DYNAMIC FIBER FLOWS MODEL

Published, peer-reviewed research to measure the complex behavior of fiber flows and the system-wide environmental tradeoffs and consequences associated with changes to paper recovery and recovered fiber utilization in paper products.



Dynamic Fiber Flows Model research sponsored by the American Forest & Paper Association at Massachusetts Institute of Technology's Department of Materials Science & Engineering.

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Introduction

Why this research was conducted

There is general agreement among paper industry stakeholders that diverting paper from landfill has environmental benefits. In fact, paper recovery in the U.S. is a true environmental success story, as the U.S. paper recovery rate reached 68.1 percent in 2018 and has met or exceeded 63 percent for the past decade. Paper industry companies have worked toward a recovery rate of more than 70 percent by the end of 2020, which is approaching what many consider the maximum practical level, or approximately 80 percent. Some papers, like soiled tissues and food contaminated products cannot be recovered, so 100% recovery is not possible.

The environmental benefits of replacing virgin wood pulp with recovered paper have been the subject of debate for years. A common public perception is that increasing the utilization of recovered fiber as a raw material in the manufacture of paper products is always more environmentally beneficial compared to that of virgin fiber pulp.

Until this model was developed, life cycle studies, tools and calculators typically compared products with varying degrees of recycled and virgin fiber content, but these were static comparisons, that did not reflect that increasing the recycled content in one grade will affect the system-wide fiber availability of other grades. Those comparisons were unrealistic in that they viewed changes in recovered fiber utilization to occur in isolation. This model reveals that measuring the system-wide consequences of replacing virgin material with recycled material is not straightforward, and there are many interactions that cascade throughout the system. Uncovering the environmental effects across the value chain will help to prevent unintended consequences of otherwise well-intentioned efforts to maximize the utilization of recovered paper.

The research for the model, led by Prof. Elsa Olivetti at the Massachusetts Institute of Technology (MIT), was funded by the American Forest & Paper Association and the National Science Foundation, and conducted in collaboration with the Research Triangle Institute and the National Council on Air and Stream Improvements (NCASI), with inputs from subject matter experts in the paper value chain.



What the Dynamic Fiber Flows Model Does

The underlying framework developed by the MIT researchers and reported in scientific literature¹, applies a systems dynamic approach to consequential life cycle assessment for U.S. paper production in order to model the system-wide effects of changes to paper recovery and recovered paper utilization for various paper product categories. It quantifies changes to the system in response to a shift in paper recovery or recovered paper utilization based upon industry data, technology and market conditions in 2017 as the baseline period. The model determines a new distribution of fiber flows according to a change in paper recovery or fiber utilization based on various technical and economic parameters. The model then quantifies energy and GHG emissions changes as consequences of changed fiber consumption pattern.

Why this model is unique

Increasing recycled content in one paper product category does not occur in isolation, but will affect the system-wide recovered fiber availability and usage for other paper products. Rather than a static comparison of products, the Dynamic Fiber Flows Model examines real-world scenarios based on marginal changes that take into account fiber substitution possibilities such as fiber performance, market demand, manufacturing capabilities and resource availability. It is a sophisticated and comprehensive approach that recognizes the complexities and dynamics across the system, from fiber sourcing to product end-of-life.

- Focus is on broader, consequences on an industry-wide scale based on changes in recovered paper utilization and paper recovery, not product comparisons
- Takes a system-wide, global view across the entire paper value chain for major paper product categories
- Considers technical and economic factors, including raw material costs, fiber availability, quality, fiber yield, and processing capability.
- Identifies GHG consequences across various product life cycle stages.

¹ Journal of Cleaner Production, Volume 241, Consequential effects of increased use of recycled fiber in the United States pulp and paper industry, 20 December 2019, 118133



Application of model results

Because of the complex interactions, the multiple variables at play, and the cascading effects that occur within fiber consumption and production of different paper product categories, AF&PA is presenting the results of the research project in the form of case studies. Each study represents a question, or a scenario related to a potential change of paper recovery or recovered paper utilization. By putting the quantitative results into context, the case studies may be useful to better inform policymakers and corporate decision makers regarding system-wide environmental effects within their supply chains.

It is important to note that these case studies are not intended to draw a specific conclusion or suggest a decision, but rather to provide a more comprehensive understanding of the opportunities and trade-offs associated with changes to paper recovery and recovered paper utilization based on the cascade of interactions that take place within the system.

These case studies examine current and emerging real-world issues within our industry. The Dynamic Fiber Flows Model may be used to explore new questions and are designed to be updated to include future industry data and system dynamics assumptions. Please direct inquiries to info@afandpa.org.

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CASE STUDY: TISSUE PRODUCTS

The effects of a 10-percent increase in recovered paper consumption in the tissue sector. This study examines the impacts of increasing recovered paper consumption in the At-Home market and the Away-from-Home market for tissue products.



American Forest & Paper Association



Background

The interest in increasing the recycled content in tissue products generally stems from a commonly held opinion that fresh fiber is best utilized when it can be recovered and incorporated in new product manufacturing so that it can remain in the system for subsequent use multiple times. Recovering paper for recycling has multiple environmental benefits. Diverting paper from landfill avoids greenhouse gas emissions (primarily methane) that contributes to climate change. In addition, utilizing recovered fiber in products extends the fiber supply and saves landfill space. The benefits of replacing virgin fiber with recycled fiber in paper products, however, can vary widely.

What may not be well understood is the level of recovered paper consumption utilized in the tissue sector, and the dynamics that influence the fresh and recycled fiber distribution in various tissue products. This industry sector encompasses a wide variety of products, including toilet paper, paper towels, napkins, facial tissues, wipes and specialty sanitary papers.

This case study examines the system-wide effects of increasing recovered paper consumption by ten percent across the tissue sector of the industry.

U.S. tissue manufacturers are major consumers of recovered paper. In 2017, over four million tons of recovered paper was utilized by U.S. manufacturers for the production of 7.6 million tons new tissue products (55 percent of total production volume). Of the recovered paper grades available for use in tissue product production, the majority of recycled fiber utilized comes from deinking grades (see Figure 1).





TISSUE MARKET OVERVIEW

While tissue products are commonly used every day, tissue manufacturers generally serve two distinct markets, based on where these products are used- primarily at home (AH) and primarily away from home (AFH). A key factor in the distribution of the type of fiber used in tissue products is the fact that each market has fundamentally distinct product preferences and performance demands.

	At-Home Market (AH)	Away-From-Home Market (AFH)
Primary Customer and Use	Purchased by consumers from retail stores and used in the home	Purchased by commercial businesses or institutions and supplied for public use in places like schools, hospitals, restaurants, hotels, offices and other public spaces.
Key Product Characteristics	Generally prioritize high quality, softness, absorbency, ease of use, efficiency, and brightness.	Often prioritize value. Packed and purchased in bulk and used in high- volume dispensers that meet the economic and replenishment needs of institutional buyers.
Fiber Concentration	Primarily fresh fiber	Primarily recovered fiber

Based on estimates from the American Forest & Paper Association, the At-Home market represents approximately 70 percent of overall tissue product production volume. Because softness, absorbency and strength are high priority performance attributes for this market segment, fresh fiber is the primary raw material. Recycled paper generally cannot achieve the required specifications for premium tissue products due to the recycled fiber being thinner, shorter and weaker than fresh fiber.



The Dynamic Fiber Flows Model simulates the effects of increasing recovered paper consumption in the tissue sector by 10 percent as follows:

Figure 2: System-wide Effects Overview





Detailed Results Analysis

Fiber Distribution Results

Increasing the recovered paper consumption of tissue by 10 percent results in increased demand for recovered fiber consumption by 382 thousand short tons. This increase in recovered fiber utilization would lead primarily to a reduction in fresh fiber pulp production with a corresponding reduction in wood fiber consumption of 578 thousand tons. The consumption volume of wood fiber is greater than recovered paper due to the lower yield of converting wood fiber to fresh fiber pulp relative to that of processing recovered paper to recycled pulp.

The primary source of additional recovered paper to meet the increased recycled fiber demand is from the export market, with a very small quantity coming from additional collection, due to the relative costs of those fiber sources.

Figure 3: Net Fiber Consumption Change by increasing the recovered paper consumption in the Tissue Sector by 10 percent.



Given the complexities of multiple product lines among the two tissue markets, as well as fiber performance and technology constraints that come into play as recovered paper utilization increases, the consumption of recovered paper would vary between the AH and AFH product segments.

- Since the AFH segment already has a high concentration of recovered paper utilization, there is a limit to how much more recovered fiber can be absorbed without additional volume demand for AFH products.
- In the AH market, there is also a limit regarding how much recovered fiber can be utilized in premium products to meet required softness and absorbency specifications.
- More than half of the manufacturing capacity in the AH segment utilizes through-air drying (TAD) machine technologies. Paper machines with this type of drying configuration are limited in their ability to utilize recovered fiber in the fiber mix in order to achieve the bulk and absorption requirements of premium tissue products.



Energy Results

The results of the fiber flow changes across the pulp and paper industry influences the energy consumption at the mills.

Increasing the recycled content in the tissue sector by 10 percent would lead to reduced use of biomass energy across the tissue mill system, as the majority of tissue paper is manufactured at mills with integrated pulp production where biomass is the primary energy source. Based on the assumption that the tissue sector had the capacity to consume all of the additional recovered paper, the model estimates the net decrease of approximately 8 million Gigajoules in biogenic-derived energy from the fiber flow shifts.

Paper Industry Fuel Sources

Energy used in the paper industry predominately comes from renewable biomass. Fossil fuel-derived sources (coal, oil, natural gas) also are used. Specifically, approximately two-thirds of the industry's energy needs comes from biomass energy produced on-site from spent pulping liquors recovered from the production of wood pulp, wood manufacturing residuals and forest residues. Unlike fossil fuel sources (coal, oil, natural gas), which have been trapped in geologic formations for a millennia, biomass for paper production is regenerated through sustainable forestry practices which have been in place for decades.



Figure 4: Energy Use from Biogenic Sources



Energy Use from Fossil Fuel Sources

Conversely, because deinking facilities and mills that primarily utilize recycled fiber are largely nonintegrated and do not have the opportunity to utilize biomass energy resulting from the fresh fiber pulping process, recycled pulp is primarily derived from fossil fuels, mostly coal and natural gas. As a consequence, the fossil fuel-based energy needed to reach an increase in recovered paper consumption of 10 percent in the tissue sector would increase. This increase is estimated to be approximately 1 million Gigajoules (Figure 5).

Figure 5:





Greenhouse Gas (GHG) Emissions Results

Like energy consumption, a change in fiber flows across the pulp and paper industry influences greenhouse gas emissions. The Fiber Flows model examines greenhouse gas changes for biogenic GHG emissions and fossil-fuel derived GHG emissions across the life cycle stages of the products. The GHG emissions are estimated from raw material acquisition in the forest through product manufacturing and end-of-life phases and the effects from changes in international trade fiber flows.

GHG Emissions in the Pulp and Paper Industry

Because of their biogenic origin, CO2 emissions from biomass fuel combustion are recognized and treated differently from fossil fuel combustion emissions by an abundance of studies, government agencies, legislation and rules around the world. CO2 is removed from the atmosphere as forests grow and the carbon in this forest biomass will return to the atmosphere regardless if it biodegrades naturally, is combusted for energy or lost in forest fires, completing the carbon cycle. Increased use of energy from fossil fuels adds new carbon to the atmosphere leading to increases in atmospheric CO2 levels. In the U.S. since 1990, sustainably managed forests and other lands have absorbed more CO2 from the atmosphere than they emit. For these reasons, GHG emissions from renewable biogenic sources are widely recognized as carbon-neutral: the emissions released from the combustion of biomass are offset by forest growth when forests are sustainably managed.

¹ U.S. EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks, 2017

GHG Emissions through Lifecycle Phases

The Fiber Flows Model accounts for both categories of GHG emissions (biogenic and fossil fuel GHG) separately, following the GHG protocol requirement (US EPA, 2009; World Resource Institute (WRI), 2013, 2011. This is consistent with the Intergovernmental Panel on Climate Change (IPCC), which counts biogenic emissions as zero, if the overall change in forest carbon stocks is neutral or positive, which is the case in the U.S.

In this scenario, the sources of recovered paper used to fill the gap of reduced virgin pulp production have a direct impact on how GHG emissions change in the various life cycle stages of tissue products.

For biogenic GHG emissions, the reduction in virgin fiber use drives GHG reduction in the gate-to-gate production phase as would be expected, and the reduced virgin fiber demand results in reduced GHG impacts in the forest.



Because the amount of recovered paper to replace virgin pulp comes from multiple sources, the fossil fuel-derived GHG emission changes are significant in several life cycle phases. Recovered paper sourced from what otherwise would have been exported would result in fossil GHG increases in international trade and other upstream phases as the loss of recovered paper available in other countries would be replaced by pulp manufactured using fossil fuel energy sources. Since some of the recovered paper to fill the gap left by the reduction in virgin pulp would come from additional paper collection, there would be a fossil GHG reduction in the end-of-life phase.

The production of recycled pulp by non-integrated processing facilities would drive an increase of fossil fuel-derived GHG emission in the gate-to-gate life cycle phase.



Figure 6: System-wide Life Cycle GHG emissions changes as a result of increasing recovered paper consumption in the tissue sector by 10 percent



Case Study Conclusions

Increasing the consumption of recovered paper in the tissue sector by 10 percent is not straightforward due to the wide variety of products and diverse marketplace preferences within the tissue sector. While the Dynamic Fiber Flows Model estimates the changes that would occur in energy use and GHG emissions as a result of shifts in fiber flows across the sector, the complexities of multiple product lines and technology constraints within the market segments come into play as recovered fiber utilization increases:

- Increasing overall recovered paper consumption by 10 percent would Require an additional 382 thousand short tons of recovered fiber to meet demand, most of which would come from recovered fiber that would otherwise be exported
- Recycled fibers are primarily utilized in the Away-from-home market segment, where it is most economic and efficient to do so. Since the concentration of recycled fiber in this segment is already high, increased market demand may be needed to significantly increase recovered paper consumption.
- The strength, softness and absorbency specifications typical in the premium tissue product lines are limiting factors for recycled fiber use in the At-home market. In addition, a significant percentage of paper machine capacity in the At-home segment is configured such that increased utilization of recycled fiber is not economical or efficient and would generate additional waste.
- Assuming a 10 percent increase in recovered paper consumption could be achieved, fossil fuel-based energy use would increase, as recovered paper deinking facilities and non-integrated paper mills are largely fossil-fuel based.
- Reduced energy consumption and GHG emissions from biogenic sources as a result of decreased fresh fiber pulp production would occur, which are considered carbon neutral under the EPA WARM model and IPCC standards.
- Fossil-fuel based GHG emissions would increase in the manufacturing, paper collection, and in the Chinese manufacturing segment as China replaced recovered fiber imports with local, fossil-fuel energy sources. Fossil-fuel GHG emissions would decrease if additional recovered paper demand was sourced from increased paper collection and diversion from landfill.



Additional Considerations

- Recovered paper is an important fiber source for the tissue sector, but the assumption that recycled fibers can be utilized uniformly across all market segments and tissue products is flawed. The economic efficiency and environmental benefits of utilizing recovered fiber are greater for AFH tissue production compared to AFH tissue manufacturing, as the fiber yield in processing recovered paper for AFH products is much greater than that of the AH products. This is because of fiber performance of premium AH products and paper machine configuration in the production represent constraints to the efficient use of additional recovered fiber for those products.
- The greatest opportunity for increased recovered paper consumption in the tissue sector, without additional investments in recovered fiber processing or paper machine technologies, would be increased market demand for Away-from-home products.
- Improvements in recovered paper quality would increase the opportunity for utilization in the tissue sector. However, the current trend in recovered paper collection is an increasing proportion of recovered paper being from packaging products, which are not very suitable to be utilized in tissue production. The primary recovered paper grade used to make tissue is Sorted Office Products (SOP), which is becoming a smaller part of the recovered paper stream, and particularly so in the most recent closures of office operations due the COVID-19 pandemic of 2020.
- The high performance characteristics of strength and absorbency in premium tissue products that utilize high levels of fresh fiber provides the opportunity to reduce waste during product use, as less of the product may be necessary to achieve the same results compared with tissue products with lower specifications.



DATA Tables

Table 1: Fiber Consumption Changes

	Product Sector	Unit	Fiber Consumption		
			Recovered Paper (Pulp Subs, Deinking)	Fresh Fiber	
	Tissue	Million Short Tons	0.382	-0.578	

Table 2: Energy Consumption Changes

	Fuel Source		
Unit	Biomass Energy	Fossil Fuel Energy	
Million Gigajoules	-7.92	1.05	

Table 3: Changes in GHG Emissions Through the Lifecycles Stages

		Life Cycle Stage Contribution				
GHG Emissions Type	Unit	1. Forest	2. Other Upstream	3.Gate-to-Gate	4. End-of-Life	5. International Trade
Biogenic GHG	Million Metric Tons of CO2 eq./year	-183.6	0	-718.1	-75.3	0
Fossil Fuel GHG	Million Metric Tons of CO2 eq./year	-108.3	21.3	63.4	-178.6	63.4