Life Cycle Assessment of Alternative Fibers with Supplemental Analyses

Population growth, economic expansion, and increases in standards of living across most regions of the globe have provided the fuel for enormous economic growth and opportunity. These trends will likely continue for years to come and they put increasing pressure on the earth’s natural resources, including forests. Forests and trees are absolutely essential to life. Trees clean the air, purify water, and control erosion. They help maintain biodiversity by supporting plant and wildlife species. Globally, forests support the wellbeing of 1.6 billion people whose livelihoods depend on them. As the largest tissue manufacturer in the world, Kimberly-Clark depends on primary tree fiber as well as recycled fiber as a critical source of raw material for our products.

We take pride in our long history of responsible use of natural resources and our record of leadership in protecting the world’s forest resources and promoting responsible forest management. Today we use large amounts of recycled fiber, only use virgin fiber from suppliers that are certified to one of five recognized, forest management certification systems, and have one of the most progressive fiber procurement policies in the tissue industry\(^1\). In an effort to continue to raise the bar for our company and industry we also have specific goals for an increasing proportion of our fiber to be “Environmentally Preferred Fiber”\(^2\).

\(^1\) Kimberly-Clark’s goal is to purchase 100 percent of our wood fiber from suppliers that gain independent certification for their woodlands or their fiber procurement activities to one of five internationally recognized sustainable forestry schemes. We additionally have a publicly stated preference for Forest Stewardship Council (FSC) certification where feasible. Further detail on our fiber sourcing leadership and Fiber Procurement Policy can be found at [http://www.kimberly-clark.com/sustainability/planet/fibersourcing.aspx](http://www.kimberly-clark.com/sustainability/planet/fibersourcing.aspx)

\(^2\) In this context, Environmentally Preferred Fiber refers to (i) Forest Stewardship Council (FSC)-certified fiber; (ii) recycled fiber (RF); and (iii) sustainable alternative fiber. The research reviewed in this document is one of several steps Kimberly-Clark will take to determine what alternative fibers can be considered as Sustainable.
As global demand for the world’s resources increases, our ability to effectively source both recycled and certified virgin fiber will come under increasing pressure. Developing additional cellulosic fiber options that can augment our current supply will improve our ability to meet and extend our commitments to responsible sourcing while simultaneously supporting our business goals around innovation, quality and costs.

Kimberly-Clark is actively exploring a range of innovative fiber opportunities. Kimberly-Clark commissioned this Life Cycle Assessment (LCA) and considers it an important component of a broader research initiative to help us understand the potential benefits and impacts of using some of these alternative fibers. This document outlines the key findings of this research and explores what insights can be drawn from those findings.

References in the document are to section numbers in the original research report which is included as an appendix. Some information in the research report, particularly the detailed description of the study assumptions and data regarding the production systems, has been removed as they contain certain business information deemed to be sensitive or confidential.

**Purposes for Research**

Kimberly-Clark wants to broaden its portfolio of fiber options and we are therefore exploring many different alternative sources of fiber, including both agricultural remnants and rapidly-renewable “purpose grown” fibers, to understand their potential to provide opportunities for innovation in meeting both our business goals and also the responsible sourcing goals mentioned above.

To better understand the potential economic, environmental and societal advantages or disadvantages of using these various fiber options Kimberly-Clark will employ many approaches and engage in a multi-stakeholder review process. This LCA and supplemental analyses are a first but significant step in this process. Kimberly-Clark has worked with the Georgia Institute of Technology’s Institute of Paper Science and Technology (IPST at Georgia Tech) to conduct a
rigorous LCA and a set of supplemental analyses evaluating several alternative fibers, as well as the conventional fiber options of northern bleached softwood kraft (NBSK) fiber and recycled fiber derived from waste paper. The alternative fibers evaluated are bamboo, wheat straw, *Arundo donax*, and kenaf.

Kimberly-Clark views LCA as one, though not the only, important measurement tool for identifying the relative environmental performance of a production system. When well-constructed, LCA can provide essential insights on a variety of important categories of environmental impact. LCA is often complemented by additional tools to gain a more comprehensive view, as is done here to address some of the challenging questions that arise when comparing various options for fiber sourcing. Supplemental analyses are included on the topics of potential invasiveness and the implications for habitat and biodiversity.

It is important to note that Kimberly-Clark was in an early exploration phase of its analysis of potentially relevant non-wood fibers when this study was commissioned. Various technical and supply chain feasibility analyses of these fibers are still underway and these analyses will continue as Kimberly-Clark explores and develops these and other potential alternative fibers. The results presented here should therefore be viewed as early insights into relative performance of the target fibers under fixed technical and supply chain scenarios. As data and assumptions are validated/refined or as new information becomes available, we anticipate the need to evolve our social and environmental analyses.

The LCA centers on a comparison\(^3\) of NBSK fiber with bamboo and a comparison of recycled paper fiber with wheat straw, kenaf, and *Arundo donax*. Currently available data suggests that certain species of bamboo could be a suitable replacement for NBSK, while agricultural

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\(^3\) Although providing comparative conclusions, the LCA was not conducted with an intention to provide definitive comparisons between fibers, such as to support marketing claims of environmental superiority. The ISO 14044 guidelines on LCA provide specific guidelines for supporting comparative assertions of superiority. Meeting those requirements has not been a goal of the present work.
remnants may be more suited to short-fiber applications as they behave more similarly to recycled fibers. Recycled fiber and certified virgin fibers remain important fiber sources to which the company remains unquestionably committed. However, long term supply risks involving quality, availability, and price are forecast in the fiber types and grades required to make quality tissue products in the future. While the LCA compares wheat straw, kenaf, and Arundo donax to recycled fiber and bamboo to NBSK, other combinations (and other fiber sources) are feasible and must be studied further. Conversely, some alternative fibers studied here may prove infeasible and therefore not developed for long term commercialization.

The LCA Approach

The study has been conducted to be in conformance with international ISO norms regarding LCA (ISO 14044). It has been externally reviewed by a panel of independent experts from:

- Quantis, a leading LCA consulting firm;
- Canopy, an environmental not-for-profit organization dedicated to protecting the world’s forests, species and climate; and
- The World Wildlife Fund, an environmental not-for-profit organization and the world's leading independent conservation body.

The study employs the leading thinking in the field of life cycle assessment and represents an effort to truly understand the implications of potential changes in Kimberly-Clark’s supply chain. The research team has been challenged to produce a comprehensive analysis which takes into account the latest thought leadership in this area. The external review panel has provided both a validation on the sensibility of the approach, as well as recommendations for further steps and improvements.

Scope of the study and modeling of fiber production and pulping

The LCA compares the fiber options on the basis of providing an equivalent function in tissue applications, for which they are assumed to serve an equal function for an equal weight of either kraft pulp (in the case of NBSK and bamboo) or mechanical pulp (in the case of recycled
paper, kenaf, wheat straw, and Arundo donax) (Section 1.2). The scope of the LCA includes all of the processes needed to produce pulp from the various sources, including both the forestry or agricultural processes and the pulping processes, as well the transportation from field to the tissue mill (Section 1.3). In the case of recycled fiber, the system boundary starts at paper collection and does not allocate any of the impacts of initial paper production to the current or future potential lives of the fiber. The comparison also includes the end-of-life of the pulp as part of tissue products, as it is expected that this stage may have an important influence on some environmental impact categories. The production, distribution to consumers, and use of tissue products are not considered because they are assumed to be equal across the different fiber options.

The pulping processes are modeled based on anticipated fiber applications. NBSK and bamboo are represented as undergoing kraft pulping, whereas kenaf, Arundo donax and wheat straw are represented as undergoing mechanical pulping and recycled fiber undergoes a deinking pulping process. Where necessary, certain input data are based on pilot scale efforts or assumptions with high levels of uncertainty. These may not represent the full commercial production scale process. In many cases we believe some resource requirements may decrease if commercial size efforts are pursued. However, where measured data were not available, this study used conservative assumptions.

Many industrial and agricultural processes produce multiple outputs of value to society. In conducting an LCA, the environmental impact associated with such a process must be allocated across the various outputs, meaning a portion of the impact is assigned to each. In such cases a determination must be made regarding on what basis such an allocation will be made. In the case of kenaf and wheat straw, fiber production (growth and harvest) produces both the fiber used in these products by Kimberly-Clark as well as an additional material which does (in the case of wheat grain) or might (in the case of kenaf core) have a strong economic value. In this study, allocation is performed among co-products based on their estimated market value (Section 1.4).
In several cases, the fiber production systems have been modeled in a way to ensure that potential areas of concern are flagged. For example, some of the examined sources are grown both with and without inputs of fertilizer, pesticides and irrigation water (Section 1.7) yet modeling performed in this study assumes use of these inputs.

**Approach to environmental impact assessment**

The LCA includes a variety of environmental impact categories (Section 1.9). A particular emphasis is placed on the categories of fossil energy use, climate change, water use and land use. However, the LCA also considers impacts in the categories of human toxicity; particulate matter emissions; freshwater and marine eutrophication; terrestrial, freshwater and marine toxicity; ozone depletion; photochemical oxidation; ionizing radiation; and mineral resource depletion.

In the case of climate change, the LCA accounts for the influence of forestry activities and agricultural practices on carbon storage, as well as the release or storage of carbon from tissue products containing the various fibers that were studied at the end of life. Consideration of the fluxes of carbon and the consideration of full biogenic carbon accounting in forestry and agriculture systems is a field still in development, and we are aware of only a few studies so far that have taken such an approach in conducting an LCA of forest operations. Although there is a level of uncertainty, this has been included in this report as it is a critical component of any comprehensive assessment of climate change implications.

The water use evaluation considers the volume of water consumed in combination with an index of the relative water stress in the region where the water is consumed. Some consideration is also given to the evapotranspiration occurring for current or projected types of land use.
In the category of land use, the area of land needed to produce an amount of fiber each year is considered to be an indicator of the overall impact on wildlife habitat and biodiversity. This is a broad metric which should be complemented with more specific assessments of the land types and locations in question.

The research team has also included supplemental research to identify and evaluate risks from the potential invasiveness and the biodiversity impacts in the areas that would potentially be affected by the production of alternative fibers, with particular focus on the potential benefits for conservation of the Canadian Boreal forest. In addition to consideration of the impact attributed to a given mass of production, the assessment also contains an alternative view of the system based on representing the expected environmental consequences of large shifts in the fiber supply chain.

**Overview of LCA Findings**

The LCA findings suggest that alternative fibers show potential to be part of a larger responsible sourcing strategy to secure a sustainable supply chain for Kimberly-Clark’s products. However, the research also highlights potential areas of concern for several of the fiber types evaluated that should be further considered. The LCA results are summarized in the figure below and full results are presented in Chapters 3 and 4 of the appended report.
With the exception of water depletion, categories of environmental impact resulting in less than 1% of the estimated result for either the Human Health or Ecosystem Quality endpoints are not shown here.

The alternative fibers are represented conservatively to ensure that potential issues are highlighted. For example, kenaf is shown to be grown with pesticides and irrigation, though not all kenaf is grown this way.

Representation of pulping of alternative fibers is based on either data from trial processes or conservative assumptions to represent a likely upper bound.
In considering the specific comparisons modeled in this report, the following advantages are highlighted:

**Bamboo**

Bamboo appears to have less impact than NBSK on most indicators. It appears to have a significant benefit in both carbon footprint (Section 3.5) and in land use (Section 3.4). A key driver of the favorable comparative results for bamboo is the rapid renewal rate (three years for regeneration) as opposed to 70 years for regeneration of NBSK. This results, on average, in higher fiber output per area of land per year and suggests a high potential for alleviating some of the impacts associated with use of land from where NBSK fiber is sourced. The high renewal rate also results in a favorable carbon footprint for bamboo growth relative to NBSK. This is due to bamboo more quickly re-sequestering CO₂ from the atmosphere to replace the carbon released when harvesting the fibers. These results suggest that, in general, bamboo which rapidly renews the amount of biomass per parcel of land holds a high potential for reducing the demand for land area for the production of fiber for tissue production as well as having a net benefit regarding climate change.

The advantage of bamboo fiber in energy use (Section 3.2) is largely dependent on the assumption of it being grown in closer proximity to the pulp and tissue mills (less transportation needed) as compared to NBSK. Identified areas of potential concern for bamboo include human toxicity (Section 3.6), freshwater eutrophication (Section 3.8), and the potential invasiveness of some species (Section 4.2.3). The higher impact in human toxicity is due to herbicide application which may take place in cases where invasive behavior is suspected, while the elevated result for freshwater eutrophication is due to fertilizer requirements. These results stem from using conservative assumptions regarding the use of fertilizer or herbicide during bamboo cultivation that may prove to be unnecessary after future study. Determining the feasibility of such alternative scenarios and assumptions would help Kimberly-Clark understand its options for mitigating these potential concerns.
**Wheat Straw, kenaf, Arundo donax**

In comparing kenaf, wheat straw, and *Arundo donax* to recycled fiber, the alternative fibers appear to have somewhat larger environmental impacts under current assumptions.

Recycled fiber has a relatively low environmental impact particularly when produced in an integrated mill as modeled in this LCA. A conservative assumption made was to not allocate any inputs for production of the original virgin fiber to recycled fiber.

Of the alternative fibers studied, wheat straw, in particular, benefits from being an agricultural remnant associated with wheat grain production (and therefore being allocated only a portion of the overall impact of wheat production, Section 1.4). There is evidence that wheat straw is burned as a means of disposal in some cases. Thus, reduced burning, although not investigated in this LCA, could be an environmental benefit (from reductions of particulate matter or toxic substance emissions).

It should be noted that the data show higher greenhouse gas emissions from kenaf, wheat straw, and *Arundo donax* as compared to recycled fiber due to the higher energy use in the specified mechanical pulping process as well as the agricultural activities to grow these alternative fibers. We believe, however, that the current comparison is a conservative one being made between early-stage developmental processes and technologies and one that is highly mature and therefore more optimally managed. Further technical developments are likely to lead to greater pulping efficiencies for these alternative fibers through time. In addition, forecasts suggest that the coming years may hold important changes for the recycled paper industry that could lead to growing inefficiencies in that system, including changes to pulping technologies.
It is important to recall that the results in the results are affected by the assumptions around crop growth and some of these areas of concern may be diminished or removed if irrigation, pesticide use or fertilizer application can be reduced or eliminated in the growth of these fibers.

**Summary of Implications**

The study pushes the boundaries of the leading thinking around responsible sourcing for tissue fibers. The research delves deep into certain issues like the uptake and release of carbon by biogenic sources, the implications of water use and the implications of crop yield on land use for biodiversity that are not fully addressed in current LCA studies. These are issues on which it is necessary to have the best information available to understand the potential implications. The LCA work completed by IPST at Georgia Tech has greatly helped to provide an informative basis for further consideration and developments at Kimberly-Clark.

A key implication of the LCA is a need to strongly consider land use efficiency and the renewal rate of the system when making evaluations of alternative fiber options. These are major influences on the results of the analysis for both land use and climate change and are also influential in other impact categories where land management practices are an influential factor. Kimberly-Clark may use such efficiency considerations as a way of broadly understanding and comparing options, while recognizing a need to eventually understand the issues more deeply at the level of the landscapes in question.

A potential implication of the improved land use efficiency of bamboo relative to NBSK is that as less land is needed for fiber production, more land might be preserved as natural habitat. As there are certain habitats and regions that are of particularly high value for preserving biodiversity, these high-value forests need to be highlighted, and evaluating their protection made a part of the land use evaluation. The current study is only a first step in understanding how a more efficient use of land may lead to greater preservation potential in natural forested landscapes.
Kimberly-Clark is planning to make assessments to ensure that areas put under cultivation for alternative fibers are not high conservation areas. In addition to the land being directly used to grow our fibers, we acknowledge that there may be indirect changes in land use associated with some of the alternative fibers that were studied in this assessment. An additional area requiring further study is the potential invasiveness of bamboo and *Arundo donax*.

**Conclusions**

The results for each fiber type reveal areas of potential for higher environmental impacts relative to recycled paper but lower than NBSK. Each of them show promise and will continue to be studies as potential options within Kimberly-Clark’s fiber sourcing. Assumptions regarding the growth of alternative fibers were made with a conservative approach to ensure that areas of concern would be identified. The LCA reveals potential areas of concern for each of the alternative fiber types that should be further understood and, if validated, mitigation strategies may be needed if Kimberly-Clark proceeds down the development path towards commercialization.

Some areas worthy of further investigation include:

- **Wheat straw**: water use and human toxicity, due to irrigation and the use of pesticides in the growing of wheat.
- **Arundo donax**: freshwater eutrophication, due to application of fertilizers. Although not addressed directly in the LCA portion of the report, the potential invasiveness of *Arundo donax* is a concern that has been flagged and must be considered.
- **Kenaf**: water use, human toxicity and freshwater eutrophication to potential for irrigation, pesticide use and fertilizer use.

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4 If cultivated without irrigation and if the kenaf core were to find a higher market value (therefore being assigned a higher portion impact, as is the case for wheat and wheat straw), kenaf fiber would have high potential. Kimberly-Clark is currently involved in the growing of kenaf from both irrigated and non-irrigated systems, demonstrating the potential to avoid irrigation in kenaf production. We are in the
• Bamboo: human toxicity and freshwater eutrophication, due to pesticide and application of fertilizers\textsuperscript{5} The potential invasiveness is a concern that has been addressed and will be considered in future studies.

• Energy consumption in the mechanical pulping of several alternatives and overall pulping efficiencies of all fibers studied.

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process of determining if more or all kenaf can be from without irrigation and are also seeking improved market options for the kenaf core.

\textsuperscript{5} Although fertilizer use is apparent in the results for bamboo as a potential area of concern, there are bamboo systems in which fertilizers are not used and so approaches for mitigating this issue may already be available.