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Energy Use, Technologies and CO_2 Emissions in the the Pulp and Paper Industry

Dolf Gielen and Cecilia Tam
Energy Technology Policy Division
International Energy Agency

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Introduction

The pulp & paper industry is the 4th largest industrial consumer of energy, consuming 5.9 ExaJoules of final energy in 2003 (6% of total industrial energy use). Unlike other industrial sectors, the pulp and paper industry also produces energy as by-product and already generates approximately 50% of its own energy needs from biomass residues. In the long term the industry could even develop into a clean energy supplier if residues are used efficiently. In theory, the production of paper from pulp can use close to zero energy, which leaves a significant potential for efficiency gains. Besides emerging technologies, completely new process designs and processing techniques could bring long-term energy efficiency improvements of 75 to 90% in paper production (De Beer, 1998).

Most energy used in paper-making is for pulping and paper drying. New processes have been proposed that would reduce the energy needs for drying. The need for large amounts of steam makes combined heat-and-power (CHP) an attractive technology in this sector, and most modern paper mills have their own CHP unit. As a result of the large amount of black liquor produced and the relatively low energy recovery from this liquor, new technologies that promise higher conversion efficiency could have important energy benefits for this sector (especially to electricity and possibly biofuels).

In principle, it is possible to develop a paper and pulp sector without CO_2 emissions, provided sufficient biomass is used and black liquor is converted with sufficient efficiency. This would imply minimal recycling, with recycling replaced by energy recovery from waste paper. This may not, however, be the optimal use of scarce biomass resources. From the viewpoint of the energy system as a whole, it might make more sense to recycle as much paper as possible, while using the wood surplus to produce biofuels or electricity. Moreover, more intensive use of forests could bring further environmental degradation. The best pathway depends on system boundaries and complex trade-offs.

In early 2007 the IEA will publish an in-depth analysis of the energy demand, CO_2 emissions and CO_2 emission reduction opportunities in industry. For each industrial sub-sector the goal is to conduct an in-depth analysis of individual countries that account for at least 80% of total production in that sub-sector. This paper sets out some of the initial data collected for the analysis that will be conducted in the pulp and paper industry for this publication. Next steps are to discuss this data and potential analysis with stakeholders to further refine the data and fill in missing information. This analysis will also be an essential input into the IEAs ongoing energy indicators programme of work, which hopes to engage developing countries as well as IEA member countries.

Paper Production and Demand Drivers

Total paper and paperboard production was 355 Mt in 2004. Chemical pulp production was 127 Mt, mechanical wood-pulp production was 36 Mt and non-wood pulp production was 19 Mt. Total fibre supply (pulp and waste paper) amounted to 339 Mt. Recycled paper accounted for 149 Mt, or 44% of the total fibre supply, but this does not account for losses in waste paper processing. Out of the 127 Mt of chemical pulp produced, the vast majority (121 Mt) was sulphate (Kraft) pulp. Half of the paper and board product mix is packaging and wrapping paper and board. About a third is printing and writing paper. The remainder is newsprint, household and sanitary paper.

Table 1: Paper and Paperboard production, 2004

	Paper & Paperboard (Mt)	Share	Cumulative
USA	83.61	23.6%	23.6%
China	53.46	15.1%	38.7%
Japan	29.25	8.3%	46.9%
Canada	20.58	5.8%	52.7%
Germany	20.39	5.8%	58.5%
Finland	14.04	4.0%	62.4%
Sweden	11.59	3.3%	65.7%
Korea	10.51	3.0%	68.7%
France	10.25	2.9%	71.6%
Italy	9.67	2.7%	74.3%
Brazil	8.22	2.3%	76.6%
Indonesia	7.22	2.0%	78.6%
Russia	6.79	1.9%	80.6%
UK	6.24	1.8%	82.3%
Spain	5.49	1.5%	83.9%
Norway	2.29	0.6%	84.5%
Portugal	1.67	0.5%	85.0%
Chile	1.17	0.3%	85.3%
Others	52.04	14.7%	100.0%
World	**354.49**		

Source: FAO (2006)

The US is the largest producer of paper and paperboard accounting for 23.6% of world production in 2004. China, Japan and Canada are the next largest producers representing, 15.1%, 8.3% and 5.8% of production respectively. Together these 4 countries account for over half of all global production. China has shown the strongest growth with paper and paperboard production more than tripling from 17.41 Mt in 1990 to 53.46 Mt in 2004. Rapid demand growth for paper and paperboard over the last two decades has lead to tremendous investments in the Chinese paper industry. Global demand for paper and paperboard will be strongly influenced by demand in China.

Table 2: Chemical and Mechanical wood pulp production, 2004

	Chemical Wood Pulp (Mt)	Share	Mechanical Wood Pulp (Mt)	Share
USA	46.11	36.3%	4.21	11.6%
China	1.79	1.4%	0.57	1.6%
Japan	9.35	7.4%	1.24	3.4%
Canada	13.45	10.6%	12.14	33.6%
Germany	0.85	0.7%	1.40	3.9%
Finland	7.78	6.1%	4.34	12.0%
Sweden	8.42	6.6%	3.40	9.4%
Korea	0.43	0.3%	0.12	0.3%
France	1.55	1.2%	0.70	1.9%
Italy	0.04	0.0%	0.37	1.0%
Brazil	8.92	7.0%	0.47	1.3%
Indonesia	5.21	4.1%	-	0.0%
Russia	5.01	3.9%	1.26	3.5%
UK	-	0.0%	0.26	0.7%
Spain	1.78	1.4%	0.10	0.3%
Norway	0.56	0.4%	1.78	4.9%
Portugal	1.95	1.5%	-	0.0%
Chile	2.83	2.2%	0.51	1.4%
Others	10.83	8.5%	3.30	9.1%
World	**126.8**		**36.1**	

Source: FAO (2006)

In OECD countries, demand in the pulp and paper sector is fueled by demand for printing and writing paper. In contrast, in non-OECD countries, pulp and paper consumption is concentrated in the category other paper and paperboard (packaging) as paper consumption in these countries is closely linked to manufacturing output. As per capita income rises we would expect to see higher demand growth for printing and writing paper.

Table 3: Global paper and paperboard consumption 1961 and 2004

Global consumption (Mt)	1961	Share	2004	Share	Average growth rate
Newsprint	14	19%	38	11%	2.2% per year
Printing and writing paper	15	20%	99	30%	4.4% per year
Other paper and paperboard	48	61%	198	59%	3.4% per year
Total	**78**		**335**		**3.5% per year**

Source: FAO (2006)

Table 3 shows that global growth in paper and paperboard consumption between 1961 and 2004 was led by increased demand for printing and writing paper with annual growth at 4.4% versus 3.5% for total paper and paper board consumption. The increased use of personal computers and especially home computers caused a change in consumer tastes with higher demand for printing and writing paper; and the rapid uptake of internet has reduced the demand for newsprint as electronic media replaces traditional newspapers and periodicals.

Higher demand for printing and writing pulp and lower growth rates for newsprint has increased demand for chemical pulp, while lowering demand for mechanical pulp. In non-OECD countries, such as China and India, where wood pulp is relatively scarce, demand for other fibers is becoming more important. Pulp demand has grown at a lower rate than paper demand during past decades as recycling rates have increased. Future demand for wood pulp could rise sharply in the future as the recycling ratio reaches its practical maximum.

Energy use in the Pulp and Paper Industry

Pulp and paper production consumes 5.9 EJ of energy per year. Energy use in this industry is divided among a number of different pulp production processes and paper production. The main processes are:

- Chemical and thermochemical pulping;
- Mechanical pulping;
- Paper recycling;
- Paper production.

In 2003, according to IEA statistics, the pulp and paper industry used 1.9 EJ of bioenergy, mainly in the form of black liquor. Actual use may be somewhat higher, as a significant amount of bioenergy is reported in IEA statistics under “non-specified industry use”, part of which may actually be pulp and paper production. Industry sources report 2.3 EJ of black liquor use in 2003.

The industry’s heavy reliance on bioenergy means that the CO_2 intensity of the energy is not very high, and the CO_2 reduction potentials in the pulp and paper industry are limited. But more efficient use of bioenergy still makes sense from an energy systems perspective, as it frees up scarce bioenergy resources to replace fossil fuels elsewhere.

Important differences in energy efficiency exist between OECD and developing countries. Chinese rural paper mills use about 23 GJ/t of primary energy. Average primary energy use for paper and paperboard making in China, including pulping, is 45 GJ/t. Even higher figures are reported for India.

Small-scale plants based on imported second-hand equipment and the use of coal for steam generation contributes to this very low energy efficiency.

This section of the paper aims to conduct a country comparison of energy use in the pulp and paper industry. Countries presented in this analysis represent over 80% of global paper and paperboard production and 90% of wood pulp production. In order to compare relative energy intensity among countries, we calculated the physical energy intensity of a country based on its energy consumption relative to best available technologies, BAT. Different BAT assumptions were applied to steam and electricity consumption in mechanical pulping, chemical pulping and paper making. Heat and electricity are treated separately to allow for CHP analysis. Table 4 shows the figures that were applied in our analysis.

Table 4: Best Available Technology

	Heat (GJ/t)	**Electricity (GJ electricity/t)**
Mechanical Pulping		7.5
Chemical Pulping	12.25	2.08
Paper and paperboard	4.5	2.0

Source: Jochem, *et al.*, 2004; STFI, 2005; and Schepp and Nicol, 2005

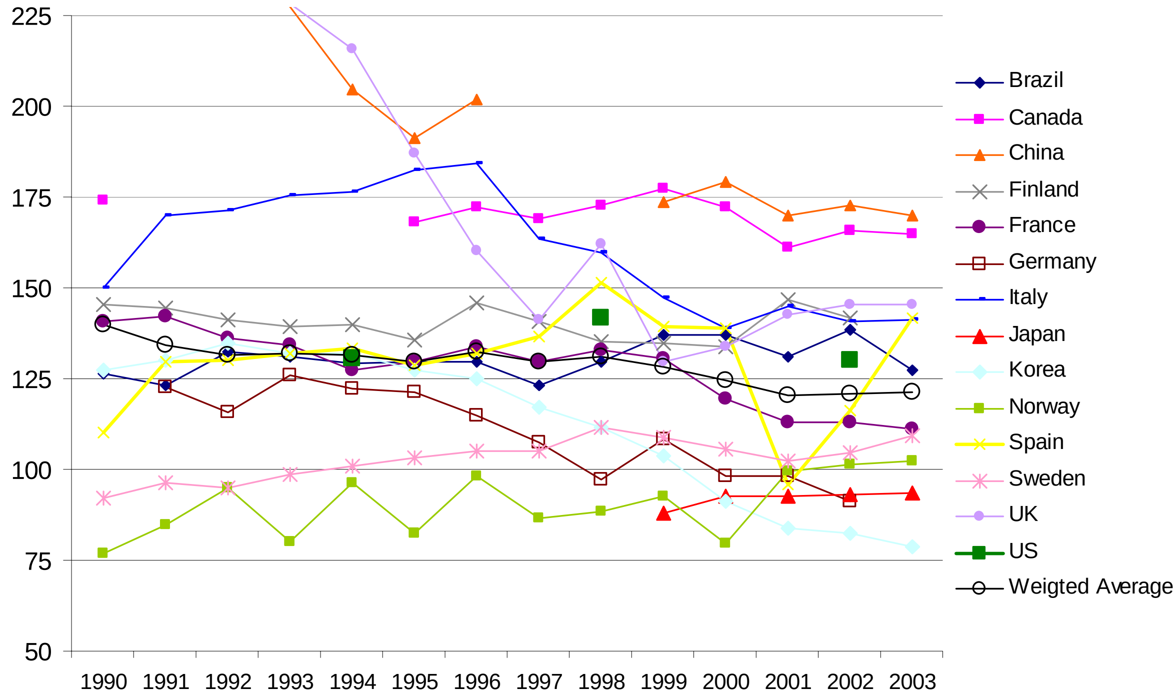
By multiplying the BAT figures with the quantity of mechanical pulp, chemical pulp and paper and paperboard produced by each country we derived what would have been the total steam and electricity consumption, if production was based on best available technology. This is then compared to the total energy which was actually used in pulp and paper production. Figures for steam consumption in each country are estimated based on reported fuel consumption in the industry. This analysis does not include energy use in recycling.

The analysis used above to compare energy efficiency across different countries does not differentiate for integrated and non-integrated mills nor does it take into account different paper grades. Data limitations make a more detailed structural analysis difficult at this stage. The benefits of higher CHP and recycling rates are also not reflected in this analysis. Future analysis will aim to adjust for these structural differences.

A country's energy to physical production index (PPI), PPI ratio would be at a level of 100 if the energy used to produce its commodities was at the same level as BAT. Figures greater than 100 indicate that energy consumption is above BAT levels and signifies an opportunity for greater energy efficiency if current BAT were applied. Figures below 100 could indicate that BAT figures may be too conservative. Figure 1 shows steam consumption[1] compared to BAT and Figure 2 shows electricity consumption compared to BAT for the key pulp and paper producing countries.

[1] Steam consumption for each country was calculated based on total final fuel consumption assuming an 80% efficiency for all countries except Canada, China and the US where 70% efficiency was assumed. Efficiency rates for steam consumption in each country will be reviewed at the workshop. The pulp and paper sector, especially in Europe, can supply heat to a district heating system or to other industrial users and may sell surplus electricity to the grid. Sale of surplus heat and electricity can cause inconsistencies in energy data as the allocation of heat and power use to different users may be subject to different methodologies within and across countries.

Figure 1: Steam consumption in Pulp & Paper Production vs. Best Available Technology (1990-2003)



Source: Empresa de Pesquisa Energética (Brazil), CIEEDAC (Canada), Enerdata (EU), China Energy Statistical Yearbook, EIA (US), METI (Japan), Korean Energy Economics Institute.

In regards to steam consumption Korea, Japan and Germany appear to be the most efficient with PPI levels well below 100. Over the last decade, the Korean paper industry has invested heavily in relatively efficient capacity expansion. Korea's PPI fell substantially, from 127 in 1990 to 79 in 2003. Korea, Japan and Germany's PPI ratio below 100 could indicate that our BAT figures are too conservative. Norway also appears very efficient in steam consumption, but this could be misleading as the country produces mainly mechanical pulp and relatively small quantities of paper; mechanical pulping uses large amounts of electricity and zero or negative net quantities of steam. During the refining process, large quantities of steam can be recovered and used for paper drying.

China and Canada appear to be the most inefficient with PPI levels of 170 and 165, respectively. In China, inefficient small scale plants in the rural region combined with the use of coal for steam generation are the cause of these low efficiency levels. Some of the world's largest and most efficient paper plants are now located in China and as large scale plants begin to outstrip and replace small rural plants we expect China's efficiency levels to rise. Canada's comparatively low energy efficiency may be attributed to the high level of energy use in its newsprint mills, which account for over 30% of all energy used in the pulp and paper industry. Newsprint mills in Canada use between 2.52 GJ to 12.69 GJ/t of process steam compared to 0.64 GJ/t for a modern newsprint mill (Francis et al 2002)[2]. The low process steam use for the modern newsprint mill is the result of significant amounts of waste heat recovery from mechanical pulping.

In the pulp and paper sector as a whole, we see that the weighted[3] PPI figure for the 14 countries analysed has fallen 10% from 137 in 1990 to 125 in 2003. This shows a significant real improvement in energy efficiency in the sector.

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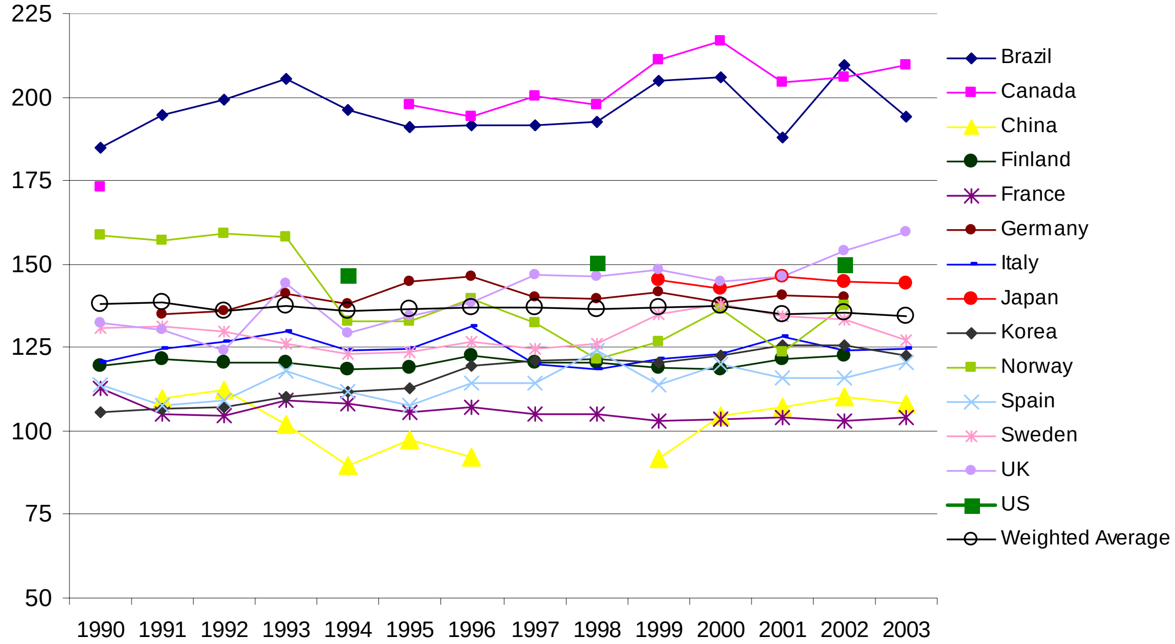
[2] The figure of 0.64 GJ/t for the modern newsprint mill includes 4.4 GJ/t of heat recovery from mechanical pulping. http://oee.nrcan.gc.ca/publications/infosource/pub/cipec/pulp-paper-industry/section-04.cfm?text=N&printview=N

[3] The weighted average for the 14 countries analysed is based on total share of production of pulp and paper and paperboard.

Figure 2: Electricity Consumption in Pulp & Paper Production vs. Best Available Technology (1990-2003)



In figure 2, France shows the best efficiency ratio for electricity consumption with a PPI of 104. China also appears to be very efficient, but this is most likely due to an inconsistency in electricity consumption data compared to the other countries in this figure.[4] Spain, Korea and Sweden also show relatively good efficiency ratios with PPI figures below or just above 125.

Contrary to seemingly high efficiency for heat use, countries such as Sweden and Norway with high proportions of mechanical pulping now appear less efficient in regards to electricity use. Mechanical pulping is very electricity intensive. The minimum electricity demand for mechanical pulping is well below actual levels and represents an important area for future efficiency gains. Canada and Brazil appear to be the most inefficient in terms of electricity use in the industry with PPI figures above or close to 200. Cheap hydroelectric power and the use of wood waste with low efficiency ratios could explain the poor performance of these two countries.

In contrast to the improvement in energy efficiency in steam consumption between 1990 and 2003, we have seen relatively little change in the overall energy efficiency of electricity consumption for these 14 key pulp and paper producing countries. The weighted average for the 14 countries remained relatively flat decreasing only slightly from 138 in 1990 to 135 in 2003.

Pulping

Mechanical pulping uses large amounts of electricity. Chemical pulping, on the other hand, yields black liquor as a by-product, which is then incinerated in a recovery boiler to produce heat and electricity. Roughly 22 GJ of black liquor per tonne of pulp can be burnt. Depending on its recovery efficiency and its configuration, a mill that uses chemical pulping can be a net energy producer. Typical energy-use data for various types of processes and products are shown in Table 5.

[4] Actual figures are most likely higher as China's accounting of electricity consumption does not account for the fuel used in electricity generation as electricity consumption, but rather as fuel consumption. This also means that the figures reported for fuel use in heat production for China in Figure 1 could be over-stated.

Table 5: Typical Energy Use for Pulp and Paper Production

	Steam (GJ/t product)	Net electricity (GJ/t product)
Mechanical pulp		7.3
Thermo-mechanical pulp	-3.4	8.3
Market chemical pulp mill – softwood	14.3	0.7
Market chemical pulp mill - hardwood	13.0	0.9
Integrated chemical pulp and fine paper mill – softwood	12.1	1.8
Integrated chemical pulp and fine paper mill – hardwood	12.9	2.0
Waste-paper preparation	0.3	0.7
Extensive waste-paper preparation	1.2	0.5

Source: Jochem, *et al.*, 2004; STFI, 2005.

The main production facilities are either pulp mills, or integrated paper and pulp mills, depending on the proximity to markets and transport facilities. An integrated mill is more energy efficient than the combination of a stand-alone pulp mill and paper mill because pulp drying can be avoided. However, such an integrated plant requires electricity from the grid, as well as additional fuel. A large modern chemical pulp mill is self-sufficient in energy terms, using only biomass and delivering surplus electricity to the grid. Such a mill typically has a steam consumption of 10.4 GJ/adt (air dry tonne pulp) and an excess of electricity production of 2 GJ/adt. A future integrated chemical pulp and fine paper mill has a typical steam consumption of 13.6 GJ/adt paper (*i.e.* a small biofuel surplus) and a deficit in electricity production of 1.8 GJ/adt paper (STFI, 2003).

High yield mechanical pulping processes are electricity intensive, and there has been relatively little progress in decreasing electricity demand in mechanical pulping so far. Much of the improvement in energy efficiency has resulted from increased heat recovery where the recovered steam is used to dry the paper. The minimum electricity demand, in principle, to produce mechanical pulp from logs is far below actual electricity use and thus suggests that major improvements should be possible.

Paper making

Paper production involves preparing the stock from pulp, forming a sheet, dewatering and drying, and sometimes coating the paper. All paper machines have three basic elements: wet end, press section, and drying section. Economies of scale have resulted in larger and faster paper machines. However, there is a parallel trend toward low cost, simple, and small paper machines for recycled paper mini-mills. Heat (steam) is needed for the drying section. Electricity is used in all process steps.

Table 6: Typical energy consumption in paper making for a non-integrated fine paper mill

	Process heat [GJ/t]	Electric power [kWh/t]
Stock preparation		202
Paper machine	8.0	350
Coating		4
Total paper mil	8.0	670

Source: European Commission 2001

During the production of different paper grades either virgin fibres (chemical or mechanical pulps) or recycled fibres are used as the main raw material. Today, the composition of raw material used for paper is influenced more than ever before by the cost of the individual components. The electricity use for stock preparation depends on the paper type and may vary from 60-1200 kWh/t. Table 7 provides an overview of the electricity needs for the production of various types of paper.

Table 7: Typical electricity consumption for the production of various types of paper

	Electricity [kWh/t]
Newsprint	500-650
Uncoated Mechanical	550-800
Uncoated Woodfree	500-650
Coated Mechanical	550-700
Coated Woodfree	650-900
Kraft papers	850
Tissue and specialty	500-3000
Boxboard	550
Containerboard	680

Source: European Commission 2001

Combined Heat and Power in the Pulp and Paper Industry

Combined heat and power (CHP) is not a specific technology, but rather an application of technologies that cogenerate heat and electricity. Steam turbines, gas turbines, combined-cycle systems and reciprocating engines are the major technologies used for power generation and in CHP. The cogeneration of steam and heat can reduce total energy needs where the energy efficiency of stand-alone electricity production and heat production is relatively low. The greatest gains come when low-temperature heat production from fossil fuels is replaced with a CHP system.

The higher the temperature of the heat that is needed, the lower the electricity yield and the lower the efficiency gain. Typically, the introduction of CHP results in fuel savings of 10% to 20%. Data availability for CHP use in the pulp and paper sector in the IEA statistics poses a challenge. If the heat is not sold, but used by the producer, part of the fuel use of the cogeneration plant is reported under industrial fuel use, rather than under CHP. Moreover, electricity production from CHP is not split by sector in IEA statistics. This makes it difficult to track the importance of CHP in the pulp and paper industry and other sources will be used.

CHP plants can be designed to meet the mills heat or electricity requirement. In most cases it is designed to meet a mills electricity requirement with the remaining heat supplied by low cost package boiler. To maximize thermal efficiency; the CHP plant should be designed to meet heat demand with excess electricity sold to the grid, but in most cases this is not the most economical option as grid prices may not justify the additional investment cost.

Compared to other industries, the use of CHP in the pulp and paper industry is very high. In most large pulp and paper producing countries, it is estimated that CHP use in the sector accounts for between 25% - 50% of CHP generation in industry. We estimate that over 50% of the CHP used in the pulp and paper sector are black liquor Tomlinson boilers.

Falling investment costs for gas turbines over the last decade has helped to boost CHP investments in the paper industry, but recent high gas prices could dampen this trend. Potential for further CHP use in the industry has been limited by economies of scale which make investments in small plants less economical. The ability to sell excess power to the grid is also crucial in making CHP investments more attractive for the industry.

Few countries have good statistics on CHP use in Industry. In order to make a more detailed analysis on CHP use in the pulp and paper industry, better data is needed. We suggest collecting data based on the following categories:

Table 8: Data required for CHP analysis in the Pulp and Paper Industry

	Fuel in (PJ)	**Fuel out (PJ)**	**MW**
Tomlinson Boilers	black liquor	electricity & steam out	Installed capacity
Combined cycles (NGCC)	gas	electricity & steam out	Installed capacity
Other CHP	gas, oil, coal, biomass	electricity & steam out	Installed capacity

In addition to the table above, we also recommend collecting detailed data on Back Pressure Turbines. Unlike the three categories above which have higher efficiency ratings, these turbines are added on to stand alone steam generation units. We suggest collecting data for MW of installed capacity in pulp and paper mills, fuel in (by fuel type) for steam generation, PJ of electricity produced and PJ of steam produced.

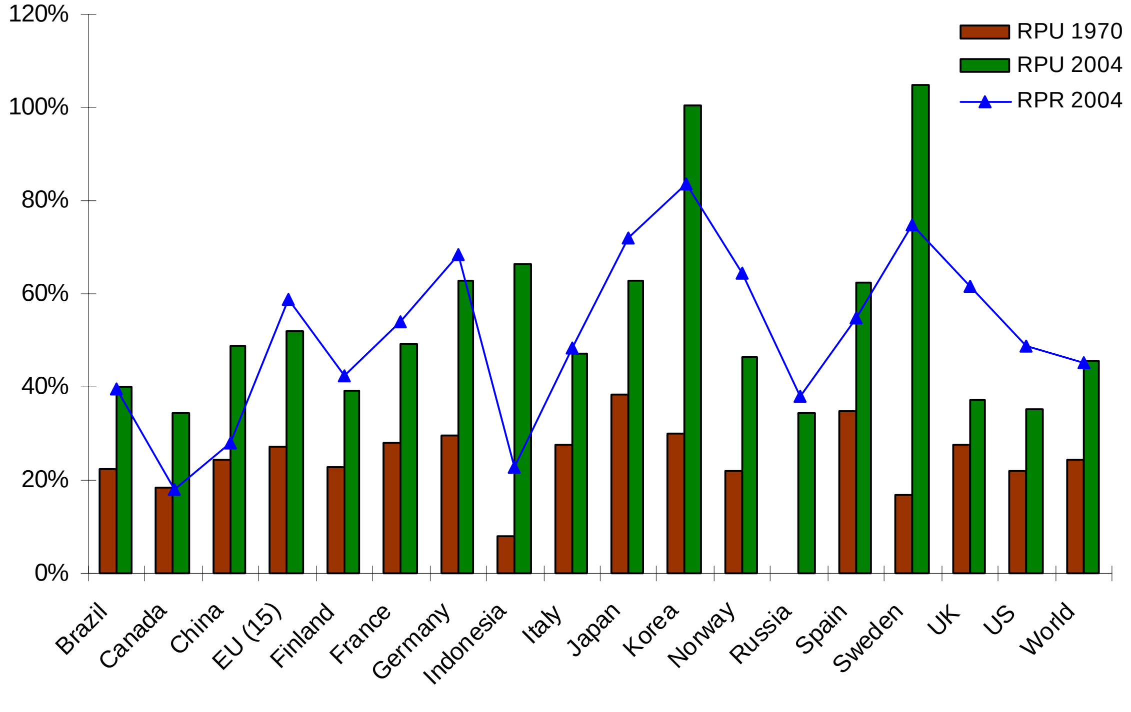
Paper Recovery and Recovered Paper Utilization

Almost half of all paper is produced from waste paper, with recycling usually taking place close to where the waste paper is generated. Recycling plants tend to be smaller and more dispersed than primary paper production facilities and their energy needs for paper making are higher. On the other hand, the energy that would have gone into pulp-making is saved. This savings by far exceeds the additional energy used. In many developed countries, paper recycling actually exceeds paper production from primary biomass.

Increased paper recycling is a key contributor to energy efficiency improvements in the pulp and paper sector. Each ton of recycled pulp used offers a net energy savings potential of 10.9 GJ/t. If we take into consideration paper that cannot be recycled such as archives and construction materials, the maximum theoretical recycling rate for paper would be 81% (CEPI 2006). Each 1% increase in paper recycling would represent a total energy savings of 39.2 PJ. Although increased recycling does present a benefit for energy efficiency its impact on CO_2 reductions is less clear. If the increased use of recycled pulp is used to replace chemical pulp from modern mills this could actually cause CO_2 emissions to rise as modern chemical pulp mills are CO_2 neutral, while the energy used in recycling mills usually is not.

Europe is the leader in paper recycling with a recycling rate of 51.9% (for EU 15 excluding exports) compared to a global rate of 45.5%. Theoretically, there remains a global recycling potential of 35%. The recycling rate or utilization of recovered paper rate is defined as net recovered paper divided by total paper consumption. As this figure does not include exports of waste paper, the collection rate or recovered paper ratio within the EU 15 is actually higher at 59%. A new European Declaration has just been announced to raise recycling rates to 66% by 2010 (ERPA 2006). This Declaration covers the EU 25 as well as Bulgaria, Norway, Romania and Switzerland. Although the global recovered paper rate must be equal to the global utilization of recovered paper rate, rates for different countries and regions can be significantly different and reflect imports and exports of recovered paper. Forecasts for waste paper will depend on future demand trends for paper as not all types of waste paper can be used as recycled pulp and certain types of paper require higher percentages of virgin pulp.

Figure 3: Recovered paper Utilization vs. Recovered Paper Ratio



Source: FAO

Over the last three decades the recovered paper ratio increased sharply from 24.5% in 1970 to 45.5% in 2004. Europe has shown the strongest increase in paper recycling; North America is the largest exporter of recovered paper; and Asia, especially China, is the main importer of recovered paper. According to the FAO, urbanization has reduced the cost of waste paper collection and recycling; and thereby increasing the availability of recovered paper (FAO 2005). Specific requirements from consumers on minimum recycled pulp content have also led to increased recovered paper utilization. The types of paper produced in a country will also impact the recovered paper ratio and its recovered paper utilization.

Recovered paper supply is strongly influenced by government policies on waste disposal and renewable energy policies. Tighter policies on waste disposal can lead to higher recycling rates and policies promoting the use of renewable energy can cause competition for wood and fiber and thus impact the supply of wood pulp. There is concern amongst the industry that the current push towards increased use of renewable energy would encourage the use of wood as an energy source rather than at the end of its life cycle. As higher paper recovery ratios maybe exponentially more expensive to attain and depending on policies on waste disposal in each country, the global economic potential for waste paper recovery may not be much higher than its current rates.

Use of Technology to Increase Energy Efficiency and Reduce CO_2 Emissions

Technology could play an important role in increasing energy efficiency and reducing CO_2 emissions in the pulp and paper industry. Current pulp and paper facilities in many OECD countries are nearing the end of their operating life and will need to be replaced over the next 10-15 years. This presents an excellent opportunity for new technology deployment to have an impact on energy savings in the sector in the medium term. The most promising energy savings technologies in the industry are black-liquor gasification and advanced drying technologies.

Black-liquor Gasification

Various industries produce low-grade fuels as a by-product, and in the paper industry, chemical pulping produces black liquor. In standard kraft pulp mills that use the sulphate process, the spent liquor produced from de-lignifying wood chips is normally burned in a large recovery boiler (Tomlinson boiler). Because of the high water content of black liquor (it is usually burned at a solids content of 65% to 75%), the efficiency of existing recovery boilers is limited. Electricity production is also limited, because the recovery boilers produce steam at low pressures for safety reasons.

Gasification offers opportunities to increase the efficiency of using black liquor. In gasification, hydrocarbons react to syngas, a mixture mainly of carbon monoxide and hydrogen. The synthesis gas can be used in gas-turbine power generation or as a chemical feedstock. This technology, called black liquor gasification-combined cycle (BLGCC), allows the efficient use not only of black liquor, but also of other biomass fuels such as bark and wood chips. Alternatively, the synthesis gas can be used as a feedstock to produce chemicals, in effect, turning the paper mill into a “bio-refinery.” In Europe, policies aimed at increasing the share of biofuels in transportation have sparked interest in using black liquor gasifiers to produce dimethylether (DME) as a replacement for diesel fuel.

Black liquor production was 185 Mt in 2003, equivalent to 2.3 EJ. It is projected to grow to 3.3 EJ by 2025. Based on the performance of a typical kraft plant in the south-eastern United States, a pulp plant will be able to produce and then sell excess electricity on the order of 220 to 335 kWh per tonne of pulp. If the overall electric efficiency were raised by 10 percentage points, and the steam efficiency remained the same, 3 EJ of black liquor per year would yield an additional 300 PJ of electricity annually. The savings in terms of primary energy would be in the range of 0.5 to 0.8 EJ, depending on whether a gas- or coal-fired power plant was displaced. The CO_2-savings potential is in the range of 30 to 75 Mt per year.

Black liquor IGCC technology is similar to coal-fired IGCC technology, and black liquor plants could be equipped with CO_2 capture. The electric efficiency of a black-liquor IGCC would be 28%, which declines to 25% with CO_2 capture. The steam efficiency would remain at 44% in both cases. Capital costs would increase by $320/kW of electricity if CO_2 capture is installed. Biomass in combination with CCS results in an energy chain that removes CO_2 from the atmosphere, a unique feature that may offset emissions in other parts of the energy system. This may become especially important if ambitious low emission targets are established.

Advanced Drying Technologies

In theory, the production of paper from pulp can be designed to use virtually no external energy. In practice, however, water is needed to process the fibres and energy is needed to remove the water from the fibres in a drying process. Technical potentials to reduce energy use in the paper industry by 30% or more have been identified in various countries, with cost-effective potentials of at least 15 to 20%. Paper drying consumes about 25 to 30% of the total energy used in the pulp and paper industry. Assuming that energy efficiency improvements of 20 to 30% are possible in this production stage, overall energy savings are estimated at 0.7 EJ.

New process designs focus on more efficient water-removal techniques by combining increased pressing with thermal drying (the long-nip press, the condebelt design or impulse drying). The long-nip press (or shoe press) is the current state-of-the-art approach to de-watering. In the long term, the need to use water can be re-evaluated, and other ways of managing the fibre orientation process for optimal paper quality, such as super-critical CO_2 and nanotechnology, may be possible. The use of ethanol or even super critical carbon dioxide has been suggested to replace water as the forming medium.

Pulp and Paper Industry Scenarios:
Building on the IEA Publication Energy Technology Perspectives: Scenarios and Strategies to 2050

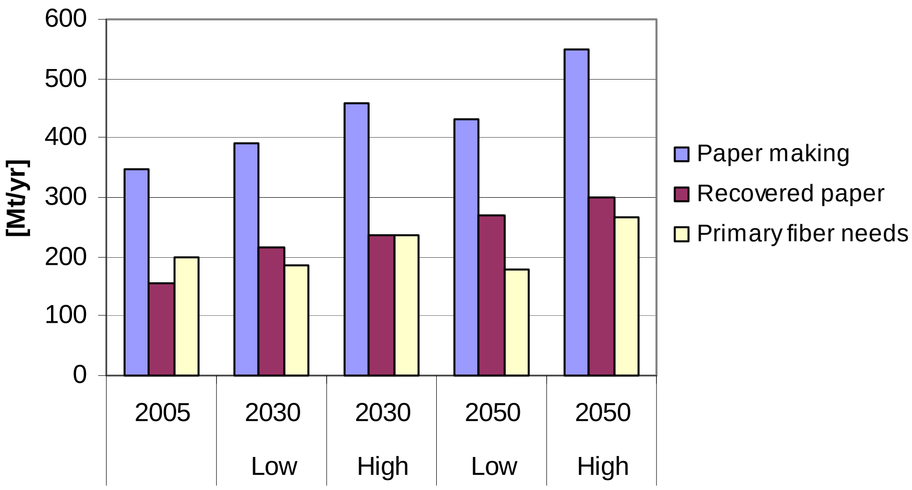
Three scenarios have been analysed: a baseline scenario without new policies and two ACT scenarios with a CO_2 reduction incentive of USD 25/t CO_2.

Paper production is projected to grow by 25-60% between 2005 and 2050. The difference between the Low and High demand ACT scenarios reflects the uncertain impact of the digital economy on paper demand and the uncertain prospects for packaging paper and board under tighter waste policies. Also policies for increased efficiency of materials use may affect paper demand in a CO_2-constrained scenario.

In the low demand growth scenario the paper production growth is completely covered by increased paper recycling while in the high demand scenario, primary fibre supply grows by 35%. The amount of recycled paper grows by 72 to 95%.

The baseline scenario w/o CO_2 policies assumes a demand that grows in line with the high scenario. Black liquor gasifiers capture only half the market, and paper recycling grows only to 250 Mt (300 Mt in the High ACT scenario). Energy efficiency gains over the 2005-2050 period amount to 10-20% and there is no CCS applied.

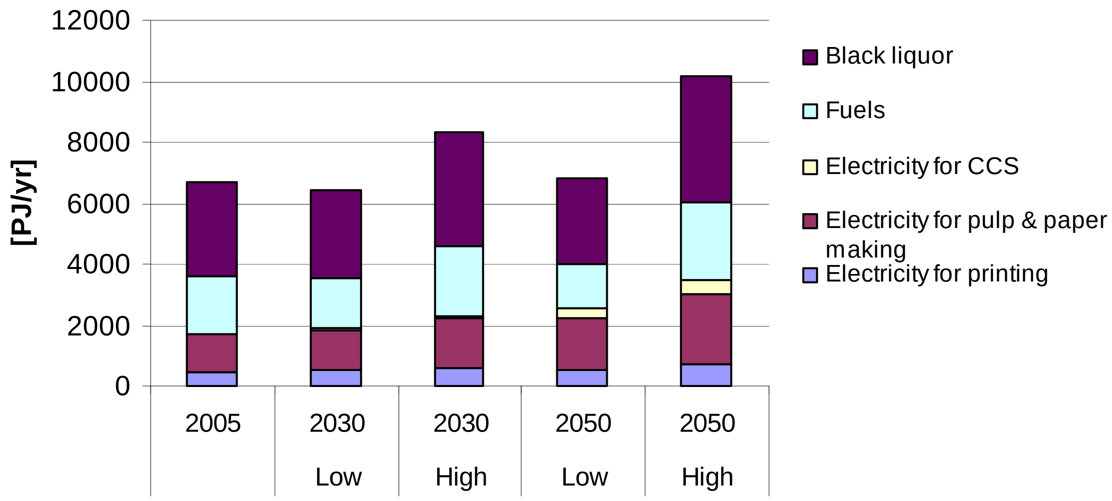
Figure 4: Paper production scenarios, 2005-2050 (Whiteman 2005)



Energy efficiency in pulp and paper making processes in the ACT scenarios improves by 15-30%. This outweighs the increased production volume in the Low demand scenario. In the High demand scenario, final energy demand grows by 47%. Electricity use increases significantly in both scenarios. Black liquor accounts for half of all energy use in the pulp, paper and printing industry.

It is assumed that all black liquor boilers are replaced with gasifiers by 2050. Both the Low and the High scenario assume that CO_2 capture and storage is introduced for black liquor gasification units. CO_2 capture and storage is introduced for black liquor gasifiers from 2015 onward. In both scenarios it is assumed that 75% of all black liquor gasifiers are equipped with CCS by 2050. The use of CCS generates additional demand for electricity for CO_2 capture and pressurization.

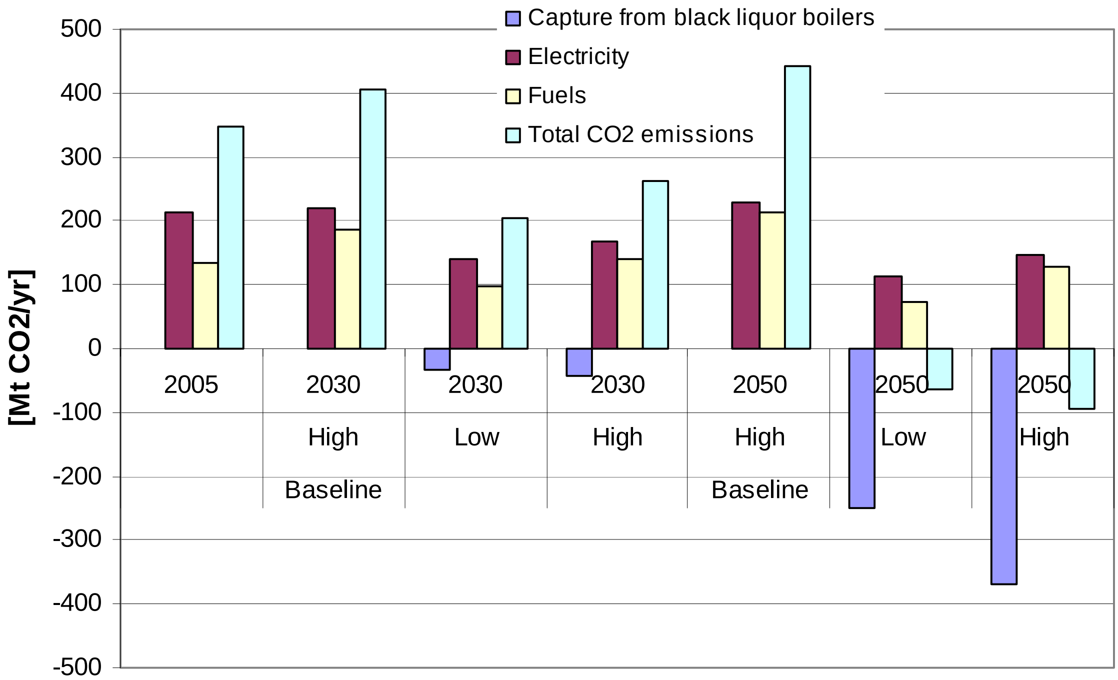
Figure 5: Energy use for the pulp, paper and printing industry in the ACT scenarios



In the Baseline scenario, the world average CO_2 intensity of electricity is virtually constant while the CO_2-intensity of fuels increases. These trends can be explained by the rising oil and gas prices and the modest rise of coal prices. In the ACT scenarios, the CO_2 intensity of electricity decreases by two thirds and the CO_2 intensity of fuels decreases by one third, compared to 2005. In 2050, 250 - 370 Mt of CO_2 is captured and stored.

In both ACT scenarios, the sector becomes a net CO_2 sink. In fact the difference in emissions between both scenarios is small. A higher production volume entails a higher energy use, but allows for more CO_2 capture from black liquor gasifiers. In both scenarios, the emissions reduction compared to the Baseline scenario amounts to 0.5 Gt CO_2 per year.

Figure 6: CO_2 emissions and CO_2 storage for the pulp, paper and printing industry in the Baseline and ACT scenarios



Conclusions

Our analysis of steam and electricity consumption versus best available technology in the main pulp and paper producing countries showed that there was significant room for improvements in many countries. Countries such as Korea, Japan, Italy, France and Germany have achieved sizable improvements in the efficiency of steam consumption over the last decade. Efficiency gains in mechanical pulping seem to offer the greatest potential for improving energy efficiency in electricity consumption. Canada, China, the UK and the US seem to have the most to gain from investing in more efficient technologies and systems. Korea, Japan, France and Sweden appear to be the most energy efficient.

Increased paper recycling and recycled paper utilization in many countries could help reduce energy consumption in the industry. While Europe appears to be close to their practical limits for paper recycling, North America and Asia could benefit from tighter policies on waste disposal to encourage higher rates of recycling. Higher shares and more efficient use of CHP systems could also help to improve energy efficiency in the industry, but this will depend on regulatory issues and grid access.

In theory production of paper from pulp can use close to zero energy, which leaves a significant potential for efficiency gains. Outdated small-scale paper plants in developing countries, notably China and India, use excessive amounts of energy. Larger plants, more-efficient drying technologies and black liquor gasification could all reduce the energy needs of paper and pulp production substantially.

We estimate that the pulp and paper industry will consume 7 – 10 EJ of energy by 2050. In both our ACT scenarios, the sector becomes a net CO_2 sink with emissions reduction of 0.5 Gt CO_2 per year compared to the Baseline scenario. In the ACT scenarios it is assumed that all black liquor boilers are replaced with gasifiers by 2050 and 75% are equipped with CO_2 capture and storage.

The pulp and paper industry is in a unique position, both in terms of improving energy efficiency and reducing CO_2 emissions. The sector has the ability to become a net supplier of bioenergy and it can become a key actor in removing CO_2 from the atmosphere. However this vision will not happen overnight, and it will imply a fundamental rethinking of the sector's strategy.

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