The Kyoto Protocol and greenhouse gas emissions — implications for mechanical pulping

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Abstract: The pulp & paper industry being heavily centered around renewable raw materials and energy sources is at the heart of efforts towards climate protection and sustainability. Its energy intensiveness and perceived emission intensiveness are analyzed. Mechanical pulps are especially under scrutiny, however, judging them only by their high electricity demand is misleading. A simulation model of papermaking and energy production is presented, illustrating also an ecological optimum use of mechanical pulps considering wood demand, energy consumption and CO$_2$ emissions.

As per Nov 26, 2003, 120 nations have ratified the Kyoto Protocol, thereby committing themselves to take measures against climate change. Therefore 38 industrialized nations have until 2008-2012 to reduce Greenhouse Gas (GHG) emissions, mainly CO$_2$, by 5.2% from their aggregate 1990 levels. These countries represent about 50% of the world’s paper production. The EC countries altogether assumed a higher share of the burden by committing to an 8% reduction. Major papermaking countries that signed on are Canada, Japan and China. Russia is expected to join. The United States is implementing programs of their own to deal with GHG emissions.

Combustion of fossil fuels for energy production and transportation account for more than 80% of all CO$_2$ emissions [8]. Energy production from so-called renewable energy sources (RES) such as hydro-power, wind, solar, (all derived from solar energy) and also from nuclear fission do not create CO$_2$. Biomass from plants also falls into the category of RES because a similar amount of CO$_2$ which is emitted during combustion, is used in the photosynthesis process as long as growth and harvest of the biomass are in balance. Energy production from biomass is therefore considered CO$_2$ neutral.

As is well known, the Kyoto Protocol aims at reducing GHG emissions as a possible cause for global warming and climate catastrophes. It is an important interim goal in the overall strive for sustainable development [5].

**DISCUSSION**

Implications of the Kyoto Protocol for the pulp and paper industry

The pulp and paper industry is at the heart of efforts towards sustainability, being heavily centered around renewable raw materials and energy sources. The implications of the Kyoto Protocol for the pulp and paper industry are manifold [1] and often more complex when compared to other industries that do not use wood as a raw material.

The main reasons are:

- Its predominant raw material, wood, is both the most important and versatile renewable raw material and the most important renewable energy source.
- The pulp and paper industry is the single largest producer and user of biomass fuels with the unique potential for actually reducing the CO$_2$ content in the atmosphere by CO$_2$ capture and sequestration.
- It is classified as an energy intensive industry together with refineries and the steel, glass, ceramic, minerals and cement industries, and therefore falls under the planned CO$_2$ cap and trade system in Europe.
- It is a rapidly growing industry, with more than 50% growth between 1990 and 2010.

The rapid growth in paper consumption has resulted in a net increase in heat and power demand in spite of constant decreases in the energy consumed per ton of paper produced. Unit or specific energy consumption in the European paper industry, as an example, fell by 12% between 1990 and 2001, but the industry is growing at an annual rate of approximately 2%, resulting in an overall increase in CO$_2$ emissions [4]. The global paper industry accounts for approximately 4% of global energy consumption and 1.2% of the fossil fuel derived CO$_2$ emissions [10].

The energy intensiveness and the perceived emission intensiveness of the paper industry needs to be properly assessed in relation to other industries. The kind of energy used, as well as the energy’s primary source should be carefully analyzed, as should the boundary or balance limits for the evaluation and the comparison. Industrial processes are typically evaluated within the narrow boundary limits of the mill premises. This is also practiced when allocating CO$_2$ emissions to pulp and paper mills in the planned CO$_2$ cap and trade system. This principle is unfavourable for the pulp and paper industry, with its major implications on forestry as well as on industrial and domestic waste management.

In 2001, the European paper industry used about 11 Gt fossil and non-fossil fuels per ton of paper for electricity and steam production [4]. The related CO$_2$ emissions are as low as some 360 kg/t paper [4], since over 90% of this energy is produced in efficient CHP plants which use an average of about 50% biogenic fuels such as waste liquor, bark and sludge [4]. Approximately 800 kWh electricity per ton of paper is purchased from outside power plants where the paper industry has no influence on the fuel mix [4].
MECHANICAL PULPING

Looking beyond the typical boundary limits, the paper industry feeds a continuous flow of biogen fuel in the form of paper into “the system.” Biogen “waste” will be increasingly used for energy production, since in most European countries the landfilling of organic material will be prohibited from 2005 onwards [12]. The energy value of waste paper which is not recycled, exceeds the energy value of all the fossil fuels used by the paper industry. If the paper industry were credited for this, its internal CO₂ emissions would at today’s worldwide average recycling rate of 46% [17], be nil or negative. By no means could it be classified as emission intensive. Other non-wood based products would unavoidably have higher overall CO₂ emissions.

The Kyoto Protocol has already resulted in a variety of directives, laws and regulations within the signatory countries which basically comprise the following measures:

• Subsidized tariffs for electricity produced from renewable energy sources and for CHP generation. In some Continental European Countries the tariffs for such green electricity, when supplied to the grid, range from EUR 80 - 150 / MWh depending on the size of the power plant. The smaller and less efficient the plant, the higher the subsidy.

• Within EC countries, CO₂ emission caps for each mill and obligatory investments for emission abatement, or purchase of CO₂ emission certificates if the cap is exceeded. This cap and trade system will be introduced between 2005 - 2008. The penalty for emitting more than covered by emission certificates will amount to EUR 40 / t CO₂ during 2005 - 2007, and EUR 100 / t CO₂ from 2008 until the end of 2012. The emission certificates will be freely traded. It is expected that the price will establish itself at EUR 10-20 / t CO₂. [2]

• Direct subsidies for investments for green energy production.

• Eco-marketing of green electricity by introducing a renewable energy certificate trading system (RECS).

• Higher taxation of fossil fuels and tax exemptions for using non-fossil fuels.

The subsidized production of, “green electricity” from wood and other measures promoting energy production from biomass are driving wood prices up. Some forecasts predict price increases of 18 - 26% in continental Europe [18]. Further implications are increasing demand and higher prices for waste paper, as well as a trend towards higher electricity prices. When it comes to benefiting from the Kyoto-induced biomass boom, the paper industry has not scored too well in spite of being the largest industrial user of wood and of adding the most value to it.

The massive quantities of pulp and papermaking residuals such as black liquor and sludges are clearly defined as biomass in the EC directive. National laws and regulations have however, excluded these approximately 40 Mio t (90%) / year biomass contained in black liquor from Western European pulp mills, from the promotion schemes for green electricity. Green electricity that qualifies for higher tariffs has to be generated separately and transformed to higher voltage and entered into the grid. Internally utilized bio power heat, do not count, although they certainly help to reduce CO₂ emissions. Consequently, more and more power generation from wood residuals is outsourced and valuable CHP generation potential is lost. Even worse, the opportunity has been missed to use these promotion schemes to accelerate the development of highly efficient energy production from biomass via, for example, gasification.

The pulp and paper industry might have other opportunities to capitalize on its position as the largest single producer and user of biomass fuels [4]. Recently, attention has been directed to technologies that could prevent CO₂ from combustion from entering the atmosphere. If these capture and sequestration technologies are applied to the CO₂ emitted from a recovery / biomass boiler, CO₂ is actually removed from the atmosphere [6].

Other emerging technologies involve gasification of biomass and CO₂ removal from the gas before it is combusted or converted to refined biofuels such as, methanol or hydrogen.

**Where does this leave mechanical pulps?**

Mechanical pulps are blamed for their high electric energy consumption. They are in a way, “trapped” between recycled fibres which are perceived as more environmentally friendly and kraft pulps, which are today produced in a more energy-efficient way using chemically dissolved wood as fuel.

For many years, recycled fibres have gradually displaced the relative percentage of mechanical and chemical pulps with the exception of bleached hardwood kraft. (Fig. 1). Fig. 1 shows that the percentages of virgin and recycled pulps are stabilizing in the new millennium. Recycling has its limits because the quality of waste paper drops with increasing collection and recycling rates, and due to unavoidable losses. The limits of recycled fibre usage are dictated by location, population, costs of collection, technology and regulations. The resource-limited and relatively isolated Japanese market could serve as an example of where the limits for recycling may be. Japan has set a goal of a 55% recycling rate, which has not yet been achieved. The EC strives for a 56% rate in 2005. The “prime example” for high recycling rates, Germany achieves its 64% (2001) level only due to a constant influx of virgin fibre-based paper and board from the Nordic countries.

Today mechanical pulps represent 13% of the global fibre furnish. Western European mechanical pulp production consumes about 24% of the total electric energy demand of the pulp and paper industry [19]. Not a good position to be in; in a world where 1000 kWh may correspond to 580 kg of CO₂, like in Germany for example [9].

Judging mechanical pulps only by their high electricity demand and possibly high CO₂ emissions is a common but oversimplified viewpoint. The real threat to the future of mechanical pulps is their image. One can foresee that some consumer groups may turn their attention to the energy content of mechanical pulps and form false perceptions on CO₂ emissions, particularly for TMP-based papers.

It is the responsibility of the pulp and paper coalition to clearly highlight the functional and ecological reasons for using mechanical pulps. Otherwise the goals set by the Kyoto protocol could result in counterproductive measures.

The reasons for using mechanical pulps as a sole furnish or in combination with...
other pulps or fillers are well known to this audience. In brief, they are the high yield, good light scattering and opacity, high bulk, and reasonable strength properties. Mechanical pulps also contribute to good formation and surface smoothness, characteristics which provide good printability. They can be bleached to higher levels than in the past, up to 80+ ISO for softwoods and 85+ for most hardwoods. The costs of producing mechanical pulps are lower than those of chemical pulps and in some instances lower than for recycled pulps.

The high bulk and high opacity of mechanical pulps provide material savings as evidenced by lower basis weights of wood containing paper and board, while retaining comparable opacity and stiffness. Such material savings are highly valued because they affect the whole lifecycle of paper products, from material supply and energy consumption, to distribution and collection. Another factor is the better recyclability of mechanical pulps. Fig. 2 shows how the so-called, “hornification process” impairs the bonding capability of chemical pulps [15].

On the contrary, TMP strength may even improve, which is explained by the flexibilization and fibrillation process during papermaking and the protection of hydrogen bonds by the lignin.

Compared to chemical pulps, mechanical pulps provide for a much better sequential use of the wood resource, first as material, followed by effective recycling and ultimately as biofuel. Due to their high yield and low amounts of residuals, mechanical pulps require about one third of the transportation costs of chemical pulps and about half of those for recycled fibres [14].

**A MODEL OF PAPERMAKING**

In an attempt to quantify many of the above features of mechanical pulps, a simplified model of papermaking has been established. To analyze CO₂ emissions and wood consumption caused by chemical pulping, TMP and recycled fibre production, papermaking

![FIG. 2. Strength Development of Bleached Pine Kraft and TMP depending on Recycling Generations.](image)

![FIG. 3. Model of papermaking.](image)
and energy generation, (Fig. 5). CO₂ neutral energy (power and steam) is produced from black liquor in the course of the recovery process and in an integrated biomass (bark, wood and waste paper if desired) powerplant. This biomass powerplant can operate in the CHP mode to cover the steam demand and in the condensing mode. Any additional energy is produced in a natural gas combined cycle power plant (or any other fossil fuel) which if required, can also operate in the condensing mode. Forestry is kept outside the boundary limits of the model, which means that any change in forest condition or forest area and its capability to store CO₂ (approximately 1.5 t CO₂ per t wood) is not taken into account. The results provide ballpark numbers which predict reality reasonably well, as long as the percentages of the three types of pulps in the furnish are kept close to practical numbers, which also means that all existing paper and board grades can be manufactured. For all processes, BAT’s or even more up-to-date technologies are applied. The balance is made on a bone dry basis without fillers. All input data are summarized in Table I.

The model offers many alternatives to produce paper and to generate energy. Nearly any case can be construed - as in the real world. However, several observations are valid in all practical scenarios: The energy efficiency of the kraft recovery process is rather low compared to straight CHP production from biomass, especially when considering that the lignin in the black liquor has approximately 50% higher heat value than cellulose. Another observation is the diminishing value of TMP steam recovery for paper drying when it competes with highly efficient combined heat and power generation. If the heat value of the accessible but not recycled waste paper is taken into account in the overall energy balance, the higher heat value of mechanical pulp fibres, as compared to cellulose fibres, makes a difference.

As an introduction to the model, Fig. 4 shows the CO₂ emissions versus TMP content in paper, at 40%, 50%, and 60% recycling. In this scenario the TMP is produced at a total of 2250 kWh/t (2000 kWh/t for refining and 250 kWh/t for auxiliary equipment). As can be expected, the CO₂ emissions drop with increasing TMP usage and increasing recycling rates, provided that wood consumption is kept constant. In other words, wood that is saved due to the high yield mechanical pulping process is used for energy production.

If in the same graph the recycling rate is for example, kept at 50% and the energy consumption of TMP is varied, (Fig. 5), it can be seen that about 2600 - 2700 kWh/t are permissible for TMP production before the CO₂ emissions equal those of a furnish without TMP (50% kraft and 50% RCF).

Fig. 6 shows the CO₂ emissions and wood consumption at three different recycling rates, varying TMP and chemical pulp usages.

Finally, Fig. 7 shows the CO₂ emissions at a constant 30% chemical pulp content at varying TMP contents and recycling rates. The electric energy consumption of TMP refining is varied between 1750 - 2750 kWh/t. Wood consumption is kept constant at.
operating costs and true Energy Conservation Opportunities (ECO), Andritz has developed technologies that achieve commercially competitive pulp properties at reduced energy consumption. One such technology is the RTS™ process, which was first commercially introduced in 1996. RTS is a high-intensity thermo-mechanical pulp refining process that preserves pulp strength and optical properties. This is achieved by a rapid heating of wood fibres while maintaining darkening reactions in a stabilized window of operation [13]. The total savings in electrical energy consumption using this technology will exceed $3\times10^6$ MWh by 2003. This is equivalent to the annual residential electricity consumption of a city of over 2 million inhabitants in the EC.

Presently only 8% of the worldwide thermo-mechanical pulp capacity operates using RTS technology. With a total conversion of conventional TMP capacity to lower energy consuming technologies, the savings could foreseeably exceed the capacity of many well-sized power generators.

Partial defibration of wood chips using chip presses [7,11] or in combination with fiberizing devices [3] will also present opportunities to further reduce energy requirements. The reason for this effect could well be connected with the observation that in partially defibrated chips, a substantial proportion of the middle lamellae are ruptured. Rupturing will reduce the amount of energy consumed during subsequent refining. However, the energy saved in refining will be more than the energy consumed in destructuring. This is because for a given amount of fibre separation, the main component of the middle lamella, lignin, being viscoelastic, absorbs less energy during destructuring than it does during the highly cyclical process of refining.

At high-intensity conditions to minimize heat loss associated with the viscoelastic properties of wood. Specific energy consumption levels below 1500 kWh/ton are foreseeable when using the new technologies for newsprint production.

Chemical-process technology, such as APMP, AP-TMP, and PRC-APMP, were also introduced by Andritz to reduce the energy requirements of pulp and paper production. Today, many grades of market chemi-mechanical pulps from hardwoods are produced using much less than 1000 kWh/ton. Hardwoods are more readily swollen than softwoods in the presence of alkali, which explains their amenability to high-intensity thermo-mechanical pulping. The subsequent fibrillation step should be conducted at high-intensity conditions to minimize heat loss associated with the viscoelastic properties of wood. Specific energy consumption levels below 1500 kWh/ton are foreseeable when using the new technologies for newsprint production.

The pulp and paper industry is the single largest producer of wood based products and of biomass fuels. It plays an important role in the striving for sustainable development and in meeting specific goals like GHG emission reduction and climate change prevention. More than most other industries, it should be valued not only within the narrow boundary limits of mill premises, but by its overall impact on the ecosystem.

Improving energy efficiency from biomass and reducing the energy demand in the biomass conversion to products and eventually also CO₂ capture, are important for compensating the effects of fossil fuel usage. Key processes in these areas are biomass gasification, energy reduction in mechanical pulp and CO₂ capture from fuel or flue gas originating from biomass. Improved technologies for reducing energy consumption in mechanical pulp are well under way and their applications will become increasingly important in the near future.

The stigma of high energy consumption and a shortage of R&D funding, arising from low market perspectives are the biggest threats to mechanical pulping. At present the market is showing good growth in worldwide mechanical pulp production. China is investing heavily in efficient mechanical pulp technologies. Prospects for growth are positive in other areas. Hardwood mechanical pulp production in Europe is projected to double in the near future.

The Kyoto Protocol has unified many countries under one goal and it appears that its attainment will become reality. Some countries are in a better position than others to achieve GHG reduction goals. Global trading of CO₂ certificates will help alleviate some of the burden. Energy reduction initiatives are a key element in the process to be implemented as effectively as possible.

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