UBC Social Ecological Economic Development Studies (SEEDS) Student Report

An Investigation Into the Wheat Straw Paper

Wei Ren Au

Hen Li Chin

Christopher Uy

Brent Au

University of British Columbia

APSC 262

April 2, 2012

APSC 262 Sustainability Project:

An Investigation Into the Wheat Straw Paper

Submitted to Dr. Dawn Mills

Prepared by:

Wei Ren Au

Hen Li Chin

Christopher Uy

Brent Au

Submitted date: April 2nd, 2012

Abstract

The University of British Columbia (UBC) hosts a Social Ecological Economic Development Studies (SEEDS) program that is dedicated to sustainable research and alternatives, including the idea of a new source of paper to be sold on campus. The papers sold at UBC are typically created from wood fibres and 30% consumer recycled content from pulp mixtures. The purpose of this report is to analyze the benefits of wheat straw paper products, primarily in terms of environmental impact, and to investigate the feasibility of wheat paper as a replacement to wood paper. Specifically, this report will evaluate the viability of "wheat sheet" from Royal Printers as a product to be sold at UBC. The report covers the ecological footprint which highlights the efficiency of the production and consumption of wheat paper. In addition, the performance of wheat straw paper will be compared to both 100% wood and recycled mixture content papers throughout the report. In order to meet the demand for wood pulp paper, many trees from forests have to be cut down every year. The paper industry has a large carbon footprint due to the fact that trees are required to maintain carbon levels. In addition, the process of producing a certain amount of paper from a single tree is fairly inefficient considering that only 25% of the tree is used while the rest is discarded. Wheat paper however, utilizes only residue waste wheat straw as a fibre source for creating pulp mixtures. Although the wheat sheet uses eucalyptus fiber to reinforce the pulp mixture, adjusting to this paper would significantly reduce the ecological impact of the paper industry. Additionally, conventional chlorine-based processing methods of wood pulps are well known for causing pollutions and adverse effects on the environment. A better alternative of practicing wheat straw pulping can prevent pollutions from processing paper. The only drawback of wheat straw pulping is the black liquor residue. Regarding the black liquor, a by-product of wheat straw pulping, Vibratory Shear Enhanced Process (VSEP) shows that lignin and hemicelluloses can be extracted from the black liquor and be used as biomass for producing energy, further proving the profitability of integrating wheat straw paper industries. The findings of this report also show that the wheat paper can be recycled much like any other sheet of wood paper. Repeated recycling of the wheat paper proves to have gradual decrease in quality of the wheat straw pulp. However, the degradation rate is lower than wood pulp, indicating the high recycle potential of the wheat pulp. For the market value of the wheat straw paper in Canada, research shows that the wheat sheet has the potential to adapt to the paper industry due to its inexpensive costs compared to wood paper. Another setback for the wheat paper is the shipment of bulk orders from popular non-wood paper industries in China or India. By integrating wheat straw paper companies in Canada, the wheat paper industry would improve both the economy and living standard of Canada as a result of job opportunities, services and other benefits. Hence, wheat straw paper is a suitable alternative to promote sustainability at UBC and around the globe.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Acedic acid	A simple carboxylic acid used as chemical reagent and industrial chemical
Acid rain	A rain or any other form of precipitation that is unusually acidic and corrosive
Black Liquor	A chemical by-product of the papermaking process. It consists of the remaining substances after the cellulose have been cooked out from the wood.
Bioaccumulation	Accumulation of substances
Biochemical Oxygen Demand	Amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period
Carbon footprint	The total set of greenhouse gas emissions caused by an organization, event, product or person
Carbon storage	Ability to prevent release of large quantities of CO_2 into the atmosphere
Catecholes	An organic compound with the formula $C_6H_4(OH)_2$
Chemical pulping	A method of converting wood chips into paper pulp for use in papermaking accomplished by chemical cooking of the chips
Chlorine bleaching	A paper bleaching process that creates a by-product called dioxin which has extremely harmful effect on the environment and humans health
Chloroform	An organic compound with formula $CHCl_3$ which is colourless and hazardous
Chlorophenolics	An organochloride of phenol that contains one or more covalently bonded chlorine atoms
Ecological footprint	Amount of biologically productive land and sea area necessary to supply the resources a human population consumes, and to assimilate waste
Greenhouse gas	A gas in atmosphere that absorbs and emits radiation within the

	thermal infrared range.
Guaiacol	An organic compound with the formula $C_6H_4(OH)(OCH_3)$
Hemicellulose	Any of a group of complex carbohydrates that, with other carbohydrates, surround the cellulose fibers of plant cells
Hydrogen Sulphite	A chemical compound with the formula H_2
Kraft process	A technology for conversion of wood into wood pulp consisting of almost pure cellulose fibers
Mechanical pulping	A method of converting logs or wood chips into paper pulp for use in papermaking accomplished by mechanical grinding
Phenols	A class of chemical compound consisting of a –OH group bonded directly to an aromatic hydrocarbon group
Recovery Boiler	Technology used to recover chemicals from black liquor to produce the reusable white cooking liquor required during the pulping process
Silica	An unreactive, colourless compound that causes viscosity in black liquor
Sulphur Dioxide	A poisonous gas with a pungent, irritating smell released in industrial processes
White Liquor	Mixture of chemicals that is used as the cooking liquid during the digestive process of the pulping process
Xylan	Highly complex and long carbohydrate molecules found in plant cell walls
Yield of paper pulp	The ratio of pulp solid mass to the original wood that it was derived from. High yield pulps are produced by mechanical means.

LIST OF ABBREVIATIONS

ADP	Air-dried pulp
CO_2	Carbon Dioxide
EFA	Ecological footprint analysis
GHG	Greenhouse gas
Ha	Hectares
VSEP	Vibratory shear enhanced process

1.0 INTRODUCTION

The average person in Canada consumes over around 200 kg of paper a year. The papers we use are typically made out of pulp made from wood chip fibres. In turn, many trees in forests are cut down every year to satisfy the demand for paper. This deforestation is currently threatening the natural state and health of the environment. If a tree is cut down in order to supply a certain amount of paper, it takes around 50 years to completely grow a new one for the forest. At this rate, there would be a rapid decline of not only the trees but also the wildlife relying on the familiar habitat. In order to cope with the rapid decline of forestry, there are many different types of paper being produced that are made out of pulp not using 100% wood fibre. For instance, some of the paper currently being sold at UBC contains 30% post-consumer recycled content. In addition, there are also paper made from pulp based non-wood fibres such as bagasse, a material resulting from juice extracted sugar canes (Judt, 1998). One candidate for alternative fibre source in pulping is using waste wheat straws as a source of fibre.

Although International Paper of the United States is the world's leading paper company, China and India are at the top of non-wood pulp and paper industry accounting for 80% of the world's paper production (Norris, 2011). India especially has paper industries that work with environmental friendly paper. Wheat straw paper may be a more sustainable option in UBC compared to conventional paper in the fact that the pulp it is created from waste wheat straw rather than fresh wood chips in addition to the other pulping ingredients. Current wheat straw paper may contain a small portion of wood fibre, but only a small amount exists compared to regular wood paper. Royal Printers, a paper company has worked with companies in India to develop the wheat straw paper without chopping down any trees. Furthermore, the wheat paper itself is very similar to regular wood paper in regards to appearance, tensile strength and usage. By introducing wheat straw paper or the "Wheat Sheet" to UBC stores, not only can we reduce the rate of deforestation but also promote the product's benefits to the general public, ultimately leading to a more sustainable outcome.

1.1 WHEAT FIBER ANALYSIS

The idea behind the wheat straw paper is to use the residue waste straw after the wheat has been harvested and the grain or any other part has been used for other purposes. As a result, there is an abundance of material to use for pulping. The wheat straw plant itself is made of different portions holding different properties such as fibre length and mass.

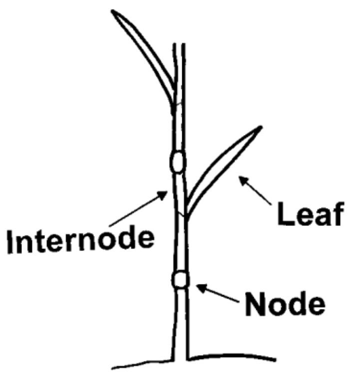

Figure 1 : Sketch of Wheat Plant

Source: (Jacobs, Mckean, 1997 p. 2-3)

Table 1: Physical Content of Wheat

	Mass (%)	NAFL (mm)	WAF L (mm)	Fines (%)
Whole		0.48	1.04	51.3
-Internodes	49	0.61	1.20	24.3
-Leaves	45	0.35	0.79	49.0
-Nodes	6	0.28	0.65	51.4

Source: (Jacobs, Mckean, 1997 p. 2-4)

The plant contains the leaves, nodes and internodes as shown in Figure 1 (Jacobs, Mckean, 1997). Table 1 shows the characteristics of the wheat plant, including the fibre length. However, the wheat fibre on its own is not enough to create the wheat sheet. To deal with the loss of paper quality, the paper contains a portion of wood fibre from farmed eucalyptus. The wood fibre in the pulp is longer and stronger, and it provides the desired structure when the wheat sheet is formed.

1.2 PULPING PROCESS AND QUALITY ANALYSIS

The fibre crops are then used at a pulp mill to mix the pulp. The pulping process of making wheat pulp mix is similar to creating regular wood based pulp. One method to create the wheat straw pulp is Soda pulping. Soda pulping, or more specifically Soda-AQ pulping is the idea of using sodium hydroxide in a chemical process to cook the mixture at high temperatures (Jacobs, Mckean, 1997). During the pulping process, the cellulose fibre is separated from the residue crop. The resulting pulp is bleached for the notable white color of paper. The wheat paper produced is almost identical to wood paper with minor exceptions of appearance. The wheat sheet still ends up with a desirable white color. The texture and durability is essentially the same in comparison to wood pulp paper. The wheat sheet can be written and printed on the same way regular paper is used.

2.0 PRELIMINARY COMPARISONS OF WOOD AND WHEAT PAPER PRODUCTION BASED ON CARBON FOOTPRINT AND ECOLOGICAL FOOTPRINT

The environmental impact of both wood and wheat paper industries are first compared by evaluating their carbon footprint and ecological footprint. The carbon footprint constitutes the total greenhouse gas (CHG) emissions caused by the paper production. Meanwhile, the ecological footprint analysis (EFA) determines the total ecosystem area (in hectares) required to produce the resources consumed and to assimilate the wastes produced by the paper production. The details of both the analysis are describes in the following sections.

2.1 CARBON FOOTPRINT ANALYSIS

The carbon footprint of wood paper production is significantly higher than the wheat paper production mainly due to deforestations. Approximately 40% of harvested tress is being used for paper production due to high worldwide consumption of paper (Shapley, 2011). The diminishing of forest has increased the emissions of greenhouse gases and lead to global warming. In fact, the forests are able about store about 50% of the world's terrestrial carbon (Shapley, 2011). The trees act as important carbon sinks to suppress the carbon level in atmosphere. Contrary to the wood paper industry, wheat paper industry would require no cutting down of trees and thus reducing tons of greenhouse gases emitted into the atmosphere. See table 2 below for the carbon storage loss due to cutting-down of Boreal forest for wood paper industry.

Table 2: Carbon Storage Loss of Previously Unmanaged Forest Based on 100 Year Crop Rotation and 500 Year Timescale

Location	**Carbon Storage of Unmanaged Land (tonnes CO_2/ha)**	**Carbon Storage of A Harvested Land (tonnes CO_2/ha)**	**Carbon Storage Loss (tonnes CO_2/ha)**
Prince Albert, Saskatchewan	304	90	214
Thompson Manitoba	362	199	163
Average	**333**	**144**	**189**

Source: Tynan, 2011 p. 6

2.2 ECOLOGICAL FOOTPRINT ANALYSIS

Pulp production consumes massive amount of natural capital, such as agricultural land and fossil energy. The ecological footprint analysis is consist of three aspects: the agricultural/forest land required for fiber production, the total energy consumed during production, and also the carbon sink area (Kissinger, Fix, & Rees, 2006). The comparisons are done between the two methods of production in order to determine which method has lower ecological load and is more sustainable. See table 3,4, and 5 below for the ecological footprint across Canada.

Table 3: Forested land/cropland Required to Grow Fiber for One Tonne Pulp

	Manitoba (ha)	**Saskatchewan (ha)**	**Alberta (ha)**
Wheat Straw	0.6	0.9	0.7
Spruce	5.6	3.7	4.5
Aspen	2.4	2.5	2.1

Source: Kissinger et al., 2006 p. 554

Table 4: Energy Eco-footprint for One Ton of Pulp Produced from Wheat Straw, Spruce, and Aspen

	Manitoba (ha)	**Saskatchewan (ha)**	**Alberta (ha)**
Wheat Straw	0.14	0.17	0.18
Spruce	0.10	0.16	0.18
Aspen	0.10	0.16	0.18

Source: Kissinger et al., 2006 p. 556

Table 5: Carbon Sink Lands Required to Assimilate CO_2 Emissions

	Manitoba (ha)	**Saskatchewan (ha)**	**Alberta (ha)**
Wheat Straw	0.06	0.09	0.07
Spruce	0.02	0.03	0.03
Aspen	0.02	0.02	0.02

Source: Kissinger et al., 2006 p. 555

Table 6: The Total Ecological Footprint of One Ton of Chemical Unbleached Bone-dry Pulp

	Manitoba (ha)	**Saskatchewan (ha)**	**Alberta (ha)**
Wheat Straw	0.8	1.2	1.0
Spruce	5.7	3.9	4.7
Aspen	2.5	2.7	2.3

Source: Kissinger et al., 2006 p. 556

Based on the findings, the total ecological footprint of pulped wheat is smaller than pulped spruce and aspen in all the regions. The result has also proven that wheat straw would require smaller agriculture land compared to spruce and aspen in order to produce an equivalent amount of pulp. In short, wheat paper production can reduce the environmental load and relieve the harvested pressure on forested lands.

3.0 POLLUTIONS FROM CONVENTIONAL WOOD PULPING AND BLEACHING PROCESSES

Wood pulping processes have been well known of causing immense environmental problems. Wood pulping is the process by which the wood is reduced to a fibrous mass via bond rupturing. Our studies have looked specifically into the most common pulping and bleaching processes for paper production using wood as feedstock. The contemporary wood pulping processes in paper mill industry are mechanical and chemical pulping. Likewise, wood pulp bleaching requires the utilization of chlorine-based bleaching agents in order to remove the remaining lignin after the pulping process. The paper pollution concerns related to these conventional wood pulping and bleaching processes are outlined below.

3.1 LIQUID EFFLUENT DISCHARGES

The most significant environmental damage caused by wood pulping and bleaching processed is water pollution. Wastewaters that contain different kinds of pollutants are discharges at a very high rate to the water streams. The contaminated fresh water changes the ecological characteristics and might leads to the death of some living organisms. Research has shown that the pollutants may exist in various forms such as suspended solids, acidic compounds, and chlorinated compounds, and they will be discussed in the following sections.

3.1.1 GENERAL ORGANIC POLLUTION AND SUSPENDED SOLIDS

The most common organic pollutants in the discharged effluents are lost cellulose fiber, carbohydrate, starch, and hemicellulose. They are quite high in biochemical oxygen demand (BOD), which is about 40kg per ton of ADP (Stanley, 1996). In fact, this level of pollutants may easily cause water opacity and blanketing of river. The blanketing of river may also result in anaerobic decomposition which then releases hydrogren sulphite into the aquatic ecosystem. In the long run, bioaccumulation and transportation through the food chain may occur.

3.1.2 ACIDIC COMPOUNDS

This form of water pollutant results mainly from mechanical pulping process. It exists as highly concentrated resin acids in softwood pulp. Compared to the other types of pollutants, the acidic compounds cause less severe impact because they are biodegradable and thus do not bioaccumulate.

3.1.3 CHLOROPHENOLICS

Chlorophenolics are formed in chlorine-bleached chemical wood pulping process and are regarded as the most hazardous waste amongst the other compounds. They are very toxic, non-biodegradable and bioaccumulative and the worst of all they can potentially transform into other distinct compounds. Phenols, guaiocols, and catecholes are categorized under the chlorophenolic group (Stanley, 1996).

3.1.4 CHLOROFORM AND OTHER CHLORINTED COMPOUNDS

Chloroform, chloro-acetones and acetic acids resulted from woold pulp bleaching process are non-bioaccumulative but they are toxic and carcinogenic. They are suspected of causing miscarriages, birth defects, and neurological problems through human exposure to contaminated drinking water.

3.2 AIR EMISSIONS

Air emissions which contain particulates, hydrogen sulphide, sulphur dioxides, nitrogen dioxides and carbon dioxides are produced mainly from chemical pulping process. Nitrogen dixoxide and sulfur dioxide are the major contributors of acid rain. Likewise, carbon dioxide is a dominant greenhouse gas responsible primarily for the global warming and climate change. Besides, the chloroform is capable of depleting the ozone level and thus worsening the UV radiation effects.

Table 7: Different Types of Air Emissions from Wood Pulping Industry

Pollutant	**Source**	**Effects**
Carbon Dioxide	Fuel Combustion resulted from transportation and pulp disposal	Global warming
Hydrogen sulphide	Kraft (chemical) process	Rotten egg odor
Sulphur dioxide	Kraft(chemical) process	Acid rain
Chloroform	Chlorine bleaching	Ozone level depletion

Source: Stanley, 1996

4.0 BLACK LIQUOR ISSUE IN WHEAT PAPER INDUSTRY

Black liquor is a chemical by-product that is produced during the pulping process of wood-chip, and wheat straw paper. The dry solid portion of the black liquor that is produced is about 70% organic and 30% inorganic, consisting primarily of alkali substance (Huang & Shi & Langrish, 2006). Before the 20th century, black liquor was disposed by filtering it out into watercourses. This method was harmful to the environment, especially to aquatic life as it polluted the waters and made it dangerously toxic (Siloxy, 2009). Recovery boilers and biological treatment plants are now used to recover essential alkaline solutions from the black liquor and to reduce its harmful environmental impacts. Although the negative impacts of black liquor have been reduced significantly in the last decade, a major difficulty in non-wood pulping is recovering the heat and chemicals from the cooking liquor, also known as white liquor (Myréen, 1998).

4.1 BLACK LIQUOR RECOVERY PROCESS

A basic diagram of the pulping process is shown in figure 2 below. The process begins as wood chips enter a mechanical digester. In the digester, an aqueous solution known as white liquor, flows through the digester and neutralizes organic acids in the chemical matrix of the wood (Marklund, 2006). The lignin, hemicelluloses and other organic substances found in the wood dissolves into the liquid and is released into the concentrators as weak black liquor. The pulp that exits the digester is material used during the paper making process. To strengthen the black liquor so that it is suitable for combustion, the liquor is evaporated inside the concentrators. Once strong enough, the black liquor goes into the recovery unit where the black liquor converts chemical energy into inorganic smelt and gases (Marklund, 2006). The inorganic smelt goes through a causticizing process where the smelt recovers to once again produce the aqueous white cooking liquor solution. The white liquor flows through the digester and the process repeats.

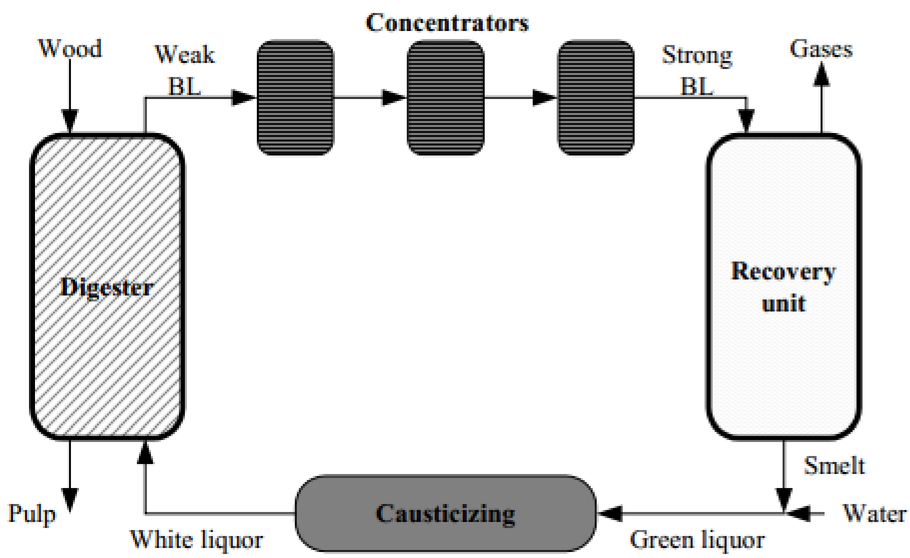

Figure 2: Diagram of the Pulping Process

Source: Marklund, 2006

4.2 BLACK LIQUOR IN WHEAT STRAW PROCESSING

One of the main components of wheat straws is silica, a hard and non-reactive chemical compound, which is digested into the black liquor waste (Zhang & Yu, 1999). The presence of silica is the primary reason for the high viscosity property of the black liquor. Experiments and observations show that due to the high viscosity of the chemical compound, attempting to evaporate the black liquor produces fewer concentrations of essential solid substances and uses much more thermal energy from the recovery boiler during the process. Due to the increase in viscosity, the silica causes scaling problems especially in the evaporation plant (Siloxy, 2009).

The most cost-efficient way to separate silicon from the black liquor is by adding carbon dioxide to the liquor at high temperatures (Myréen, 1998). This process is referred to as the desilication method. It is difficult to perform this process because the precipitation of silica occurs at a pH where other substances also start to precipitate as seen in figure. The main issue is not due to the loss of organic substance from the black liquor, but it is from the formation of a gelatinous substance which reduces the filter capacity by blocking the filter (Myréen, 1998).

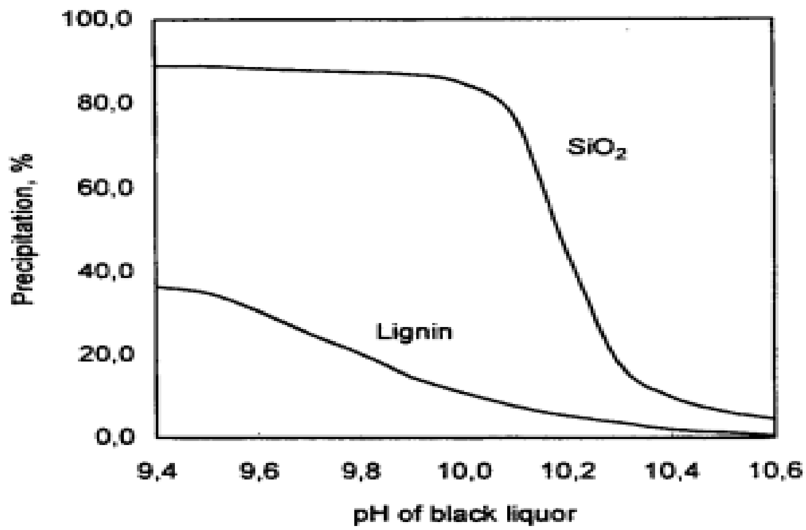

Figure 3: Precipitation Vs PH Graph

Source: Myréen, 1998

Although the presence of silica in wheat straws generate some obvious complications in the black liquor treatment process, there are also some profits that can be made regarding non-wood black liquor. For instance, after the black liquor is treated for reuse under specific alkaline conditions, a portion of the liquid substance can also be reused to produce cooking oil by adding extra concentrations of NH4OH and KOH chemicals.

More importantly, there is research being done on a Vibratory Shear Enhanced Process (VSEP) technology to improve non-wood black liquor processing. The VSEP technology is beneficial because it is able to extract lignin and hemicelluloses from black liquor during the straw pulp processing. The extractions of lignin are converted into biomass products that are used in energy production and the remaining residues could be further processed as fertilizer (Norris, 2011). Since the non-wood black liquor typically does not undergo combustion as a means of processing, 100% of the residues can be reused to improve the crop soil.

Table 8: Comparison Between the Solid Components of Black Liquor from Hardwood and Wheat

	Hardwood	***Straw***	
	From Digester ***%***	***From Digester*** ***%***	***Desillicated*** ***%***
Lignin-derived organic matter	27.1	24.2	16.2
Other organic matter	42.3	30.8	32.8
Silicate as $\mathbf{Si0_3^{2-}}$	0.1	10.9	1.2
Other inorganic matter	30.5	34.1	49.3
Gross calorific value MJ/kg	14.1	10.9	9.5

Source: Myréen, 1998

5.0 RECYCLING POTENTIAL OF WHEAT PULP

Paper recycling is an important part of pulp and paper industry due to the reduction of landfill loadings, less dependence on forest resources and economics profitability concerns. The Environmental Protection Agency estimates that the production of recycled paper reduces the water usage by 50% and air pollution by 74% compared to the production of new, virgin paper (Sheikhi, Talaeipour, Hemasi, Eslam & Gumuskaya, 2010 p. 1702). Hence, several studies on the recycle properties of wheat paper have been done to evaluate its recycling potential. An important feature of cellulosic fibres is that they can be used repeatedly for paper-making but they undergo irreversible changes during the process which could lower their paper-making potential in the subsequent cycles. In fact, low-yield chemical pulps experience significant changes on tensile strength and related properties upon recycling (Garg & Pal Singh, 2004 p. 25). Therefore, some important properties of wheat pulp after recycling are examined in the following.

5.1 TEAR, TENSILE AND BURST STRENGTH

Tear strength is the ability of the paper to withstand tearing force and it can be used to evaluate the behaviour of paper in various end use situations. Tensile strength is indicative of fibre strength, fibre length and fibre bonding and it can be used as a potential indicator of resistance to web breaking during converting or printing. Burst strength indicates the amount of pressure paper can tolerate before rupture and it is very important for bag paper. Therefore, these three properties of paper are analyzed in order to evaluate the recycling potential of wheat straw paper.

The percentage of change in tear index as a function of recycling number for wheat pulps is shown in Figure 4. WCP 42, WCP 49 and WSCP 60 are wheat pulps in different dried stage and there is no definite trend observed for the change in tear strength upon recycling. For some wheat pulps, tear strength increases with recycling; for others, it decreases or remain the same after recycling. Due to the complex relationship of tear strength with fibre length, fibre strength and fibre-fibre bonding, it has been difficult to generalize the dependence of tear strength on recycling (Garg & Pal Singh, 2004 p. 27).

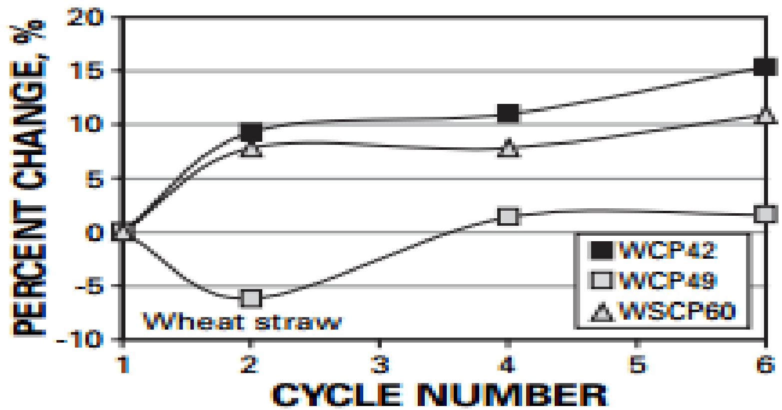

Figure 4: Effect of Recycling on Tear Index of Wheat Pulps

Source: Garg & Pal Singh, 2004 p. 27

On the other hand, recycling causes loss in tensile and burst strength of wheat straw pulps as shown in Figure 5 and Figure 6. Three of the different dried stage wheat pulps demonstrate similar trend on the changes of tensile and burst strength upon recycling. These strengths do not reduce to a large extend on recycling and they are considered fairly high in comparison with other pulps as shown in Figure 7.

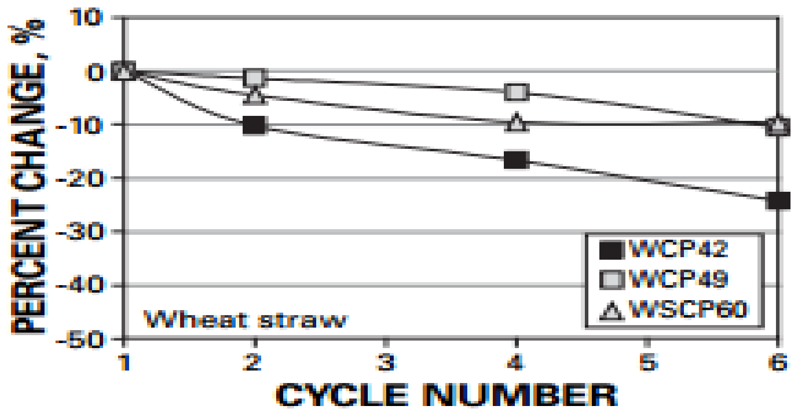

Figure 5: Effect of Recycling on Tensile Index of Wheat Pulps

Source: Garg & Pal Singh, 2004 p. 27

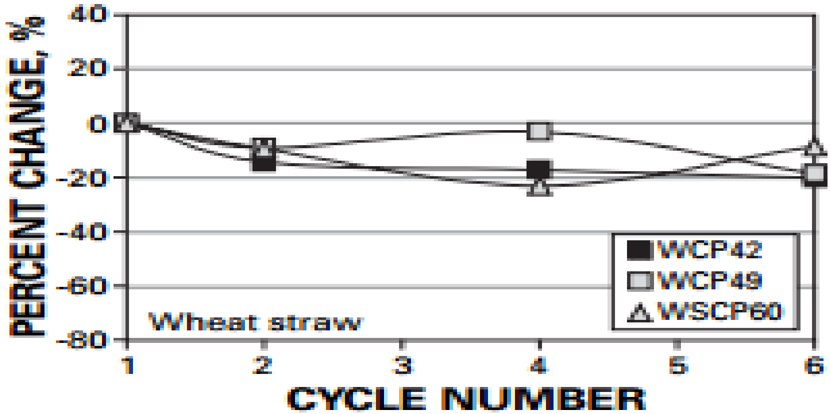

Figure 6: Effect of Recycling on Burst Index of Wheat Pulps

Source: Garg & Pal Singh, 2004 p. 27

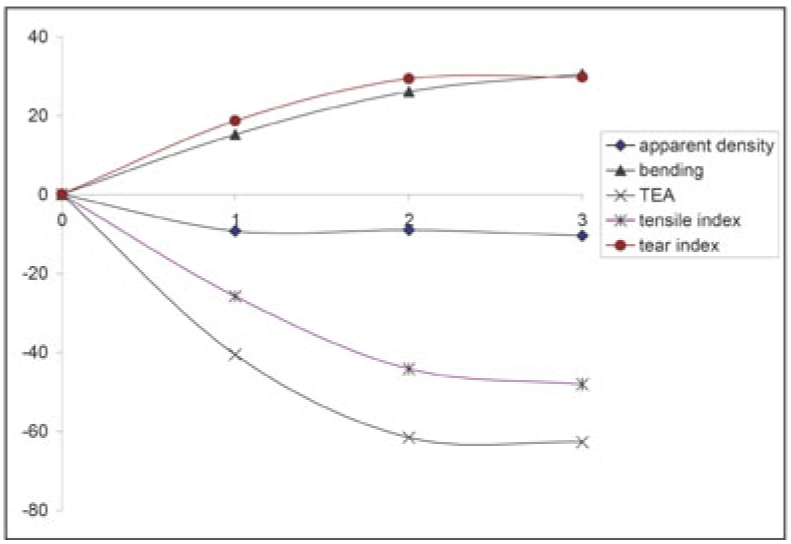

Figure 7: Effect of Recycling on Some Strength Properties of Hardwood Pulp

Source: Sutjipto, Li, Pongpattanasuegsa & Nazhad, 2008

As shown in Figure 5 and Figure 7, the change in tensile index of hardwood pulp is higher than wheat pulp and this suggests that the loss of strength of hardwood pulp is greater than wheat pulp. In other words, wheat pulp has higher recycling potential than hardwood pulp.

5.2 APPARENT DENSITY

The apparent density of paper is the ratio of the mass of a paper sample to its volume, each being determined under prescribed conditions. Apparent density is one of the important properties of paper because it basically influences almost all physical, mechanical and optical properties of paper as well as quality of printing, absorption and flexibility (American Society for Testing and Materials, 1981 p.122). Apparent density also has economic significance where paper is purchased on a weight basis and consumed on an area basis. Thus, change in apparent density of wheat pulps after recycling is examined in order to assess the recycling potential of wheat straw paper.

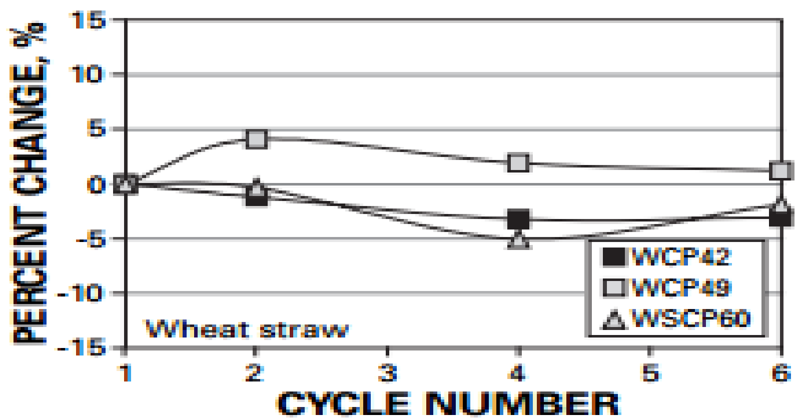

Figure 8: Effect of Recycling on Apparent Density of Wheat Pulps

Source: Garg & Pal Singh, 2004 p. 29

As shown in Figure 8, the apparent density for three different dried conditions of wheat pulps does not have significant changes. Hence, it is a good indication that wheat pulp is capable of maintaining its apparent density without significant changes upon recycling which in turn justifies its high potential of recyclability.

5.3 CHEMICAL COMPOSITION

During recycling, the loss in strength related properties is caused by physical changes in the fibre rather than minor chemical changes (Garg & Pal Singh, 2004 p. 25). The generally held view is that the main reason for bonding strength loss during recycling is caused by the effect called "hornification". Hornification is a process in which the fibres' flexibility decreases, subsequently results in the reduction of fibre-fibre bonding (Barsness, Keeler, Tschirner, 2007 p. 539).

Many studies conducted by the experts in the pulp and paper industry have shown that the xylan of pulp increases the potential of recycling due to the fact that the pulps containing high amount of xylan are able to maintain the fibres' flexibility upon recycling compared to the low-xylan content pulps (Sheikhi, Talaeipour, Hemasi, Eslam & Gumuskaya, 2010 p. 1702). So, the effect of hornification can be reduced if the fibres' flexibility is maintained throughout the recycling process.

As a result, the wheat straw, being rich in xylan, is able produce pulps of high recycling potential (Garg & Pal Singh, 2004 p. 25). As shown in Table 9, the chemical composition including xylan content remains almost the same during recycling. This result suggests that the ability of maintaining the fibres' flexibility during recycling is preserved and hence it justifies that wheat straw pulps are recyclable with minimum effect of hornification.

Table 9: Chemical Composition of Wheat Straw Pulp During Recycling

	Glucan [%]	Xylan [%]	Galactan [%]	Arabinan [%]
Starting	68.1	22.4	0.8	1.9
Cycle 1	69.1	23.7	1.1	2.1
Cycle 2	70.0	23.5	0.9	2.0
Cycle 3	70.0	23.1	0.8	1.0
Cycle 4	70.7	23.1	0.9	1.9
Cycle 5	69.9	22.9	1.0	2.1

Source: Barsness, Keeler, Tschirner, 2007 p. 540

6.0 POTENTIAL ECONOMIC BENEFITS OF WHEAT STRAW PAPER INDUSTRY

The adaption of wheat straw paper production will bring economic benefits mainly to the farmers. Wheat straw applications can give additional income to the farmer from food crops or cattle production. Traditionally farmers have harvested wheat and burnt or disposed of straw and other residues. With the new trend of making paper by using wheat straw as feedstock, the farmers can reap a secondary harvest from the wheat plantings. Additional income can be earned by selling the wheat straw to paper manufacturers and establishing a long term partnership with them. Also, by not burning the straw wastes, soil crusting and decrease in soil biological activity can be prevented and thus the annual yields will rise.

In addition, as the wheat straw paper industry grows, the value of agricultural residues is likely to fluctuate. Based on previous market research, wheat straw can sell up for $45 per ton (Hayes, 1997). Thus, by producing wheat straw in bulk for commercial purposes, the annual income of the participants in this field will significantly increase. In the long run, the increase in farm earnings will possibly eliminate the need for farm subsidies. The farmers will rely less on the government support and eventually taxpayers would no longer have to pay high taxes to the government. Besides, the high potential of wheat straw applications as a profitable business will prompt investors and enterprising companies to make profits by using straw and other similar agricultural residues in their products.

7.0 POTENTIAL SOCIAL IMPROVEMENT BY WHEAT STRAW PAPER INDUSTRY

The developing of wheat straw paper industry may also improve the living standards of some rural areas. Paper mills will most likely be mushrooming in rural areas, near the farms that supply the wheat straw, in order to save the cost of transporting the straw to be processed in urban areas. This will definitely provide more job opportunities, services, infrastructures and a higher tax base which then boost the local economies. Local civilians will no longer have to seek for jobs outside from homeland and in the long run the local population will increase. Eventually, the balance of living standard between urban areas and rural areas can be achieved due to the reduced economy gap.

8.0 CONCLUSION

The report finds that wheat straw paper is a feasible alternative to wood fiber paper mainly because it causes only trivial environmental impact. Wheat straw paper industry has lower carbon footprint and may cause smaller ecological load to the environment compared to wood paper industry. Also, unlike conventional wood pulping and bleaching processes, wheat straw pulping process requires no chlorine-based agents and produces less pollutants. Regarding the black liquor problem in wheat paper industry, modern research centers have come out with effective ways to tackle this problem by pulping the wheat straw with caustic potash-ammonia, in order to obtain the desired cooking liquor that is required during the digestive process of the pulp production. Additionally, VSEP research shows that other extractions from the black liquor can be recovered and reused as fertilizer for the land. In terms of recyclability, the wheat straw pulp has a great recycling potential as there are no major losses of important properties upon recycling. Moreover, the losses of tensile strength and burst strength are particularly smaller compared to other pulps such as hardwood pulp. Besides, wheat paper industry would improve the economy and living standard of Canada by increasing the value of agriculture products and providing more job opportunities. In short, implementation of wheat paper practice may save millions of trees each year and ease the pollutions caused by paper manufacturing, while providing a new source of income for grain growers. Based on the findings of this report, we would recommend the use of wheat paper in UBC. UBC would then advance this sustainable practice across Canada and fulfill its goal: commit, integrate, demonstrate, and inspire.

REFERENCES

American Society for Testing and Materials. (1981). Paper and paperboard: characteristics, nomenclature, and significance of tests. Retrieved from http://books.google.ca/books?id=UG0goERQH4wC&pg=PA122&lpg=PA122&dq=paper apparent density&source=bl&ots=0OHhm9-EF1&sig=8nSP3Kplsw5bQbVTb0l2L52lRU4&hl=en&sa=X&ei=zsF4T5_SIaOaiQKnreCnDg&ved=0CEQQ6AEwBA

Barsness, J. , Keeler T., Tschirner U. (2007, September 4). Recycling of chemical pulp from wheat straw and corn stover. Retrieved from http://www.ncsu.edu/bioresources/BioRes_02/BioRes_02_4_536_543_Tschirner_BK_Recycling_Wheat&Corn.pdf

Chen Z., Huang G., Zhang C. (2006). *Pulping of wheat straw with caustic potash-ammonia aqueous solutions and its kinetics*. Retrieved from http://ac.els-cdn.com/S1004954107600032/1-s2.0-S1004954107600032-main.pdf?_tid=a28c2cbf9dfa8512ca38f2abcd4ac442&acdnat=1333320889_622854e97b249675fc86518ae20639cf

Csóska, L., Lorincz, A., Winkler, A. (2008). Sonochemically Modified Wheat Straw for Pulp and Papermaking to Increase its Economical Performance and Reduce Environmental Issues. Retrieved from http://www.ncsu.edu/bioresources/BioRes_03/BioRes_03_1_0091_Csoka_LW_Sonochem_Wheat_Straw.pdf

Fix, J., & Tynan, S. (2011). *The carbon footprint analysis for wood&agriculture residue source of pulp* . Manuscript submitted for publication, Retrieved from http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/sag13757/$FILE/Final_Report_CFA.pdf

Garg, M., Pal Singh, S. (2004). Recycling potential of bagasse and wheat straw pulps. Tappi Journal, 3(9), 25-31. Retrieved from http://www.tappi.org/Downloads/unsorted/UNTITLED---04SEP25pdf.aspx

Hapley, D. (2007, October 2). *15 facts about the paper industry, global warming and the environment*. Retrieved from http://www.thedailygreen.com/environmental-news/latest/7447

Huang G., Shi J., Langrish T. (2006). *A new pulping process for wheat straw to reduce problems with the discharge of black liquor.* Retrieved from http://www.sciencedirect.com/science/article/pii/S0960852406004937

Hurter, R. W. (1998, August). ***Will non-woods become an important fiber resource for North America?***. Paper presented at World Wood Summit. Retrieved from http://www.paperonweb.com/Articles/World_wood_summit.pdf

Jacobs R., Mckean T., The Clean Washington Center (June 1997). Wheat Straw as a Paper Fibre Source. Washington DC: Clean Washington Centre.

Judt M. (1998). Practical Experiments in Papermaking with Wheat Straw Pulps. Retrieved from http://www.tappi.org/Downloads/unsorted/UNTITLED---NANF98291pdf.aspx

Kissinger, M., Fix, J., & Rees, W. E. (2006). Wood and non-wood pulp production: Comparative ecological footprinting on the canadian prairies. Ecological Economics, 62, 552-558. Retrieved from http://upi-yptk.ac.id/Ekonomi/Kissinger_Wood.pdf

Marklund, M. (2006). *Pressurized entrained-flow high temperature black liquor gasification* Retrieved from http://books.google.ca/books/about/Pressurized_entrained_flow_high_temperat.html?id=xceFNAAACAAJ&redir_esc=y

Myréen, B. (1998a). *A novel recovery process for small-scale non-wood pulp mills.* Retrieved from http://www.tappi.org/Downloads/Conference-Papers/ICR98823.aspx

Myréen, B. (2001b). *A new approach to the non-wood black liquor problem.* Retrieved from http://www.siloxy.com/pdf/a_new_approach_tech_paper.pdf

Norris, K. (2011). *Technology turns straw into paper and profits.* Retrieved from http://www.risiinfo.com/technologyarchives/papermaking/Technology-turns-straw-into-paper-and-cash.html

Sheikhi, P., Talaeipour, M., Hemasi, A. M., Eslam, H. K., Gumuskaya, E. (2010). Effect of drying and chemical treatment on baggase soda pulp properties during recycling. Bioresources, 5(3), 1702-1716. Retrieved from http://www.ncsu.edu/bioresources/BioRes_05/BioRes_05_3_1702_Sheikhi_THEG_Drying_Chem_Treat_Bagasse_Na_Pulp_Recycling_1012.pdf

Siloxy, a NORAM company. (2009). *Nonwood pulp mill - wheat straw.* Retrieved from http://www.siloxy.com/WheatStraw.htm

Sridach, W. (2010). The environmentally benign pulping process of non-wood fibers. Suranaree J.Sci.Technol., 105-123. Retrieved from http://sutlib2.sut.ac.th/Sutjournal/Files/H133456f.pdf

Stanley, A. (1996, October). *The environmental consequences of pulp and paper manufacture* . Retrieved from http://www.foe.co.uk/resource/briefings/consequence_pulp_paper.html

Sutjipto, E. R., Li, K., Pongpattanasuegsa, S., and Nazhad, M. M. (2008). Effect of recycling on paper properties. Retrieved from http://www.tappsa.co.za/archive3/Journal_papers/Effect_of_recycling_on_paper_p/effect_of_recycling_on_paper_p.html

Zhang, K., Yu, Z., (1999). *A technical guide of alkali recovery for wheat straw pulping*. House of Light Industry of China.