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.

American Forest & Paper Association

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

This research project was also supported by:

The National Science Foundation (NSF), award 1605050 CBET program;

The National Council for Air and Stream Improvement, Inc. (NCASI);

Research Triangle Institute International

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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 literature[1], 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: PRINTING-WRITING

The system-wide effects of an increase in the recovered fiber content of printing-writing freesheet papers from the current level of 7.8 percent to an average of 15 percent

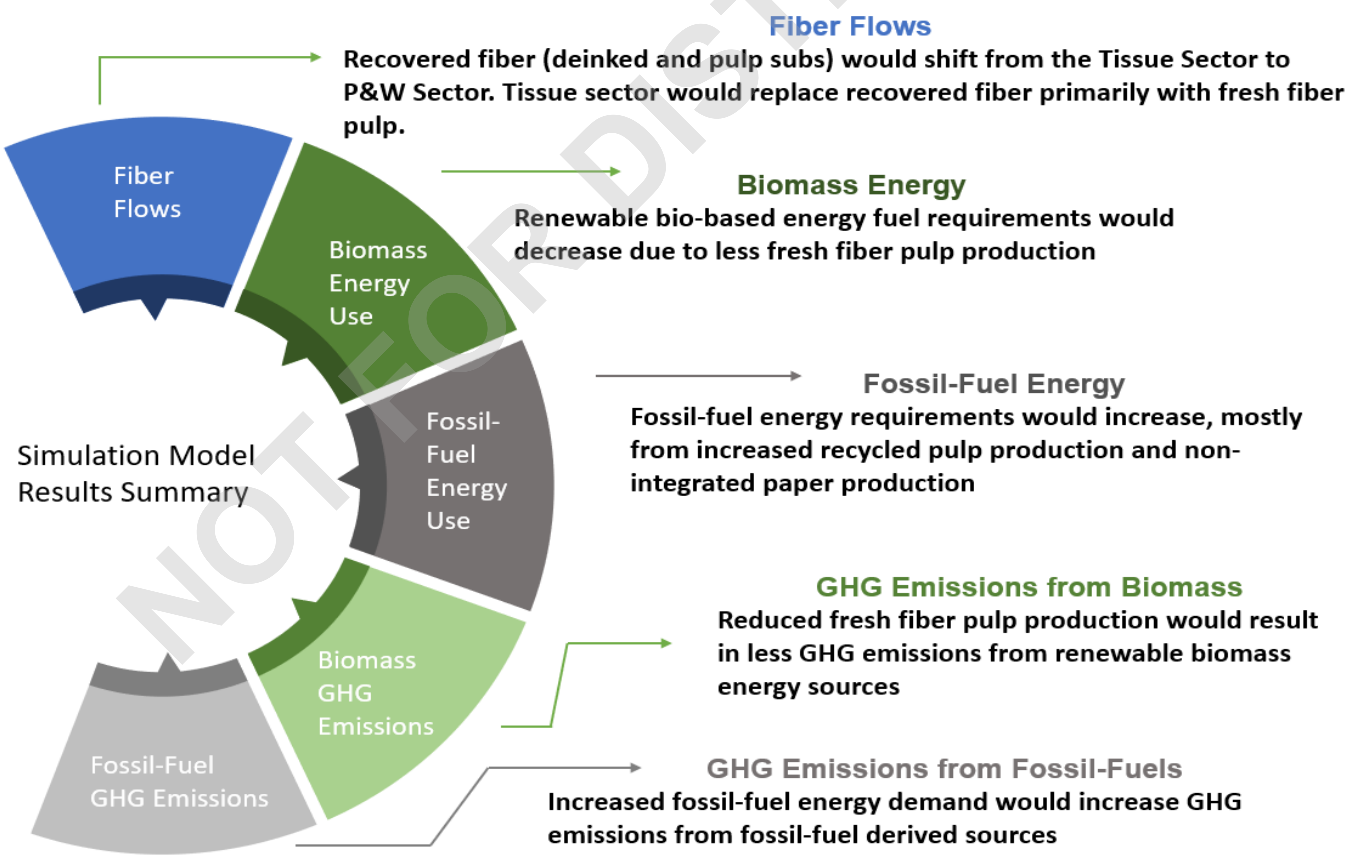
American Forest & Paper Association

Background

Recovering paper for recycling has multiple environmental benefits. Diverting paper from the landfill avoids greenhouse gas emissions (primarily methane) that contribute 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 can vary widely, depending on manufacturing methods and products produced. This case study examines the **system-wide effects** of increasing the recovered fiber content of printing-writing (P&W) freesheet papers from the current level of 7.8 percent to an average recycled content level of 15 percent. This increase would effectively double the current recycled content in P&W freesheet papers.

The Dynamic Fiber Flows Model simulates this scenario with the following results:

Figure 1: System-wide Effects Overview



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Detailed Results Analysis

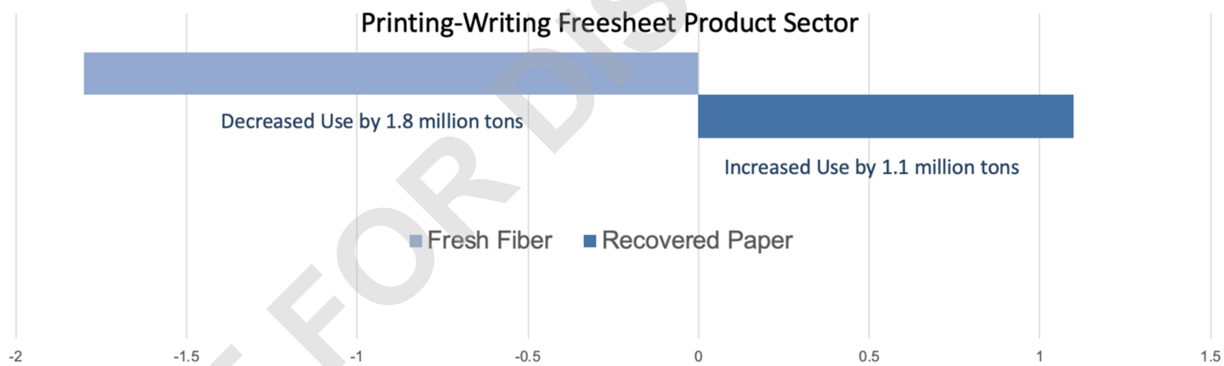
Fiber Distribution Results

In order to achieve an average recycled content of 15percent, P-W freesheet producers would increase consumption of recovered paper by 1.1 million tons. The types of recovered paper most suitable to fulfill this increased demand for recovered fiber are pulp substitutes and high-grade deinking grades. Other recovered paper grades like corrugated, newsprint and mixed papers are not economically feasible because of the increased level of processing needed to meet high- quality fiber standards of printing papers, may have limited availability, or be too contaminated for use in making printing papers.

The increase in recovered fiber consumption would result in a reduction of virgin (fresh fiber) pulp consumption made from wood fiber by P-W freesheet producers. 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.

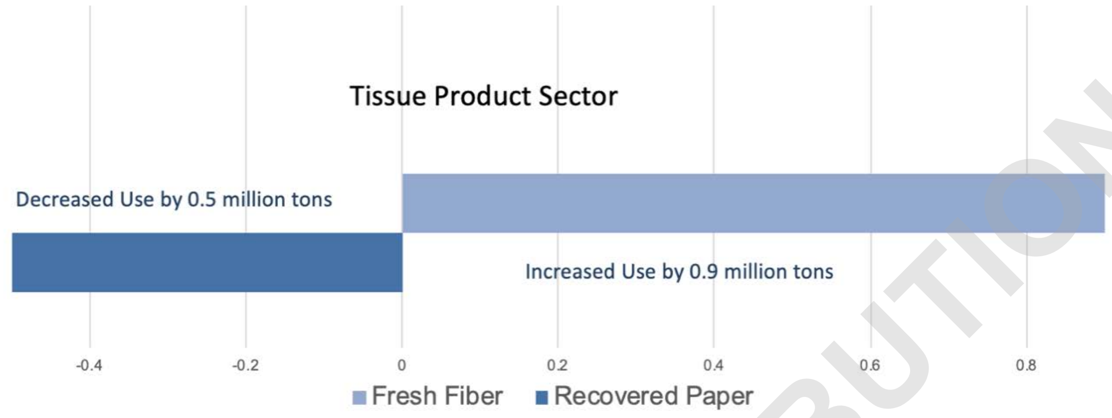
Net Fiber Consumption Change by the Printing-Writing Sector by increasing the average recycled content to 15%

Figure 2



The source of the additional recovered paper demand by the P-W freesheet sector would primarily come from the Tissue sector, as this sector of the industry uses the same type of recovered paper grades as P-W freesheet manufacturers. In this case, Tissue manufacturers, based on economic and environmental factors, would replace the recovered paper diverted to the P-W sector primarily by consuming additional fresh fiber, and then filing the remaining gap from the export market and from landfill diversion.

Figure 3



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

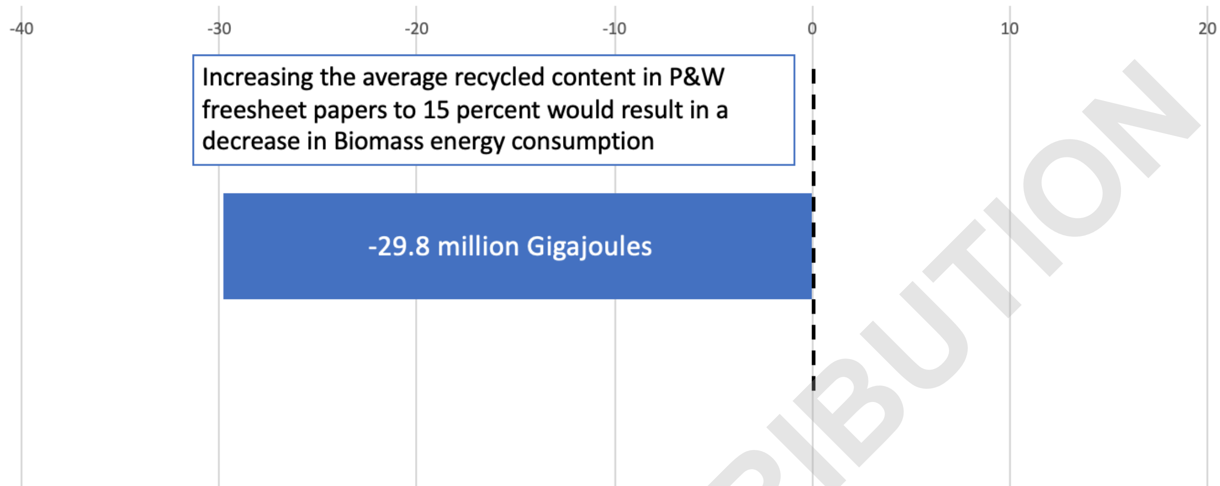
Increasing the average recycled content of paper to 15 percent would lead to reduced use of biomass energy across the P&W freesheet mill system, as the majority of P&W freesheet paper is manufactured at mills with integrated pulp production where biomass is the primary energy source. The tissue mills would increase the use of fresh wood fiber pulp to partially replace the shift of recovered paper to the P&W freesheet sector. The model estimates the net decrease of approximately 30 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.

Energy Use From Biogenic Sources

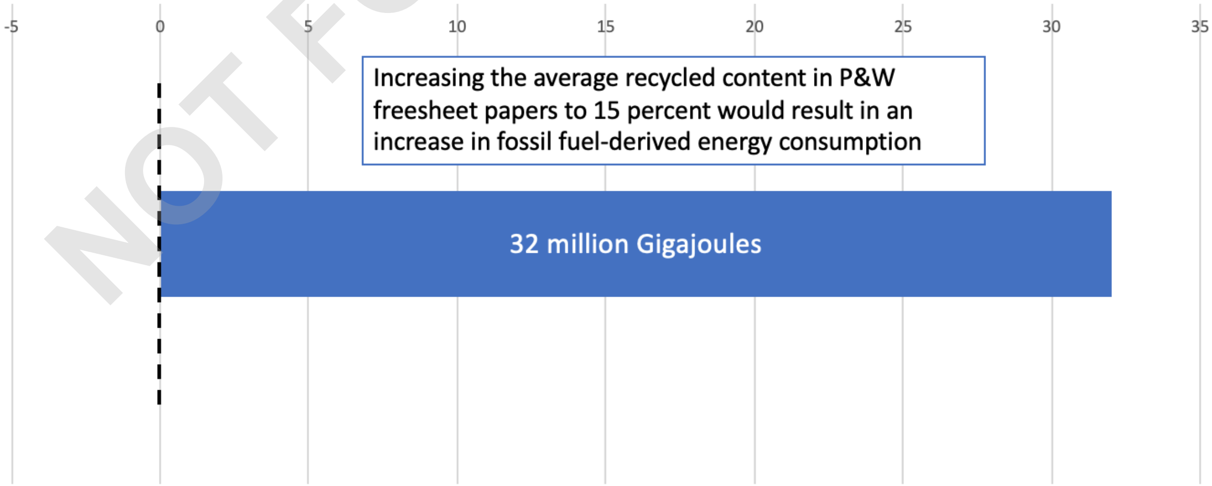
Figure 4



Energy Use from Fossil Fuel Sources

Conversely, because deinking facilities and mills that primarily utilize recycled fiber are largely non-integrated and do not have the opportunity to utilize biomass energy resulting from the fresh fiber pulping process, recycled pulp is primarily produced using fossil fuels, mostly natural gas. As a consequence, the fossil fuel-based energy needed to reach an average recycled content level of 15 percent in the P&W freesheet sector would increase. This increase is estimated to be approximately 32 million Gigajoules.

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 product end-of-life phases.

GHG Emissions in the Pulp and Paper Industry

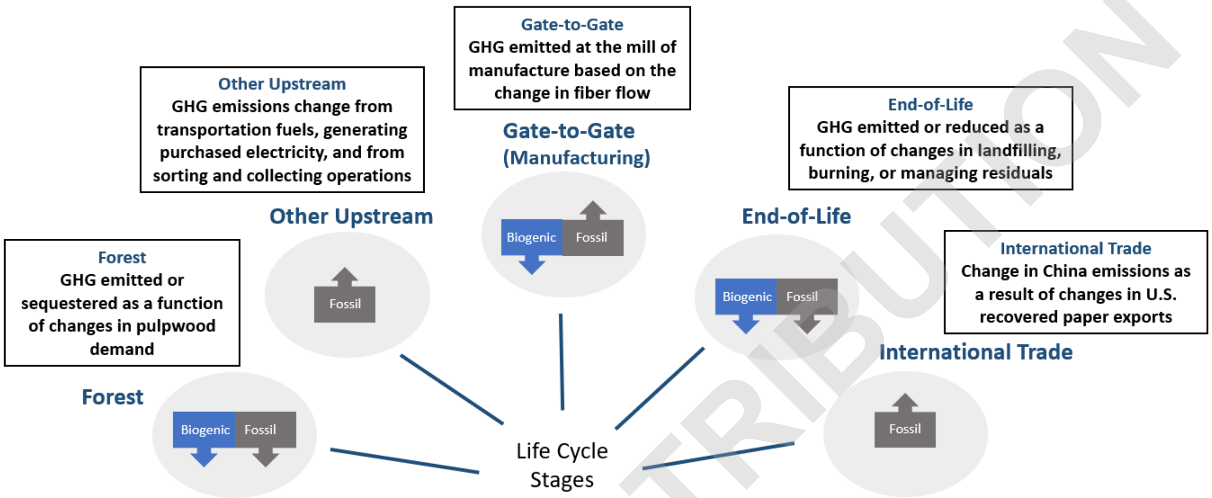
Because of their biogenic origin, carbon dioxide (CO2) emissions from biomass fuel combustion are recognized and treated differently from fossil fuel combustion emissions by an abundance of studies, government agencies, legislation and rules around the world. CO2 is removed from the atmosphere as forests 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.[1] 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*

The Fiber Flows Model accounts for both categories of GHG emissions (biogenic and fossil fuel GHG) separately, following the GHG protocol guidelines (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.

Figure 6

System-wide Life Cycle GHG emissions changes
as a result of increasing the average recycled content in P-W freesheet papers from 7.8 to 15%



In the case of increasing recycled content in P&W freesheet papers, the largest change in both biogenic and fossil-fuel based GHG emissions occurs in the manufacturing (Gate-to-Gate) life cycle stage. This is primarily due to reduced biogenic energy consumption that would otherwise occur as a result of reduced P&W mills pulp production, and an increase in fossil GHG emissions due to the energy used by deinking facilities that process recovered paper, which are largely fossil-fuel based.

Case Study Conclusions

Increasing the average recovered paper content of P&W freesheet paper from the current level of 7.8 percent to 15 percent would:

- Change fiber flows such that pulp production from fresh fiber at P&W freesheet mills would be reduced and replaced by a shift of deinked recovered paper and pulp substitutes from the Tissue sector.
- Cause the Tissue sector to replace the recovered fiber shifted to the P&W freesheet sector primarily with virgin pulp made from fresh fiber, with some recovered paper diverted from landfill, and a small amount from recycled paper that would have been exported.
- Increase fossil-fuel derived energy consumption resulting from an increase in recovered paper utilization at primarily non-integrated paper mills and recovered paper de-inking facilities, which are largely fossil-fuel based.
- Increase net GHG emissions from fossil-fuel sources across the life cycle of P&W freesheet papers, primarily in the manufacturing stage.
- Reduce energy consumption and GHG emissions from biogenic sources, resulting from decreased fresh fiber pulp production, which are considered carbon neutral under the EPA WARM model and IPCC standards.

Additional Insights

- The quantity of available recovered paper that can be suitably applied to P&W freesheet grades, is not unlimited. The model estimates that the maximum average recycled content achievable in this product segment would be approximately 18 percent.
- Replacing virgin pulp production from wood fiber with recovered paper would likely reduce pulp mill operating rates, decreasing the economic and environmental efficiency of integrated P&W freesheet paper mills, as pulp mills are designed to run at high operating rates.
- Since fiber can be utilized multiple times following recovery, it is important to note that a shift in increased virgin fiber consumption to make tissue products would limit the potential useful life of recovered fiber. Because tissue products are not typically recovered for recycling, the additional virgin fiber consumed by the tissue sector would enter the waste stream after use, eliminating the opportunity for the fiber to be recycled for subsequent uses.
- Results are not linear. Applying the results from this case study to other levels of recovered paper content through extrapolation would lead to incorrect conclusions. A separate scenario would need to be examined for different levels of recycled content.

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DATA Tables

Table 1: Fiber Consumption Changes

Product Sector	Unit	Fiber Consumption	
		Recovered Paper (Pulp Subs, Deinking)	Fresh Fiber
P-W Freesheet	Million Short Tons	1.1	-1.85
Tissue	Million Short Tons	-0.5	0.9
Total	Million Short Tons	0.63	-0.95

Table 2: Energy Consumption Changes

	Fuel Source	
Unit	Biomass Energy	Fossil Fuel Energy
Million Gigajoules	-29.8	32.0

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	-0.27	0	-2.1	-0.52	0
Fossil Fuel GHG	Million Metric Tons of CO2 eq./year	-0.16	0.54	1.87	-1.24	0.01