Unclassified **ENV/EPOC/WGWPR(2009)9/FINAL**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development

17-May-2011

English - Or. English

ENVIRONMENT DIRECTORATE
ENVIRONMENT POLICY COMMITTEE

ENV/EPOC/WGWPR(2009)9/FINAL
Unclassified

Cancels & replaces the same document of 30 March 2011

Working Group on Waste Prevention and Recycling

A SUSTAINABLE MATERIALS MANAGEMENT CASE STUDY

WOOD FIBRES

Contact person: Peter Börkey, tel: +33 1 45 24 13 85; Fax: +33 1 44 30 61 79; email: peter.börkey@oecd.org

JT03301898

Document complet disponible sur OLIS dans son format d'origine
Complete document available on OLIS in its original format

English - Or. English

NOTE FROM THE SECRETARIAT

In addition to aluminum, critical metals and plastics, wood fibres have been identified as an important material for which a sustainable materials management approach might provide valuable insight. The objective of this case study on wood fibres is to analyse the environmental impacts of wood fibres throughout their lifecycle and to explore policy opportunities and barriers to SMM, as a way of demonstrating the utility of the SMM concept for policy-making.

This case study was presented at the OECD Global Forum on Sustainable Materials Management held in Belgium from 25 to 27 October 2010, together with other policy and case study materials.

This report has been prepared by ICF International, Washington DC, USA. The main authors were: Mr. Adam Brundage, Mr. Christopher Evans, Ms. Deanna Lizas and Mr. Randy Freed.

This project was made possible through voluntary contributions from Canada, Finland, Japan, Spain and Switzerland.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Background

This study seeks to identify opportunities for sustainable materials management (SMM) of wood fibres (*i.e.* pulp and paper products). The pulp and paper industry is a key sector in the global economy with substantial opportunities to reduce energy use, greenhouse gas (GHG) emissions and water use throughout the fibre product life-cycle.

The report first provides an overview of the important physical, economic and environmental aspects of the life-cycle of fibre products. Next, it describes energy use, GHG emissions and water use across the fibre life-cycle including harvesting, pulping, papermaking, transportation and end-of-life in order to identify where environmental impacts are the largest. The study focuses on mechanical and chemical pulps that include kraft, newsprint, coated and uncoated paper, tissue and specialty paper, boxboard and paperboard. It considers recycling, combustion with energy recovery and landfilling as primary options for end-of-life management. Life-cycle data are compiled from North American and European sources.

The study identifies technologies and management practices that could reduce environmental impacts across the wood fibre life-cycle in order to evaluate where substantial opportunities exist for SMM. It also discusses key drivers of SMM within the fibres industry that promote key management practices and technologies and barriers to SMM that impede their implementation.

Objectives

This case study intends to offer policy makers an improved understanding of i) current state of the life-cycle of wood fibres, with a focus on associated environmental impacts and consideration of economic and social issues; ii) most promising SMM practices at different life-cycle stages of fibre products; iii) key practices and life-cycle stages that could reduce environmental impacts across the wood fibre life-cycle; and (iv) drivers and barriers that facilitate or hamper the rate at which SMM practices are adopted.

Results

The report finds that reductions in energy use on the order of 20 to 30% could be achieved in conventional pulp mills with existing technologies. Chemical and thermo-mechanical pulp mills offer the greatest potential for energy savings. Paper drying is the most energy-intensive process across the life-cycle, consuming 15 to 25% of total energy.

Chemical pulping can be roughly twice as water-intensive as mechanical pulping. Reductions in water use on the order of 25 to 50% are possible in conventional mills using technologies such as dry debarking, partial or full closure of certain water loops, washing system improvements and elemental chlorine-free (ECF) or enzymatic bleaching.

Increased and more efficient use of biomass energy—considered to have zero net GHG emissions if sourced from sustainably managed forests—can mitigate GHG emissions. Sustainable forest management practices and certification are essential to ensuring that biomass fuels remain carbon neutral.

The transportation component of the life-cycle is a relatively small contributor to energy use, GHG emissions and water use. Nonetheless, opportunities exist, such as optimization of supply chains in order to reduce distances, coupled with improvement in the efficiency of transportation.

At end-of-life, recycling paper products saves 7 to 19 GJ of energy per tonne of paper recycled and results in GHG emission reductions relative to the virgin manufacture of paper. Focusing on improving recovered paper collection efficiency, reducing the rates of contamination and developing new technologies and pulping processes can enable even greater efficiencies in the utilization of recovered paper.

Although overall energy use is lower in recycling paper, GHG emissions from the manufacturing stage can be larger due to the fossil energy used in recycled mills compared to the low- or zero-carbon biomass energy used in virgin paper production. Even so, the GHG reductions from avoided fibre landfilling more than outweigh the additional GHG emissions from recycled paper manufacture and the overall GHG profile for recycling paper could be even more beneficial if biomass and other non-fossil fuel sources are used in the manufacture of recycled paper.

Combustion facilities in OECD countries normally employ energy recovery systems, so fibre discards sent to these facilities can produce electricity for the grid, potentially displacing fossil electricity generation.

Pulp and paper discards and residues that are sent to landfills generate GHG emissions in the form of methane and represent a significant portion of the GHG emissions associated with the pulp and paper life- cycle. Therefore, it is most important to divert paper which has high methane generation potential from disposal in landfills.

Finally, across the entire life-cycle, source reduction of paper – in practices such as lightweighting packaging, double-sided printing and copying and paper re-use – offers a comprehensive approach to reducing the size of the environmental footprint.

Conclusions

The wood fibre products industry is a heavy manufacturing sector in terms of consumption of natural resources and energy. Paper and paperboard consumption is expected to increase, particularly in emerging markets such as China and India, so this industry has the potential to increase the size of its already large environmental footprint.

The study finds that technical, economic, social and political barriers exist that impede adoption of technologies and practices that contribute to SMM. Technical barriers include slow rates of capital turnover, while high capital costs and volatility in energy and recovered paper prices are key economic barriers. Social and political barriers facing the industry involve gaps in information sharing, a lack of resources to promote SMM opportunities and weak enforcement of regulated practices as well as current insufficiency of policies that require SMM.

At the same time, important opportunities are available for reducing energy use, GHG emissions and water use across the entire fibre life-cycle. From a carbon management perspective, the wood fibre industry actively manages larger carbon stocks and greater annual carbon throughput than any other industries except oil & gas, organic chemicals, coal, electric power and agriculture. Excluding agriculture, pulp and paper sector is unique among industries in terms of its management of substantial quantities of biogenic carbon. Ultimately, the GHG emissions profile of the pulp and paper industry is dictated by i) the management practices at forests from which biomass is utilised (*i.e.* whether they are sustainably managed or not); ii) the GHG-intensity of other fuels use to generate process heat and electricity; and iii) the management of fibre products at end-of-life.

Given the increased attention on reducing energy use, GHG emissions and water use globally and considering that OECD member countries produce and consume the majority of the world's paper, the opportunities for SMM of wood fibres outlined in this study represent key elements in OECD’s portfolio of options to support its member countries in developing and implementing such SMM goals.

RÉSUMÉ

Contexte

Cette étude vise à identifier les opportunités de gestion durable des matières (GDM) dans le secteur mettant en œuvre des fibres de bois (c'est-à-dire des pâtes à papier et papiers). L'industrie des pâtes et papiers est un secteur clé de l'économie mondiale, qui offre des gisements importants de réduction de la consommation d'énergie, des émissions de gaz à effet de serre (GES) et de la consommation d'eau, tout au long du cycle de vie des fibres.

Le rapport présente tout d'abord un aperçu général des principaux aspects physiques, économiques et environnementaux du cycle de vie des produits à base de fibres. Il décrit ensuite la consommation d'énergie, les émissions de GES et la consommation d'eau tout au long du cycle de vie de ces produits – récolte, mise en pâte, fabrication du papier, transport et fin du cycle de vie – de façon à identifier les étapes du cycle où les impacts environnementaux sont les plus importants. L'étude est axée sur les pâtes mécaniques et chimiques qui comprennent le papier kraft, le papier journal, le papier couché et non couché, le papier-mouchoir et le papier pour usages spéciaux, et le carton. Le recyclage, l'incinération avec valorisation énergétique et la mise en décharge sont les principales solutions examinées pour la gestion des produits en fin de vie. Les données relatives au cycle de vie sont compilées à partir de sources nord-américaines et européennes.

Pour évaluer où se trouvent les possibilités importantes de GDM, cette étude recense les technologies et les pratiques de gestion de nature à réduire les impacts environnementaux tout au long du cycle de vie des fibres de bois. Elle examine aussi les principaux éléments moteurs qui, dans l'industrie mettant en œuvre les fibres, encouragent les pratiques et technologies clés pour la gestion durable des matières, ainsi que les obstacles qui en freinent l'application.

Objectif

Cette étude de cas a pour objectif de permettre aux décideurs de mieux cerner i) la situation actuelle concernant le cycle de vie des fibres de bois, et plus particulièrement ses impacts environnementaux ainsi que les aspects économiques et sociaux qui lui sont associés ; ii) les pratiques de GDM les plus prometteuses aux différentes étapes du cycle de vie des produits à base de fibres ; iii) les pratiques clés et les étapes du cycle de vie permettant de réduire les impacts environnementaux tout au long de la durée de vie des fibres de bois; et (iv) les moteurs et obstacles qui accélèrent ou freinent le rythme d'adoption des pratiques de GDM.

Résultats

Il ressort de l'étude que les usines productrices de pâtes mécaniques peuvent réduire leur consommation d'énergie de 20 à 30 % avec les technologies existantes. Mais ce sont les usines de pâtes chimiques et thermomécaniques qui offrent le gisement d'économies d'énergie le plus important. Le séchage du papier est le processus le plus énergivore du cycle de vie, puisqu'il consomme entre 15 et 25 % de l'énergie totale.

La fabrication des pâtes chimiques peut consommer près de deux fois plus d'eau que celle des pâtes mécaniques. Des réductions de l'ordre de 25 à 50 % de la consommation d'eau sont possibles dans les usines classiques en recourant à des techniques comme l'écorçage à sec, à la fermeture partielle ou totale de certains circuits d'eau, à l'amélioration des systèmes de lavage, et au blanchiment sans chlore élémentaire (SCE) ou au blanchiment enzymatique.

Les émissions de GES peuvent être atténuées par une utilisation accrue et plus rationnelle de l'énergie de la biomasse – considérée comme sans émissions nettes de GES si elle est issue de forêts faisant l'objet d'une gestion durable. Les pratiques de gestion durable des forêts et leur certification sont indispensables pour garantir que les combustibles issus de la biomasse restent neutres en carbone.

L'étape « transports » du cycle de vie représente une part relativement faible de la consommation d'énergie, des émissions de GES et de la consommation d'eau. Néanmoins, il existe des gisements d'économies, notamment en optimisant les chaînes d'approvisionnement pour réduire les distances et en améliorant l'efficacité des transports.

A la fin du cycle de vie, le recyclage des produits à base de papier permet d'économiser entre 7 et 19 GJ d'énergie par tonne de papier recyclé et de réduire les émissions de GES par rapport aux fibres neuves. L'utilisation des papiers récupérés peut être rendue encore plus efficace en optimisant la collecte des vieux papiers, en réduisant les taux de contamination, et en développant de nouvelles technologies et de nouveaux procédés de fabrication de la pâte.

Même si la consommation globale d'énergie est plus faible pour le papier recyclé, les émissions de GES produites au stade de sa fabrication sont plus importantes car les usines mettant en œuvre des fibres de récupération utilisent de l'énergie fossile, alors que les usines utilisant des fibres neuves consomment de l'énergie de la biomasse sans émissions nettes de GES ou à émissions faibles. Pourtant, même dans ces conditions, les réductions de GES résultant de la non-mise en décharge font plus que compenser les émissions supplémentaires de GES provenant de la fabrication de papier recyclé. En outre, le profil global des émissions de GES du papier recyclé pourrait être encore amélioré en utilisant de la biomasse et d'autres sources de combustibles non fossiles pour le fabriquer.

Les installations d'incinération des pays de l'OCDE étant généralement équipées de systèmes de valorisation énergétique, les rebuts de fibres envoyés dans ces installations permettent de produire pour le réseau public une électricité qui pourrait remplacer l'électricité d'origine fossile.

Les rebuts et résidus de pâtes et papiers qui sont mis en décharge émettent du méthane et, de ce fait, représentent une part importante des émissions de GES associées au cycle de vie des pâtes et papiers. Il est donc indispensable d'éviter la mise en décharge de papiers dont le potentiel de production de méthane est élevé.

Enfin, sur l'ensemble du cycle de vie, la réduction à la source des papiers – sous forme d'emballages légers, d'impressions et de photocopies recto-verso et de papier recyclé – constitue une solution globale de réduction de l'empreinte écologique.

Conclusions

Le secteur des produits à base de fibres de bois est une industrie manufacturière lourde en termes de consommation de ressources naturelles et d'énergie. La consommation de papiers et de cartons étant appelée à augmenter, en particulier dans les marchés émergents de la Chine et de l'Inde, ce secteur risque d'accroître encore son empreinte écologique qui est déjà importante.

Cette étude fait apparaître qu'il existe des obstacles techniques, économiques, sociaux et politiques qui freinent l'adoption de technologies et de pratiques contribuant à la GDM. Parmi les obstacles techniques figure la lenteur du renouvellement des équipements, tandis que les obstacles économiques comprennent notamment le niveau élevé des coûts d'équipements et la volatilité des prix de l'énergie et des papiers récupérés. S'agissant des obstacles sociaux et politiques, l'industrie est confrontée, entre autres, à un déficit d'échange d'informations, à un manque de ressources pour promouvoir les possibilités de GDM et à une mise en œuvre peu rigoureuse des pratiques réglementées, ainsi qu'à un nombre insuffisant de mesures prescrivant une gestion durable des matières.

Parallèlement, il existe d'importants gisements de réduction de la consommation d'énergie, des émissions de GES et de la consommation d'eau dans l'ensemble du cycle de vie des fibres. S'agissant du carbone, le secteur mettant en œuvre des fibres de bois gère activement des stocks de carbone plus élevés et une production annuelle de carbone plus importante que toute autre industrie, à l'exception des secteurs du pétrole et du gaz, de la chimie organique, du charbon, de l'électricité et de l'agriculture. Hormis le secteur agricole, l'industrie des pâtes et papiers est sans équivalent pour ce qui est de sa gestion de quantités importantes de carbone d'origine biologique. Enfin, le profil des émissions de GES du secteur des pâtes et papiers est fonction i) des pratiques de gestion des forêts dont on utilise la biomasse (c'est-à-dire de leur gestion durable ou non) ; ii) de l'intensité en GES des autres combustibles utilisés pour produire de la chaleur industrielle et de l'électricité ; et iii) de la gestion des produits à base de fibres de bois à la fin de leur cycle de vie.

Compte tenu de l'attention accrue portée à la réduction de la consommation d'énergie, des émissions de GES et de la consommation d'eau à l'échelle mondiale, et étant donné que les pays membres de l'OCDE produisent et consomment la majeure partie du papier mondial, les possibilités de GDM dans le secteur des produits à base de fibres de bois, présentées dans cette étude, constituent des éléments clés de la panoplie d'options envisageables par l'OCDE pour aider ses pays membres à définir et mettre en œuvre des objectifs de gestion durable des matières.

GLOSSARY OF ACRONYMS

Adt	Air-dry tonne
AF&PA	American Forest & Paper Association
BAT	Best available technologies
BMP	Best management practices
CCS	Carbon capture and sequestration
CEPI	Confederation of European Paper Industries
CHP	Combined heat and power
CO_2e	Carbon dioxide equivalent
CSA	Canadian Standard Association
CTMP	Chemo-thermo-mechanical pulp
EC	European Commission
ECF	Elemental chlorine-free
EDF	Environmental Defense Fund
EMS	European Modular System
EPA	U.S. Environmental Protection Agency
ERP	Enterprise Resource Planning
ETC	European Topic Centre
FAO	Food and Agricultural Organisation
FPAC	Forest Products Association of Canada
FSC	Forest Stewardship Council
GHG	Greenhouse gas
GJ	Gigajoule
ICFPA	International Council of Forest and Paper Associations
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPST	Institute of Paper Science and Technology
MJ	Megajoule
$MtCO_2e$	Megatonnes of carbon dioxide equivalent
N	Nitrogen
NCASI	National Council for Air and Stream Improvement
OECD	Organisation for Economic Co-operation and Development
P	Phosphorous
PEFC	Programme for the Endorsement of Forest Certification
REACH	Registration, Evaluation, Authorisation and Restriction of Chemical Substances
SFI	Sustainable Forestry Initiative
SFM	Sustainable forest management
SMM	Sustainable materials management
TCF	Total chlorine-free
TMP	Thermo-mechanical pulp
UNCED	United Nations Conference on Environment & Development
VDP	Verband Deutscher Papierfabrikin
WBSCD	World Business Council for Sustainable Development
WRAP	Waste & Resources Action Programme

1. INTRODUCTION

1. The global pulp and paper industry is one of the most important sectors of the global economy, employing approximately 13 million people across nearly 200 nations and providing a wide range of essential products used in communications, packaging, sanitation and construction (ICFPA, 2007). Almost 400 million tonnes of paper are produced and consumed annually worldwide (CEPI, 2007a). The average global citizen alone consumes roughly 58 kg of paper per year with the Organisation for Economic Co-operation and Development (OECD) member countries consuming even considerably more per capita (VDP, 2008a). In 2000 the gross value added by the forest sector (including wood industries, pulp and paper) contributed to 1.2% of the global gross domestic product (FAO, 2005).

2. The market for paper and board is projected to grow globally at 2.3% per year to 2030, with particularly rapid increases in developing and emerging economies (OECD, 2008). Most likely, the growth of the market for paper and paperboard in emerging economies (particularly in Southeast Asia) will change the current pattern of trade flows described earlier in this report.

3. Currently, the confluence of slow global economic growth and high capital costs has lowered profitability within the pulp and paper sector. The sector is also vulnerable to a weakening demand for printing and publishing, which the continued rise of electronic media may affect. Alternative materials for packaging, such as plastic, steel and aluminium create other challenges for the pulp and paper sector.

4. The importance of this industry is characterised by its intensive use of energy and natural resources in the production and distribution of its many products. The pulp and paper industry is the fourth largest industrial consumer of energy representing 5.7% of global industrial energy use (IEA 2006). Unique characteristics of the pulp and paper industry are that it generates roughly 50% of its own energy needs through biomass fuel use (IEA, 2006), it produces products from renewable raw materials and these products can be readily recycled. This industry and its products are responsible for nearly 600 million tonnes of carbon dioxide-equivalent (CO_2-e) emissions per year (NCASI, 2007a). This accounts for approximately 2% of global CO_2 emissions (IPCC, 2007).[1]

5. Given the industry's size and economies' dependence on it for livelihood and products, combined with the industry's reliance and impact on vast natural resources and the climate, it is an excellent candidate for review in the context of Sustainable Materials Management (SMM). Considering that OECD member countries produce and consume the majority of the world's paper, the purpose of this report is to explore and identify the most promising opportunities for Sustainable Materials Management (SMM) of wood fibres (*i.e.* pulp and paper products) for OECD member countries.

6. At the first OECD workshop on SMM in 2005, a working definition was developed for SMM. The working definition states that "SMM is an approach to promote sustainable materials use, integrating actions targeted at reducing negative environmental impacts and preserving natural capital throughout the life-cycle of materials, taking into account economic efficiency and social equity" (OECD, 2005).

---

[1] In this report, unless otherwise indicated, statistics on greenhouse gas emissions are given in accord with the accounting conventions used by the Intergovernmental Panel on Climate Change. Thus, the CO_2 emissions associated with burning biomass fuel from sustainably harvested sources do not "count" as anthropogenic greenhouse gas emissions. Unless otherwise stated, wood fibre products are assumed to originate from sustainable forestry (*i.e.* forest growth is in balance with harvesting and decomposition).

7. The main objective of the second workshop held in 2008 was to identify possible barriers and challenges when developing SMM strategies and policies and explore what role the OECD can play in supporting this process. Conclusions were then drawn on how to increase awareness of SMM and on how the OECD can assist its member countries to develop SMM policies, while accounting for economic efficiency and social equity.

8. This report is one of a series of case studies that examine the role of SMM in different material industries including aluminium, critical metals, wood fibres and plastics. These case studies will provide input to OECD's Global Forum on SMM to be held in October 2010.

9. This case study focuses on wood fibres for the following reasons:

1. Opportunities exist to reduce energy use, GHG emissions and water use throughout the wood fibre product life-cycle especially considering unique issues such as carbon sequestration in managed forests and fibre products, the extensive use of biomass and forest wastes as an energy source and the importance of end-of-life waste management;
2. Wood fibre products form a significant fraction of the waste stream, contributing to over 30% of generated waste in OECD countries and therefore fibre products have a significant impact on the environment and the economy in general; and
3. Wood fibre products constitute a renewable resource with a stable, established market.

10. Section 2 of the report establishes the scope of this case study. Section 3 provides an overview of the wood fibre life-cycle including international trade and the general production process. Section 4 provides detailed description of energy use, GHG emissions and water use across the fibre life-cycle. Section 5 discusses the specific SMM practices that offer a significant opportunity to realise environmental, economic and/or social benefits in the management of fibres. Section 6 identifies the drivers that can promote these practices and the barriers that may impede their implementation. Finally, Section 7 provides trends in pulp and paper markets and concludes key opportunities and technical, economic and political barriers for intervention in order to promote SMM of wood fibres.

2. SCOPE AND OBJECTIVES

11. This section outlines the scope and objectives of this case study.

2.1 Geographic Boundaries

12. The investigation of the pulp and paper life-cycle, including environmental impacts, is limited geographically to OECD member countries. Life-cycle data collected for the assessment come from North American and European sources. To investigate the international flows of fibres, the report focuses on major trade flows based on the import and export of pulp, paper and recovered paper.

2.2 Material Types

13. Due to nomenclature variations from different sources, it is difficult to compare and delineate between distinct paper types. Although detailed data on specific paper types are compiled by various countries and companies, this information is inconsistent in its taxonomy of paper types, or, in many cases, not publicly available. Therefore, this case study focuses on the broader range of paper types made from both mechanical and chemical pulp including kraft, newsprint, coated and uncoated paper, tissue and specialty paper, boxboard and paperboard.

2.3 Life-cycle Boundaries

14. The life-cycle stages of wood fibre products considered in this report include: i) raw material harvesting, pulping and paper production; ii) transportation associated with raw material input and delivery to end-use markets; and iii) end-of-life. Printing, publishing and conversion processes—such as folding boxes and cartons—were not included. The use phase of fibre products is not considered by this study given that the environmental, economic and social impacts during that stage are relatively minor and the opportunities for SMM practices are primarily within the manufacturing stages and at end-of-life.

2.4 Waste Management Options

15. This report considers recycling, combustion with energy recovery (or waste-to-energy incineration) and landfilling (without landfill gas capture and with landfill gas capture for energy production) as the primary options for end-of-life management of fibre products. Composting was not included in the study, as it is not currently a common option for management of fibre products at their end-of-life.

2.5 Environmental Impacts

16. This study uses a literature survey of sources relevant to the manufacturing, transport and disposal of fibre products to evaluate the life-cycle environmental impacts. Though the wood fibre product life-cycle involves all kinds of environmental impacts, the study focuses on the areas where impacts are the most significant in terms of resource consumption and emissions: energy use, greenhouse gas (GHG) emissions and water use. Good SMM practices in pulp and paper making plants may thus have a positive influence on climate change, water pollution and resource consumption. Other impacts include local air pollution and smog formation from the combustion of fuels for energy, human toxicity, ecotoxicity and ozone depletion. In general, there is less readily-available life-cycle data on these impact categories. Also, in the context of the wood fibres life-cycle, these impacts were judged to be secondary given the fact that the pulp and paper industry is energy

intensive, manages large stocks of carbon and consumes significant quantities of water during bleaching and papermaking.

2.6 Social and Economic Impacts

17. The social and economic impacts of SMM in the pulp and paper industry are considered briefly in this assessment, although not as rigorously as the environmental impacts due to limited availability or access to information. Certain social impacts, however, such as job creation and employment benefits, have been studied in detail. The social and economic drivers and barriers of achieving best management practices (BMPs) to enhance SMM in the pulp and paper industry are discussed.

2.7 Objectives

18. The main objective of this case study is to offer policy makers an improved understanding of i) current state of the life-cycle of wood fibres and their environmental, economic and social impacts; ii) most promising SMM practices at different life-cycle stages of fibre products; iii) key practices and life-cycle stages on which OECD member states can focus to promote environmental, economic and social benefits through SMM practices; and iv) drivers and barriers that facilitate or hamper the rate at which SMM practices are adopted in the fibre industry.

3. OVERVIEW

19. This section provides an overview of the important physical, economic and environmental aspects of the life-cycle of fibre products. It first summarises the physical flows of wood resources, pulp and fibre products, including information on regional and international flows of pulp, paper and recovered paper resources. To the extent that information is available, economic flows from the global trade of forest products and recycled fibres are also summarised. The impacts of these economic issues on the trade of paper, the effects on recycling and waste flows and environmental issues are briefly discussed to set the context for the next section.

3.1 Physical Aspects

20. In order to produce paper products, the manufacturing process consists of extracting cellulose fibres from trees into relatively thin, homogenous end products through various stages including pulping, bleaching and papermaking. As a result, the wood fibre products industry is a heavy manufacturing sector, especially in the consumption of natural resources. Globally, the consumption of coniferous and non-coniferous based industrial round wood (which comprises pulpwood, veneer logs, chips, particles and wood residues) for wood and wood products amounts to roughly 1,592 million m^3 (FAO, 2005). The world consumes about 900 million tonnes of wood each year for wood-based commodities.[2] In Europe alone, roughly 120 million tonnes of wood resources were consumed for pulp and paper production in 2007 (CEPI, 2007a).

21. In terms of paper production processes, experts indicate that individual paper mills are highly variable, even mills that produce the same paper type (IEA, 2007). No standardised paper mill exists and thus comparisons across mills or paper types should be interpreted cautiously. However, recognizing that the wood fibre industry, particularly the pulp and paper industry, is complex, there are general stages involved in the production of paper beginning with raw material harvesting. The following figure represents a schematic of the overall life-cycle stages of the paper system including end-of-life (Figure 3.1).

[2] Assuming an average density of 0.575 tonnes/m^3.

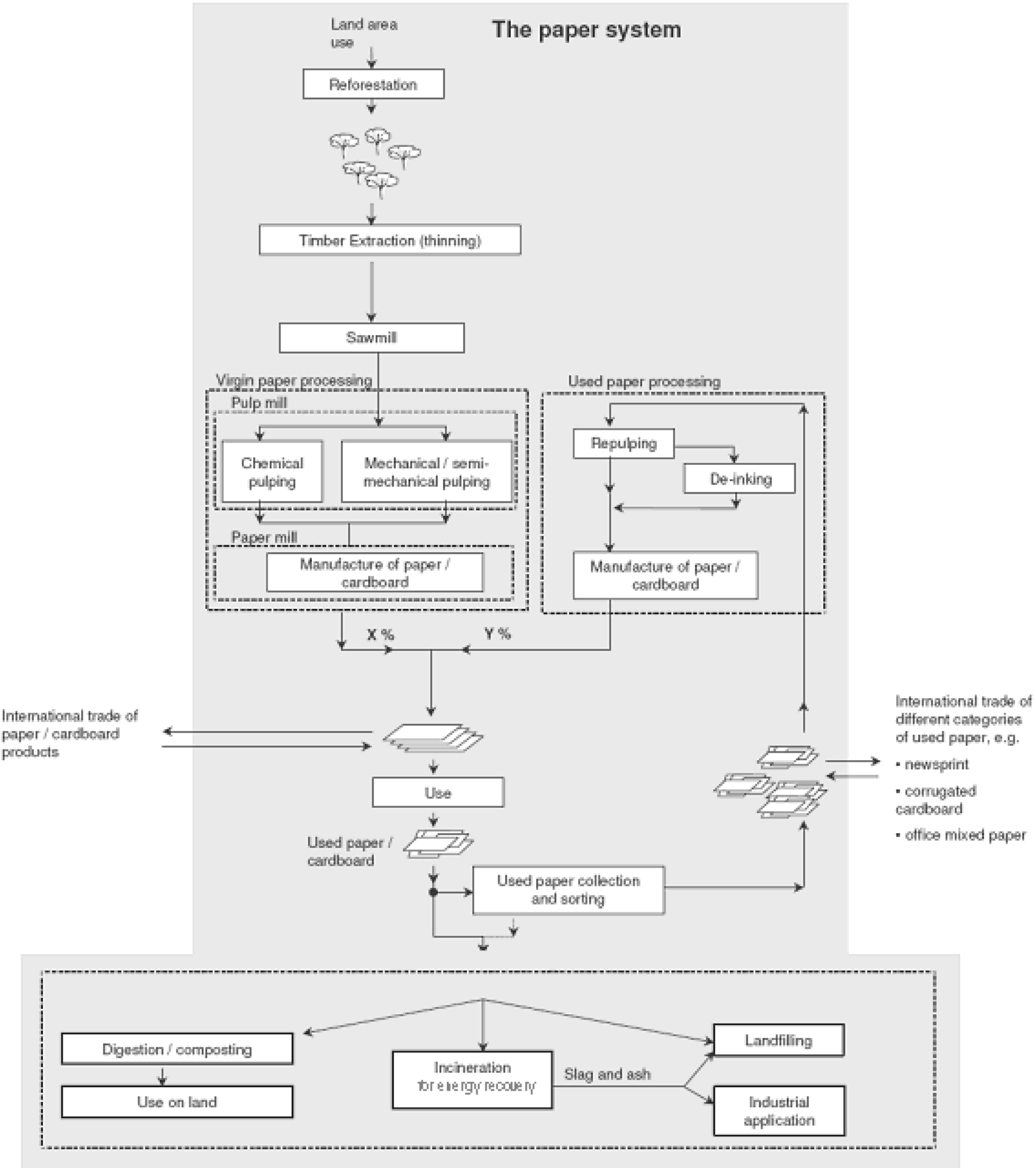

Figure 3.1: Life-cycle diagram of the entire paper system from manufacture to end-of-life
Source: (ETC, 2004)

22. The main raw material for producing paper is wood, with the preferred variety generally being coniferous wood due to its longer fibres. The vast majority (95%) of pulp is produced using wood as a raw material base. Non-wood raw materials such as certain crops (flax or hemp) and agricultural residues (like sugar cane bagasse) make up the remainder of raw materials used for pulp production (EDF, 1995a).The wood comes primarily from forest thinning operations. Importantly, wood chips from the sawmill industry are used as ingredients in the pulping process.

23. The three major categories of underlying "feedstock" for paper manufacture are wood pulp, non-wood pulp and recovered paper pulp. The processes to generate pulp primarily involve mechanical pulping, chemical pulping and recovered paper pulping (mostly a mechanical process) (Figure 3.2).

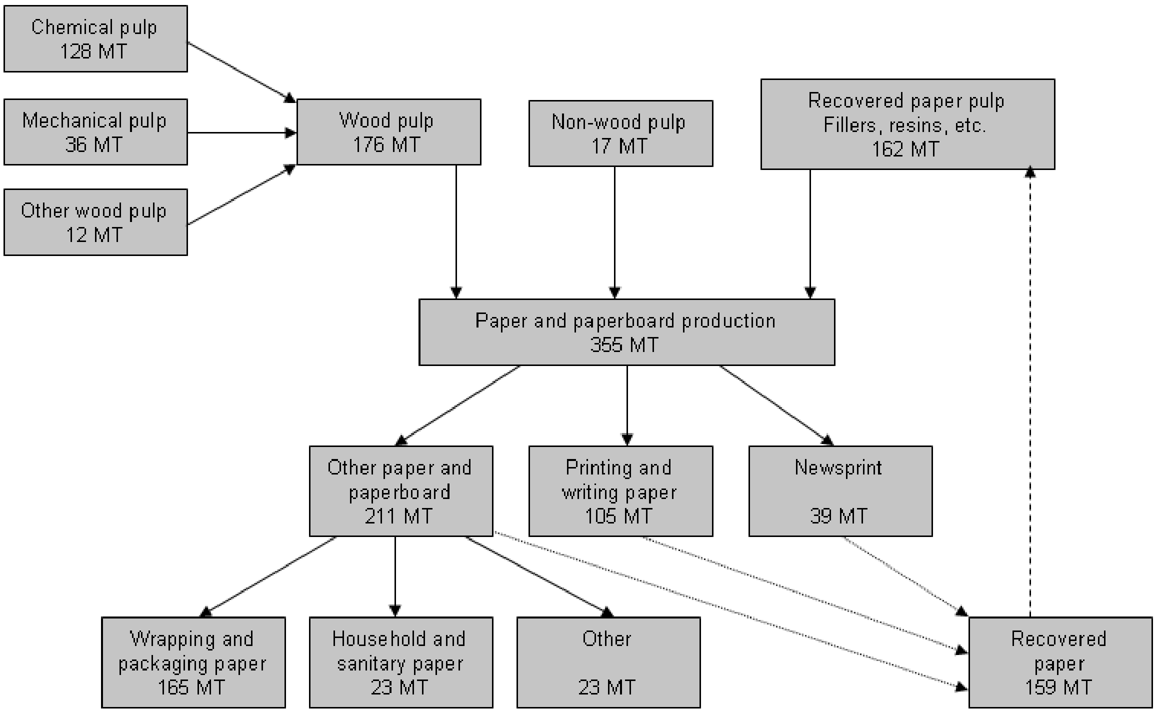

Figure 3.2: World paper production and application as of 2004
Source: (IEA, 2007)

24. Mechanical pulping is a process in which cellulose fibres are physically separated from the wood raw material. The global production of mechanical pulp represents roughly 20% of total wood pulp, although Canada alone represents more than one-third of global mechanical wood pulp production (IEA, 2007). First, the debarked logs are ground down using stone cutters into fibres 1-4 mm long and mixed with hot water. The ratio of short and long fibres determines the pulp quality. The pulp is subsequently screened and refined with the addition of mostly wood chips. Depending on the ultimate type of paper being created, at this stage, the pulp may be bleached. Within the refining process, additional industry developments have allowed for a more efficient process of breaking down and refining wood into fibres. With the thermo-mechanical refining process (TMP), pre-steaming the wood chips allows for lignin removal and easier transition into longer fibres. In the chemo-thermo-mechanical (CTMP) refining process, chemicals are introduced that ensure lignin removal, again translating into higher proportion of long fibre production. The material efficiency of mechanical pulp is superior to chemical pulp. Its final yield is roughly 90-95 kg of pulp produced from 100 kg of wood material (VDP, 2008b).

25. Chemical pulping, also known as kraft pulping, is a process in which the wood fibres are isolated by removing the surrounding lignin in the wood raw material. The global production of chemical pulp represents over 70% of total wood pulp with the United States alone generating more than one-third of the world's chemical wood pulp (IEA, 2007). Wood is broken down into wood chips and heated with water and chemicals to ensure a breakdown of the lignin and a smooth transition of the wood chips into long fibres. After this step, the pulp is refined and thickened and at this stage sometimes bleached. Compared to mechanical pulping, chemical pulp is higher quality since most of the fibres are longer and more uniform in length. Other chemical

pulps (such as higher grade chemical pulps) are produced for special product types. The chemical pulp yield is significantly less than mechanical pulping (only 50 kg of pulp produced from 100 kg of wood material). This is because the kraft processes extract the lignin present in the wood raw material.

26. Due to the sheer volume of recovered paper pulp (compared to virgin wood pulp), recovered paper pulp has its own separate process although it is primarily a mechanically based pulping process. The usability of recovered paper in the recycling process is determined by the amount of contaminants present, the strength of the recovered paper fibres and the capacity to recycle specific paper types (EDF, 1995a). Depending on the feedstock and desired end product, the two general categories include 1) strictly mechanical processes without de-inking to produce various types of paperboard; and 2) a combined mechanical/chemical process that includes de-inking to produce paper types such as newsprint and copy paper (ETC, 2004).

27. The initial step is collection, sorting and storage of recovered paper which separates out any non-paper substances (ETC, 2004). Subsequently, the recovered paper is separated into its fibre constituents in a large pulping machine known as a hydrapulper (EDF, 1995a). Contaminants are removed via this type of screening. Once the recovered paper pulp has been thoroughly de-contaminated, the paper is then sent to a de-inking plant for ink removal. Although the de-inking step uses mostly mechanically-based processes such as centrifuges and kneading units to remove ink from recovered pulp, a minority of de-inking plants use special chemicals for ink removal (EDF, 1995a).

28. After pulping, the next phase of the paper life-cycle is paper production. Although there are subtle differences in the equipment used between paper mills depending on the various paper types, generally there are four similar stages to paper production including stock preparation, papermaking, coating/laminating and finishing (VDP, 2008b).

29. In the stock preparation stage, pulp is introduced into the papermaking plant as a combination of chemical pulp, mechanical pulp and/or recovered paper. Water is added to dissolve the pulp further into single fibre form and chemicals are added to improve the consistency of the fibre/water slurry. The most important "filling agents" include kaolin clay and chalk; these are added to reinforce the chemical durability and brightness of the pulp. Next is the papermaking stage, which serves the basic function of pressing the fibre stock into sheets. Within this stage, the fibre/water mixture is first laid out onto wire meshes to drain out the water. Subsequently, the paper web is further drained via mechanical pressing, then dried and smoothed using various rollers. Finally, the paper (containing only 5-7% water) is wound onto a steel shaft for further coating using various colouring pigments and/or strengthened using binding sealants. As the last step before packaging, the paper is cut into smaller rolls using a reel cutter.

30. Paper then makes its way into various end uses. As depicted in Figure 3.3 below, the majority of the world's paper is utilised for packaging, followed by printing and newsprint (IEA, 2007).

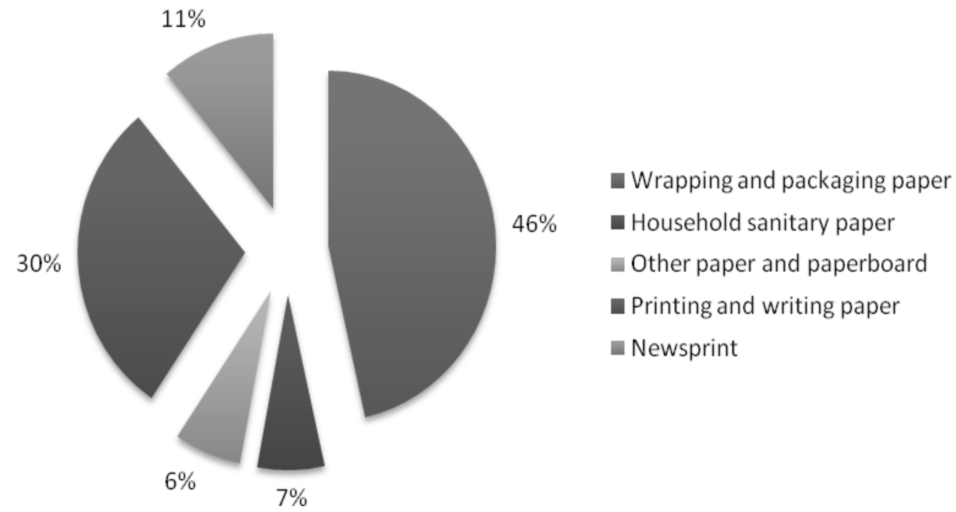

Figure 3.3: End use application of world's paper in 2004
Source: (IEA, 2007)

31. In terms of the end-of-life profile for paper products, the recovery rates vary among countries, but the global rate is about 45% with a maximum theoretical potential of roughly 80% (IEA 2007). The ability to re-pulp recovered paper faces a technical limit because fibre lengths degrade over time. The maximum limit to recycling recovered paper is six to seven times, meaning that the recovered paper pulping process must incorporate some virgin fibre (ETC, 2004).

32. The United States recovered 53% of pulp and paperboard in 2007 (EPA, 2007). Of the paper and paperboard that is disposed of (*i.e.* not recovered), approximately 80% is landfilled and 20% is combusted. In Europe, the average recycling rate is as high as 64.5% as of 2007 (average in 29 European countries; EU 27 as well as Norway and Switzerland) (CEPI, 2009). Paper recovery rates specific to various developed nations are shown in Figure 3.4 below. Information is lacking (and probably highly variable) on the breakdown of non-recovered paper products that are landfilled and combusted.

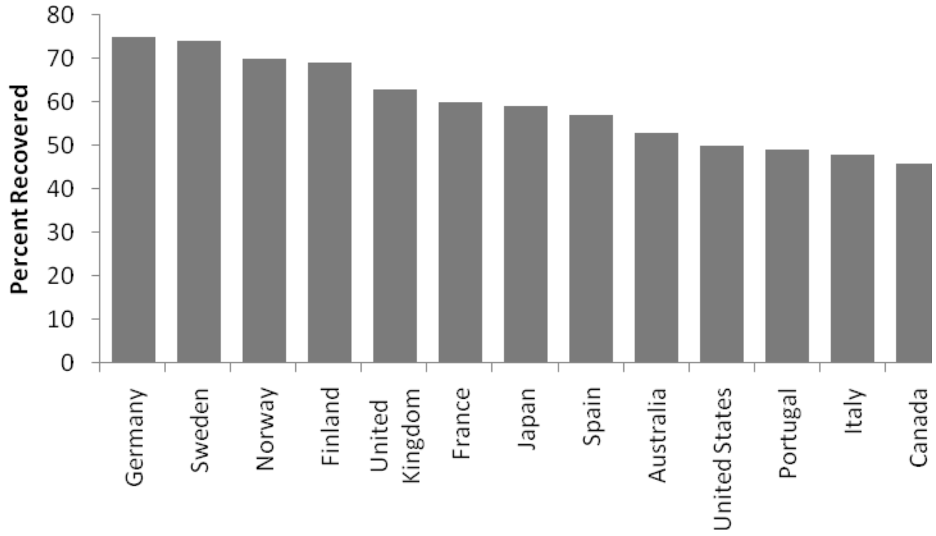

Figure 3.4: Paper recovery rates in selected countries as of 2007
Source: (WBCSD, 2007)

33. Part of the reason for the high rate of recycling in Europe compared to that of North America is that the European paper industry adopted a voluntary commitment to achieve 66% recycling rate in the European region by 2010. This commitment (the "European Paper Recycling Declaration") includes not only a recycling rate target but provides guidance to fourteen industry sectors along the paper value chain to ensure higher recyclability of paper at the end-of-life (CEPI, 2006). Also, the European Union mandated under the Directive on Packaging and Packaging Waste (94/62/EC) that no later than 31 December 2008 the minimum recycling target for paper and board shall be 60 % by weight.

3.2 Economic Aspects

34. The pulp and paper industry provides almost 130 billion € (USD 175 billion) in gross value added to the global economy (FAO, 2005). The relatively large manufacturing output of the wood products industry (accounting for roughly 1.2% of global GDP in the year 2000) translates into a parallel relationship between economic output and paper production and demand in many countries (FAO, 2005). In communities that are mostly dependent on the forest products industry, global economic downturns dictate economic stress (FPAC, 2007b).

35. A holistic picture of the global trade flow (in terms of dollars of trade) shows the flow of wood products in 2003 (FAO, 2003). It is clear that most of the traded wood products (by economic value) are travelling from Europe and North America into China (Figure 3.5).

36. Regional consumption patterns indicate that demand for pulp and paper in OECD countries is driven by paper needs for printing and writing, whereas in non-OECD countries pulp and paper consumption is driven by other paper types including paperboard. It is expected that as global per capita income rises, the demand for printing, writing and specialty paper will also increase, although these products will face competition from the emergence of electronic media (IEA, 2007, p. 180; OECD, 2008).

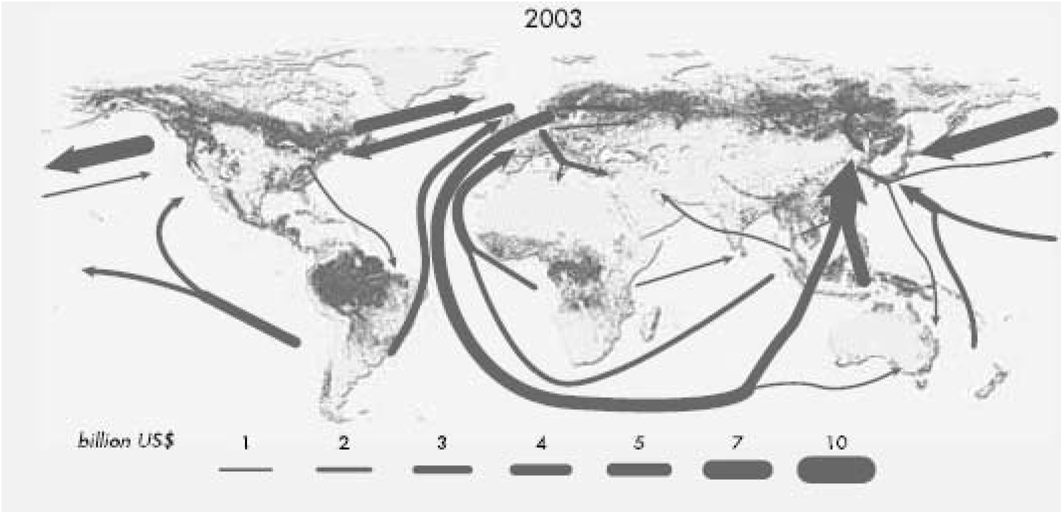

Figure 3.5: Main trade flows of wood products as of 2003
Source: (FAO, 2005)

37. There are three main flows involved in the global pulp and paper industry that illustrate a snapshot of the pulp and paper trade. In terms of pulp use in the production of paper, Canada and the United States dominate the export market accounting for almost half (42%) of total global pulp exports. On the import side, China and the United States receive much of the pulp, roughly 16% and 15%, respectively, of world total pulp imports (Table 3.1).

Table 3.1: Pulp for paper trade as of 2003

Exports		
	million tonnes	%
Canada	11.4	29
United States	5.1	13
Sweden	3.3	9
Brazil	2.6	7
Finland	2.4	6
Indonesia	2.4	6
Chile	2.1	5
Russian Federation	1.8	5
Portugal	1.0	2
Spain	0.8	2
Others	5.9	15
World Total	**38.7**	**100**

Imports		
	million tonnes	%
China	6.5	16
United States	6.1	15
Germany	4.2	11
Italy	3.4	9
Republic of Korea	2.4	6
Japan	2.3	6
France	2.1	5
United Kingdom	1.5	4
Netherlands	1.0	3
Belgium	0.9	2
Others	8.9	23
World Total	**39.5**	**100**

38. A similar profile exists in the export and import of finished paper and paperboard but note that there are some interesting differences with countries like Finland and Germany being larger exporters of finished paper and paperboard as compared to pulp (Table 3.2).

Table 3.2: Paper and paperboard trade as of 2003

Exports	million tonnes	%
Canada	15.4	15
Finland	11.7	11
Germany	10.4	10
Sweden	9.1	9
United States	8.3	8
France	5.1	5
China	4.3	4
Austria	3.9	4
Netherlands	3.0	3
Italy	2.9	3
Others	28.0	27
World Total	**102.2**	**100**

Imports	million tonnes	%
United States	16.6	16
China	10.4	10
Germany	9.7	10
United Kingdom	7.1	7
France	6.0	6
Italy	4.6	4
Spain	3.6	4
Belgium	3.6	3
Netherlands	3.3	3
Canada	2.8	3
Others	34.4	34
World Total	**102.0**	**100**

39. The recovered paper trade profile is perhaps the most interesting as clearly China is the leader in recovered paper imports, as of 2003, (Table 3.3). Over 30% of total the recovered paper flow was imported by China, more than four times the quantity imported by the next largest importing nation.

Table 3.3: Recovered paper trade as of 2003

Exports	million tonnes	%
United States	12.6	41
Germany	3.2	11
Netherlands	2.3	7
Japan	2.0	6
United Kingdom	1.9	6
Belgium	1.9	6
France	1.3	4
Canada	0.7	2
Italy	0.5	2
Denmark	0.4	1
Others	3.7	12
World Total	**30.7**	**100**

Imports	million tonnes	%
China	10.5	32
Canada	2.4	7
Netherlands	2.1	6
Germany	2.0	6
Indonesia	2.0	6
Mexico	1.3	4
Republic of Korea	1.3	4
India	1.3	4
France	1.2	4
Thailand	1.1	3
Others	7.5	23
World Total	**32.8**	**100**

40. Looking more closely at the trade profile the largest recovered paper flow is from the United States into China (Figure 3.6). In 2006, China imported almost 9 million tonnes of recovered fibre from the United States, which accounted for over 40% of total recovered paper imports in China.

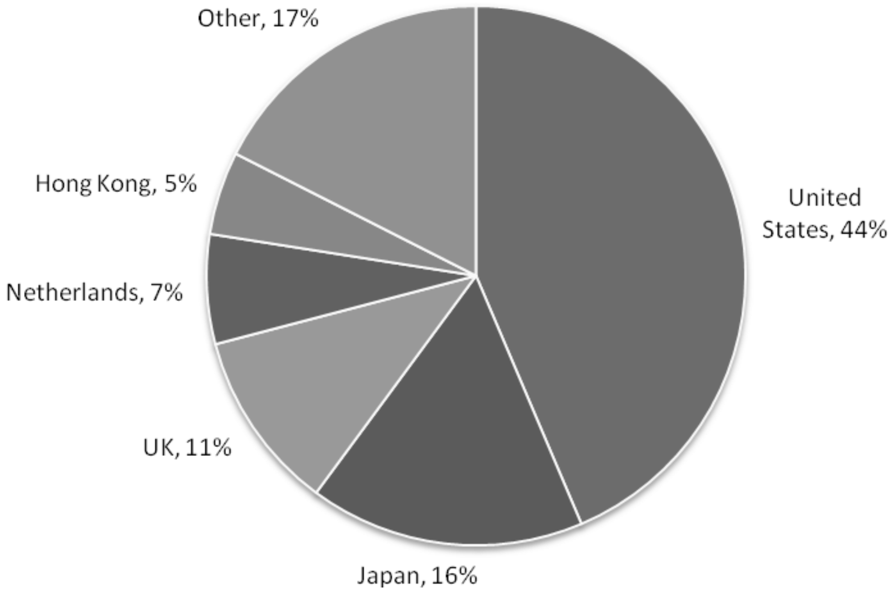

Figure 3.6: Sources of imported recovered paper fibre to China as of 2006 (tonnes)
Source: (Potter 2008)

41. Other important flows of recovered paper include Europe to China, Japan to China and within the European countries (Ervasti, 2008).The flow of exports out of and imports into Europe alone includes over 4 million tonnes exported to other EU States and 10 million tonnes exported to China (Potter, 2008). Not surprisingly, the effect of increased imports of recovered paper has allowed China's recovered paper utilisation rate to increase from 38% in 1997 to 51% in 2004 (IEA, 2007).

3.3 Environmental Aspects

42. According to the IEA, the pulp and paper industry is the fourth largest industrial consumer of energy representing 5.7% of global industrial energy use (IEA, 2006). A large fraction of the energy consumed within the pulp and paper industry is supplied by the combustion of fossil fuels either directly or in the form of fossil fuel-based electricity (WBCSD, 2007). On a global level, it is estimated that the pulp and paper industry's direct emissions (*i.e.* manufacture-related) of GHGs associated with fossil fuel combustion total 240 million tonnes of carbon dioxide equivalent (CO_2e) per year. Another 25 million tonnes CO_2e are associated with other wood products. Indirect emissions associated with electricity generation (140 million tonnes of CO_2e), transportation (40 million tonnes of CO_2e) and end-of-life methane emissions from landfills (150 million tonnes of CO_2e) contribute a total of approximately 330 million tonnes of CO_2e (NCASI, 2007a). European data suggest that GHG emissions from the pulp and paper industry in Europe amounted to roughly 40 million tonnes of CO_2e in 2006 (CEPI, 2007a). In the United States, corresponding direct and indirect GHG emissions were roughly 94 and 120 million tonnes CO_2e in 2004 (NCASI, 2008).

43. Although a significant amount of energy consumption is derived from the combustion of fossil fuels, a unique characteristic of the pulp and paper industry is that it generates roughly 50% of its own energy needs through biomass fuel use (IEA, 2006). GHG emissions from the combustion of biomass is considered biogenic and provided that the biomass is harvested on a sustainable basis *(i.e.* biomass growth = harvest + decomposition), it is not counted in the accounting for carbon emissions according to the Intergovernmental Panel on Climate Change (IPCC). The assumption is that if consumption is done on a sustainable basis, the CO_2 emitted from burning biomass will not alter the total atmospheric CO_2 profile.

44. The National Council for Air and Stream Improvement (NCASI), a non-profit environmental research organisation that focuses on analyzing the North American forest products industry, recently assessed the GHG and carbon profile of the global forest products industry. The results of the assessment are summarised in Table 3.4. Direct emissions from fuel consumption at mills, mill waste management and secondary manufacturing operations account for roughly one-third of direct and indirect emissions from the forest products industry (which includes pulp, paper and wood products). Indirect emissions from electricity generation, harvesting operations and transportation account for another 25%. In total, the pulp and paper industry represents roughly half of direct and indirect GHG emissions from the forest products industry (NCASI, 2007a). The emissions profile assumes the consumption of biomass-derived fuel combustion to be biogenic and sustainable and thus is not counted below.

Table 3.4: Global GHG emissions from harvesting for the pulp and paper industry, pulping and paper manufacturing, relative to direct and indirect emissions from the entire forest products industry

Type of Emissions	Description	Emissions (million tonnes CO_2e / yr)	Uncertainty	% of Total Emissions
Direct Emissions	Fuel consumption in pulp and paper mills	205	+ / - 15%	35%
	Management of mill wastes	20	+ / - 25%	3%
	Secondary manufacturing operations (e.g., printing)[1]	12	+ / - 50%	2%
Indirect Emissions	Electricity purchases by pulp and paper mills	140	+ / - 25%	24%
	Electricity purchases by secondary manufacturing operations (e.g., printing)[3]	13	+ / 50%	2%
	Harvest and transport emissions from the pulp and paper value chain	40	+ / - 50%	7%
	Methane emissions from paper products in landfills at end-of-life	150	+ / - 50%	26%
Total direct and indirect emissions from pulp and paper industry (not including other forest products)		580	+ / - 50%	100%

Source: (NCASI, 2007a)

45. Direct and indirect GHG emissions do not provide a complete picture of the GHG implications of the pulp and paper industry. Because the wood utilised by the pulp and paper industry represents a carbon pool, the use of these materials for fuel and for fibre products has two important implications:

1. Carbon storage in products (use phase and end-of-life). Fibre products are made of wood and depending on how products are treated at end-of-life, the carbon they contain may be stored (*i.e.* embedded in the product), or it may be released into the atmosphere. Releases as methane are included in the NCASI tally, but releases as CO_2 are not. And to the extent that carbon is permanently (or nearly permanently) removed from the rapidly cycling carbon pool by disposal in landfills, this process can result in long-

[3] Note that these emissions include emissions from both the pulp and paper and wood products industries.

term carbon storage. For more details on the GHG implications of end-of-life carbon storage and GHG emissions, please see Section 4.

2. Forest carbon sequestration. At equilibrium, the carbon cycle between the forests and the atmosphere is such that the growth of trees in forests is equal to tree removals plus tree decomposition. If harvested trees are replanted and allowed to grow to the same age, the CO_2 released by burning this wood for fuel can be considered GHG-neutral. That is, the amount of CO_2 emitted by burning the harvested wood is equal to the amount of CO_2 that will be absorbed and sequestered by the tree planted in its place. Using wood as a GHG-neutral fuel source therefore offsets GHG emissions that would have otherwise been produced from burning fossil-fuels, such as coal or natural gas. Similarly, using the wood sourced from sustainably managed forests would provide additional forest carbon sequestration. Alternatively, if tree harvesting and decomposition are greater than growth, utilizing biomass would generate net emissions.

46. In its Global Carbon Footprint report, NCASI did not separate avoided emissions or carbon storage in the pulp and paper industry from other forest products and there is large uncertainty associated with these estimates. The report did find, however, that direct and indirect GHG emissions from the entire forest product sector were largely offset by sequestration and carbon storage in forest products (NCASI, 2007a).

47. In addition to its influence on global GHG emissions, the wood fibre industry is a major user of water for consumptive and non-consumptive uses. According to the American Forest and Paper Association (AF&PA), paper manufacturing is the largest industrial user of water per unit of finished product. In Australia, water use represents almost 30 m^3/tonne of finished product (ICFPA, 2007). According to Environment Canada, approximately 32 m^3 of water is used to produce 1 tonne of paper on average. This is on par with data on the cumulative water consumption for the production of paper in Europe based on mechanical pulped printing paper (approximately 30 m^3 per tonne) (Dehoust, 2006). However, the amount of water effluent ranges greatly as shown in the table below (Table 3.5). Data based on production information for the United States indicate that water use is very significant throughout the papermaking process (EDF, 1995a).

Table 3.5: Typical water use (mean effluent flow) per tonne of final product

Paper Type	Litres per tonne
Coated Unbleached Kraft	47,000
Lightweight Coated Groundwood	69,000
Bleached Kraft Pulp with 20% chemithermomechanical	76,000
Solid Bleached Sulphate	85,500
Coated Freesheet	85,500
Bleached Kraft Pulp	85,500

Source: (EDF 1995a)

48. Global production of final paper products is around 350 million tonnes (IEA, 2007). Using the conservative water consumption value of roughly 32 m^3 per tonne, global water use for the pulp and paper industry is at least 11 billion m^3 per year.

49. Overall, the pulp and paper industry is a large consumer of energy and natural resources, which results in an impressive amount of productive capacity. The industry is complex but provides necessary and fundamental products for consumption and use. In addition to the consumption of resources (energy, water and wood), the production process results in significant environmental impacts, mainly GHG emissions and water releases. Other impacts include local air pollution and smog formation from the combustion of fuels for energy, human toxicity, ecotoxicity and ozone depletion. In general, there is less readily-available life-cycle data on these impact categories and, therefore, the following sections present the life-cycle implications of pulp and paper production with special attention to energy, water use and GHG emissions.

4. LIFE-CYCLE ENVIRONMENTAL IMPACTS OF WOOD FIBRES

50. This section presents environmental impacts of energy use, greenhouse gas (GHG) emissions and water use across the life-cycle of wood fibres. The primary stages in the fibre life-cycle include: wood harvesting, pulping, papermaking, transportation and end-of-life management. This section summarises general ranges of energy use, GHG emissions and water use for harvesting, pulping, papermaking and transportation life-cycle stages based on review of European and North American literature sources.[4]

4.1 Harvesting, Pulping and Papermaking

51. This section discusses the environmental impacts within the following stages of the fibre life-cycle:

- Harvesting of lumber from forests for pulp and paper manufacture;
- Wood preparation and pulping (including cooking, washing, evaporation, chemical preparation, bleaching and drying); and
- Papermaking (includes refining, screening, stock pumping, forming, pressing, drying and optional processes such as calendering and coating).

4.1.1 Harvesting

52. Harvesting involves the felling of trees, preparing them for transport and transportation via ship, rail or truck. If wood is harvested upstream of the mill site, logs may also be transported by floating the logs to the mill site (EC, 2001, p. 18). Energy use, GHG emissions and water use from harvesting are small relative to the rest of the fibre life-cycle. Only 2% of the total energy consumed to produce paper is consumed at the harvesting stage, including transportation (Dahlbo *et al.,* 2005, Appendix 8, p. 113).

4.1.2 Pulping

53. Wood pulping accounts for a larger part of environmental impacts. Energy use, GHG emissions and water use depend upon a number of complex factors, including:

- **The pulping process**. There are large differences in both the amount and the mix of energy consumed—and the associated GHG emissions produced—from chemical, mechanical and recovered paper pulping.
- **The type of paper produced**. Energy use, GHG emissions and water use will depend upon: whether pulp is bleached or non-bleached; paper characteristics such as strength, freeness, brightness and texture; and the processes involved in papermaking, such as sizing, coating, calendering and dyeing.
- **Plant-specific characteristics**. Facility parameters that can have an effect are numerous and include the age of the equipment used in the facility, the operating point of the facility and how equipment is operated and maintained.
- **Regional factors**. The location of the plant can influence the mix of fuels used to produce the electricity supplier to the plants and market dynamics including the distances to markets for paper, which can reduce opportunities for integrating pulp and paper mills (IEA, 2007, p. 202).

[4] The European source (EC, 2001) includes information on select modernised mills whereas the North American source (Jacobs & IPST, 2006) is dependent on industry average data survey information.

54. The processes that consume the largest share of energy in chemical pulping are shown in Figure 4.1 and Figure 4.2. These include wood preparation, cooking, evaporation, chemical preparation, bleaching and oxygen delignification and pulp drying for transport if the pulp mill is not integrated with a papermaking facility. These figures combine both electricity and process heat energy consumption, but they do not include energy losses associated with electricity generation or boilers (i.e., powerhouse losses).

55. Figure 4.1 provides information on average energy use in current U.S. pulp mills versus energy use using best available technologies (BAT). Figure 4.2 shows energy use that is representative of retrofitted and modernised mills in Europe, which employ some level of BAT. Depending on paper type, the average energy consumption for conventional non-integrated U.S. mills is roughly 15-18 GJ per air-dry tonne (GJ/Adt)[5] and 12-16 GJ/Adt under BAT. In modern European integrated mills, energy use is roughly 8 – 9 GJ/Adt for kraft pulp, while energy use in non-integrated mills is around 13 GJ/Adt.

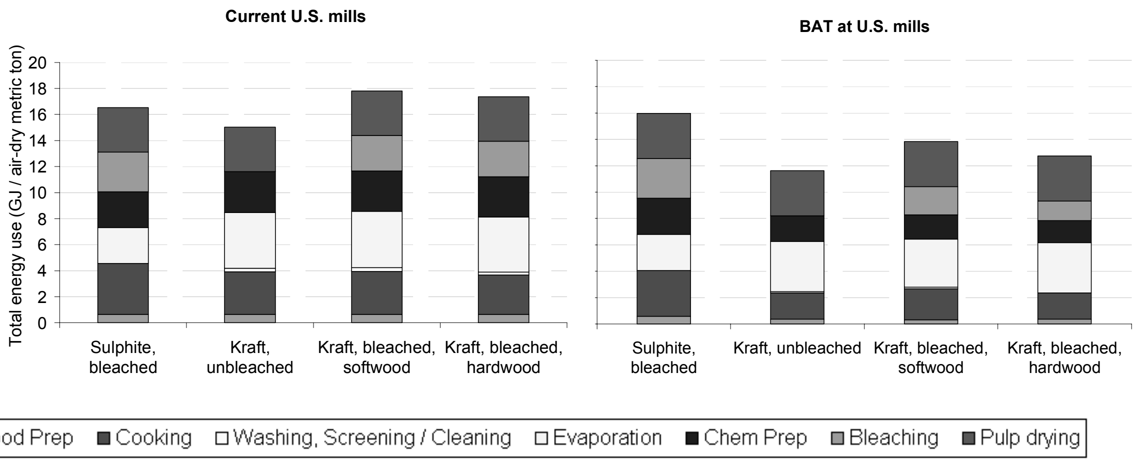

Figure 4.1: Total energy use for sulphite and kraft pulping processes in current U.S. mills and energy use using BAT
Source: (Jacobs & IPST, 2006)

[5] Throughout this report, an air-dry tonne is assumed to refer one tonne of dry pulp with 10% moisture content.

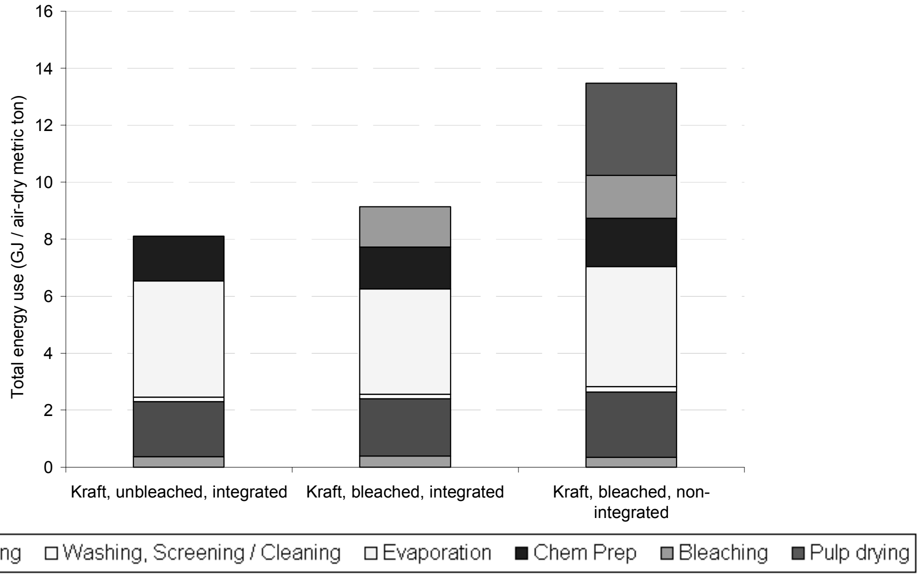

Figure 4.2: Total energy use in kraft pulping process,[6] modern European mills
Source: (EC, 2001, pp. 53-56)

56. While the total energy use in modernised mills is lower as a result of efficiency improvements and advanced technologies in modernised mills, the relative shares of the major sources of energy use, shown in Table 4.1, are relatively consistent across the plants.

Table 4.1: Major sources of total energy consumption in chemical pulping

Stage	Share of total energy consumption
Wood preparation	5%
Cooking	20 – 25%
Evaporation	20 – 50%
Chemical preparation	15 – 20%
Bleaching	10 – 20% (if applicable)
Pulp drying	20 – 25% (if applicable)

Source: (EC, 2001 and Jacobs & IPST, 2006)

57. The processes that consume the largest share of energy in mechanical pulping are grinding and bleaching, as shown in Figure 4.3 for both current and BAT U.S. mills. Total energy use in mechanical pulping at modernised European mills is roughly 7 to 8 GJ/Adt for thermo-mechanical pulp (TMP) (EC, 2001). Here, the grinding and bleaching stages demand the most energy. Grinding the wood into pulp consumes roughly 70% of total energy use at the pulping stage. Since energy for grinding wood into pulp is supplied by electricity, mechanical pulping processes consume a larger share of electricity than chemical pulping processes.

[6] For consistency across the U.S. and European data sources, energy use from recovery and auxiliary boilers, causticising, lime kilns and other miscellaneous sources have been omitted. Refer to EC, 2001, pp. 53-55.

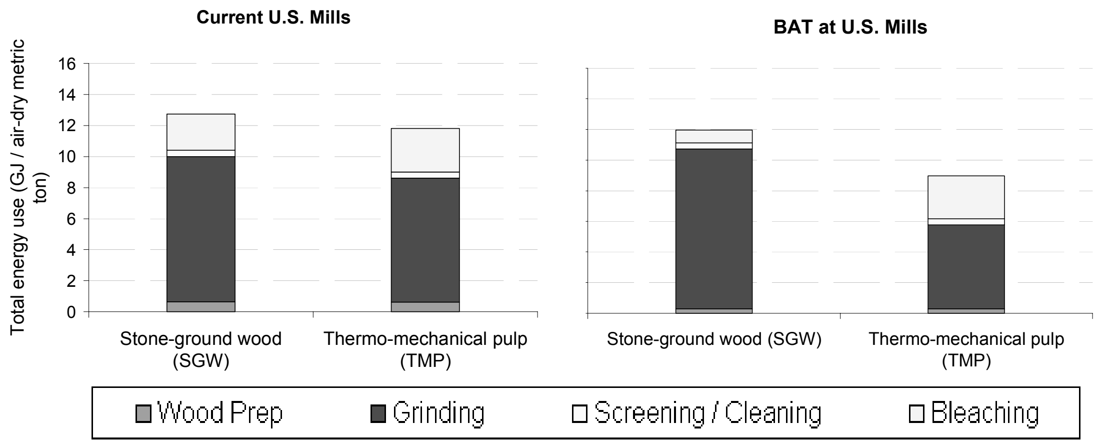

Figure 4.3: Total energy use in mechanical pulping process, current and BAT at U.S. mills
Source: (Jacobs & IPST, 2006)

58. Table 4.2 shows the share of total energy use that electricity (produced in cogeneration plants on-site, or purchased through the grid) represents for a variety of pulp types.

Table 4.2: Ratio of process heat consumption to electricity consumption for different pulp and paper mills

Pulping process	Mill description	Electricity as a share of total energy use	Source
Chemical	Kraft, non-integrated bleached kraft pulp mill	13% 14%	Jacobs, 2006 EC, 2001
	Kraft, non-integrated bleached kraft	12%	Jacobs, 2006
	Kraft, integrated bleached kraft pulp & paper mill	14%	EC, 2001
	Kraft, integrated unbleached kraft pulp & paper mill (e.g., kraftliner)	9%	EC, 2001
	Sulphite, non-integrated bleached pulp	13%	Jacobs, 2006
Mechanical	Stone-ground wood	71%	Jacobs, 2006
	Thermomechanical pulp	92%	Jacobs, 2006
	Integrated newsprint paper mill	98% (pulping only) 62% (pulp & papermaking)	EC, 2001

59. As shown in Table 4.2, since the grinding process consumes electricity, mechanical pulps have a much higher share of electricity consumption than chemical pulps. Nearly all of the input electricity is imported from external electricity grids, while heat can be recovered from the grinding for use at other process steps. Based on data from a modern Swedish integrated mechanical pulp and paper mill, up to 96% of electricity and 45% of heat energy is supplied externally to the plant. Finnish integrated mills reportedly recover a greater share of steam from grinding to entirely offset process heat energy requirements within the facility (EC, 2001, p. 184).

60. The energy use requirements for recovered fibre pulp shown in Table 4.3 are in the range of 1 to 4 GJ per air-dry tonne depending on the process requirements—much lower than either chemical or mechanical pulping. Less energy is required to re-pulp the recovered fibres because they have already been extracted from

wood feedstock. The recovered fibre suspension must be de-inked and bleached for paper grades that require a high brightness, which increases the energy use requirements.

Table 4.3: Energy use for pulp from recovered paper[7]

Recovered Fibre Type	Process Heat (GJ / air-dry tonne)	Electricity (GJ / air-dry tonne)	Total (GJ / air-dry tonne)	Source
Double-lined kraft, non-deinked	0.00	0.60	0.60	Average of current mills in U.S. (Jacobs & IPST, 2006)
Old corrugated cardboard, non-deinked	0.98	1.48	2.46	
Mixed office waste, non-deinked	0.98	1.72	2.70	
Mixed office waste, deinked	1.71	2.22	3.93	
Old newspaper[8], deinked	1.71	1.85	3.56	
Old newspaper, deinked	0.20	1.08	1.28	Modern European integrated recovered fibre paper mill (EC, 2001, p. 244)

4.1.3 Papermaking

61. In papermaking, the processes that consume the most energy are stock preparation and drying, as shown in Figure 4.4 for U.S. mills. Stock preparation involves screening and cleaning out impurities from the fibre suspension and refining the pulp to improve its strength and suitability for papermaking. After the suspension is formed into sheets, the pulp is pressed to remove water from the paper sheet. In the press section, the water content drops from 80 – 85% initially to 50 – 55% after pressing; in the drying stage, the sheet is passed over steam-heated cylinders to remove all but 5 – 10% of the water. Certain types of paper may also involve other optional processes such as sizing, coating, or calendering, which are used to improve paper characteristics such as surface strength and smoothness. Figure 4.5 shows total energy consumption in modern European paper mills for different types of paper. Note that the energy consumption categories are grouped differently relative to Figure 4.4.

[7] Includes energy only associated with de-inking (if applicable), washing, screening and bleaching (if applicable). Does not include powerhouse losses or energy inputs associated with papermaking.

[8] “Newspaper” is the paper type used to describe the recovered paper stream. “Newsprint” is used when describing upstream production of this particular type of fibre.

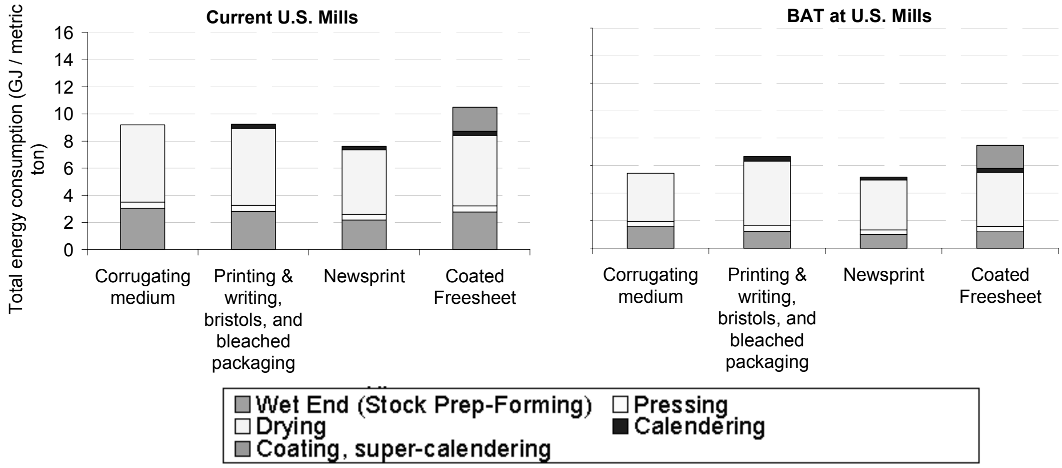

Figure 4.4: Total energy use in the papermaking process, current and BAT at U.S. mills. Wet end processing includes refining, screening and cleaning, stock pumping and forming
Source: (Jacobs & IPST, 2006)

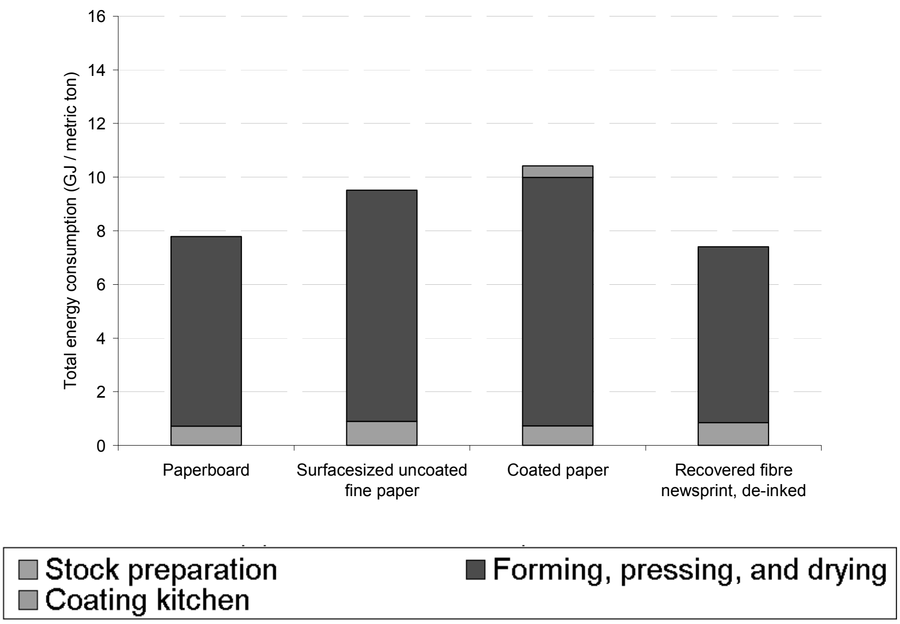

Figure 4.5: Total energy use in the papermaking process, modern non-integrated European mills
Source: (EC, 2001, pp. 53-56, 244)

62. Estimates of GHG emissions for the manufacturing (including harvesting, pulping and papermaking) of various paper types are shown in Table 4.4. The estimates vary widely depending on the type of paper, whether it is sourced from pulp produced from 100% virgin inputs (*i.e.* virgin pulp) or from a mix of virgin and recovered fibres (*i.e.* recovered fibre pulp)[9] and the various processing steps that are assumed, such as coating, de-inking, bleaching, etc.

Table 4.4: GHG emissions estimates for the manufacturing of different paper types made from virgin pulp and recovered fibre pulp

Paper Type	Description	Virgin Pulp[9] (kg CO_2 / tonne of paper)	Recovered Fibre Pulp[9] (kg CO_2 / tonne of paper)	Original Source
Kraft paper, unbleached	From unbleached Kraft pulp made in Switzerland; recovered fibre is assumed to contain 83% recycled pulp	1,080	633	BUWAL, 1998
Corrugated board	Virgin pulp is assumed to contain 25% recycled pulp	644	522 – 556	BUWAL, 1998
Newsprint	No information	1,755	849	EEA, 1999
	Recovered fibre is assumed to contain 100% recycled content	2,263	1,374	EPA, 2006
	Assumes 68% recycled content	Not estimated	291	BUWAL, 1998
Graphic paper	Uncoated, with recovered fibre de-inking	436	586	BUWAL, 1998
	Coated, without recovered fibre de-inking	730	380	BUWAL, 1998
Average pulp and paper	Average of Swedish pulp and paper production from 2001 – 2008; not distinguished between virgin and recovered fibre pulps.	80 – 120		Skogs Industrierna, 2009, p. 9

Source: (Smith et al. 2001, p 175)

63. The GHG emissions associated with pulp and paper production are closely tied to energy use. Generally, the more energy-intensive the process is, the more GHG emissions will be generated. In addition, however, there are three other important factors that influence net GHG emissions from the fibre life-cycle at the harvesting, pulping and paper manufacturing stages:

- The way in which forests are managed; whether they are replanted after wood is harvested for paper production (as explained earlier, if trees are replanted, CO_2 emissions from the harvested wood can be considered GHG-neutral, because an equal amount of CO_2 will be absorbed by the newly planted trees);
- The GHG-intensity of the mix of fuels used to supply on-site process heat or cogenerated electricity to the pulp and paper mill;
- The GHG-intensity of the mix of fuels used to generate electricity that is purchased externally from the grid.

[9] Virgin pulp refers to pulp from 100% virgin inputs unless otherwise noted. For recovered fibre pulp, the mix of virgin and recovered fibre inputs is noted where information was available.

Table 4.5: GHG-intensity of fuels

Fuel Type	Description	GHG-intensity (kg CO_2-equivalent / GJ)			
		CO_2	CH_4	N_2O	Total $kgCO_2e$ / GJ
Fossil fuels	--	55 – 125	0.006 – 21	0.009 – 2	55 – 127
Biomass	Sustainably harvested	0	0.02 – 0.9	0.3 – 2.7	0.3 – 3.6
Coal	All types including anthracite, bituminous, sub-bituminous, lignite and coke.	91 to 108	0.24	0.45	92 to 108
Electricity, at point of generation	U.S. average[10]	167	0.08	0.77	168
	Finland, average[11]	56	1.17	0.47	57
Fuel Oil	Distillate and Residual Fuel Oil	69 to 75	0.07	0.17	70-75
Natural Gas	Natural Gas	50	0.02	0.03	50
Pulping liquors	Without replanting harvested wood	25	0.05	0.5	26
	Sustainably harvested	0	0.05	0.5	0.6
Wood Waste	Without replanting harvested wood	98	0.6	1.2	98-99
	Sustainably harvested	0	0.6	1.2	1

Source: (NCASI 2007a, p. 3; EPA 2008, Tables A1, B1, B2)

64. As shown in Table 4.5, the GHG emissions generated by different fuel types vary widely. GHG emissions from firing pulping liquors from non-sustainably harvested wood feedstocks are roughly one-quarter that of combusting coal and half of the emissions produced by burning natural gas. In OECD countries, most pulping liquor emissions are sustainably harvested—that is, the CO_2 emissions from combustion are offset by planting and re-growing additional trees—and thus CO_2 emissions can be considered zero, resulting in a very low GHG-intensity fuel.

65. In terms of water use, the major types of emissions to water from pulp mills include (EC 2001, p. 32):

- Oxygen-consuming organic substances (measured as chemical oxygen demand [COD] and biochemical oxygen demand [BOD]);
- Organically-bound chlorine compounds (measured as adsorbable organically bound halogens [AOX]);
- Nutrient emissions such as phosphorous (P) and nitrogen (N), which contribute to eutrophication; and
- Metals and toxics, such as resin acids that leach from the wood during processing.

[10] eGRID2007 version 1.1, updated January 2008. Available at: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

[11] Dahlbo *et al.*, 2005, Table 5.5, p. 108.

66. In chemical pulping, releases to water occur at the following process steps: wood handling, cooking, pulp washing, bleaching and other processes such as pulp drying, condensate treatment, white liquor preparation and episodic emissions from spills and leaks. These sources of water emissions are summarised in Table 4.6.

Table 4.6: Releases to water from chemical (kraft) pulping and sources of water use

Stage	Description of water releases	Recirculation or reuse prior to external treatment	Water use	Dissolved organic substances, COD (kg / air-dry tonne)
Wood handling	Fibres, sand, bank, dissolved organic substances and toxic substances can leach from wood, particularly during debarking.	Can be recirculated	0.6 – 2 m^3 per m^3 of wood, wet debarking	1 – 10
Cooking	Condensates from vapours that escape from the cooking and evaporation processes. Contain organic compounds, nitrogen.	Recirculated for chemical recovery	No information	2 – 8
Pulp washing	Black liquor is produced by press washing the pulp before bleaching.	Black liquor is burned in recovery boiler; white liquor is prepared for recirculation at cooking stage.	No information	6 – 12
Bleaching	Large source of emissions to water; including organic substances, chlorinated organic substances, phosphorous and metals.	Presence of chlorides makes it difficult to recirculate effluent through chemical recovery due to corrosion problems.	20 – 40 m^3 per tonne of pulp	15 – 65
Other	Dissolved organic solids and salts form condensate treatment and white liquor preparation. Other temporary emissions from spills and leaks.	No information	No information	2 – 10 (from spillage)

Source: (EC, 2001, pp. 32-38)

67. Releases to water in mechanical pulping are largely dissolved organic substances that occur during wood handling and washing stages. Nitrogen and phosphorous nutrients are also leached from the wood and from chelating agents that are added at the bleaching stage. Mechanical and recycled pulp bleaching does not involve chlorides, so there are no releases of chlorinated compounds. Table 4.7 summarises releases to water and water use for chemical pulping, integrated mechanical pulp and paper mills and recovered fibre processing.

Table 4.7: Releases to water and water use across various pulp and papermaking processes, European mills (Adt = air-dry tonne; BAT = best available technology)

Type	BOD (kg / Adt)	COD (kg / Adt)	TSS (kg / Adt)	AOX (kg / Adt)	P (kg / Adt)	N (kg / Adt)	Flow (m^3 / Adt)	Source
Chemical Pulp Mills								
Kraft, unbleached	1 - 20	7 – 50	0.2 – 15	--	0.003 – 0.04	0.1 – 1	20 – 80	EC, 2001, p. 38
Kraft, bleached	0.2 - 40	4 – 90	0.2 – 10	0 - 2	0.005 – 0.09	0.1 – 0.8	30 – 110	
Sulphite chemical pulp	0.5 – 75	10 - 190	1.7 – 10	0 - 1	0.01 – 0.15	0.18 – 1	40 - 100	EC, 2001, p. 135
Finland average, 2001	0.3 – 6.8	8 – 40	0.3 – 3.0	0 – 0.30	0.003 – 0.06	0.06 – 0.6	22 – 100	Nilsson et al., 2007
Finland average, 2004	0.2 – 4.9	4 – 34	0.2 – 2.9	0 – 0.27	0.003 – 0.04	0.05 – 0.5	20 – 95	
Integrated Mechanical Pulp and Paper Mills								
Integrated mechanical pulp and paper plant (BAT)	0.2 – 0.5	2 - 5	0.2 – 0.5	0 - 0.01	0.004 – 0.01	0.04 – 0.1	12 – 20	EC, 2001, p. 211
Finland average, 2001	0.1 – 2.0	2 – 6	0.3 – 1.0	--	0.002- 0.01	0.05 – 0.1	10 – 35	Nilsson et al., 2007
Finland average, 2004	0.1 – 1.0	2 – 9	0.1 – 4.0	--	0.002 – 0.01	0.04 – 0.3	8 – 32	
Recovered Fibre Processing								
Without de-inking	0.05 – 0.15	0.5 – 1.5	0.05 – 0.15	0 – 0.005	0.002 – 0.005	0.02 – 0.05	0 - 7	EC, 2001,p. 299
With de-inking	0.05 – 0.02	2 - 4	0.1 – 0.3	0 – 0.005	0.005 – 0.01	0.05 – 0.1	8 - 15	

4.2 Transportation

68. Transportation is not a single life-cycle stage, but occurs through the paper life-cycle because of the need to transport raw materials and pulp, finished paper products and recovered paper. The main transportation pathways occur at the wood harvest preparation stage (transport of chips and wood to pulp mills), the papermaking stage (transport of wood pulp to paper mills), the retail distribution stage (transport of pulp and

paper products to consumers) and the end-of-life stage (transport of paper to either re-pulping facilities or landfills/incinerators).

69. Globally, transport-related emissions account for roughly 40 million tonnes CO_2 per year for the paper and paperboard sector, which amounts to roughly 10% of total GHG emissions for the pulp and paper industry (NCASI, 2007a). In the United States alone, the CO_2 emissions per year are estimated to be around 20 million tonnes CO_2 (NCASI, 2008). In Europe, the distribution of paper has been estimated to emit roughly 70 kg of CO_2 per tonne of paper, which translates into roughly 7 million tonnes CO_2 (NCASI, 2007a).

70. According to a life-cycle study by the Heinz Centre (2006), the GHG emissions associated with transport of wood fibre to pulp mills comprise a small but variable amount of GHG emissions throughout the life-cycle of wood products depending on the product type. The transport of wood fibre from the forest where it is harvested to pulp mills comprised as much as 8% of total life-cycle GHG emissions for magazines (Heinz Centre, 2006). In terms of the transport of wood products to consumers, the Heinz study found that the transport of magazines to the consumer comprised a larger share (10%) of the total life-cycle GHG emissions profiles.

71. The transport of pulp- and paper-related materials (from wood pulp to recovered paper) is delivered via diesel truck, rail, cargo ship, or a combination of modes (The Heinz Centre, 2006). Total transport-related emissions are based on the product of total distance travelled and the fuel efficiency of fuel consumed (The Heinz Centre, 2006). The vast majority of inputs and products of the forest products industry throughout the life-cycle is delivered via diesel truck (NCASI, 2007a).

72. The fuel efficiency and carbon emission factors for each transport mode (shown as a function of transported mass and distance) are vastly different as shown in Table 4.8 below. Delivering a ton of forest products via rail or water is more efficient than delivering a ton via truck or air.

Table 4.8: Fuel efficiency and carbon emission factors for transport modes

	Rail Freight	Waterborne freight	Combination Truck	Airborne freight
Fuel efficiency (litres per 100 km)	n/a	n/a	39.8	619
Fuel efficiency (MJ/tonne-km)	0.24	0.37	2.31	20.23
Carbon emission factor (kg CO_2/tonne-km)	0.02	0.03	0.16	1.28

*Assuming a heating value of 39 MJ/litre (140,000 Btu/Gal) for diesel and 35 MJ/litre (125,000 Btu/Gal) for aviation gasoline.
Source: (EPA, 2008b)

73. Based on the major trade flows of pulp and paper (including recovered paper) discussed in the overview section, Table 4.9 illustrates the associated transportation energy and GHG emissions per kg of pulp, paper product and recovered paper. It was assumed that most of the transport for each major trade flow discussed below was either via truck or waterborne.

Table 4.9: Trade flow for major trade routes for pulp, paper and recovered paper

Major Trade Flow	Assumed Mode	Average distance (km)	Pulp* (million tonnes)	Paper* (million tonnes)	Recovered Paper* (million tonnes)	Energy (million GJ)	CO_2 emissions (million tonnes)
U.S. and Canada	Truck	1,500	5.1	14.5	2.8	78	5.34
Inter-Europe	Truck	200	1.0	9.2	1.1	5	0.36
North America and China	Waterborne	12,000	2.8	1.2	8.3	55	3.77
Europe and Asia	Waterborne	8,000	1.2	5.0	8.8	45	3.06

* Yearly amount transported (exports plus imports between regions)

Sources: All European data from CEPI, 2007a. North American data for recovered paper flow from Ervasti, 2008 and for pulp and paper flows from FAOSTAT, 2009.

4.3 End-of-life

74. As outlined in the overview section, there are three main pathways for end-of-life including landfilling, combustion and recycling. In this report, composting is not included as an end-of-life pathway for paper because it is not occurring on a large scale. However, it is important to recognise the practice and benefits of composting by-product solids in the production stages within the pulp and paper industry (Thacker, 2005), as well as potential benefits of composting end-of-life paper.

75. Associated with each pathway are various profiles of energy and GHG. The profile for water use is less clear at the end-of-life since it is likely that only the recycling pathway utilises water significantly (see Table 4.14).

76. The relative GHG and energy benefits of each end-of-life pathway summarised in Tables 4.10 and 4.11 are based on a streamlined life-cycle study of alternative waste management methods for materials in the municipal solid waste stream in the United States (EPA, 2006). These factors address the GHG and energy implications of recycling, combustion and landfilling of various paper types and describe the relative savings (or additional burden) from a waste management perspective. The negative values indicate an energy or GHG benefit whereas the positive values indicate an additional energy or GHG emissions burden. The recycling pathway includes the net energy and emissions from using recovered paper in lieu of virgin paper *(i.e.* it incorporates a recycled input credit for displacing the production of virgin paper). It also incorporates the forest carbon sequestration credit associated with the avoided harvesting of virgin paper (discussed below). The landfilling pathways (with and without methane recovery) incorporate a carbon sequestration benefit for the fraction of degradable carbon content that remains stored in a well-managed landfill over time as well as the amount of methane that is released into the atmosphere from the anaerobic breakdown of the paper materials (EPA, 2006). The combustion pathway incorporates a carbon offset for the emissions and energy associated with fossil fuel combustion for the generation of electricity, based on the average fuel mix for U.S. generation.

Table 4.10: Net GHG emissions via waste management pathways based on U.S.-specific data (tonnes CO_2e/tonne)

Paper type	Recycling (with forest carbon sequestration)	Recycling (without forest carbon sequestration)	Landfilling, no methane recovery	Landfilling, with methane recovery for energy	Combustion, with energy recovery
Corrugated	-3.43	-0.06	1.64	-0.51	-0.73

board					
Magazines	-3.38	-0.02	0.15	-0.72	-0.52
Newspaper	-3.08	-0.86	-0.53	-1.30	-0.83
Coated Freesheet	-3.14	0.23	4.09	0.46	-0.70

Table 4.11: Net energy via alternative waste management pathways based on U.S.-specific data (GJ/tonne)

Paper type	Recycling (Post-Consumer)	Landfilling, no methane recovery	Landfilling, with methane recovery for energy	Combustion, with energy recovery
Corrugated board	-17.92	0.61	-0.59	-8.74
Magazines	-0.80*	0.61	0.13	-6.44
Newspaper	-19.17	0.61	0.19	-9.91
Coated Freesheet	-11.72	0.61	-1.42	-8.43

*The assumed recycled content of each paper type varies and in practice ranges from 10 to 100%, being in this particular case 10% for magazines.

77. In the European context, using recycled pulp as opposed to virgin pulp offers a net energy savings potential of roughly 7-11 GJ per tonne (IEA, 2007 and CEPI, 2006). In contrast to the North American profile, end-of-life GHG benefits in Europe indicate a smaller magnitude but are likely due to some differences in assumptions, described below. The GHG benefits associated with each waste management pathway are indicative of a general paper material category and are described in Table 4.12 below (Smith *et al.*, 2001). The landfilling pathway does incorporate a carbon sequestration benefit for the fraction of degradable carbon content that remains stored which is similar to the U.S. data above.

Table 4.12: GHG emissions via waste management options based on European data (tonnes CO_2e/tonne)

Paper type	Recycling (without forest carbon sequestration)	Landfilling, no methane recovery	Landfilling, with methane recovery for energy	Combustion, with energy recovery
Paper	-0.6	n/a	0.223	-0.234

Source: (Smith *et al.*, 2001)

78. Although there are differences in net GHG savings between North America and Europe and among different paper types, the overall indication relative to the different waste management pathways is similar. Recycling paper results in the largest GHG savings followed by combustion with energy recovery. The inclusion of the forest carbon sequestration benefit clearly drives the majority of the GHG benefits, however. The landfilling with energy recovery pathway is less clear as some paper types (magazines and newsprint) indicate an additional GHG burden (*i.e.* positive emissions). There are some important assumptions regarding these values that deserve special attention.

79. The most important end-of-life implications of disposal include carbon sequestration both in forests through recycling practices and in landfills at disposal. When fibre products are landfilled, a portion of the organic material degrades into CO_2, methane and a relatively small proportion of dissolved organics in leachate. Some of the organic material, however, does not degrade and the carbon contained within this organic fraction remains stored within the landfill (EPA, 2006, p. 80; Miner, 2003, p. 17). For paper products, this carbon

storage would not occur naturally since all of the organic material would normally degrade into CO_2. Although the amount of storage will vary with environmental conditions in the landfill and across paper types, landfill carbon storage can act as a carbon sink. As shown in Table 4.10, the GHG benefit of landfilling certain paper types such as newspaper is high even with no landfill methane recovery. As paper products continue to be sent to landfills and the additional carbon is compared against the carbon emitted as CO_2 and methane at the landfills, over time the forest product carbon stocks in landfills increase by roughly 90 million tonnes of carbon per year (NCASI, 2007a).

80. The removal of atmospheric carbon by forests through the process of photosynthesis is an important element of the carbon cycle. If the rate of carbon storage in forests (i.e., biomass growth) is greater than the CO_2 emitted from a) conversion of carbon in wood products to CO_2 and methane and b) decomposition of organic materials within the forest, then the net effect is carbon accumulation, which from a GHG inventory standpoint counterbalances other GHG emissions (Freed *et al.,* 2006). Globally, the amounts of biomass (and thus carbon) in forests are stable or increasing in essentially all developed countries.[12] Increased recycling of fibre products offsets the demand for fibre production from virgin wood. To the extent that these changes in demand are not accounted for in the planting decisions of forest managers over the short-term, this incremental reduction in harvesting preserves trees that would have otherwise been harvested and increases the level of carbon sequestration in forests (Freed *et al.,* 2006).

81. In Table 4.10 above, the majority of GHG savings for recycling various paper types occurs as a result of the forest carbon sequestration "credit." Without this credit, there are still GHG benefits across most paper types (except for coated freesheet). A key determinant of the relative GHG benefits of recycling paper is whether carbon sequestration in forests is a suitable assumption. In the short-term and considering the sustainable management of industrial forests, this assumption seems valid and appropriate.

82. For the landfilling pathway, several key assumptions include the avoided emissions resulting from landfill methane capture and recovery and the associated collection efficiency of landfill gas. Landfilling fibre products results in anaerobic degradation that produces methane emissions; in this case, these emissions would be included in the assessment, since they would not have been produced without the human activity of landfilling (EPA, 2006, p. 13). Depending on whether the landfill gas is captured and whether the captured landfill gas used to generate electricity that displaces marginal or baseload electric power, the resulting emissions credit has a variable and large impact on the emissions profile from landfilling paper at end-of-life.

83. A similar condition applies for combustion at end-of-life. Since paper and paperboard have relatively high heating values, their combustion produces energy in the form of heat and/or electricity. The displacement of grid-generated electricity is a key assumption in assessing the GHG benefits of combustion as an end-of-life pathway (EPA, 2006, p. 7).

4.4 Summary

84. Tables 4.13 and 4.14 provide a summary of energy use, GHG emissions and water use across the fibre life-cycle. The information in Table 4.13 shows that the pulping stage either via chemical or mechanical processes and the papermaking stage use the most energy across the life-cycle. Chemical pulping uses more energy and water than mechanical pulping per tonne of paper. The GHG emissions are dependent upon the fuel mix used to provide electricity and process heat for pulping and papermaking. Although emissions are correlated with energy use, the variability of GHG emissions from fuels used in the pulp and papermaking industry makes it difficult to estimate GHG emissions in general for each life-cycle stage across paper types and regions.

[12] In many developing countries, however, forests are not harvested on a sustainable basis and thus there are net emissions from the forest sector.

Table 4.13: Summary of environmental impacts for pulp, papermaking and transportation across different paper types and regions

Life-cycle stage	Energy use*		GHG emissions	Water use
	(GJ / tonne)	(% of total)	(tonnes CO_2e / tonne)	(m^3 / tonne)
Wood harvesting and preparation	1	3 – 5%	--	0.6 – 2.0
Pulping				
Chemical pulp				
Pulping (includes cooking, washing, evaporation, chemical preparation)	7 – 11	30 – 35%	--	15 – 20**
Bleaching	2 – 3	10%	--	20 – 40
Mechanical pulp				
Pulping (includes grinding, screening)	8 – 9	30 – 40%	--	5 – 50
Bleaching	1 – 3	5 – 10%	--	
Pulp drying (for non-integrated pulp mills)	2 – 3	5 – 10%	--	n/a
Papermaking (including stock prep, forming, pressing and drying)	8 – 11	30 – 40%	--	5 – 50
Transportation	3	15%	--	negligible
Total (not including end-of-life)				
Chemical pulping	23 – 32	n/a	0.08 to 2	20 – 110
Mechanical pulping	21 – 30	n/a		10 – 50

* Energy use estimates do not include powerhouse losses from converting fuel inputs into energy. Boiler efficiencies can vary from roughly 60 to 90%.

-- Not estimated due to variability in fuel mix.

**Estimated value.

Sources: (Jacobs & IPST, 2006, EC, 2001and EDF,1995a)

85. Table 4.14 below summarises energy, GHG emissions and water use for the various end-of-life management pathways discussed in more detail in Section 4.3.

Table 4.14: Summary of environmental impacts for end-of-life management of pulp and paper products across Europe and North America

	Energy use (GJ / tonne)	GHG emissions ($MtCO_2$e / tonne)	Water use (m^3 / tonne)
Recycling including forest carbon sequestration	-19 to -7	-3 to -0.6	0 to 15
Combustion with energy recovery	-10 to -6	-0.8 to -0.2	Negligible
Landfilling with methane recovery	-1.4 to 0.2	-1.3 to 0.2	Negligible
Landfilling without methane recovery	0.6	-0.5 to 4	Negligible

Note: negative values indicate savings

Sources: (EC, 2001 and EPA, 2006)

5. BEST PRACTICES FOR SUSTAINABLE MANAGEMENT OF WOOD FIBRES

86. This section identifies some of the most significant technologies and management practices that could further reduce environmental impacts across the wood fibre life-cycle, taking into account economic and social impacts. The goal of this section is to identify, within the limits of available data and across the various dimensions of sustainability: i) which management methods and technologies would make a difference (and whether that difference is quantifiable); ii) for which processes and products; and iii) across which life-cycle stage(s).

87. The technologies and management practices summarised in this section were identified through a review of numerous literature sources and consultation with experts.[13] The following table highlights the practices according to life-cycle stages; each stage is discussed in further detail in the sub-sections that follow. Although this is not an exhaustive list, it is meant to outline general strategies to promote SMM in the pulp and paper industry and to highlight the relative potential impact of these practices on energy use, GHG emissions and water use.

Table 5.1: Summary of technologies and management practices that contribute to SMM

Environmental Impact[14]	Description of Possible Practices or Technologies	Potential Impact
Harvesting		
Reduce energy use and / or GHG emissions	• Forest certification through sustainable forest management	High; sustainably managed forests are potential large carbon sinks in the short-term
	• Wood sawing advances • Wood reconstitution and pressing technology advances	Low but beneficial
Pulping		
Reduce energy use and / or GHG emissions	• Power (heat and electricity) generation improvements: o Combined heat and power o Integration of chemical, mechanical and recycled pulp mills o Black liquor gasification (currently at a developmental stage, applicable to chemical pulping) • Switching to less GHG-intensive fuels; wood waste recovery and reuse • Carbon capture and sequestration (currently at a research stage) • Digester modernisation (chemical pulping) • Evaporator modernisation (chemical pulping) • Pressurised groundwood grinding; exhaust steam recovery (mechanical pulping) • Biotechnology improvements (mechanical pulping)	25 to 30% reduction in total energy use, relative to conventional mills, depending upon type of pulping process, age of plant and location of plant
Reduce water use	• Dry debarking • Closed-cycle pulp screening and cleaning; improved	Chemical pulp: 25 to 50% reduction in water use relative

[13] The valuable contribution of the following experts is greatly appreciated: Agneta Melin, Ambiolex Miljöstrategi AB; Ilpo Ervasti, Pöyry Consulting; Reid Miner, National Council for Air and Stream Improvement (NCASI); Jori Ringman, Confederation of European Paper Industries (CEPI); and Michael Suhr, European Commission – DG Joint Research Centre.

[14] The environmental impacts of interest in this study are explained in the scope section. This is not a comprehensive list, but reflects the information that was available in the literature.

Environmental Impact[14]	Description of Possible Practices or Technologies	Potential Impact
	closure of water loops and greater internal recirculation of water • Washing system modernisation • Improved lignin removal through extended cooking and oxygen delignification (chemical pulping) • Elemental chlorine-free or total chlorine-free bleaching using ozone or enzymes (chemical pulping)	to conventional mills, depending upon process, age of plant and location.
Papermaking		
Reduce energy use and / or GHG emissions	• Stock preparation system modernization • High-consistency forming • Compact wet-end systems • Press modernization • Drying system modernization	30 – 40% reduction in total energy use, relative to conventional mills depending on process, paper type, age of plant and location.
Reduce water use	• High consistency forming • Efficient water usage	Up to a 50% reduction in wastewater relative to conventional mills, depending upon paper type, process, age of plant and location.
Transportation		
Reduce energy use and / or GHG emissions	• Decreased transportation distances for fibre to pulp mills • Supply chain optimization • Increased use of rail versus truck for transportation mode and/or increased truck and rail energy efficiency	Decrease of transportation distance could save 2 MJ per km and 0.14 kg CO_2 per tonne Switch to train transport mode could lower transportation GHG emissions by 50%
Reduce water use	• N/A	
End-of-life		
Reduce energy use and / or GHG emissions	• Increased paper recycling and use of recovered paper in production • Enhanced collection and sorting for recovered paper • Selection of inks and paper designs that promote, or at least do not impair recyclability • Incineration with energy recovery and landfill methane capture for electricity generation after recycling options are already exhausted	Significant energy savings for recycling (7-19 GJ/tonne) depending on paper type GHG emissions benefit for recycling Incineration/landfilling with energy recovery GHG benefit if offsetting fossil-dominated energy source
Reduce water use	• N/A	

5.1 Harvesting

88. One of the most important aspects of enhancing SMM in the wood fibres sector is to harvest and source virgin wood fibre from sustainably managed forests. Forests that are sustainably managed integrate the production of wood products with environmental, social and economic incentives and provide a number of benefits including the conservation of air and water quality, displacement of fossil fuel emissions by providing a source for carbon-neutral biomass fuels and creation or conservation of large carbon reservoirs.

89. The annual carbon flux between the atmosphere and global forests is estimated to be 75 billion tonnes carbon (WBCSD, 2007). Each hectare of healthy trees grown for harvesting forest products is capable of absorbing 6.8 tonnes of CO_2 during their growth (AF&PA, 1994). Globally, it is estimated that the carbon sequestered in sustainably managed forests amounts to at least 60 million tonnes of CO_2 per year (NCASI, 2007a).

90. The United Nations Food and Agriculture Organisation (FAO) has adopted a definition of SFM as "the stewardship and use of forests and forest lands in a way and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels and that does not cause damage to

other ecosystems" (EC, 2006). Thus, by definition Sustainable Forest Management (SFM) implies that forests be managed with a recognition that there are multiple uses of forests beyond their use in the wood products industry, including ecological services and diversity, spiritual and cultural values and their role as biological carbon sinks.

91. The FAO, guided by international conferences, has identified key thematic components to SFM including broadening the extent of forest resources, maintaining biological diversity, improving forest health and vitality, providing productive functions of forest resources, allowing for protective functions of forest resources, capturing socio-economic functions and maintaining a legal, policy and institutional framework (FAO, 2009).

92. Certification by internationally recognised programmes including Forest Stewardship Council (FSC), Sustainable Forestry Initiative (SFI) and Programme for the Endorsement of Forest Certification (PEFC), CSA (Canadian Standard Association) for SFM helps assure that sustainable practices are followed in managing forests for use in the wood products industry. Table 5.2 below illustrates the SFM certified forest area by region and type of programme as of December 2006.

Table 5.2: Certified forest area by scheme and region as of December 2006 (million hectares)

Certification Program	North America	South & Central America	Europe	Asia	Oceania	Africa	Russia	Total
FSC	27.3	9.6	29.6	1.6	1.3	2.5	12.3	84.2
PEFC	128.3	2.3	57.4		5.7			193.7
Other*	11.0			4.8		1.2		17.0
Total	**166.6**	**11.9**	**87.0**	**6.4**	**7.0**	**3.7**	**12.3**	**294.9**

**In North America, "Other" refers to American Tree Farm System; in Asia, "Other" refers to the Malaysian Timber Certification Council; and in Africa, "Other" refers to areas in Gabon recognised under the Dutch Keurhout system.*
Source: (ICFPA, 2009)

93. The forest certification schemes typically include four main elements: 1) forestry management standards; 2) independent third-party certification of conformance to standards; 3) accreditation of third-party certification competence; and 4) control mechanisms to establish certification claim credibility. Forest certification essentially promotes and standardises SFM and consumption of sustainably sourced forest products.

94. Globally, around 30% of the commercially exploited forests (or roughly 300 million hectares) are certified for sustainable management, which represents roughly 8% to 10% of global forest area (CEPI 2009). As shown in Figure 5.1 below, Canada is clearly the leader in forest certification accounting for 124 million hectares or 40% of the total amount of certified forest in the world (FPAC, 2007a).

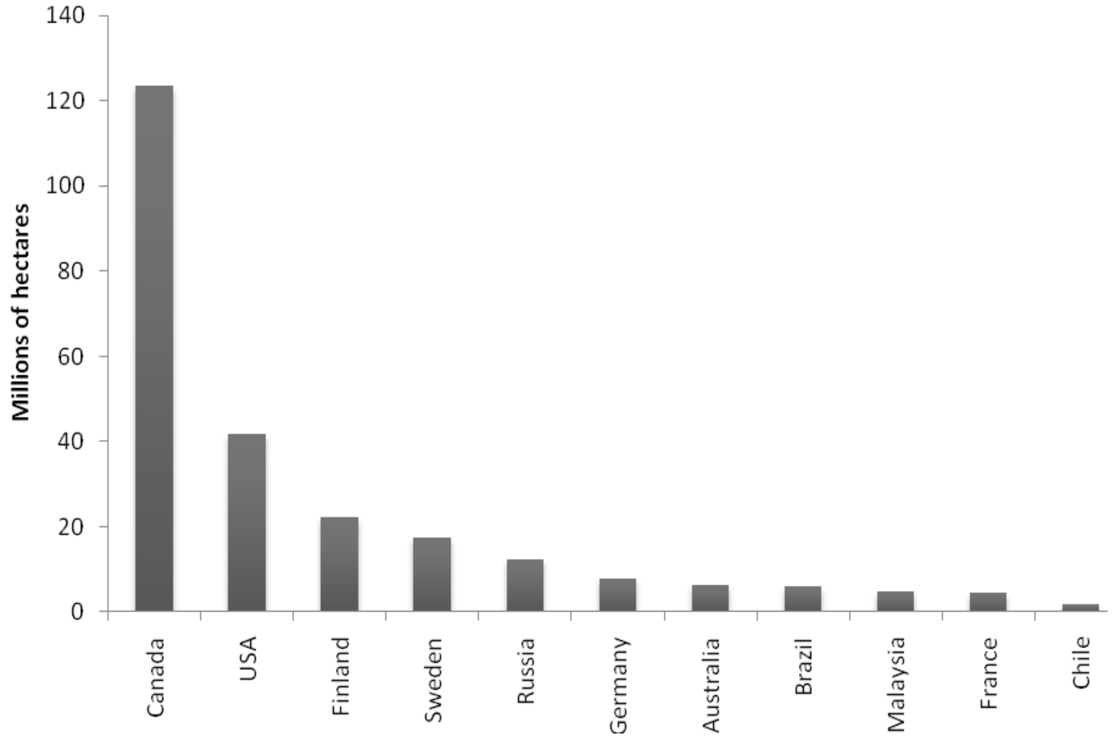

Figure 5.1: Certified forest area for select countries (millions of hectares as of December 2006)
Source: FPAC, 2007a

95. The potential is great to increase the area of forests that are sustainably managed. The International Council of Forest and Paper Associations (ICFPA) has recently prioritised the support of an increase in the certification of SFM (ICFPA, 2005). Continued international collaboration and discussion on promoting and certifying SFM is an important initiative for the pulp and paper industry.

5.2 Pulping

96. The pulping stage of the fibre life-cycle is a major contributor to energy use, GHG emissions and water use. There are considerable opportunities for reducing these environmental impacts at this stage.

5.2.1. Energy Use and GHG Emission Reduction Opportunities

97. There are important opportunities for reducing energy use and GHG emissions by: 1) power generation improvements via efficiency gains of boilers and electricity generators at pulp mills; 2) reducing the GHG-intensity of fuels used in pulp mills; and 3) capturing and sequestering carbon. In addition, within the pulping and bleaching processes, existing technologies and process improvements could improve energy efficiency in a conventional pulp mill from 5 to 30% on average, depending upon a mill's process, age and location (Jacobs & IPST, 2006).

Power generation improvements

Three examples of technologies for improving the efficiency of boilers and electricity generators in pulp and paper mills include: 1) combined heat and power (CHP) systems; 2) integration of pulp and paper mills; and 3) the potential for commercial-scale development of black liquor gasification (IEA, 2007; Jacobs & IPST, 2006).

1. ***Combined heat and power:*** CHP involves the on-site cogeneration of electricity and steam for use in pulp and papermaking (or other industrial) processes. When CHP is used to replace stand-alone electricity or heat production at low efficiencies, large improvements in energy efficiency are possible. The IEA estimates that CHP typically results in efficiency savings of 10 to 20% in pulp and paper mills and that more than 50% of CHP used in the pulp and paper industry is produced from combustion of black liquor in recovery boilers (IEA, 2007, pp. 196, 197). An additional opportunity is to use gas turbine cogeneration systems for CHP. Depending on the system configuration, total gas turbine system efficiencies can reach as high as 95%—much higher than the efficiencies achieved by conventional boilers using steam turbine generators for electricity cogeneration (Upton, 2001, p. 47).

2. ***Integration of mechanical, chemical and recycled pulp mills:*** Integration of pulp and paper mills, where possible, can also realise a large reduction in energy use across pulping and papermaking processes. Integration eliminates the necessity for drying pulp before the papermaking process and enables greater opportunities for waste heat recovery opportunities between the two plants. Through these opportunities, integrated pulp and paper mills can achieve efficiency gains between 10 and 50% relative to non-integrated mills (EC, 2001, pp. 52-56; IEA, 2007, p. 189).

3. ***Gasification of black liquor and pulping chemicals (chemical pulping***): Black liquor gasification is a developmental-scale technology that has a significant potential to improve the efficiency of on-site heat and power generation if established on a commercial-scale. Currently, black liquor is typically fired in Tomlinson recovery boilers at relatively low efficiencies due to the high water content of black liquor and the low boiler operating pressures. Pressurised gasifiers could offer a safer, more efficient alternative that would produce a clean-burning syngas which could be used in highly-efficient gas turbine systems (Jacobs & IPST, 2006, pp. 48, 65). Using current gasification technologies, the IEA estimates that a typical non-integrated kraft pulp plant could produce 220 – 335 kWh excess electricity per tonne of pulp, improving electric efficiency by 10% for the same level of steam efficiency. Gasification is currently in use on a demonstration scale, but further research is required to improve operational reliability and integration with gas turbine technologies (IEA, 2008, pp. 506-507).

Switching to less GHG-intensive fuels
A second category of opportunities involve switching to fuels that emit less GHGs. The pulp and paper industry already supplies a large amount of its own energy from biomass resources, which is considered GHG-neutral if sourced from sustainably managed forests. To the extent that electricity and fossil fuels are still purchased from external sources, however, effective utilisation of biomass and switching to low-GHG fuels such as natural gas can contribute to GHG reductions. Opportunities for increasing recovery and use of wood wastes are also beneficial for reducing GHG emissions. As an example, from 1980 to 2008, the Swedish pulp and paper industry increased biofuel use by 70% while reducing oil consumption by two-thirds; this has helped achieve a 40% reduction in fossil CO2 emissions since 1990, while pulp and paper production has increased (Skogs Industrierna, 2009, pp. 26, 30).

Carbon capture and sequestration
A third opportunity involves capturing CO2 emissions from fuel combustion and sequestering these emissions in underground storage reservoirs. Carbon capture and sequestration (CCS) technology is unlikely to be deployed on a commercial scale in the near term, but sizeable reductions in GHG emissions might be realised over the long-term. By 2050, the IEA estimates that CCS could reduce global emissions from black liquor combustion by 200 million tonnes of CO2 under aggressive GHG-reduction policies (IEA, 2008, p. 508). It is conceivable that, from the standpoint of net carbon flux, the

pulp and paper industry could actually remove CO2 from the atmosphere via the extensive use of CCS and continued combustion of sustainably sourced biomass (NCASI, 2009).

5.2.2. Chemical Pulping Energy and Water Use Reduction Opportunities

98. Within the specific steps of the pulping process, there are many opportunities to reduce energy and water use across all the major sources of consumption that were outlined in Section 4.1. Examples of practices that can be applied along different stages of the chemical pulping process are given in Figure 3.4 and described below, roughly in the order of the different process steps.

Table 5.3: Potential practices for reducing energy use, GHG emissions and water use during chemical pulping

Process Step	Practice	Category	Description of Benefit	Source
Wood preparation	Dry debarking	Energy, GHG emissions and water use	Debarking is done without water; water is used only for log washing after debarking and for de-icing logs in cold climates. Reduces toxic emissions leaching from wood into water; can reduce water use by 80% at debarking stage. Lower moisture content in the waste sent to hog fuel boilers, which improves boiler efficiency.	EC, 2001, p. 61
Cooking	Digester modernisation	Energy use, GHG emissions	Digesting consumes 20 – 25% of energy used for pulping and bleaching; efficiency improvements in modern digesters can halve the steam required for cooking, relative to conventional batch digesters.	Jacobs & IPST, 2006, p. 45
Screening and washing	Closed screening of unbleached pulp	Water use	Closing the screening water loop eliminates discharges from the screening plant. Organic compounds can be recovered and combusted in the recovery boiler.	EC, 2001, p. 65
Screening and washing	Recirculate clean condensate from evaporators	Energy use, GHG emissions	Recirculating clean condensate from the evaporators minimises shower water use, which reduces energy use requirements at the evaporation stage.	EC, 2001, p. 61
	Efficient washing	Water use	Modern washing systems can halve the amount of organic pollutants carried over into the bleaching stage, which reduces chemical use and effluent discharges in the bleach plant.	EC, 2001, p. 77
Evaporation	Evaporator modernization	Energy use, GHG emissions	Evaporation consumes 20 – 50% of energy use during pulping and bleaching. Modern evaporators can reduce energy use by 10 – 15% relative to conventional systems.	Jacobs & IPST, 2006, p. 48.

Process Step	Practice	Category	Description of Benefit	Source
Additional lignin removal	Extended delignification and oxygen delignification	Water use	Extended delignification increases the rate of lignin removal in the cooking process. Oxygen delignification occurs between pulp washing stages and exposes the pulp to oxygen at elevated temperatures. Lowering the lignin content of chemical pulps reduces bleaching chemical requirements. Increased lignin recovery can de-bottleneck the recovery boiler when pulp production at a mill is increased.	EC, 2001, p. 65-68 Jacobs & IPST, 2006, p. 46
Bleaching	Elemental chlorine-free or total chlorine-free bleaching	Water use	Bleaching without elemental chlorine can reduce the presence of molecular chlorine by nearly an order of magnitude. Chlorine-free bleaching eliminates discharges of organically-bound chlorine compounds and corrosion issues, which makes it easier to reduce discharges from the bleach plant by recirculating water to the chemical recovery plant.	Zhi Fu *et al.*, 2005
	Enzymatic bleaching	Energy use, GHG emissions and water use	Pre-treating unbleached pulp with enzymes can facilitate lignin removal and reduce the need for bleaching chemicals (i.e., bleach boosting). Can reduce energy use and GHG emissions associated with producing bleaching chemicals by 7% relative to conventional bleaching.	Skals *et al.*, 2008
	Mild acidic hydrolysis	Energy use, GHG emissions and water use	Hexenuronic acids in the unbleached pulp can be removed by treating the pulp with a mild acidic stage just prior to bleaching. Removing these acids reduces the consumption of bleaching chemicals required for the same level of paper brightness.	Nilsson et al. 2007, p. 19
	Use of secondary heat in bleaching	Energy use, GHG emissions	Pre-heating chlorine dioxide in elemental chlorine-free (ECF) bleaching can reduce steam demand at the bleaching plant, reducing energy use.	Jacobs & IPST, 2006, p. 46

Dry debarking
During wood preparation, the logs received at the pulp mill can be debarked dry, instead of in large pools of water. This practice can reduce the volume of water consumed during wood preparation by 5 – 10 m3/air-dry tonne and can also improve the efficiency of hog fuel boilers that burn the bark and wood residues from wood preparation by reducing the moisture of these fuels. Emission levels from dissolved organic compounds, nutrients and toxic resin acids that leach from wood into the water are also reduced with dry debarking (EC, 2001, p. 61).

Digester modernisation (chemical pulping)
In the cooking stage where wood chips are converted into fibres, efficiency improvements in modern batch or continuous digesters can achieve substantial reductions in energy use relative to conventional

systems. A U.S. Department of Energy study estimated that modernised digesters consume half of the 4 GJ/air-dry tonne of pulp required from steam in conventional batch digesters (Jacobs & IPST, 2006, p. 45). Since cooking accounts for roughly 20 to 25% of total energy use from pulping and bleaching, improving the efficiency of older systems is a significant area for reducing energy consumption.

Closed-cycle pulp screening and cleaning
After cooking, effluent water discharges can be reduced or eliminated by closing, or re-circulating, the water loop used to screen knots and shives (wood fragments) from the unbleached pulp (i.e., brown stock). In a closed screening loop, organic compounds in the water are recovered and sent to the recovery boiler, water is reused in the process and the screening plant does not discharge effluent (EC, 2001, p. 65).

Washing system modernisation
Efficiency improvements in pulp washing can also yield important energy and water use benefits. Since evaporation of the black liquor extracted from the washing process is the one of the largest sources of energy consumption during pulping and bleaching, reducing the amount of washing water can also have an important effect on reducing energy use (Jacobs & IPST 2006, p. 45). At the same time, washing is important since the fraction of black liquor that remains in the pulp after washing consumes chemicals in the bleaching stage and increases overall emissions to water. Efficient washing systems can halve the amount of pollutants that are carried over into the bleaching stage (EC, 2001, p. 77).

Evaporator modernisation
Opportunities to reduce energy use in the evaporation plant are very important, since this step is the largest source of energy consumption in the pulping and bleaching process. The evaporator uses steam to evaporate water from black liquor retrieved after washing until the fraction of liquor solids is high enough for firing in a recovery boiler. Multiple evaporative stages can be used to improve the efficiency of steam utilisation. Compared to a 4-stage system that consumes 670 kJ/kg of water evaporated, a 7-stage evaporator consumes 42% less energy. Vapour re-compression evaporative units can also be used to raise the liquor solids fraction with waste steam before the evaporator (Jacobs & IPST, 2006, pp. 47, 48).

Improved lignin removal through extended cooking and oxygen delignification (chemical pulping)
Chemical consumption and effluent discharges in the bleach plant can also be reduced by removing a greater share of the lignin from unbleached pulp. At the cooking stage, this can be done through extended cooking in either batch or continuous digesters. After cooking, oxygen delignification can be performed between washing steps. Under oxygen delignification, the unbleached pulp is exposed to oxygen at elevated temperatures to remove as much of the remaining lignin as possible. Oxygen delignification can achieve a delignification efficiency of 40 to 60% (EC, 2001, p. 66).

Elemental chlorine free (ECF) or total chlorine free (TCF) bleaching using ozone or enzymes (chemical pulping)
The bleaching stage of chemical pulping is the largest source of water use and water emissions. Chlorine-based bleaching chemicals result in emissions of organically-bound chloride compounds. These compounds create corrosion problems that make it difficult to circulate effluent from bleaching through the chemical recovery plant; as a result, effluent is typically discharged to external wastewater treatment. Elemental chlorine-free (ECF) bleaching uses chloride dioxide instead of elemental chloride to reduce the formation of molecular chlorine by nearly an order of magnitude, which in turn lowers the emission of organically-bound chloride compounds to water. Total chlorine-free (TCF) bleaching uses other chemicals, such as peroxide, to bleach the pulp, eliminating chlorine from the process entirely (EC, 2001; Zhi Fu *et al.*, 2005).

Alongside ECF and TCF bleaching, ozone is typically added as a bleaching step. Exposing the pulp to ozone in the bleaching process lowers the amount of chlorine dioxide required for ECF bleaching and it facilitates the peroxide TCF bleaching process (EC, 2001, p. 68). Unbleached pulp can also be treated with special enzymes in a "bleach boosting" step that facilitates the removal of lignin and reduces the need for bleaching chemicals. A recent study by Skals *et al.* (2008) found that the use of a xylanase enzyme in bleach boosting can reduce the GHG emissions from producing bleaching chemicals by 7%. The authors did not quantify the reduction in chlorine compound emissions to water, but asserted that enzyme pretreatment provides important environmental benefits. . Similar to "bleach boosting", the partial substitution of ECF by enzyme bleaching was studied by Zhi Fu *et al.* (2005) who found that enzyme bleaching significantly improved environmental performance, particularly when the enzyme mediator is manufactured on-site.

5.2.3. Energy and Water Use Reduction Opportunities in Mechanical Pulping

99. With respect to mechanical pulping, the largest source of energy is in the form of electricity consumption from grinding the wood into fibres. During this process, 90% of the electrical energy input is converted into heat through friction (IEA, 2007, p. 182). Opportunities for reducing energy and water use for mechanical pulping are summarised in Table 5.4 below.

Pressurised groundwood grinding
In conventional groundwood pulping, logs are forced against rotating stones with a hydraulic ram. During grinding, water is used to wash and cool the stone. By pressurising the conventional groundwood process, higher water temperatures can improve fibre separation by softening the lignin bonds. Steam removed from the pressurised vessel can also be recovered for secondary heat.

Recover exhaust steam from thermomechanical pulping
In thermomechanical (TMP) pulping, chips are ground between steel discs in refiners. Exhaust steam from refiners can be recovered and used to heat water or to produce clean steam for other processes. Installing pressurised refiners maximises opportunities for heat recovery. Recovered heat from the refiners can offset energy inputs for paper drying or stock heating in integrated pulp and paper mills (Upton, 2001, p. 118).

100. Biotechnology-related techniques such as the development of biochemically modified fibres, the use of enzymes and membranes, using starch and synthetic polymers and the use of genomics to maximise fibre quality could also aid in increasing the efficiency in the mechanical pulping process (CFIC, 2006).

5.2.4. Water Use Reduction Opportunities

101. Similar opportunities exist for mechanical pulping plants to improve washing efficiency and to close or recirculate water loops in order to avoid discharging organic pollutants and nutrients. Chemithermomechanical (CTMP) pulps commonly use an activated sludge treatment to reduce discharges of organic pollutants. In situations where a high level of treatment is necessary, or where existing water resources are scarce, it may be possible to evaporate some or all of the contaminated wastewater and incinerate the remaining solids for energy recovery (EC, 2001, pp. 195-197).

Table 5.4: Potential practices for reducing energy use, GHG emissions and water use during mechanical pulping

(TMP = thermomechanical pulping; CTMP = chemithermomechanical pulping)

Process Step	Practice	Category	Description of Benefit	Source
Wood preparation	Dry debarking	Energy, GHG emissions, and water use	See dry debarking in Figure 34.	EC, 2001 p. 61
Grinding	Replace conventional groundwood grinding with pressurised groundwood grinding; biotechnology-related improvements	Energy use, GHG emissions	Can improve the quality of pulp produced, or reduce the amount of energy required per tonne of pulp. Improves opportunities for exhaust steam recovery.	Upton, 2001 p. 123
	Recover exhaust steam from TMP pulping	Energy use, GHG emissions	Overall, efficiency improvements in TMP pulping could reduce energy use by one-third relative to conventional TMP pulping.	Jacobs & IPST, 2006
Screening and washing	Efficient washing	Water use	Can improve the amount of organic pollutants removed from pulp for the same amount of water consumption.	EC, 2001, pp. 191-197
Screening and washing (con.)	Close, recirculate water loops	Water use	Can improve the efficiency of water use while lowering effluent discharges.	EC, 2001, pp. 191-197
Wastewater treatment	Evaporate wastewater from CTMP process	Water use	Where water resources are limited, can reduce or eliminate water discharges by evaporating some or all of contaminated wastewater and incinerating the remaining waste solids for energy recovery.	EC, 2001

5.3 Papermaking

102. Large amounts of energy are required in the papermaking process, primarily for drying the paper once it has been formed from pulp. Any reduction in water use during stock preparation, forming and pressing can result in important energy savings during the drying stage. The IEA estimates that 25 to 30% of total energy use across the pulp and paper industry is consumed by pulp drying and that opportunities exist for a 20 to 30% improvement in energy efficiency (IEA, 2008, p. 507). Examples of some of the many practices for reducing energy use, GHG emissions and water use across the papermaking process are shown in Table 5.5.

Table 5.5: Sample of potential practices for reducing energy use, GHG emissions and water use during papermaking

Process Step	Practice	Category	Description of Benefit	Source
Stock Preparation	Cleaning and screening improvements	Energy use, GHG emissions	Improvements in screening can reduce sheet breaks and can eliminate need for centrifugal cleaners.	Jacobs & IPST, 2006, p. 50

Process Step	Practice	Category	Description of Benefit	Source
	Refining improvements	Energy use, GHG emissions	Hybrid conical refiners can provide high maintenance and refining efficiencies and can reduce refining energy consumption by 40 to 70%. Generally, best practice refining techniques can result in energy savings of approximately 20% relative to conventional processes.	Jacobs & IPST, 2006, p. 50 EC, 2001, p. 394
Stock Preparation (con.)	Compact wet-end systems	Energy use, GHG emissions	Compact wet-end systems can realise lower pumping, agitation requirements. Also allows a shorter time for changing grades which reduces stock loss and overall energy use. Can reduce energy consumption by 25% in certain cases.	Jacobs & IPST, 2006, p. 50
Forming	High-consistency forming	Water use, energy use, GHG emissions	Can achieve consistencies of 4% to potentially 8 or 10%, relative to 0.5 to 1% in traditional paper machines. Reduces water use and yields a reduction in energy required to dry the paper after forming.	Jacobs & IPST, 2006, pp. 63-64
Pressing & drying	Press and drying system modernization	Water use, energy use, GHG emissions	Improved removal of water through pressing can greatly increase drying efficiency. General rule of thumb is a 1% improvement in press consistency equals a 4% improvement in drying efficiency. Use of shoe presses (or wide-nip presses) can achieve a 20 – 30% improvement in drying efficiency.	EC, 2001, p. 390; Jacobs & IPST, 2006, p. 51.

5.4 Transportation

103. As discussed in the Section 4, transportation is an important component of the pulp and paper industry allowing for the movement of raw materials, finished goods and recovered fibre. There are three main transportation pathways that should be considered as a means to reduce energy and associated GHG emissions within the paper life-cycle.

5.4.1 Decreased Transportation Distances for Wood Fibre to Pulp and Paper Mills

104. The first is a strategy to decrease transportation distance from the wood fibre to mills (note that this strategy does not apply to situations where timber is rafted to riverside mills from upstream forests; in such situations, where transportation-related emissions are limited to skidding the wood to the river and guiding the lumber rafts downstream with tugs, emissions are only weakly related to distance to the mill). Clearly, paper mills that are located closer to harvested forests will require less transport and therefore less energy and associated GHG emissions. This strategy is in some ways an ancillary benefit to the overarching best management practice of the integration of pulp and paper mills to achieve greater energy efficiency across the life-cycle (discussed in Section 5.2). However, an important trade-off to consider is the relative proximity of the consumer market for finished pulp and paper products. Transportation-related energy and associated GHG emissions could be somewhat larger at this stage of the pulp and paper life-cycle. Locating papermaking facilities near demand centres makes sense both economically and from a GHG reduction standpoint since this will minimise transportation distances of wood fibre to pulp and paper mills. However, market demand fluctuations could complicate the strategic placement of papermaking facilities.

5.4.2 Increased Use of Rail versus Truck for Transportation Mode and/or increased Truck Fuel Efficiency

105. In concert with minimising transport distance, another important best management practice is using more efficient transportation modes (i.e., use of rail vs. truck) throughout the pulp and paper life-cycle. Both in terms of energy and GHG emissions, the use of rail as a transport mode of choice would greatly reduce environmental impacts. Theoretically, using rail to transport pulp and paper materials (either upstream as raw material input or downstream as finished product) rather than truck transport could reduce energy use by approximately 2 MJ per km and GHG emissions by 0.14 kg CO_2 per tonne of material based on the relative fuel efficiency. Practically, the Heinz study found that the GHG emissions from transport of raw wood materials to mills using rail is roughly half as compared to similar transportation distances using truck (The Heinz Centre, 2006).

5.4.3 Supply Chain Optimisation

106. The efficient transport of materials via an optimised pulp and paper supply chain system can reduce energy consumption and GHG emissions. Information systems, such as Enterprise Resource Planning (ERP) systems are becoming increasingly important in optimising pulp and paper supply chains and enabling more efficient routing of materials across the fibre life-cycle (Carlsson *et al.*, 2006). In Europe, longer and larger trucks (up to 44 tonnes carrying capacity) and flexible systems, such as the European Modular System (EMS), are currently under discussion (CEPI, 2009). The adoption of these systems would decrease the number of freight journeys and subsequently reduce energy use and the associated GHG emissions from transport.

5.5 End-of-life

107. Considering the assumptions and issues discussed in Section 4, the recovery and recycling of paper is considered a best management practice towards achieving enhanced SMM. A recent metastudy of LCA studies on the recycling and disposal of paper and cardboard concluded that less environmental and energy impacts occur via recycling than either landfilling or incineration (ETC, 2004).

108. Generally speaking, more energy is consumed in virgin paper production (and subsequent disposal via landfilling or incineration) than recycling (ETC, 2004). Other meta-analyses have also shown that using recycled fibre as opposed to virgin fibre has a lower energy use profile than either landfilling or incineration (The Heinz Center, 2006). When compared to the virgin paper manufacturing process, the recycling process is less integrated and has additional energy requirements for generating pulp (such as de-inking and decontamination), but the overall energy profile indicates large savings as opposed to virgin paper production (IEA, 2007). In other words, the energy that otherwise would have been used in raw material harvesting and virgin pulp production is saved via recycling. In the North American context, the energy savings associated with recycling paper at the end-of-life far outweigh both landfilling and combustion with energy recovery. As shown in Table 4.11 in Section 4, the energy savings for recycling paper range from 12-19 GJ per tonne (except for magazines). Factoring in the diversion of paper to a landfill without methane recovery would add almost another 1 GJ to avoid the energy associated with transport and equipment use at the landfill.

109. In the European context, using recycled pulp as opposed to virgin pulp offers a net energy savings potential of roughly 7-11 GJ per tonne (IEA, 2007 and CEPI, 2006). The IEA Energy Technologies Perspectives 2008 notes that "between 10 and 20 GJ/t can be saved per tonne of paper recycled, depending on type of pulp and the efficiency of the pulp production it replaces". Although there is a range of absolute energy savings across different regions and studies, there is a clear indication that recycling paper saves energy.

110. Depending on key assumptions such whether forest or landfill carbon storage are considered and variations in the fuel mix associated with the production of virgin versus recycled content fibre, a comparison of GHG emissions from recycling versus disposal via landfilling or combustion is less clear. Generally, the majority of the energy consumed in virgin fibre paper production is derived from biomass, which is considered biogenic and sustainable. Such emissions are not included in the accounting of total GHG emissions consistent

with guidance from the Intergovernmental Panel on Climate Change (IPCC) for developing national GHG inventories. In contrast, in the production of paper from recovered fibre (*i.e.* the paper recycling process), the majority of energy is derived from fossil fuels (for electricity and/or direct use) (ETC 2004). The relative GHG benefit of recycling as opposed to virgin paper production is largely dependent on the underlying fuel mix associated with the production of the various paper types. As discussed in Section 4, the forest carbon sequestration benefit of incremental reduction in harvesting via recycling also greatly determines the net GHG benefit (EPA, 2006).

111. Finally, carbon storage in landfills, particularly for mechanically pulped papers such as newspaper, also affects the GHG landfilling benefit for certain paper types (see Table 4.10). Noting these key assumptions, there can be significant GHG benefits from paper recycling. In the United States the range is roughly 2 – 4 tonnes CO_2e/tonne compared to landfilling with methane recovery for energy and 2 – 3 tonnes CO_2/tonne compared to combustion with energy recovery. In Europe, the range is almost 1 tonne CO_2e/tonne compared to landfilling with methane recovery for energy and less than 0.5 tonnes CO_2e/tonne compared to combustion (EPA, 2006; Smith *et al.,* 2001).

112. Also, it is important to note that the electricity grid fuel mix differs greatly across regions. In the United States, the electricity grid mix is more carbon-intensive because of a heavy reliance on fossil fuels, particularly coal (almost 50% of electricity is generated using coal) (EIA, 2007). In Europe, the fuel mix is less carbon-intensive (less than 30% of electricity generated in Europe is from coal) (EC, 2009). Therefore, the avoided emissions credit for combustion with energy recovery and landfilling with energy recovery will differ greatly depending on the regional fuel mix. Generally, regions with heavy reliance on carbon-intensive fuels for electricity generation are the ones where avoiding these emissions shows the greatest GHG benefit.

113. The marginal benefits from recycling versus landfilling and incineration need to be weighed against the additional GHG burden of transport to and from long distance recycling facilities (*e.g.* to China), where most of the recovered paper global trade flow is occurring (see Section 3). As mentioned in Section 4, the largest trade flows for recovered paper occur as exports from North America and Europe to China. Even though the distance is large between the generation and reprocessing of recovered paper, the transportation mode is via ship, which on a per tonne basis has a relatively small energy and GHG emission impact. A recent study conducted in England to assess the relative benefits of shipping recovered paper to China found that the additional transportation-related impacts did not change the conclusion that recycling of paper has a lower GHG emissions impact as opposed to virgin production. The absolute transport emissions of recovered paper to China from England comprised only 10% of the median savings from recycling (WRAP, 2008a). Ultimately, there is a benefit from recycling (*i.e.* avoided emissions from harvesting and pulping virgin paper) regardless of location (Potter, 2008).

114. Within the context of an increased focus on recycling as an end-of-life best management practice, there is increased incentive to utilise inks and adhesives that do not impair recyclability (CEPI 2009). It is equally important to improve collection and sorting of recovered paper through specific collection schemes (source segregated or multi-stream as opposed to co-mingled or single stream as discussed in Section 6) allowing for an increase in the use of recovered materials in products that require increasing performance and quality (AF&PA, 1994 and CEPI, 2009).

115. Paper cannot be recycled indefinitely and recovered paper does not normally have the same quality and functionality as virgin paper (ETC, 2004). Therefore, sustainably sourced virgin fibre will continue to play an integral role in the manufacture of paper. However, there is large potential to increase the global paper recycling rate to a theoretical maximum estimated at 81% (IEA, 2007). For the remaining fibre stream bound for disposal, combustion with energy recovery is the preferable fate since paper and paperboard have relatively high heating values and their combustion produces energy which can displace utility-generated electricity. Finally, although the landfill disposal of fibre types that generate more methane as compared to the carbon that remains stored in the landfill (see Table 4.10) should be avoided, there is still potential for landfill methane capture and energy generation to displace utility-generated electricity. Most likely, methane emissions from paper products in landfills will continue to be reduced over time as recovery rates increase (NCASI, 2007a).

116. Finally, it should be recognised that source reduction of paper in practices such as lightweighting packaging, double-sided printing and copying and paper reuse are important aspects of the paper life-cycle and will ultimately prevent the harvesting, production and the necessity to dispose and manage paper at the end-of-life. Options to re-use paper can be implemented across a wide-variety of applications (*e.g.* scratch writing pads, animal bedding liners, packaging fillers, etc.) as well as the options for source reduction (*e.g.* electronic communication, reduced packaging, re-usable grocery bags, etc.).

6. DRIVERS AND BARRIERS TO SUSTAINABLE MANAGEMENT OF WOOD FIBRES

117. This section discusses key drivers and barriers to Sustainable Materials Management (SMM) in the wood fibres industry. Based on the promising technologies and management practices identified in Section 5, the factors that can lead to their adoption or are likely to slow or impede their implementation are examined.

118. This section uses three broad categories to define key drivers and barriers that influence SMM for wood fibres products:

- Technical, or physical drivers and barriers;
- Economic, or market-based drivers and barriers; and
- Social and policy-based drivers and barriers.

119. For each category, the drivers and barriers are discussed in Sections 6.1, 6.2 and 6.3 through examples from the best management practices and technologies that were summarised in Section 5. We use these major drivers and barriers to broadly assess the technical, economic and social impacts of best management practices and technologies in Section 6.4.

6.1 Technical Drivers and Barriers

120. Technology can be a powerful lever for achieving the best management practices (described in Section 5) of reduced energy use, GHG emissions and water use across the fibres life-cycle. However, it is also important to acknowledge practical realities and technological limitations. Three specific ways in which technologies drive improved environmental performance include the following:

1. Incremental upgrades and improvements in existing or retiring equipment and processes, over time, add up to achieve significant improvements in environmental performance at similar—or better—levels of reliability, safety, cost and product quality.
2. New technologies that are realised at a commercial scale in pulp and paper mills can contribute to step-changes in environmental performance, enabling new capabilities that were previously unavailable.
3. Technologies can enable synergies with one another, resulting in additional reductions in environmental impacts.

121. An example of an SMM opportunity that is being promoted by these technology-based drivers is increased and efficient use of biomass resources as fuel within the pulp and paper industry. Although the three drivers outlined above are not the only factors that influence this practice, they play a central role in increasing the effectiveness and extent of biomass utilisation. For example, pulp and paper mills have achieved substantial efficiency improvements in the use of biomass and other fuels. The IEA estimates that the global pulp and paper sector has increased the energy efficiency of its heat consumption by roughly 10% on average from 1990 to 2003 and that a significant potential exists for further improvement using currently-available technologies (IEA, 2007, p. 192). Alongside these incremental improvements, black liquor gasification, while still at a developmental stage, could realise a sizeable improvement in the efficiency of black liquor combustion if becoming viable at a commercial scale. The IEA estimates that between 2030 and 2050 with a financial investment of USD 300 per tonne of pulp, black liquor gasification could reduce energy consumption at pulp mills globally by 15-23% (IEA, 2008, p. 507). Finally, deployment of black liquor gasification could in turn facilitate carbon capture technologies and enable greater use of highly-efficient gas turbine CHP systems.

122. At the same time, technologies and practices that improve environmental performance must be applied in a way that is consistent with technical and operational characteristics of pulp and paper mills. In some cases, the timeframes, trade-offs and operational requirements that plant operators face may limit the opportunities to implement specific technologies or improve certain aspects of environmental performance. These considerations include the following:

1. Slow rates of capital turnover limit the opportunities available for reducing energy and water use in the short term. New technologies that replace or change existing equipment in many cases must follow maintenance, expansion or turnover cycles, which can be on the order of years to decades.
2. Trade-offs exist among opportunities to reduce energy use, GHG emissions, water use and other environmental impacts from pulp and paper mills. Pulp and paper mill operators must optimise among multiple criteria including, such as operational reliability, product quality, health and safety, energy efficiency, water efficiency, air emissions, solid waste generation
3. Decisions made to reduce environmental impacts within one area or phase of the fibre life-cycle may limit opportunities in other areas or phases.

123. First, the capital investment required to build and maintain pulp and paper facilities is high. Once operational, equipment life-time can be long: the average chemical pulp mill has a design lifetime of 25 years or more (WBCSD, 2007, p. 8). Early retirement of capital stock can be expensive and difficult and long lead-times may be required to implement changes in facility designs and processes. Due to the complex and extremely energy-intensive capital equipment employed in the pulp and paper industry, there are noticeable cycles in building capacity and the transition to better technologies in order to meet increasing demand. The cycles for the entire industry are related to the demand cycle, with profitable periods providing the resources to build capacity later. Capacity-building cycles for major renovations and technology transitions from planning through construction have a period of roughly five years (EDF, 1995b).

124. In general, older equipment is less advanced and less efficient than new equipment. To the extent possible, increasing the rate of capital stock turnover can speed the adoption of modern technologies and processes and can lead to significant efficiency gains. In order to evaluate energy efficiency across different regions, Pöyry Consulting uses a measure of "technical age"—the relative age of a particular plant, accounting for upgrades and improvements. Roughly speaking, North American and Latin American plants tend to be older than in Europe; for example, the average technical age of printing and writing paper mills currently in North America is estimated at 18 years, compared to 12 to 13 years in Europe (IEA, 2006, p. 7).

125. Second, trade-offs among various opportunities can impose technological limits on the extent to which energy use, GHG emissions and water use can be reduced. For example, Nilsson *et al.* (2007, pp. 17-19) noted that, while closure of water loops in pulp and papermaking can reduce effluent discharges from plants, closure also increases the complexity of the process, which can cause breaks in the paper forming process, higher energy use and solid waste generation and can limit the quality of paper produced. As a result, it is important to consider the integrated environmental impacts of best available technologies and practices and to promote overall improvement in environmental performance with an understanding of the interrelated nature of the fibre life-cycle (Nilsson *et al.*, 2007, pp. 10-12).

126. As noted earlier, carbon capture and sequestration (CCS) has been identified as a potential long-term technology for the fibres industry that could, at least conceptually, make the industry a net sink of GHGs provided that the CO_2 that is captured and sequestered is of biogenic origin and sustainably harvested. There are a number of technical barriers to this technology that are the subject of intense research throughout the world. Although this research is primarily in the context of prospects for reducing the net emissions from the electric power sector, it applies to other large industrial point sources such as the wood fibre industry. The basic technology for CCS has been demonstrated in the petroleum extraction for several decades, but not at the scale or geographic extent that would be needed for application at paper mills. Key technical barriers at this juncture include the integration of capture, transport and storage technology, demonstrating the ability to capture and store large volumes of CO_2 and the development of monitoring technologies to ensure minimal leakage to the atmosphere.

127. Implementing certain technologies or practices at one stage may limit opportunities for reducing environmental impacts at a later stage. Designing or retrofitting pulp and paper facilities requires certain decisions to be made that may constrain the range of opportunities available to reduce certain environmental impacts. As explained by Nilsson *et al.* (2007, p. 11):

> *A well-known, old example illustrates a mill, which has first concentrated on emissions to air and water and then on water consumption, achieving very good performance. When turning to solid waste, its options are already limited by the choices made and for energy and chemicals the limitations increase even further.*

128. Even when considering environmental impacts integrated across the fibre life-cycle, prioritising certain attributes such as pulp type, paper quality, operational reliability and health and safety issues, may limit the range of opportunities for reducing energy use, GHG emissions and water use.

6.2 Economic Drivers and Barriers

129. The costs and benefits of SMM practices for fibres are a central issue in deciding how to set priorities and reduce environmental impacts. For SMM to be realised efficiently, efforts should seek to maximise societal benefits and minimise societal costs. In many places, economic considerations drive reductions in energy use, GHG emissions and water use. In other areas, market barriers may prevent SMM from achieving efficient outcomes.

130. Three examples of key economic drivers that contribute to SMM of fibres include the following:

1. Cost savings that are achieved by reducing energy use, water use, or by eliminating effluent streams that require extensive treatment. Reductions in these areas use resources more efficiently and also lower GHG emissions and the discharges of pollutants from pulp and paper mills.
2. Access to markets that enable the sale of by-products or recycled material streams in the fibre life-cycle. As the demand and access to markets for by-products and recycled materials from fibre products increases, private-sector decision-makers have a greater incentive to use resources more efficiently and recover materials streams to a greater extent.
3. Including environmental benefits when evaluating the costs and benefits of decisions to implement SMM practices for fibre products.

131. For example, economic drivers have played a role in the adoption of CHP by the pulp and paper industry. First, by generating electricity alongside the heat requirements for the facility, pulp mills can generate energy more efficiently and realise cost savings. The economic incentive to be energy efficient is greater in areas with higher average electricity prices, as shown in Figure 6.1. Other factors, such as the types of pulp produced, industry size and structure and regional market differences are also important factors in this relationship that are not captured in this plot. Second, in some cases pulp mills are able to sell excess electricity generated from CHP systems back to the grid. The added benefit of selling electricity is a key factor in making CHP investment decisions attractive, so access to electricity markets can be important in promoting CHP technologies (Upton, 2001; IEA, 2006, 2007, p. 4), particularly when economic incentives exist to provide favourable rates for the electricity sold into the grid.

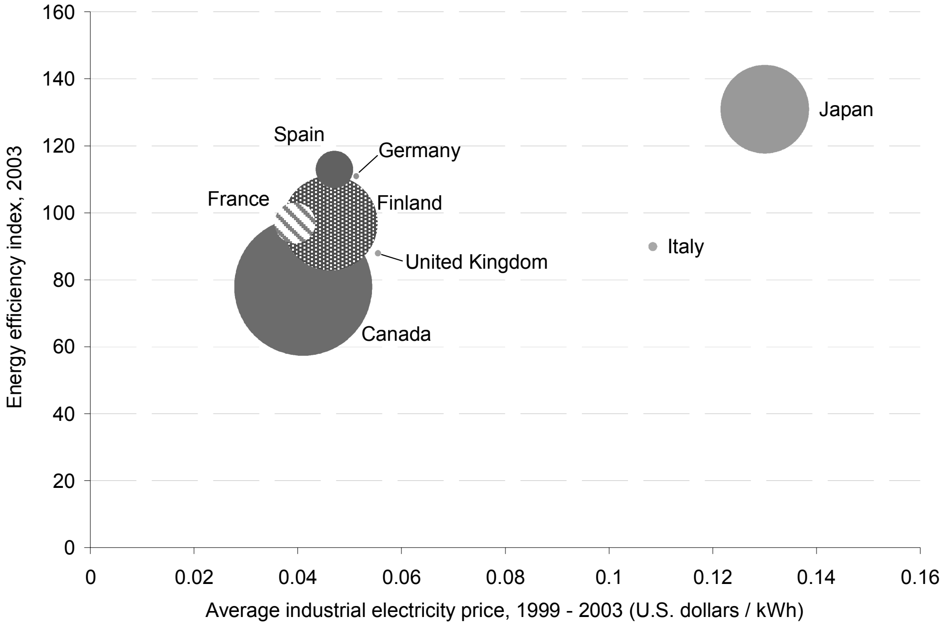

Figure 6.1: Energy efficiency (electricity and heat combined) of pulp and paper industries in 2003, for various countries, versus the average industrial electricity price between 1999 and 2003. The amount of chemical and mechanical pulp produced in each country is denoted by the size of each circle.
Source: (EIA, 2008; IEA, 2007, p. 197)

132. Finally, the economic drivers discussed above are strengthened when environmental costs and benefits are internalised in cost-benefit analysis. Although certain environmental benefits can be very difficult—if not impossible—to value appropriately, mechanisms for monetising environmental benefits can help promote SMM policies. For example, the pulp and paper industry is included within the European Trading System, an instrument that requires firms to hold permits to emit GHGs from their facilities. When implemented effectively, such an instrument can provide an efficient price incentive for firms to reduce, or abate, their emissions in order to sell the right to emit GHGs to other firms with higher abatement costs. Policies such as this may be essential for promoting higher-cost, low-carbon technologies that are emerging, such as CCS.

133. There are also opportunities for internalising environmental costs at the end-of-life of fibre products. In many of the OECD countries municipalities have implemented unit-pricing waste disposal programmes (pay-as-you-throw), which charge users based on the amount of waste they discard to landfills. Pricing waste disposal services in this way can increase the incentive for establishments to recover and recycle greater shares of paper and other recyclable material commodities.

134. Based on the review of environmental impacts and best management practices for promoting SMM of fibres, important economic barriers can include:

1. High capital investment requirements for certain technologies that can achieve substantial environmental benefits.
2. Uncertainty or variability in market prices and the demand for products with a lower environmental impact.
3. Economic trade-offs between improved environmental performance at one point in the fibre life-cycle or increased costs and environmental effects at another point.

135. CCS provides a good example of the first barrier. Despite the current potential to capture and sequester emissions from biomass burning, a principal barrier to realising this technology at a commercial scale

is the cost to capture CO_2, which is estimated to be roughly USD 30-70/tonne CO_2. This cost takes into account the cost of the solvent to capture the CO_2, as well as the large amount of energy required for both capture and compression. Transport and storage costs are less by comparison, though not insignificant, at USD15-30/tonne CO_2. Overall, the substantial amount of capital needed to design, construct and operate a CCS system remains a large obstacle to deployment of these technologies. In addition, there is currently a lack of insurance instruments available to industry, which will be necessary to manage projects with a risk.

136. An example of a second type of economic barrier is variability in the secondary market for recovered wood fibres. Like other commodities, the market prices fluctuate with the global economy and recently, market prices for recycled products have decreased drastically (Biddle, 2008). In the United States, fibre products in particular have seen dramatic decreases in recycling market prices including cardboard (decrease of 75%), mixed paper (decrease of 90%) and newsprint (decrease of 92%) in the last quarter of 2008. While pulp mills may benefit from decreases in recycled paper feedstock costs, the decrease in recycling markets means that processors and brokers of the recovered materials will likely lose money in the reprocessing of paper products. Certain paper recovery systems may be buffered against economic volatility: multi stream collection scheme systems, where the recovered fibre is of higher quality, have shown resilience to recent price variations. For example, the European recovered paper market, which largely utilises a source-separated multi stream collection scheme, continued reasonably well amidst the global economic slowdown in 2008, while the low quality recovered paper from single stream collections in the UK suffered (CEPI, 2009).

137. Finally, it is important to take an integrated view of economic issues along the fibre life-cycle. Improvements in environmental performance at one life-cycle stage must be balanced against costs, product quality and environmental impacts at earlier or later stages. For example, the system costs of recycling are dependent mainly on the collection scheme. The two most common approaches for the collection of recyclables include single-stream (co-mingled) or multi-stream (source-separated). Single-stream recycling is a system that collects a mixture of all recyclables together and subsequently separates and processes these materials. Multi-stream recycling is a system where recyclable materials are separated at source (*i.e.* prior to collection, such as at curbside) and subsequently recovered and processed.[15]

138. In some regions, there is an ongoing debate on which system is ultimately superior. Each system has pros and cons that can be complicated to evaluate across the fibre life-cycle. Single stream recycling incorporates increased costs for processing recovered paper after collection, but overall paper recovery can be greater due to the simpler collection scheme. At the same time, multi-stream recycling can realise reduced processing costs after collection and lower rates of paper contamination, at the expense of increased collection costs (CRI, 2009). The quality and usability of the recovered material in the multi-stream collection scheme is generally superior and prevents transportation and handling of unusable materials (CEPI, 2009). The relative advantages of increased paper recovery under a single-stream collection need to be weighed against potential increases in post-collection processing costs and the associated increase in contaminated and therefore, lower-value or unusable recovered materials.

139. A recent AF&PA paper described the systems cost for single-stream versus dual-stream collection (*i.e.* a multi-stream programme with separate collection for paper products vs. other recyclables) with an emphasis on recovered paper (AF&PA, 2004). It concluded that the savings associated with collection (8 to 13€ per tonne), additional cost for processing (4 to 12€ per tonne) and additional cost for recovered fibre at mills due to quality issues (4 to 11€ per tonne) resulted in an overall systems cost increase of 2.5€ per tonne for a single stream collection system versus a dual stream system (AF&PA, 2004). The savings from the collection-related simplicity of the single stream system were less than the additional processing requirements for the recovered paper material thereby increasing overall costs. Even though the volume of recovered paper increases with single-stream, the AF&PA study concluded that the sacrifice is lower quality pulp at the mills (indicating that an

[15] In Europe, a recently revised Waste Directive dictates that all member states install a multi stream (*i.e.* source separated) collection scheme for recovered paper by 2015 (CEPI, 2009). Single stream recycling is more prevalent in the United States (AF&PA, 2004).

additional 1% volume of single-stream recovered paper is needed in order to obtain the same amount of recycled paper output as compared to dual stream recovered paper). The analysis demonstrates that an additional 37 million euro in costs to paper mills would occur for single-stream sourced recovered fibres for newsprint and corrugated cardboard alone due to quality issues (AF&PA, 2004). Another study conducted in England on multi-stream recycling demonstrates that it is economically beneficial to have separate collection as the potentially higher collection cost is more than offset by the higher value of the recovered material. The study concludes that dual stream collection schemes offer the best prospect for achieving high quality recovered materials (WRAP, 2008b; WRAP, 2009).

140. In contrast, a study on hypothetical curbside recycling programmes in California concluded that the installation of a single-stream recycling system lowers overall net cost, mostly due to improvements in collection efficiency and avoided landfilling of un-recovered materials (Chester, 2008). Single stream sorting technologies at material recovery facilities have been improving, which could lead to higher quality feedstock in the future (WRAP, 2008b). Single-stream technologies, however, can pose quality challenges that impact the paper remanufacturing sector due to increased production costs. Specifically for paper, potential cost savings associated with single-stream collection efficiency shift to cost increases to the remanufacturers and processers (CRI, 2009). Table 6.1 shows the average overall net costs differential based on two different studies and the respective collection schemes. The cost differential is based on switching to single stream collection meaning that positive values indicate increased costs. These costs are not specific to recovered paper but across all recyclables (except for the AF&PA study, which analysed recovered fibre specifically).

Table 6.1: Average overall net recycling system costs

Study	Description	Materials Included	Single-Stream (€/tonne)	Multi-Stream (€/tonne)	Cost Differential(Single-Stream vs. Multi-Stream)
WRAP, 2008	"Systematic appraisal" of collection systems in the United Kingdom	Fibres and other curbside recyclables	110	70	40€/tonne
AF&PA, 2004	Value-chain analysis of collection, processing and pulping costs for the United States	Fibres only	No information available	No information available	2.5€/tonne

Note: the cost data includes revenue from recovered material sale. Recognizing that secondary markets are extremely volatile and regionally dependent, the cost differential does not necessarily reflect the current situation.

141. In the short-term, whether a single-stream or dual-stream recycling system is in place, pulp and paper mills may need to adjust their operations based on the quality of the recovered paper feedstock to optimise production costs. This requires an investment in areas like pulping modification, cleaning/decontamination and drum pulpers (AF&PA, 2004). The quality of recovered paper determines its market value and can be an important component in the economics of recycling of wood fibres, so it is important to study the full life-cycle implications of economic and environmental impacts in order to maximise the benefits of recycling efforts relative to their costs.

6.3 Social Drivers and Barriers

142. As with any large industry, social and political pressures sometimes drive the adoption of certain management practices in the pulp and paper industry. Improving SMM in this sector will be motivated by some key societal and policy-related drivers including:

1. Increased consumer awareness of environmental sustainability issues associated with the paper manufacturing sector;
2. Domestic and multi-national regulations and policy frameworks that seek to address global challenges, such as climate change and other forest-related environmental impacts; and

3. The contribution of wood fibre products to society in terms of employment and community well-being.

143. Growing consumer demand for environmentally friendly products and the significant role that forests play in the mitigation of climate change are key drivers in the sustainable management of forests. Sustainable forest management (SFM), in turn is a key best management practice to SMM and one in which policy can provide further expansion of this practice. SFM integrates social, environmental and economic functions of forest resources, recognizing that the ability to efficiently use these resources in the pulp and paper industry is of paramount importance (Nabuurs *et al.,* 2007). Increased consumer awareness on corporate sustainability and the application of product- and company-specific carbon footprints also serve as important societal drivers for pulp and paper companies to source their fibre from SFM forests.

144. Since emerging as a global priority at the 1992 United Nations Conference on Environment and Development (UNCED), both the EU and North America have regulated forest resource management and adopted high rates of forest certification that verifies SFM. In Europe, the European Commission created a strategy for sustainable management and development of forests that helps to improve the ecological and environmental stability of forests and the production of forestry-related products. This strategy includes five approaches that will encourage continuous improvement in SFM, including implementation of environmental regulation, integration of environmental issues into policy, collaboration with businesses and consumers, access to data and information and improved land use conservation ideals (EC, 2006).

145. In the United States, regulations on forest management have guided the development of laws for the protection of national forest systems in terms of resources, cultural values, minerals and wildlife (Brown, 2004). For example, all 175 company members of the American Forest and Paper Association (AF&PA) must comply with the Sustainable Forestry Initiative (SFI) and promote sustainable forest management practices on all sourced forests they own as a condition of their membership.

146. In Canada, the Forest Products Association of Canada (FPAC) pledged that all of its forestry operations would become certified to one of three internationally recognised standards for SFM (Canadian Standards Association, Forest Stewardship Council or Sustainable Forestry Initiative). This has been achieved across 138 million hectares that are now third-party certified for almost all (93%) of Canada's publicly-owned and regulated forests (FPAC, 2007). The Programme for Endorsement of Forest Certification Schemes (PEFC) has certified 194 million hectares worldwide, which covers a quarter of global round wood production.

147. Conversely, public acceptance can also pose a barrier to certain SMM practices, as is the case with carbon CCS. Recent studies have shown that only a small percentage of the population have even heard of CCS and those that have heard know little about the technology and risks. While demonstration projects have shown that the risks of CCS are low, misperceptions about how CO_2 is stored as well as concern about the creation of large "CO_2-disposal" sites beneath the ground have the potential to be major barriers.

148. Second, creating policies to promulgate SFM is an important step to promoting SMM in the pulp and paper industry. Guidance from the United Nations Forum on Forests includes policy frameworks that incorporate forest law, science and research, monitoring and reporting and public awareness, among others. In this context it is important to utilise various incentives and tools to promote SFM on the national level but especially in developing nations. Incentives include "creation of market access to non-timber forest products, promotion of agro-forestry, creation of payment for environmental services schemes and the decentralisation of management in the form of community based forest management" (Patosaari, 2007). The expansion of SFM is also a political tool for reducing deforestation and illegal logging. The causes of deforestation are complex and driven mainly by agriculture, infrastructure development and urbanisation factors, but promoting SFM policies, particularly in developing nations, is an opportunity to mitigate deforestation and enhance the credibility of SFM (The Forest Dialogue, 2008).

149. Finally, another important driver for SMM is the global interconnectedness and diversity of the pulp and paper industry and its contribution to economic development worldwide. For an industry that employs

almost 13 million people across 200 nations, the importance of SMM cannot be overstated. Particularly for poorer nations that depend on forest resources and their products, the very existence of the pulp and paper industry contributes to alleviating poverty and advancing community well-being.

150. At the same time as social and political drivers can encourage SMM practices, implementing these practices can also be hindered by social and political barriers including:

1. A lack of access to data and information in areas that can support SMM practices;
2. Imbalanced resources available for promoting SMM related practices in developing countries relative to developed countries; and
3. Weak enforcement and governance of existing SMM practices and incipient legal and regulatory frameworks for emerging SMM opportunities.

151. The lack of data collection and information sharing can hinder the adoption of practices, technologies and lessons learned that could otherwise promote SMM of fibres. Currently, governments, individual companies and pulp and paper trade organisations collect data concerning energy, emissions, water use and production. However, not only do quality and availability inconsistencies exist on data collected per paper type across various national or corporate level entities, but often the underlying data are kept confidential. The IEA has recently discussed the need for "international effort to harmonise data collection" to allow for energy and resource comparisons and improvements (IEA, 2007).

152. The industry could benefit from information sharing, which would allow for important industry benchmarking measures and a more complete assessment of best practices employed, energy consumed and technological obstacles overcome. The International Council of Forest and Paper Associations (ICFPA) Sustainability Progress Update for the pulp and paper industry describes that effective environmental management systems are key necessities in establishing measurable targets and consumption levels, while driving performance improvements (ICFPA, 2007). Currently, these systems are lacking in various paper companies throughout the industry. In Europe, CEPI has a target of 100% coverage of environmental management systems in the European pulp and paper production; in 2006, a level of 83% was achieved (CEPI, 2007b). Trade organisations can influence members to submit and share data on their processes. Paprican has recently conducted a benchmarking study that details energy consumption per mill in terms of specific unit process areas, which can be applied to different mills across Canada (Paprican, 2008). These types of benchmarking studies will be valuable in assessing and tracking energy use across the pulp and paper industry, particularly since individual mills vary greatly.

153. The EU recently instituted a tracking/measuring programme through its REACH (Registration, Evaluation, Authorisation and Restriction of Chemical substances) Regulation. This programme strives to identify and track chemical substances used across all industries. Individual companies contribute data on the properties and use of various chemicals to a central database to which both consumers and stakeholders will have access. Through these improvements in registering chemicals and communicating chemical hazards, industry can realise safety and public health benefits, as well as improved control over chemical releases to the environment across the pulp and paper industry. A similar voluntary programme for the pulp and paper industry (in concert with other manufacturing industries) to track raw materials, chemicals and fuels consumption would provide a transparent repository of data. In terms of recovered paper supply chain, a traceability system[16] was recently launched in Europe that attempts to keep track of recovered paper supplies as well as enforcing quality management (CEPI, 2009). Ultimately, these tracking and reporting programmes will allow for more focused polices and best management practices to have a greater impact on reducing consumption of natural resources and energy while also mitigating emissions.

154. Second, another important challenge in achieving SMM, particularly in regards to SFM, is the financing and availability of funding for these efforts as well as weak policy frameworks for direct investment

[16] For more information, see www.recoveredpaper-id.eu.

in SFM practices in some regions (The Forest Dialogue, 2008). In developing nations, capitalising on SFM's benefits has remained a challenge as the internal costs and benefits of maintaining the sustainably sourced forest goods are imbalanced (The Forest Dialogue, 2008). There is a general difficulty of obtaining external funding in developing nations which is crucial to the development of SFM practices. Private sector funding in forest related goods and services could likely impact the desirability of sustainably managed forests. Climate change mitigation strategies could also provide valuable revenue and incentives to allow for SFM to become more economically attractive (The Forest Dialogue, 2008).

155. Even with adequate funding, unless sufficient enforcement practices behind achieving best management practices are in place, it will be difficult to achieve high rates of adoption. Governance is particularly important at the harvesting stage (to enforce SFM) and at end-of-life (to promote recycling). Strict enforcement of raw material sourcing from sustainably managed forests will encourage the continued increase in SFM global forest area and discourage illegal logging practices and deforestation. At the end-of-life, increased accountability of paper recycling efforts on individual consumers and corporations will offer a clear signal that paper recycling is encouraged and important.

156. In the case of CCS, incipient legal and regulatory frameworks pose a barrier to deployment. Issues that still need to be resolved include the permitting process to create, monitor and close CO_2 storage sites, surface and underground property rights, long-term liability for damages, pipeline infrastructure development and regulation, crediting and ownership for CO_2 storage and legal uncertainties over how and whether other environmental laws may apply.

6.4 Assessment of Impacts of Technical, Economic and Social Drivers and Barriers on Best Management Practices

157. Of the drivers and barriers discussed above, Table 6.2 below illustrates a simplified list of technical, economic and social drivers and barriers that affect each of the best management practices described in Section 5. Although this is not an exhaustive list, its intent is to show how various best management practices are influenced by the drivers/barriers across the pulp and paper life-cycle stage.

Table 6.2: Summary of specific drivers and barriers as they affect best management practices in the wood fibres industry

Life-cycle stage	SMM practice	Technical		Economic		Social	
		Drivers	Barriers	Drivers	Barriers	Drivers	Barriers
Harvesting	SFM	--	--	Inclusion of environmental benefits when evaluating the costs and benefits	--	Global regulations and policy frameworks, particularly in regard to climate change Increased consumer awareness	Weak governance Imbalanced resources in developing countries relative to OECD countries
Pulping	Power generation improvements (*e.g.* CHP, black liquor gasification, pulp and paper mill integration, etc.)	High energy demand of industry and large potential efficiency gains if realised at a commercial scale	Slow rates of capital infrastructure turnover	Cost savings achieved by reducing high fossil fuel costs Access to markets to sell excess electricity back to grid	High costs of capital investments	--	Lack of data and information sharing
Pulping (con.)	Increased biomass and switching to less GHG-intensive fuels	High current use of biomass in industry	--	Cost savings achieved by reducing high fossil fuel costs	Value of biomass for use in forest products chain Increased competition with other demands, such as biofuels, electricity generation	Increased consumer awareness of environmental sustainability issues	Balance with use of biomass against social and other commercial uses

Life-cycle stage	SMM practice	Technical		Economic		Social	
		Drivers	Barriers	Drivers	Barriers	Drivers	Barriers
Pulping (con.)	CCS	Large potential to avoid CO_2 emissions if realised on a commercial scale	Technological capability of transport and storage as well as monitoring technologies to ensure minimal leakage to the atmosphere. Further R&D still required to realise on a commercial scale	Putting a price on environmental benefits (*i.e.* carbon market prices)	High level of capital investment required	Global regulations and policy frameworks, particularly in regard to climate change	Incipient legal and regulatory frameworks particularly in regard to permitting, crediting and monitoring
Pulping (con.)	Reducing energy, GHG emissions and water use during pulping and bleaching processes	Large potential for improvement from incremental upgrades using existing technologies	Slow rates of capital turnover Trade-offs between reducing environmental impacts and other criteria (*i.e.* safety, quality, reliability) Improvements at one stage may limit opportunities in later stages	Cost savings achieved by reducing high fossil fuel costs Inclusion of environmental benefits when evaluating costs and benefits	High capital investments required Economic trade-offs between improving environmental performance and other criteria (*e.g.* quality)	Regulations and policies that seek to address environmental challenges (*e.g.* climate change, water conservation, etc.)	Lack of data and information sharing Imbalanced resources for promoting SMM in developing countries relative to OECD countries Weak enforcement and governance

Life-cycle stage	SMM practice	Technical		Economic		Social	
		Drivers	Barriers	Drivers	Barriers	Drivers	Barriers
Papermaking	Reducing energy use, GHG emissions and water use during papermaking	Large potential for improvement from incremental upgrades using existing technologies Technology that offers synergistic benefits for reductions in energy use and water use	Slow rates of capital turnover Trade-offs between reducing environmental impacts and other criteria (*e.g.* safety, quality, reliability) Improvements at one stage may limit opportunities in later stages	Cost savings achieved by reducing high fossil fuel costs Inclusion of environmental benefits when evaluating costs and benefits	High capital investments required Economic trade-offs between improving environmental performance and other criteria (*e.g.* quality)	Regulations and policies that seek to address environmental challenges (*e.g.* climate change, water conservation, etc.)	Lack of data and information sharing Imbalanced resources for promoting SMM in developing countries relative to OECD countries Weak enforcement and governance
Transportation	Increased rail vs. truck	More efficient shipment logistics	Lacking transportation infrastructure	Lower fuel costs per tonne/mile	Fuel price volatility	--	--
End-of-life	Increased recycling	Recovered pulp is a major component of the productive capacity of the industry Substantial gains available using existing technologies / practices to recover paper	Recovered fibre has varying qualities and, after tapping the best sources, decreasing marginal quality	Cost savings from using recovered fibres to offset production of virgin fibres Access to markets for recovered paper	Secondary market price volatility Economic trade-offs between maximizing paper recovery and the quality of paper that is recovered	Increased consumer awareness of environmental sustainability issues Increased employment in the recycling industry	Consumer and commercial awareness and participation

Life-cycle stage	SMM practice	Technical		Economic		Social	
		Drivers	Barriers	Drivers	Barriers	Drivers	Barriers
	Enhanced recyclability of paper product in manufacture	Current use and availability of adhesives and inks that do not impair recyclability	The demand for high quality paper products which are generally utilise a lower percentage of recycled materials	Lower cost for paper production	Potentially higher costs for development and production of recycling friendly inks and adhesives	Increased consumer awareness of environmental sustainability issues	Weak policy framework to standardise recyclability of fibre products

7. CONCLUSIONS

158. The primary goal of this section is to provide an overview of the future of the global pulp and paper industry and conclude key opportunities and barriers for SMM in the fibres industry from the above sections. The key opportunities and barriers highlight the intersection of large environmental impacts (by fibre type or life-cycle stage), low economic costs (or net economic benefits) and high social benefits (such as increased employment, lower human health impacts, etc.).

7.1 Trends

159. The market for paper and board will continue to grow globally at 2.3% per year to 2030, with particularly rapid increases in developing and emerging economies (OECD, 2008). Most likely, the growth of the market for paper and paperboard in emerging economies (particularly in Southeast Asia) will change the current pattern of trade flows described earlier in this report.

160. Currently, the confluence of slow global economic growth and high capital costs has lowered profitability within the pulp and paper sector. The sector is also vulnerable to a weakening demand for printing and publishing, which the continued rise of electronic media may affect. Alternative materials for packaging, such as plastic, steel and aluminium create other challenges for the pulp and paper sector. Despite these constraints, the baseline scenario in the OECD Environmental Outlook projects growth of the pulp and paper sector to2030 assuming a continuation of current trends in global production and demand for paper (OECD, 2008).

161. On a national and regional level, China will continue to be a significant global producer (it is currently the second largest producer of pulp and paper), as well as a significant importer, requiring upwards of 50% of its own domestic demand to be met with imports. In India, although the paper market is relatively small, continued growth of roughly 6% is expected through 2020 driven by strong demand for high quality printing. A reduction in growth of production in Western Europe coupled with an increase in demand in Eastern Europe will likely cause Europe to become a net importer by 2030. Overall, there is an expected shift in production capacity from the traditional large producers (*i.e.* North America and Western Europe) to emerging markets such as China, India and Latin America. As paper and paperboard consumption continues to increase, with particular contributions from emerging markets, the barriers to improved SMM in the pulp and paper sector are important to recognise and overcome. Similarly, the opportunities for SMM can be seized by emerging markets with guidance from developed markets.

7.2 Opportunities

162. The wood fibre products industry is a heavy manufacturing sector, especially in the consumption of natural resources and energy. There are, however, opportunities for reducing energy use, GHG emissions and water use across the entire fibre life-cycle. Given the increasing importance of reducing energy use, GHG emissions and water use and considering that OECD member countries produce and consume the majority of the world's paper, the opportunities for SMM of wood fibres (*i.e.* pulp and paper products) outlined in this study represent key elements in OECD's portfolio of options to support its member countries in developing and implementing such SMM goals.

163. From a carbon management perspective, the wood fibre industry actively manages larger carbon stocks and greater annual carbon throughput than any other industries except oil and gas, organic chemicals, coal, electric power and agriculture. Excluding agriculture, it is unique among industries in terms of its management of substantial quantities of biogenic carbon.

164. There is a direct correlation between energy use and GHG emissions. Ultimately, the emissions profile of the pulp and paper industry is dictated by i) the management practices at forests from which biomass is utilised (*i.e.* whether they are sustainably managed or not); ii) the GHG-intensity of other fuels use to generate process heat and electricity; and iii) the management of fibre products at end-of-life. OECD nations could significantly reduce overall GHG emissions resulting from the wood fibre products industry by increasing sustainably sourced biomass fuel use and using less carbon-intensive fuels to generate energy within the industry, while improving recovery and recycling of fibres products at end-of-life.

165. Research and development for promising technologies and practices, such as black liquor gasification and recycling infrastructure efficiency gains, will play an important role over the medium- to longer-term. Support for new approaches and technologies, such as carbon capture and sequestration (CCS), should also be made available to enable further opportunities in the future.

166. To promote SMM across the wood fibre life-cycle, the following opportunities across the wood fibre life-cycle could be pursued:

- **Harvesting**
  - One of the most important focus areas is to promote sustainable forestry management (SFM) both within OECD and particularly with developing nations. This can be done through certification systems and through support by OECD member countries. Independent third-party certification and effective enforcement capabilities are crucial to establishing credibility of SFM sourced paper products.
  - The use of wood biomass for paper products stores carbon and paper products are important commodities with valuable economic and social benefits. It is important to recognise the balance between using biomass as fuel within the pulp and paper industry and in other industries and with its effective use as a raw material for pulp and paper products.

- **Pulping and papermaking**
  - Energy use, GHG emissions and water use are influenced by factors such as i) the type of pulping process; ii) the type of paper produced; and iii) plant-specific characteristics such as age, capacity, operation and maintenance. As noted earlier, the complexity of pulp and paper mills implies that different technologies will have different potentials for individual mills, so it is difficult to adopt a “one size fits all” approach in adopting technologies and practices. Instead, interventions that modernise older equipment and speed up the rate of capital turnover can be particularly effective, particularly at stages where energy use, GHG emissions and water use are high.
  - In the pulping stage, reductions in energy use between 20 to 30% could be achieved in conventional mills by adopting existing technologies such as combined heat and power (CHP) systems. Chemical and thermo-mechanical pulp mills offer the greatest potential for energy savings.
  - In the papermaking stage, energy use could be reduced by roughly 30 to 40% in conventional mills by adopting existing technologies. Paper drying in the papermaking stage is the most energy-intensive process across the life-cycle consuming 15 to 25% of total energy.
  - The use of biomass as a fuel source is an important asset in the pulp and paper industry. Modern chemical pulp mills can technically be completely self-sufficient in energy production and even be net energy producers. The continued and expanded use of sustainably sourced biomass as an energy source – notably as a supplement for fossil fuel use – is critical for the wood fibres industry.
  - Chemical pulping can be roughly twice as water-intensive as mechanical pulping. Reductions in water use on the order of 25 to 50% are possible in conventional mills by adopting technologies such as dry debarking, partial or full closure of certain water loops, washing system improvements and elemental chlorine-free (ECF) or enzymatic bleaching.

- **Transportation**

    - The transportation component of the life-cycle is a relatively small contributor to energy use, GHG emissions and water use. Nonetheless, some opportunities exist for energy and GHG reduction such as optimisation of supply chains in order to reduce distances, coupled with the improvement of the efficiency of transportation modes (*i.e.* more use of rail as opposed to truck).

- **End-of-life**
    - Increasing recovery and recycling of wood fibre products offers significant environmental benefits. The improvement of paper recycling through education, technology and policy is crucial to achieving SMM.
    - Greater utilisation of recovered paper can be achieved by improving recovered paper collection efficiency, reducing the rates of contamination and developing technologies and pulping processes.
    - Revenue from the sale of recovered paper is a strong economic driver to fibres recycling. Interventions that expand access to markets for recyclable commodities and pursue high-quality, high-value recovered paper streams, can lever this economic driver for recycling and reduce the impact of price volatility and uncertainty.
    - Recognizing that paper cannot be recycled indefinitely, discards sent to combustion facilities should employ energy recovery systems. Pulp and paper discards and residues that are sent to landfills should be minimised. Most paper types (especially those that are based on chemical pulping) generate more methane in landfills as compared to the embodied carbon that remains stored in the landfill. However, paper types high in lignin exhibit different decomposition characteristics in landfills and degrade to a lesser extent. For example, newspaper may degrade at a very slow pace, such that even when one accounts for the high global warming potential of methane, the emissions are outweighed by the accumulation of carbon within the landfill. In general, it is most important to divert paper types that have high methane generation potential from disposal in landfills. The presence or absence of landfill gas collection systems has a large effect on net GHG emissions from landfills. If a landfill gas collection system is present, energy recovery (which can displace some electric power from the grid that is otherwise generated by fossil fuels) can further reduce net emissions.
    - Although overall energy use is lower for the production of recycled paper as opposed to virgin paper, in some cases and regions (*i.e.* coated freesheet paper types in the United States), the GHG emissions for recycling are marginally larger than virgin production. This is due to the large amount of biomass used in the production of virgin paper in contrast to the large amount of fossil fuels used in the production of recycled paper. However, when considering the full life-cycle of paper, recycling reduces the amount of paper that otherwise would have been landfilled and would subsequently produce GHG emissions in the form of methane. The GHG reductions from avoided fibre landfilling more than outweigh the additional GHG emissions from recycled paper manufacture. The overall GHG profile for recycling paper will be even more beneficial if biomass and other non fossil fuel sources are used in the manufacture of recycled paper.

167. Finally, across the entire life-cycle, source reduction of paper – in practices such as lightweighting packaging, double-sided printing and copying and paper re-use – offers a comprehensive approach to reducing the size of the environmental footprint of wood fibres.

7.3 Key Barriers to SMM

168. The study identified several technical, economic and social / political barriers that are already impeding adoption of technologies and practices that would contribute to SMM. The barriers identified in this study are not necessarily specific to the pulp and paper sector, but may as well exist in other sectors.

169. Key technical, economic and political barriers to achieving SMM include:

- Limited data collection, monitoring and reporting via environmental management systems;
- High capital costs of equipment and infrastructure as well as the volatility of fuel and electricity costs;
- Limited enforcement of regulated SMM best management practices, particularly SFM;
- Limited outreach and education on consumer awareness of wood fibre sustainability issues, particularly on end-of-life management to increase paper recycling efforts; and
- Limited access to funding for research and development within the wood fibres industry, especially on emerging, unproven, but promising technologies.

REFERENCES

AF&PA (1994), Agenda 2020: *A Technology Vision and Research Agenda for America's Forest*, Wood and Paper Industry.

AF&PA (2004), Paper Recycling – *Quality is Key to Long-term Success*, American Pulp and Paper Association, prepared by Jaakko Pöyry Consulting (JPC Consulting) and Skumatz Economic Research Associates (SERA).

Biddle, David. (2008), Recycling Market Woes*, BioCycle 49*, no. 11 (November): 54, http://www.jgpress.com/archives/_free/001763.html .

Brown, Amie. (2004), *Selected Laws Affecting Forest Service Activities*, USDA Forest Service, available at: http://www.fs.fed.us/publications/laws/selected-laws.pdf .

BUWAL (1998), 'Life Cycle Inventories for Packagings', Environmental Series no. 250, Swiss Agency for the Environment, Forests and Landscape (SAEFL), Berne, cited in Smith et al., 2001.

Carlsson, D., S. D'Amours, A. Martel & M. Ronnqvist (2006), *Supply Chain Management in the Pulp and Paper Industry*, Universite Laval, http://www.cirrelt.ca/DocumentsTravail/2006/DT-2006-AM-3.pdf, accessed May 12, 2009.

Calcott, P., & M. Walls (2002), *Waste, Recycling and "Design for Environment": Roles for Markets and Policy Instruments*, Resources for the Future, http://www.rff.org/rff/Documents/RFF-DP-00-30-rev.pdf, accessed March 30, 2009.

CEPI (2006), *Special Recycling 2005 Statistics: European Paper Industry hits new record in recycling*, Confederation of European Paper Industries (CEPI), http://www.cepi.org/content/default.asp?pageid=7, accessed October 27, 2008.

CEPI (2007a), *Key Statistics 2007: European Pulp and Paper Industry*, Confederation of European Paper Industries (CEPI), Brussels.

CEPI (2007b), *CEPI Sustainability Report 2007*, Confederation of European Paper Industries (CEPI), http://www.cepi.org/Objects/1/Files/CEPI%20SR%20FINAL%20WEB.pdf, accessed July 7, 2009.

CEPI (2008), *Key Statistics 2007*, Confederation of European Paper Industries (CEPI), http://www.cepi.org/content/default.asp?pageid=226, accessed October 27, 2008.

CEPI (2009*),* Email correspondence from Jori Ringman, CEPI, to Christopher Evans, ICF, April 16, 2009.

CFIC (2006), Canadian Forest Innovation Council, Forest Science Policy Forum on Transformative Technologies, Canadian Forest Innovation Council, Prepared by The Conference Board of Canada, May 31, 2006.

CRI (2009), *Understanding economic and environmental impacts of single-stream collection systems,* Container Recycling Institute (CRI), http://www.container-recycling.org/assets/pdfs/reports/2009-SingleStream.pdf, accessed December 15, 2009.

Chester, M., E. Martin and N. Sathaye (2008), Energy, Greenhouse Gas and Cost Reductions for Municipal Recycling Systems, *Environmental Science and Technology*, 42:2142-2149.

Dahlbo, H., J. Laukka, T. Myllymaa, S. Koskela, J. Tenhunen, J. Seppälä, *et al.* (2005), *Waste management options for discarded newspaper in the Helsinki Metropolitan Area,* Finnish Environment Institute (SYKE), http://www.miljo.fi/print.asp?contentid=131301&lan=en&clan=en, accessed April 21, 2009.

Dehoust, G., M. Buchert, W. Jenseit, F. Schulze, A. Hermann, J. Ferenz, *et al.* (2006), *Development of the Closed Cycle and Waste Management Policy Towards a Sustainable Substance Flow and Resources Policy: Sub-project "Identification of Relevant Substances and Materials for a Substance Flow-Oriented Resource-Conserving Waste Management",* Institute for Applied Ecology, Öko-Institut e.V, http://www.bmu.de/english/waste_management/reports/doc/37341.php, accessed March 13, 2009.

EDF (1995a), *Paper Task Force: Recommendations for Purchasing and Using Environmentally Preferable Paper,* Environmental Defence Fund, Duke University, Johnson & Johnson, McDonald's, The Prudential Insurance Company of America and Time Inc., Chapter 5: Pulp and Paper Manufacturing 1995.

EDF (1995b), *Paper Task Force: White Paper No. 9: Economics of Manufacturing Virgin and Recycled-Content Paper,* Environmental Defence Fund, Duke University, Johnson & Johnson, McDonald's, The Prudential Insurance Company of America and Time Inc.1995.

EC (2001), *Reference Document on Best Available Techniques in the Pulp and Paper Industry,* European Commission (EC), http://eippcb.jrc.es/reference/, accessed April 14, 2009.

EC (2006), *Forest-Based industries - Sustainable development,* European Commission (EC), available at: http://ec.europa.eu/enterprise/forest_based/311_en.html.

EC (2009), *Statistical Pocketbook 2009. European Commission (EC): Energy,* available at: http://ec.europa.eu/energy/publications/statistics/statistics_en.htm.

EEA (1999), *Environment in the EU at the turn of the century*, European Environment Agency (EEA), cited in Smith *et al.*, 2001.

EIA (2008), *Electricity Prices for Industry 1999 – 2007,* Energy Information Administration (EIA), http://www.eia.doe.gov/emeu/international/elecprii.html, accessed May 5, 2009.

EIA (2007), *Annual Energy Review: 2007 "Electricity Flow for 2007",* Energy Information Administration (EIA), available at: http://www.eia.doe.gov/emeu/aer/pdf/aer.pdf.

EPA (2002), *Profile of the Pulp and Paper Industry*, 2nd Edition, U.S. Environmental Protection Agency (EPA), http://www.epa.gov/Compliance/resources/publications/assistance/sectors/notebooks/pulp.html, accessed March 30, 2009.

EPA (2006), *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*, U.S. Environmental Protection Agency (EPA), http://epa.gov/climatechange/wycd/waste/reports.html, accessed October 22, 2008.

EPA (2007), *Municipal Solid Waste in the United States: Facts and Figures for 2006*, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, DC., available at: http://www.epa.gov/epaoswer/non-hw/muncpl/msw99.htm .

EPA (2008a), *Direct Emissions from Stationary Combustion Sources*, U.S. Environmental Protection Agency (EPA), http://www.epa.gov/stateply/resources/cross-sector.html, accessed April 21, 2009.

EPA (2008b), *Direct Emissions from Mobile Combustion Sources*, U.S. Environmental Protection Agency (EPA), http://www.epa.gov/stateply/documents/resources/mobilesource_guidance.pdf, accessed April 21, 2009.

ERPC (2006), *European Declaration on Paper Recycling: 2006 - 2010*, European Recovered Paper Council (ERPC), http://www.citpa-europe.org/NeoDownload?docId=114632, accessed April 2, 2009.

Ervasti, I. (2008), "The Limits of Paper Recycling", Pöyry, Presentation given in Romania, October 2008.

ETC (2004), *Review of Existing LCA Studies on the Recycling and Disposal of Paper and Cardboard,* European Topic Centre on Waste and Material Flows, Final Draft Report to the EC, April 21, 2004

FAO (2005), *Trends in Wood Products*, United Nations Food and Agricultural Organization (FAO), available at: http://www.fao.org/docrep/008/a0142m/a0142m00.htm.

FAO (2008), Food and Agriculture Organisation of the United Nations: Forestry Department, available at: http://www.fao.org/forestry/home/en/.

FAO (2009), FAOSTAT forest products data base, United Nations Food and Agriculture Organisation, http://faostat.fao.org, accessed May 8, 2009.

FPAC (2007a), *Annual Review,* Forest Products Association of Canada, available at: http://www.fpac.ca/documents/fpac_annual_review_e_2007.pdf.

FPAC (2007b), *Industry at a Crossroads: Choosing a Path to Renewal,* available at: http://www.fpac.ca/documents/TASK_FORCE.pdf.

Freed, R., A. Choate & S. Shapiro (2006), *Revised Estimates of Effect of Paper Recycling on Forest Carbon*, ICF International.

ICFPA (2007), *Sustainability Progress Update*, The International Council of Forest and Paper Associations, http://www.icfpa.org/ICFPA_sustainable_summary_update.pdf, accessed May 11, 2009.

ICFPA (2009), On-Line Comparative Matrix of Forest Certification Schemes, available at: http://www.forestrycertification.info/.

IEA (2006), *Energy Efficient Technologies and CO2 Reduction Potentials in the Pulp and Paper Industry*, International Energy Agency (IEA), in collaboration with the World Business Council for Sustainable Development (WBCSD), Final version of workshop proceedings, http://www.iea.org/Textbase/work/workshopdetail.asp?WS_ID=264, accessed February 11, 2009.

IEA (2007), *Tracking Industrial Energy Efficiency and CO2 Emissions*, International Energy Agency (IEA), available at: http://www.iea.org/textbase/nppdf/free/2007/tracking_emissions.pdf.

IEA (2008), *Energy Technology Perspectives 2008*, International Energy Agency (IEA), http://www.iea.org/Textbase/techno/etp/index.asp, accessed April 27, 2009.

IPCC (2007), *Climate Change 2007: Synthesis Report Summary for Policymakers,* available at: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf.

Jacobs, & IPST (2006), *Pulp and Paper Industry Energy Bandwidth Study*, American Institute of Chemical Engineers (AlChE), http://www1.eere.energy.gov/industry/forest/bandwidth.html, accessed April 7, 2009.

Miner, R. (2003), *Characterizing Carbon Sequestration in Forest Products*, International Council of Forest and Paper Associations, http://www.climatebiz.com/files/document/CustomO16C45F64210.pdf, . accessed October 22, 2008.

Nabuurs, G.J. *et al*. (2007), "Forestry", in B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds.), *Climate Change 2007: Mitigation*, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change , Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

NCASI (2007a), *The Greenhouse Gas and Carbon Profile of the Global Forest Products Industry*, National Council for Air and Stream Improvement, http://www.ncasi.org/publications/Detail.aspx?id=2952, accessed October 22, 2008.

NCASI (2007b), *The Greenhouse Gas and Carbon Profile of the Canadian Forest Products Industry*, National Council for Air and Stream Improvement, http://www.ncasi.org/publications/Detail.aspx?id=3013, accessed October 22, 2008.

NCASI (2008), *The Greenhouse Gas and Carbon Profile of the U.S. Forest Products Industry*, National Council for Air and Stream Improvement, http://www.ncasi.org//Publications/Detail.aspx?id=3108, accessed October 22, 2008.

NCASI (2009), Email correspondence, Reid Minor, NCASI to Adam Brundage, ICF, May 9, 2009.

Nilsson, P., K. Puurunen, P. Vasara, & T. Jouttijärvi (2007), *Continuum - Rethinking BAT Emissions of the Pulp and Paper Industry in the European Union*, Finnish Environment Institute (SYKE), http://www.ymparisto.fi/default.asp?node=11174&lan=en, accessed April 14, 2009.

OECD (2005), *Outcome of the First OECD Workshop on Sustainable Materials Management*, ENV/EPOC/WGWPR/RD(2005)5/FINAL, OECD, http://www.olis.oecd.org/olis/2005doc.nsf/Linkto/env-epoc-wgwpr-rd(2005)5-final, accessed March 17, 2008.

OECD (2008), *OECD Environmental Outlook to 2030,* OECD, Paris.

Paprican (2008), *Benchmarking Energy Use in Canadian Pulp and Paper Mills*, Natural Resources Canada (NRCan), http://oee.nrcan.gc.ca/industrial/technical-info/benchmarking/pulp-paper/index.cfm?attr=24, accessed February 5, 2009.

Patosaari, P. (2007), *Forest and Climate Change: Mitigation and Adaptation through Sustainable Forest Management*, Remarks presented to the 60th Annual DPI/NGO Conference, United Nations, New York, September 2007.

Potter, A. (2008), *Beyond Waste: Towards Sustainable Recycling in Selected EU Regions and Member States*, South East England Regional Assembly, October 16, 2008.

Prognos (2008), *Resource Savings and CO2 Reduction Potential in Waste Management in Europe and the Possible Contribution to the CO2 Reduction Target in 2020,* available at: http://www.prognos.com/index.php?id=609.

Skals, P., A. Krabek, P. Nielsen, & H. Wenzel (2008), Environmental assessment of enzyme assisted processing in pulp and paper industry, *The International Journal of Life Cycle Assessment*, 13(2): 124-132, doi: 10.1065/lca2007.11.366 .

Skog, K., L. Heath, J. Smith, R. Miner, B. Upton, J. Urwin, *et al.* (2008), *The Greenhouse Gas and Carbon Profile of the U.S. Forest Products Sector*, National Council for Air and Stream Improvement (NCASI).

Skogs Industrierna (2008), *The Forest Industry – A natural part of Sweden*, Swedish Forest Industries Federation, http://www.skogsindustrierna.org/LitiumDokument20/GetDocument.asp?archive=3&directory=1293&document=9365, accessed April 30, 2009.

Skogs Industrierna (2009), *The Swedish Forest Industries: Facts and figures 2008*, Swedish Forest Industries Federation, http://www.skogsindustrierna.org/LitiumDokument20/GetDocument.asp?archive=3&directory=1399&document=10101, accessed April 30, 2009.

Smith, A., K. Brown, S. Ogilvie, K. Rushton, & J. Bates (2001), *Waste Management Options and Climate Change,* European Commission, http://ec.europa.eu/environment/waste/studies/climate_change.htm, accessed November 26, 2008.

Thacker, W. (2005), *Composting of by-product solids from the pulp and paper industry*, National Council for Air and Stream Improvement (NCASI).

The Forest Dialogue (2008), *Beyond REDD: The Role of Forests in Climate Change,* available at: www.wbcsd.org/includes/getTarget.asp?type=d&id=MzE4NTI.

The Heinz Center (2006), *Following the Paper Trail*: *The Impact of Magazine and Dimensional Lumber Production on Greenhouse Gas Emissions,* A Case Study, Washington, DC.

Upton, B. (2001), *Technologies for Reducing Carbon Dioxide Emissions: A Resource Manual for Pulp, Paper and Wood Products Manufacturers*, National Council for Air and Stream Improvement (NCASI).

VDP (2008a), *Facts on Paper 2008,* Verband Deutscher Papierfabrikin e.V., available at: http://www.marketplacepaper.org/pdf/Kompassenglisch.pdf.

VDP (2008b), *Papermaking: Information on Raw Materials and Papermaking*, Verband Deutscher Papierfabrikin e.V. , available at: http://www.marketplacepaper.org/pdf/Papermaking.pdf.

WBCSD (2007), *The Sustainable Forest Products Industry, Carbon and Climate Change*, World Business Council for Sustainable Development, available at: http://www.wbcsd.org/DocRoot/tpQeE6CBA7qSB2KWvhns/sfpi-cop11.pdf, accessed on May 6, 2009.

WRAP (2008a), *CO2-Impacts of Transporting the UK's Recovered Paper and Plastic Bottles to China*, Waste & Resources Action Programme (WRAP), http://www.wrap.org.uk/applications/publications/publication_details.rm?id=698&publication=5760&programme=corporate, accessed November 26, 2008.

WRAP (2008b), *Kerbside Recycling: Indicative Costs and Performance*, Waste & Resources Action Programme, available at: http://www.wrap.org.uk/downloads/Kerbside_collection_report_160608.527d453f.5504.pdf.

WRAP (2009) *Kerbside or Co-mingled Collections: Quality should come first*, Waste & Resources Action Programme (WRAP), http://www.wrap.org.uk/wrap_corporate/news/kerbside_or.html, accessed on July 7, 2009.

Zhi Fu, G., Chan, A., & Minns, D. (2005), "Preliminary Assessment of the Environmental Benefits of Enzyme Bleaching for Pulp and Paper Making", *The International Journal of Life Cycle Assessment*, 10(2): 136-142.