AIMS Energy

AIMS Energy, 6(1): 187–202.
DOI: 10.3934/energy.2018.1.187
Received: 29 November 2017
Accepted: 06 February 2018
Published: 23 February 2018

http://www.aimspress.com/journal/energy

Research article

Paper making in a low carbon economy

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Abstract: Paper and pulp manufacturing industry produces versatile products from renewable feedstock that are easily recycled. It is the fourth largest industrial sector in terms of energy use. Much of the energy used comes from biomass derived fuels or high efficiency combined heat and power plants so the industry is not considered as carbon intensive. But at production paper making emits five times the CO_2/tonne of steel; this is gradually removed from the atmosphere by the growth of replacement trees which can take between 7 and 90 years. This study reviewed existing literature to establish estimates for future energy requirements, and way that these could be met with minimum carbon emissions in a world where there are electricity grids with low carbon intensities, high recycling rates and growing demand for sustainable biomass. It was found that energy consumption could be reduced by 20% using technologies that have been demonstrated at an industrial scale. Most virgin pulp is made using the kraft chemical processing method. It was found that it should be possible to eliminate all fossil fuel use from this process, by combustion of by-product while exporting a small amount of electricity. Recycled paper is becoming the largest source of pulp. In this case the waste streams cannot provide sufficient energy to power the process, but process heat can be produced by burning some of the collected waste paper in steam plants or by using electric heat pumps. The energy needed to produce high quality office paper is nearly twice that required for non-deinked packaging paper. This couples with the lower pulp yields obtained with high quality pulp means that the environmentally preferred option for energy supply to the recycling process is dependent on the grade of pulp being produced.

Keywords: paper making; energy efficiency; carbon emissions; recycling; biomass use

1. Introduction

Paper is a versatile material which has a wide range of uses, it is made from biomass but requires considerable amounts of energy and water to produce. Paper is made by depositing a slurry of fibres suspended in water onto a traveling mesh conveyor (or wire). The water is then removed by gravity, mechanical pressure, suction and heating. The dried paper is then wound onto a reel. The majority of fibres used in papermaking are cellulose fibres extracted from wood, although it is also possible to use bamboo or grasses. Fillers and coating are added to the slurry or the paper to give the required finish. Coatings are applied as solutions and need a secondary dryer stage. The finished paper can be buffed in a process known as calendaring to smooth the finished surface. Comprehensive explanations of these process can be found in [1–3]. Although this basic process is used for all grades of paper the actual energy used depends on: the feedstock used, method of pulping, grade of product being produced, size of the plant, running pattern of the plant and location.

Although energy intensive the paper industry is not normally considered to be carbon intensive for the following reasons:

(1) The paper making process does not inherently emit greenhouse gasses (GHG).

(2) The need for low pressure steam and electricity mean that paper mills are suitable sites for combined heat and power plants (CHP) [1]. CHP plants have lower carbon emissions than fossil fuelled power stations using the same fuel.

(3) The widespread use of Black Liquor from the kraft chemical pulping process to provide process heat for paper mills means that the industry uses a significant amount of renewable biomass derived fuel.

Currently the use of gas fired CHP plants is considered as the best available technology BAT [1]. However, it is recognised that as part of strategies to reduce the impact of manmade climate change electricity grids in will need to be decarbonised [4,5]. EURELECTRIC, an organisation representing European electricity generators estimates the European grid average will need to fall from its 2009 value 84 kg CO_2/GJ to 6.9 kg CO_2/GJ by 2050 [5]. Natural gas CHP generation has a minimum carbon dioxide intensity of 67 kg CO_2/GJ, so it will shortly be considered as a high carbon electricity source. Consequently, there will be strong incentives for the industry to minimise its energy use and reassess the energy sources it uses.

This paper examines options for reducing GHG emissions and energy use in the paper and pulp industries by reducing energy use, increasing biomass use (including waste) and using low carbon electricity grid.

Paper mills are capital intensive and have a long service life, consequently it takes many years before innovations are fully adopted across the industry. So, the technology that will be in use in the 2030's is likely to have already been demonstrated as a prototype plant and reported in the broader literature. By examining this literature it should be possible to estimate future energy profiles of paper mills by the following procedure:

Step 1 establish the likely energy requirements of paper mills in the mid-century assuming the introduction of demonstrated energy saving technology.

Step 2 estimate how much of this energy demand can be met from combustion of process by-products and waste.

Step 3 Investigate options for satisfying the residual energy demand from low carbon sources using biomass or low carbon grid electricity.

2. Literature review

Forty papers and reports were reviewed as part of a review of benchmarking which is the subject of a separate paper currently under review. These studies reported energy use for different scopes of supply and different products. The findings of four of the more detailed benchmark reports by Worrell [6] which considers world practice, Jacobs [2] which is concerned with the USA, Blum [7] which covers Europe and NRC [8] which covers Canada were compared. Their extent of supplies was adjusted so that values from studies based on whole mill consumption and those that report process stream consumptions had similar scopes. The energy consumption data was converted to GJ per metric tonne of dry product for both heat and electricity. It was found that for the production of wood free coated paper in non-integrated mills (those that use pulp produced off site) used between 5.8–7.5 GJ/t of steam and 2.4–2.9 GJ/t of electricity. Similar spreads of values were found for other products.

The Energy Bandwidth Study conducted by Jacobs in 2006 [2] for the US Department of Energy's Industrial Technologies Program reported current use and estimates for energy consumption using best available techniques (BAT), practical minimum (PM) as assessed by industry experts and theoretical thermodynamic minimum (TM). The BAT values from this report are shown in Figure 1.

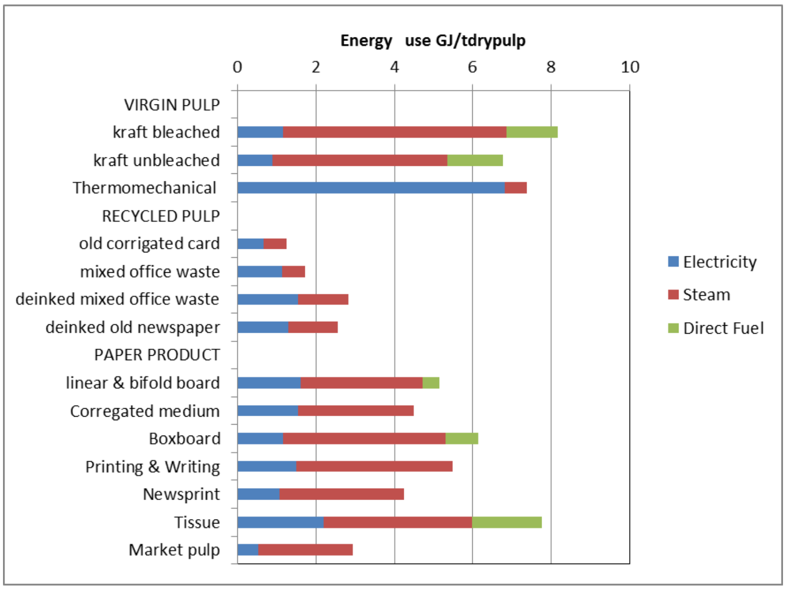

Figure 1. BAT Specific energy requirements for various paper products.

Figure 1 distinguishes between heat supplied by steam and heat provided via direct combustion of fuel. Steam is used to provide low temperature heat for paper drying, process heating and space heating. Direct fuel is used in high temperature lime kilns (which are part of the chemical recovery system in the kraft pulping process), high temperature air heaters for Though Air Driers (TAD) used to make some tissue and in radiant heaters used in some coating processes.

Table 1. Range of bat measures found in the literature.

Technology	Process	Application	Saving	Comments
black liquor gasification	kraft pulp	chemical preparation	16.0%	savings based on using CCGT only possible if surplus steam exist now
biomass gasification	all	energy recovery		gas can be used for electricity generation or lime kiln fuel
direct green liquor utilisation	kraft pulp	cooking liquid evaporation bleaching	25.0%	30% used for pre-treatment avoids need for causticicizing
biological pre-treatment	mechanical pulp	pre-treatment	20–40%	chips pre-treated with fungus or enzynes to open structure
membrane concentration of black liquor	kraft pulp	liquor evaporation	36.0%	new anti-fouling coating, membrane concentration from 15% to 30%
dry kraft pulping	kraft pulps	cooking liquid evaporation chemical preparation	30.0%	chip pre-soaked then digested without further liquid being added
oxalic acid technology	SGW TMP	bleaching	25.0%	pre-treatment of chips reduces mechanical pulping electricity 25%
Borate auto causticizing	kraft pulp	recovery boiler		sodium borate added to pulping liquor this takes part in a recausticizing reaction in the recovery boiler reducing the need for lime
Steam cycle washing	kraft	washing/ separator	20% electricity	steam is used rather than water to wash out the pulping chemicals from digestant
recycle paper fractionation	recycled paper	deinking	11–13% electricity 40% heat	long and short fibres are separated before deinking allows removal of ink particles earlier in process
Surfactant spray deinking	recycled paper	deinking	3%	surfactant spray added to deinking tower improves yield
new fibrous fillers	all	dryers, drying	40.0%	improve pressing reduces dryer load limited by strength issue
dry sheet forming	tissue	wet end dryer	50.0%	use turbulent air in place of water as carrier
high consistency forming	Low weight paper	forming	8.0%	less water to be removed, saves electricity for vacuum
gas fired dryers	paperboard	drying	10.0%	no need for blow through steam
condibelt dryers	paperboard	drying	33.9%	alternative to drum drier
impulse drying of paper	newsprint, tissue	pressing drying	59.0%	blast paper with hot air during final press

The BAT assessment was based on emerging technology identified in the US bandwidth studies [2,9]. More recent reviews carried out by WSP, Parsons Brinckerhoff in 2015 [10] and Kong in 2016 [11] identified the same BAT technologies with similar estimations of energy saving potential. The range of techniques that generate the BAT savings are shown in Table 1.

The Confederation of European Paper Industries (CEPI) have produced a road map for the industry to become a low carbon bio-economy by 2050. They recognised that this could not be achieved with existing technology and set up two teams of experts drawn from across the sector (i.e., researchers, scientists, manufactures, suppliers and industry representatives) to come up with possible innovations [12]. By considering their findings and suggestions from an earlier European collaborative project called ECOTARGET [13] with the PM suggestions from the Bandwidth studies [2,13]. The main opportunities for energy saving that they identified are included in Table 2.

Table 2. Areas under development which could yield savings beyond current bat.

Technology	Description	Potential saving
Deep Eutectic Solvents	These are newly discovered natural solvent that are used by plants to survive water stress conditions by extractive chemicals from their own structure. This science is at an early stage of development, but it looks like DES solvents can be found for lignin and hemicellulose and probably cellulose. This opens up the possibility of chemically extracting cellulose from a wide range of biomass at low temperatures without milling.	Up to 40% reduction in primary energy consumption and yield valuable bio chemical by-products.
virgin fibre supply	Using enzymatic pre-treatment of wood chips before mechanical pulping or chemical pre-treatment before TMP pulping	Energy savings 8% to 28% with enzymes, up to 25% with chemical but some pulp deterioration
Recovered paper sorting improved by new sensors	Sensors developed to help automate recycled feedstock sorting. Also work package also developed a single loop deinking plant.	Deinking plant could save 16% of electricity and 30% of steam and 20% reduction in material loss
Furnish solution	The aim of this work package was to select fibres for particular grades of paper. This was done using enzyme treatment and improve fractionalisation techniques.	
Papermaking solutions	Stratified forming, producing a multi layered product by simultaneous stratified forming thus avoiding the need laminate and glue multi layered products.	Energy savings estimated as 16%.
Additives	Starches were used to decrease build-up of organic substances in white water allowing lower bleed and fresh water makeup rates.	
Functional surface	Developments in formation and pulps could allow the same physical properties to be achieve with a reduce weight product	30% weight reduction possible
Flash condensing with steam	Dry fibre, filler, and chemicals are mixed into a turbulent steam flow which them passes into a condensing zone where the paper is formed in the condensing fog. The paper is formed with a 70% solid content.	Needs less than 50% of the drying energy required by todays dryers.

Continued on next page

Technology	Description	Potential saving
Superheated Steam Drying	Use dry steam (steam that is at a temperature greater than the saturation point for the steam pressure) to remove the evaporated moisture from the paper in the dryer. The steam can then be used for steam forming or other processes.	Energy savings of 25% are envisaged
Dry pulp for cureformed paper	Fibres are coated with a protective film than suspended in a viscous solution, after forming the viscous fluid is removed in a press and the paper is them cured. This process can be adapted to produce multi layered products in a single step	Energy savings estimated to be around 25%.
Supercritical CO_2	This can be used to freeze dry paper in place of conventional dryers. Supercritical CO_2 can also be used in the deinking and cleaning processes in recycled pulp	Primary energy saving of up to 20%
Electrification	Use TMP as a flexible load for intermittent renewable electricity and high efficiency electrical drying techniques.	
Toolbox	Basically uses multiple incremental developments in biochemical processing, advance forming and 3 D printing to provide evolving bio based products that replace many of the conventional paper products (and some new ones).	Toolbox

In a paper on optimising energy efficiency of conventional multi cylinder driers [14] Laurijssen identifies several improvements that could achieve a total primary energy saving of 38% in the drying process. It has also been proposed that further improvements can be made in heat recovery and loss reduction [1,15,16]. Some of these techniques are mutually exclusive or will restrict the savings from other operation so the potential savings are not cumulative. It is not within the scope of this paper to try and identify which of these measures will be adopted however it is apparent that given favourable economics it should be possible to make energy savings in the order of 20% beyond the established BAT values.

3. Energy consideration

3.1. Predicted energy demand for different products

Paper can be made from wood pulp produced on site (integrated paper mill), recycled paper processed on site or market pulp produced offsite. These three routes will have different energy requirements for producing the same product. In Europe over 90% of the pulp used for newsprint and packing cases comes from recycled paper where 88% of the pulp for graphic paper comes from virgin pulp the ratio of recycled to virgin pulp for household and sanitary (mostly tissue) is 52% to 48% [17]. Table 3 shows the potential energy requirement for some common feedstock and product combinations. It has been assuming that emerging technical improvements have resulted in an energy requirement 20% lower than the current BAT value.

Table 3. Potential specific energy requirement for some common paper products.

	Electricity GJ/t	Steam GJ/t	Fuel GJ/t
recycled board from old corrugated card	1.36	3.52	0.00
newsprint from deinked old newspaper	1.89	3.56	0.00
tissue from deinked mixed office waste	2.98	4.05	1.43
tissue from kraft pulp	2.65	7.30	2.43
Printing and writing from deinked mixed office waste	2.44	4.20	0.00
Printing and writing from kraft pulp	2.11	7.46	1.00

3.2. Energy use in integrated paper mills

Timber used for paper making has its bark removed before being chipped and pulped. This bark and undersized wood is a potential fuel source. In 2010 US pulp mills burnt 7.5 GJ of bark and waste wood for each tonne of dry pulp produced [9]. This was burnt in steam boilers, but it has been gasified to provide gas for lime kilns, gas air heaters or combined heat and power units [18]. Biomass gasifiers using non-dried biomass have conversion efficiencies around 65% [19].

In the kraft (sulphate) chemical pulping process woodchips are heated under pressure in a solution of sodium hydroxide (NaOH) and sodium sulphide (Na_2S). This dissolves the lignin in the wood leaving the cellulose fibres. The dissolved lignin and chemicals (Black Liquor) are washed out of the pulp and are sent to a chemical recovery cycle. The black liquor is concentrated then burnt in an energy recovery boiler to remove the lignin and raise steam. The pulping chemicals are recovered from the recovery boiler as a sold smelt of Na_2CO_3 and Na_2S. The smelt is then diluted and filtered to produce "green liquor" which is then causticized by adding lime (CaO). After causticization the lime is separated from the "white liquor" in the form of lime mud ($CaCO_3$) this is heated to over 980 ℃ to produce lime for reuse in the causticization process. In 2010 US kraft pulp mills produced 19 GJ of black liquor for each tonne of dry pulp produced [20].

The energy produced from biomass by-products in US kraft mills was equivalent to a combined heat and power unit with an electrical efficiency of 23% and a heat efficiency of 35% [20]. Assuming these are the CHP plant efficiencies for a single mill's CHP plant the 26.5 GJ of by-product fuel produced per tonne of dry pulp should produce 6.0 GJ of electricity and 9.3 GJ of steam if it was all used in the CHP plant. These are more than the energy requirement for producing "printing and writing paper". It is usually possible to find a market for surplus electricity, but it is unusual to find a suitable all year-round heat demand to use surplus heat. An alternative strategy is to run the CHP plant to supply the steam load by consuming all the black liquor (in order to recover the chemicals) and some of the bark. The remaining bark is gasified to provide direct fuel for the lime kiln with any excess bio-gas sold or used a vehicle fuel. A kraft paper mill used to make "printing and writing" paper using the energy shown in Table 3 should export 2.8 $GJ/t_{drypulp}$ of bio electricity and 2.4 $GJ/t_{drypulp}$ of biogas. On the same basis a kraft tissue mill should export 2.1 $GJ/t_{drypulp}$ of bio electricity and 1.2 $GJ/t_{drypulp}$ of biogas consequently, integrated paper mills could be powered from renewable fuels derived from the processing of biomass.

3.3. Energy use in mills using recycled pulp

3.3.1. The availability of bioenergy in a recycled paper mill

The implication of paper recycling on the energy requirement of paper production at an industry level was discussed using life cycle analysis by Laurijssen [21] however, he considered all waste biomass streams to be used in municipal waste CHP incinerators rather than as energy sources to be used in the plants themselves.

Paper for recycling is re-pulped using hot water and mechanical agitation (or refining) this separates the fibres in the paper and dislodges impurities (glues, coatings, filler, dirt etc.) which are separated from the recovered pulp. Inevitably some fibres are damaged in the process and the fibre fragment are separated along with the fine contaminates. This slurry is a potential fuel. If the pulp requires to be deinked it is further refined with chemical to help dislodge ink particles from the fibres these are flocculated off with the use of air bubbles. It is clear from Figure 1 that the amount of refining and deinking has an impact on the energy required. The mass of these steams is given in IPPC BAT guide [1] this has been used with heating values from [22] to calculate the available energy in the waste slurries these are shown in Table 4.

Table 4. Energy content of waste from paper recycling.

product being produced	waste kg_{dry}/t_{paper}	energy in slurry GJ/t_{pulp}	waste paper required for fuel kg/t_{pulp}
Packaging	50–100	0.1	380
Newsprint	170–190	1.7	264
Printing & Writing	450–550	2.1	300
Tissue & market pulp	500–600	3.8	150

The slurry energies in Table 4 are mid-point values and may vary by ± 50% depending on the quality of paper being recycled. These slurries have a high water and ash content and consequently a low heating value. They are frequently co-fired with fossil fuels to maintain stable combustion [23,24]. An alternative approach is to dry the sludge before combustion. In trials a DRY-REX ambient air dryer took deinked sludge from a belt press with 30% solids and dried it to 80% solids with a claimed electricity consumption of around 0.36 MJ/kg. This would raise the lower heating value (LHV) of fuel from 1.4 to 8.3 MJ/kg. The DRY-REX works by granulating the sludge then blowing dry air over it while it progresses along a chain of conveyors. This dryer relies on the ambient air being dry and a heat exchanger (fed from recovered process heat) can be fitted to the air inlet of the dryer to ensure this [25].

It is clear from Tables 3 and 4 that there is insufficient energy in the waste streams from recycling to satisfy the process heat demands. Some of the paper for recycling could be used as a fuel as it is renewable, the handling facilities already exist at the mills and the replacement of some recycled fibres with stronger virgin ones improves the product quality. The amount needed has been calculated based on an average LHV for waste paper of 13 MJ/kg from [22] and a boiler efficiency of 70% from [9] this is also shown in Table 4. The impact of the use of recycled paper as fuel will be discussed further in section 6.1.

3.3.2. Enhanced heat recovery with heat pumps

The pulp and paper making process has many uses for low temperature heating including heating process water, wash water and heating dryer ventilation air. There are also a number of warm waste streams like liquid effluent and dryer air exhaust which have been exploited as heating sources. However, the main atmospheric discharge points from the paper making process all contain a considerable amount of latent heat in the form of water vapour. This constitutes a heat loss to the process.

This heat is not normally recovered as it requires the exhaust gas to be cooled to below the water dew point and there are insufficient heat loads at this temperature. However, heat pumps can be used to raise the recovered heat’s temperature to the level where it could be used to provide low pressure steam for the paper dryers. Heat pumps are machines that take energy from a low temperature source and raise its temperature to supply a high temperature load. The ratio between the heat delivered and the energy used by the heat pump is known as the coefficient of performance (COP), this falls with increasing temperature difference between the source and load. Steam raising heat pumps that could supply paper dryers are beginning to be commercialised [25,26]. These have COPs in the region of 2 when taking heat from a 60 ℃ source and supplying it to a 175 ℃ steam load at 0.8 MPa (performance taken from a SGH165 heat pump with integrated steam compressor [26]). It has been proposed that the operating conditions of paper dryers should be raised to a dew 75 ℃ [14], if this is done it should be possible to recover the latent heat in the dryer exhaust by cooling it down to below 75 ℃.

There are two types of condensing heat exchanger direct and indirect [27]. In indirect heat exchangers the exhaust gas flows through a tube nest (the tubes may have fins or lamella welded on them to increase their contact area). The water flows through the tubes in an opposite direction to the gas i.e. the last tube that the water flows through is the first that the gas flows over this means that the hot end of the exchanger can operate like a conventional boiler economiser. As the flue gas cools water condenses on the heat exchanger tubes and drips down into a collection sump. There is a relatively small temperature difference between the gas stream and the water, so the tubes need a large surface area, high thermal conductivity and thin walls to collect a high proportion of the heat. Making them bulky and costly. In direct heat exchangers sprays of fine droplets drench the flue gas. There is heat exchange between the flue gas and the droplets and water vapour condenses on the droplets. Packing materials can be used to aid the mixing of the flue gas and the droplets. The air in the spray zone must remain saturated which limits the water temperature (there would be no useful heat exchange if the spray water started to evaporate). The high surface area of the spray droplets mean that direct heat exchangers can be smaller than indirect one. The acidity of the condensate will be diluted by the spray, but it will still need to be neutralised in any conservative system and corrosion resistant materials are still needed. The sprays also wash out fine particles from the flue gas, this helps with pollution control but does lead to contamination of the condensate. Direct heat exchangers can harvest more waste heat than Indirect one but at a lower temperature. This low temperature heat can be used for space heating, to preheat boiler feed water or be used as a cold heat source for a heat pump.

Figure 2 shows the amount of low carbon electricity or additional biomass needed to produce different grades of paper from recycled pulp.

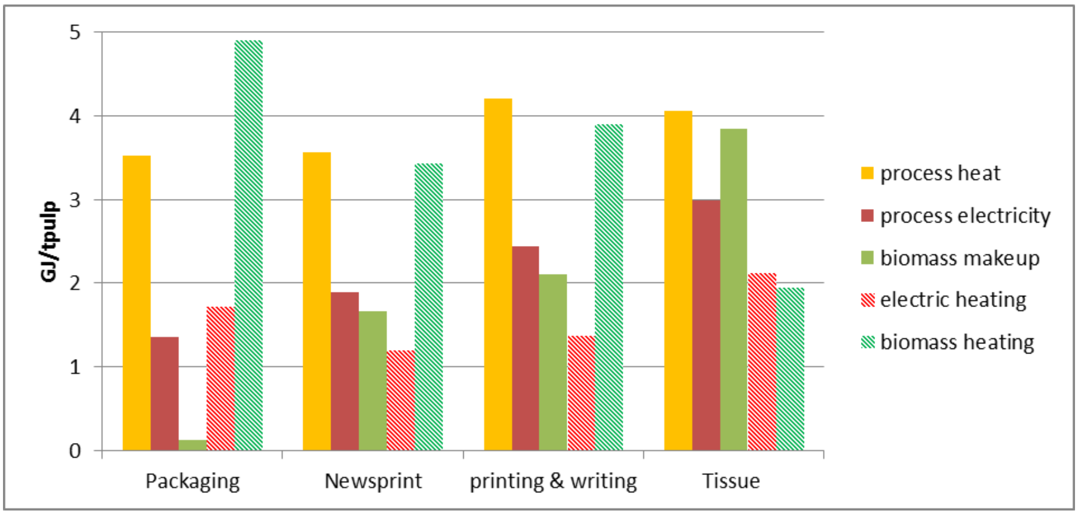

Figure 2. potential energy sources for recycled paper mills.

The biomass makeup is the amount of biomass needed to replace the losses from the re-pulping processes shown in Table 3. It is noticeable that the sum of the biomass makeup and biomass heating is between 4.8 and 5.7 GJ/t for all grades. In the electric heating options, it has been assumed that the waste is combusted to produce heat and heat pumps are used to satisfy the remaining heat demand.

3.4. Disruptive developments

Energy demand can be affected by incremental improvements to the process or radically new processes or products.

3.5. Product change

There is ongoing development of fibre based products [28], some of them are for new applications but others like light weight paper [10] and reusable cardboard boxes have the potential to reduce the energy used by the sector.

An external development is the switch from high street retailing to direct internet retailing. Traditionally the packaging of a product has been part of its retail presentation which means that it frequently needs a graphic quality finish. If goods are ordered over the internet they could be packaged in non-deinked cardboard which as shown in Figure 1 and Table 3 uses considerably less energy to produce.

3.6. Bio refineries

Bio refineries are industrial plants that produce chemicals and fuels from biomass. The initial stages of these processes involves breaking down the biomass using chemical, biological or thermal techniques. The kraft pulping process can be used as the initial stage in a bio-refinery [18,29,]. This topic is too divers to discuss here but it is likely that extraction of chemicals from black liquor or timber waste will result in a reduction in the available energy from by- products this will intern effect the energy self-sufficiency of kraft mills.

4. Discussion

4.1. Low carbon energy sources

Chemical pulping using the kraft process can potentially satisfy its energy requirements from biomass derived co-products of the process. However, developments of bio-refineries where high value chemicals are also extracted as part of the pulping process could reduce the energy in the black liquor [18].

Paper recycling requires external energy sources. This would imply that kraft pulping it is a lower carbon process than recycling, however this overlooks two key points:

(1) there is only a limited supply of sustainably manage trees and conversion of wilderness into manged plantation releases large amounts of sequested carbon dioxide [30].

(2) the carbon dioxide from the combustion of biomass is only reabsorbed by trees by the time that reach harvestable size [31] and this can take between 7 and 90 years [32], during this time it is adding to global warming.

There is also a rising demand for biomass for use as renewable fuel consequently, timber needs to be used efficiently [21]. The use of timber in paper making can be expressed as cumulative pulp yields. The pulp yields from 1 t of dry timber have been calculated based on: kraft pulp yield of 50% [18], the recycling waste rates in Table 4, and the recycled material that would need to be burnt to heat the process from Table 4. Cellulose fibres get damaged during recycling and it is considered that seven recycling cycles is the upper limit on recycling [33,34], so it was assumed that fibres would be recycled seven times.

Table 5. Lifetime pulp yields for 1t timber with different recycle heat sources.

	t_{pulp} electric heating	t_{pulp} Recycled paper heating
Packaging	3.86	1.66
Newsprint	2.64	2.24
Printing & Writing	2.41	1.47
Tissue	1.89	1.52

Recycling greatly increases the pulp yield from a tree compared to kraft virgin pulping. The use of heat pumps increases the yield more than using recycled paper as fuel, but is an environmentally beneficial use of low carbon electricity? This will depend on the availability of low carbon energy. A simple test would be to see if the timber saved by using heat pump drying is more than the fuel required by a biomass fired power station to generate the electricity consumed by the heat pump this would arrear to be a beneficial option.

Assuming 1 t of paper pulp has the same heating value as waste paper 13 MJ/kg [22] and it could be burnt in a steam power plant with an electrical efficiency of 38% [9] it would produce an electricity yield of 5 GJ/t_{pulp}. It follows that if a heat pump uses less than 5 GJ of electricity to save 1 t of pulp it should be environmentally beneficial. This is shown for different grades of product in Table 6.

Table 6. The impact of using heat pumps on lifetime pulp yields from recycling.

	Extra yield from using heat pumps t_{pulp}	Electricity used by heat pumps GJ	heat pump demand to save 1 t of pulp GJ/t
Packaging	2.20	8.8	4.0
Newsprint	0.40	3.4	8.3
Printing & Writing	0.93	4.9	5.3
Tissue	0.37	2.6	7.1

From Table 6 heat pumps should be beneficial for package materials and marginal for printing and writing paper.

The combustion of paper industry waste is covered by waste incineration regulations [1] and appropriate emission reduction equipment will have to be installed on the combustion plant. This could mean that it may be possible to licence the plant for some classes of municipal or general business waste as a fuel rather than use some of the paper for recycling.

There are ongoing developments for finding alternative uses for the slurries in the production of building materials and oil sorbents [20,23] if these become popular there will be more incentive to use heat pumps.

4.2. Significance of product appearance

Virgin pulp is naturally brown in colour and recycled pulp has ink speckles in it. Considerable amounts of energy are used to make the pulp white. Cardboard packaging is frequently made of unbleached pulp, but other packaging is bleached so that it can produce a package that helps with marketing. If the environmental impact of producing bleach ink free pulp was understood by consumers, there could be a movement towards using more unbleached packaging and envelopes. The move towards online retailing could aid this as it would be the appearance of the product that would appeal to potential customers not the look of the packaging.

4.3. Design for recycling

It is apparent from Figure 1 that it takes less energy to deink and recycle a simple product like Newspapers than mixed office waste. The situation is worse for paper with waterproof coatings or composite materials [35]. This problem could be addressed in two ways; the product could be designed using materials that could be simply separated on recycling [36] or it could be made so that it could be cleaned for reuse.

5. Conclusions

There appears to be a consensus that current energy use in the paper and pulp industries could be considerably reduced using known technologies.

The most common process for producing virgin pulp can be powered from its process waste and by-products. If the efficiency of the pulping process or papermaking process is improved kraft paper mills should be able to export renewable electricity or gas.

Although recycling paper requires energy inputs it effectively increases the pulp mass yield from timber by 400–950%. The energy required for recycling could come from a mixture of low carbon grid electricity, combustion of dewatered waste slurries from the re-pulping process, electric heat pumps, combustion of some of the paper to be recycled or combustion of general waste. The best approach will depend on the product being produced, the material being recycled and the availability of low carbon electricity.

This paper uses data from international benchmarking reports and its conclusions may not be true for all cases. This may be particularly true for plants that are part of district heating schemes or who sell excess heat to industrial customers. Only one pulping technology was considered and from Table 2 there are a number of developments that could give rise to increased use of combined ensign/thermal/mechanical pulping techniques which would not produce black liquor.

This paper does not cover a review of environmental life cycle analysis (LCA) studies of the pulp and paper industries. This topic is covered in the EU BAT reference document [1]. Comparisons of different LCA reports is hampered by the need to exactly match scope between reports. The impact of different forestry strategies and the treatment of the green house gas emissions from renewable fuels are likely to overwhelm the impacts of the paper making process so a comparison of existing LCA literature is unlikely to yield meaningful information.

Further work is needed on the application of heat pumps to the paper making process where optimisation techniques like pinch point analysis could refine the energy estimates. There are wide bands in the estimates of both fibre yield and energy use in the recycling process. Further work that helps quantify these parameter for both feedstock and product would be useful to plant designers, waste reclaimers and regulators.

It is possible to make paper using low carbon energy sources, but it will only happen if the economic conditions are favourable for both capital investment and operational energy costs.

Acknowledgment

This research was carried out as part of Centre for Industrial Energy, Materials, Energy and Products (CIE-MAP) under the UK government EPSRC grant EP/N022645/1. I would like to acknowledge the help given to me during the preparation of this paper by members of the CIE-MAP team in particular Dr Sam Cooper and Dr Jon Norman.

Conflict of interest

The author declares no conflicts of interest in this paper.

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