Phase 2.

- May include challenges and/or barriers to work and solutions

The short time available to produce research and the small amount of funding available for individual projects resulted in no resources being available for “anything else”. As a consequence, there was little uptake of the Phase 1 sustainability work by the other platforms of the NAFGEN network.



**Table 1.** Cost performance summary.

- To be completed by AAFC and provided to the Network by 15 February 2011.

ABIP_201 NAFGEN								
	2008-2009		2009-2010		2010-2011		Total	
	Planned	Actual	Planned	Actual	Planned	Actual	Planned	Actual
Votes 1 and 5								
AAFC NPO	\$366,715	\$313,534	\$433,345	\$430,469	\$474,718	\$279,820	\$1,274,778	\$1,023,824
Salary <sup>1</sup>	\$337,974	\$337,974	\$348,427	\$348,427	\$644,870	\$644,870	\$1,331,270	\$1,331,270
OGD	\$566,384	\$454,286	\$513,885	\$513,885	\$522,535	\$522,534	\$1,602,804	\$1,490,705
Equipment <sup>2</sup>	\$562,000	\$181,156	\$1,036,253	\$717,282	\$523,878	\$502,382	\$2,122,130	\$1,400,821
<b>Sub-Total</b>	<b>\$1,833,073</b>	<b>\$1,286,950</b>	<b>\$2,331,909</b>	<b>\$2,010,063</b>	<b>\$2,166,000</b>	<b>\$1,949,606</b>	<b>\$6,330,982</b>	<b>\$5,246,619</b>
Vote 10 Contribution								
Original CA	\$1,207,353	\$1,060,322	\$2,270,553	\$1,957,942	\$1,600,293	\$497,691*	\$5,078,198	\$3,515,954
Amended CA <sup>3</sup>	\$1,060,322		\$2,105,018		\$1,912,858			
<b>Total</b>	<b>\$2,893,394</b>	<b>\$2,347,271</b>	<b>\$4,436,927</b>	<b>\$3,968,005</b>	<b>\$4,078,858</b>	<b>\$2,447,297</b>	<b>\$11,409,180</b>	<b>\$8,762,573</b>
Original Funding Awarded							<b>\$9,620,000</b>	

I hereby certify that the above Agricultural Bioproducts Innovation Program related financial figures are correct.

Responsible Officer

Date

<sup>1</sup> Salary for AAFC staff in Fiscal Year 2008/2009 is an estimate (3% less than the salary coded for FY 2009/2010) since staff salary was not coded to the ABIP Fund Centre in 2008/2009.

<sup>2</sup> Variations may exist for equipment between planned and actual expenditures due to some equipment approved in one fiscal year and delivered and paid in a subsequent year.

<sup>3</sup> Most recent Contribution Agreement amendment.

\* Funding paid out to Recipient-Agent as of February 14, 2011 for FY 2010-11. This does not include U of SK claim in amount of \$46,731.02 which is currently being finalized.

NOTE: All information contained in Table 1 was accurate as of 14 February 2011. Any transactions completed after this date are not included



**Agriculture and  
Agri-Food Canada**

**Agriculture et  
Agroalimentaire Canada**

Research Branch

Direction générale de la recherche

**Table 2. Cost-shared funds report.**


- To be partially populated by AAFC by 15 February 2011, and completed and signed by the Network Responsible Officer.


Matching Funds Report / Rapport de fonds de contrepartie	2008-2009		2009-2010		2010-2011		Total	
Source of Funding / Source de financement	Planned/ Prévisions	Actual/ Réelles	Planned/ Prévisions	Actual/ Réelles	Planned/ Prévisions	Actual/ Réelles	Planned/ Prévisions	Actual/ Réelles
University Cash / Fonds universitaires	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Industry Cash / Fonds industriels	\$0.00	\$0.00	\$0.00	\$42,000.00	\$0.00	\$31,500.00	\$0.00	\$73,500.00
Other Sources / Autres	\$0.00	\$79,639.23	\$0.00	\$45,568.49	\$0.00	\$0.00	\$0.00	\$125,207.72
Other Sources of Federal Government Funding / Autres fonds gouvernementaux fédérale	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Other Sources of Provincial Government Funding / Autres fonds gouvernementaux provinciales	\$0.00	\$10,845.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$10,845.00
In-Kind Contribution / Contribution en nature	\$1,215,328.60*	\$490,480.10	\$987,059.60*	\$363,681.79	\$796,621.80*	\$382,754.04	\$2,999,010.00	\$1,236,915.93
<b>Total</b>	<b>\$1,215,328.60</b>	<b>\$580,964.33</b>	<b>\$987,059.60</b>	<b>\$451,250.28</b>	<b>\$796,621.80</b>	<b>\$414,254.04</b>	<b>\$2,999,010.00</b>	<b>\$1,446,468.65</b>

Note: If you held a conference or workshop and charged attendees a registration fee please indicate the total amount of registration fees collected in appropriate FY under "Other Sources", indicate it with an asterisk, and put a reference to indicate that you used these funds to cover of the costs of the meals and coffee breaks offered during the conference/workshop and that no profit was made.

This table was partially populated by AAFC (planned amounts are based on Schedule E of the CA). This is to be completed and signed by the Responsible Officer of the Network.

**I hereby certify that the above Agricultural Bioproducts Innovation Program related financial figures are correct.**

  
Responsible Officer

  
Date

\* Where there was no indication of a "date required" the fair value of the in-kind contribution was divided equally between the 3 fiscal years with the third fiscal year capturing any extra pennies when the amount did not divide by 3 equally.



**Table 3.** Summary of leveraged funding.

* Funding Source	2008-2009	2009-2010	2010-2011	Total
ABIP	\$199,000	\$42,500	\$66,000	\$307,500
ECO AMU	\$80,000	\$0	\$0	\$80,000
NRC	\$876,000	\$0	\$40,000	\$916,000
NSERC	\$0	\$1,500	\$0	\$1,500
PERD	\$279,000	\$679,000	\$0	\$958,000
Other	\$0	\$209,345	\$179,500	\$388,845
<b>Total</b>	<b>\$1,434,000</b>	<b>\$932,345</b>	<b>\$285,500</b>	<b>\$2,651,845</b>

**\*Note: Funding Source categories were modified to match the categories in the Cooperative Research portion of the Performance Management Report.**

## Part 4. Benefits to Canada

- *Increased the generation of new knowledge, IP, and technology with the potential to strengthen Canada's rural (growers/producers) and industrial base and generate wealth;*

The creation of NAFGEN provided significant opportunities for the generation of new knowledge, IP and technology. Key to this was the structure of NAFGEN, wherein seven platforms were structured in a value chain of processes for both flax and hemp. This began with varietal analysis and plant breeding and moved to harvesting practices with particular reference to harvesting equipment design and utilization. Optimized breeding and targeted straw management techniques enables significant successes in whole crop utilization. Next steps included fibre classification and sample preparation for forwarding to other researchers for chemical and physical analysis and trials. Utilization of straw into profitable industrial application will have a direct financial benefit to rural Canada where the crops are grown as well as to areas where the fibre is processed. Processing the fibre as compared to the current situation where some of the straw is burned in the field is a significant environmental improvement.

Agriculture is no longer restricted to food and feed. Increasingly, agricultural products are being processed to meet nonfood/feed demands. The emerging bioeconomy presents Canada's producers with new opportunities to satisfy growing demands for sustainably produced agriculture based products to expand into areas such as feedstock for renewable energy, or non food agri-products (bioproducts). Indeed some of these opportunities are exciting because they turn the byproducts of traditional crop production into economically valuable outcomes.



Natural bast fibres production is one promising area of Canada's bioeconomy. Biofibres are cellulosic fibres obtained from flax and hemp as well as several different plants. They exhibit strength and are lightweight relative to substitute materials, two important attributes for commercial and industrial use. Biofibres already have commercial application (e.g. in the manufacture of non-structural components for the automotive sector; in green building materials for the construction sector) and their prospective uses are even more extensive (e.g. structural automotive components in the motor coaches industry; and for aircraft interiors). Moreover, the byproducts derived from biofibre processing hold significant commercial potential (e.g. shives, byproducts rich in lignin, and hemicelluloses, from which green chemicals and biopolymers can be extracted).

Future demand for biofibres will likely be influenced by the need to mitigate greenhouse gas emissions, as well as increased consumer interest in environmentally sustainable production. Canada, like its trading partners, has already set targets for GHG reductions and estimates suggest that biofibres can contribute significantly to their attainment. Furthermore, broader industry interest in the automotive, aerospace, appliances and construction industries arises from the need to reduce ecological footprints. Several industry-led strategies seek to replace petroleum products with ones based on renewable resources, with some reductions of up to 30% or more in the next 2 or 3 years. At the same time, biofibres are economically attractive because their costs are lower than those of cotton or fibre glass.

By virtue of scientific and technological expertise and natural resource endowments Canada could become a global leader in biofibre production and development. A total crop utilization approach is critical to ensuring that Canadian flax producers maximize farm gate value. Whereas today straw effectively imposes a cost on producers and acts as a barrier to increased production, the path forward must instead allow farmers to capitalize on its true value. Strong biofibre value chains would permit this capitalization, thus encouraging the significant expansion of both flax and hemp production.

The Natural Fibres for a Green Economy Network actively engaged in addressing the scientific and technological issues that challenged the biofibre industry development. These include the need for:

- Optimized plant breeding for total crop utilization;
  - Better straw management to exploit unused material;
  - Bioresource engineering to develop and improve technical processes;
  - Grading systems and processes to accurately quantify the fibre properties;
  - Novel conversion technologies for the processing of flax and hemp fibre into intermediate and end products and integration of conversion technologies into biorefinery models.
- 
- *Increased the cooperation, collaboration, integration and partnership involving Canadian-based researchers; and*



As a result of NAFGEN, researchers that might not have even communicated in the past were able to collaborate not only on their similar research areas, but with other researchers in the value chain. This enables more targeted research in the future because of that increased awareness.

NAFGEN is blessed with a very diverse membership including several universities, AAFC, NRCan, NRC, and commercial corporations, both privately and publicly traded. This unique membership profile combined with the value chain approach and sharing of semi-annual and annual reports as well as two workshops yielded excellent knowledge and technology sharing and transfer.

The Natural Fibres for the Green Economy Network assembled top Canadian researchers, industry and producers to directly address the identified knowledge gaps that constitute a barrier to the full exploitation of the potential of bast fibre (flax and hemp) containing crops in Canada. This network, national in scope, represents an unparalleled alignment of Canadian research assets around the development of a domestic Canadian natural fibres industry.

This multi-disciplinary network pursued the generation of knowledge at key points all along the natural fibre value chain, in a network structure that incorporates heavy industry participation through the integration of leading corporate players throughout the network's research efforts, coupled with an intellectual property strategy that encourages and facilitates uptake of network successes by Canadian commercial partners.

- *Increased transfer of knowledge, technology and expertise between research and commercialization organizations.*

The same response as in the previous question is appropriate.

- *Other (e.g., impact on regulatory system, etc.)*

Effective policy plays a pivotal role in launching the sector's success. A bioproducts policy that builds on biofuels could significantly catalyze growth, both by signaling Canada's commitment to the sector and by creating incentives for the necessary stakeholder investment in infrastructure. Renewable content targets analogous to those for biofuels, for instance, would create strong incentives for private sector investment. Moreover, such a policy could serve as a means to integrate the many and diverse organizations and companies that possess relevant expertise. e.g. federal government departments and agencies; and private sector companies already part of natural fibre value chain)

### **The Importance of a Comprehensive Biofibres Policy**





Canada's biofuel policy has set replacement targets for gasoline and diesel in the transport sector. However, no similar policy has been developed for Canadian natural fibres. The development of Canadian policy is an important step towards the establishment of renewable content targets, akin to biofuel targets. A biofibre policy would both signal Canada's commitment to developing the biofibres industries and create incentives for significant investment by stakeholders, especially SMEs, filling existing (infrastructure gaps in the value chain). Venture capitalists, for example, are not showing much interest in biomaterials, their investments being focused on clean technologies, primarily biofuels (DFAIT Clean Tech Strategy, 2010-2011). Producing good fibres requires new processing facilities, followed with downstream processing (enzymes, chemicals, etc) compounding to supply end-users, none of which are currently present in Canada on a large scale. There is potential to attract the participation of companies like Novozymes, Dupont and others.

A comprehensive biofibre policy must also consider the large and diverse set of organizations and companies with expertise relevant to the development of a Canadian natural value chains (e.g., within universities, provincial and federal departments, and industry). Federal government departments with relevant expertise include AAFC, Natural Resources Canada and the National Research Council. A number of private Canadian companies and organizations with specific expertise in natural fibre-based materials do exist and are contributing to the development of a Canadian natural fibre chain. This activity aligns with a number of AAFC's national science and innovation priorities including enhancing the economic benefits for all stakeholders; improving the environmental performance of Canadian agriculture; and, developing new opportunities for agriculture from bioresources. Without this integrated effort, it is expected that it will take a significantly longer period of time for the Canadian natural fibres sector to reach this tipping point in fully realizing potential as total utilization crops with environmental, economic and social benefits.

### **Greenhouse Gas (GHG) Reductions and “Green” Consumption: Drivers of Future Demand**

Future industrial and commercial demand for biofibres and biofibre products is expected to be influenced by trends in GHG mitigation and increasing consumer interest in environmentally-sustainable production.

Canada, like its trading partners, has already set targets for GHG reductions by 2020. Biofibres can contribute significantly to reaching these targets and so generate demand. For instance, in transportation GHG reductions can be achieved through the lightening weight of automotive vehicles. The Fraunhofer Institute indicated that significant GHG reductions can be achieved by using lightweight design and materials (26.2%) and by reducing aerodynamic resistance of cars (13.1%) (Fraunhofer Institute, June 2010). Based on a GHGenius evaluation, up to 1 million tons of carbon dioxide reduction can be achieved by the replacement of fibre glass with biofibres in automotive manufacturing in North America (Tampier 2008).



Broader industry interest in the automotive, aerospace, appliances and construction industry arises from a need to reduce ecological footprints, because of regulations, national objectives and energy savings/conservation policies. Industry also has a strategy of replacement of petroleum products by renewable resources in the range of 30% or more in 2-3 years (Source: Woodbridge, Magna, Ford, Whirlpool, Boeing, etc.). Moreover, natural fibres will replace synthetic materials in reinforced bioplastics, reducing the use of petroleum as well as reducing energy use in the manufacturing process. Currently, replacement is between 15-25% and is increasing. Costs of natural fibres are lower than cotton or fibre glass. Because of reduced density of the biomaterials made with natural fibres, the cost of biofibres for the same quantity of fibre glass is competitive with fibre glass.

### **Geographic Issues**

Given the significant costs in transporting biomass, natural fibre processing and manufacturing facilities will need to be located in close geographical proximity to the source of production. This will bring bio-industries directly to rural areas, with attendant high value jobs and increases in the local tax base. The development of a strong Canadian natural fibres sector will also help align rural and urban agendas, more directly connecting the traditionally rural domain of natural resource production with the more typically urban manufacturing sector.

### **Trade-Based Concerns**

Biotechnology, genomics and nanotechnologies are opening up new possibilities for flax and hemp production, by accelerating the pace of crop development and expanding genetic diversity. However, regulatory processes and trade barriers (e.g., as they related to plants with novel traits) could pose challenges to the commercial release of flax and hemp crop varieties. This is observed in the case of low level presence of CDC Triffid contamination of the flax seed supply and its effect on the trade of flax to Europe. While authorized in Canada and the US, CDC Triffid is not approved elsewhere. This led to the suspension of Canadian flaxseed exports to the EU and other markets. Despite the finding of GM material and restricted access to certain markets, during the 2009-10 crop year, Canada exported approximately 756,533 metric tonnes, or \$345.9 million worth of flaxseed, to all countries. Although exports have recovered due to increased exports to China and the United States, significant risk remains due to the zero tolerance policies for unapproved events in key export markets.



## Part 5. Recommendations for Follow-on Activity

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The network as such no longer has priority activities. Post March 31, 2011, individual former NAFGEN members will establish their own priorities and direction based on a number of factors specific to each party's resources and goals.

*In addition, comment on:*

- *New alliances/partnerships that would benefit the Network;*

Based on NAFGEN winding up March 31, 2011, and no known funding for future similar activities, it will be entirely up to former NAFGEN members to work together or with others on their own accord. We expect that the familiarity gained among NAFGEN participants will enhance this collaborative opportunity.

- *Strategies for managing regulatory processes;*

As NAFGEN will cease to exist as of March 31, 2011 there will be no ongoing strategy for managing regulatory resources. Each member will be responsible for managing in their particular regulatory environment.

- *Further public communication of results post-ABIP funding;*

It is the intent of NAFGEN to publish on the Saskatchewan Flax Development Commission website, following the wrap up, selected excerpts from the final report showing the list of projects, the researchers involved and their contact information. In this way established networking contacts may be maintained and new ones developed. This venue will also allow the highlighting of some key accomplishments.

- *Intellectual property disposition; and*

NAFGEN members will function under the Network Agreement for IP as long as it is in effect. Article 13 of the Network Agreement deals specifically with "Surviving Obligations." It references Article 5 which deals with "Licensing of Intellectual Property." All NAFGEN parties, including Her Majesty The Queen In Right Of Canada are signatories to this agreement.

- *Follow-on commercial development.*

Post March 31, 2011, commercial development will be entirely up to the former members to pursue.



## Part 6. Lessons Learned

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- *Comment on the unanticipated outcomes/benefits as well as the strengths, weaknesses, opportunities, and challenges of the Network.*

NAFGEN goals and expectations were quite high from the onset. While there were many outcomes and benefits they were not unexpected.

The strength of the network lies in its structure and the scope and diversity of its membership. The structure was built around a value chain concept stretching from plant breeding all the way through to finished product research involving evaluation of extracts from highly refined fibre particles.

Weakness of the network centred in the lack of commitment of some researchers to meet deadlines for semi-annual and annual reports and for filing expense claims. This made sharing of research information among participants impossible to provide in a timely fashion. Especially in the early stages of the network delays in processing claims

Considerable opportunities exist as a result of NAFGEN, both for members and for others who become aware of potential collaboration and market potential due to exposure to network achievements.

- *Comment on Network management, scientific activities, and commercialization efforts.*

From a Flax Canada perspective the role of Lead Recipient has not been an easy one. The program was launched without many of the tools such as financial reporting formats and definitions of allowable overhead expenses in place. The reprofiling of some NAFGEN funds from NGO to OGD required a completely reworked budget and work plan, with some projects and even one platform being deleted. This created a late launch, decreased the research time, and increased the frustration level as well as the cost of preparation.

Once truly up and running the support from individual AAFC staff members has been excellent. Especially in the first half of the program these individuals efforts kept the program running despite what appeared to be many gaps in the process.

Scientific activities were for the most part directionally on target with the plan and the responsibilities within the time allotted. While some of the research by design was primary and required for next steps, those particularly in the private sector were focused in their desire to commercialize products.

Network Management by FC 2015 was supported by a Steering Committee. As well, each of the seven platforms has a Lead. Our Technology Management committee includes each of these Leads.



- *Recommended improvements to future programs of a similar nature.*

The program itself and the reporting expectations should be clear right at the time of application so that required resources can be recognized when budgets are prepared. The process and rational for allowable administrative and other overhead expenses should be clear at time of application. Payments to participants should be made within 30 days of filing. If possible, program management infrastructure within AAFC should be in place and program recipients selected in time for the program to run for the amount of time originally planned.

It would be advisable for networks to recognize that, within the administrative requirements, there are limitations to the number of members that a network can contain in order to function to the level required. This is especially critical where there is a significant number of members from a cross section including Industry, academia, NGO and AAFC. The expectations and research history and practices of these various members are so varied that they may not play well together as team members.

A budget allowance adequate for the Lead Recipient to wrap up the network reporting requirements is required, even if it falls into the next fiscal year. Currently, the research either has to be cut off early or the Lead Recipient has to find financing from another source to wrap up the program.



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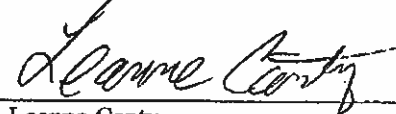
Research Branch

Direction générale de la recherche

Signature Page / Page de signatures

The signatures below verify that the information in this Final Report provided by the Natural Fibres for the Green Economy Network (NAFGEN) (ABIP #201) is complete and accurate.

Prepared by / Préparé par

  
\_\_\_\_\_  
Leanne Canty  
Title: Network Executive Assistant

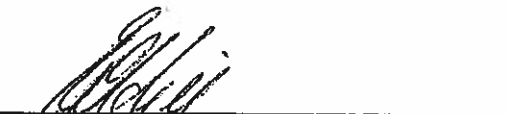
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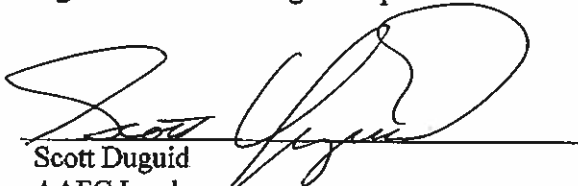
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\_\_\_\_\_  
Network Lead(s) / Responsable(s) du réseau

\_\_\_\_\_  
Date

  
\_\_\_\_\_  
William Hill  
Flax Council of Canada  
Lead Recipient Agent/Responsible officer  
Agent bénéficiaire / agent responsable

Date June 29, 2011

  
\_\_\_\_\_  
Scott Duguid  
AAFC Lead  
Responsable d'AAC

Date August 15, 2011

\_\_\_\_\_  
Les Rankin  
Flax Canada 2015 Inc.  
OGD Lead(s)  
Responsable(s) autres ministères

\_\_\_\_\_  
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Leanne Canty  
Title: Network Executive Assistant

\_\_\_\_\_  
Date

As required / au besoin:

\_\_\_\_\_  
N/A  
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