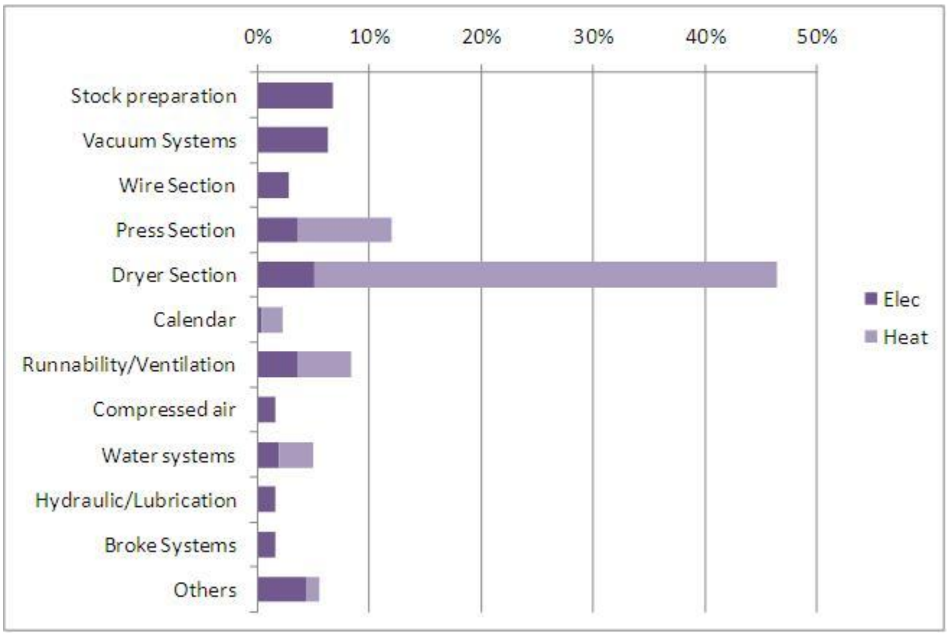
Industrial Energy Efficiency Accelerator - Guide to the paper sector

The paper sector emits approximately 4.7 million tCO2 per annum from a production output of approximately 5.2 million tonnes. The CO2 emissions for the numerous manufacturing processes in paper making are dominated by the dryer section. This report focuses on the Print and Write and the Packaging subsectors, given the importance of these to the overall production of the European paper industry and the similarity of the technologies employed.

Executive summary

The paper sector emits approximately 4.7 million tCO2 per annum (see Table 1) from a production output of approximately 5.2 million tonnes. The CO2 emissions for the numerous manufacturing processes in paper making are shown in Figure 1 and are dominated by the dryer section.

Figure 1 *Carbon Emissions from a typical Mill*



The initial engagement and investigational work identified that the key areas of focus for improving energy efficiency were:

- Hood relative humidities;
- Inlet moisture control to the dryers;
- Low carbon energy supplies.

The energy saving potential of other major users, such as compressed air and motors and drives, are well understood and solutions generally available.

The overall maximum carbon saving potential for the sector through both good practice actions and future innovation is estimated to be 23.5% or 1,100,000 tCO2/yr. The good practice element of this, which includes measures that are well documented and mature, can deliver around 10.4% carbon savings (490,000 tCO2/yr). Innovative opportunities offer carbon saving potential of 606,000 tCO2/yr. Clearly the actual carbon savings achieved will depend on the take up of these opportunities by the sector as well as the technical feasibility of innovations identified.

The innovation opportunities identified as having the greatest carbon impact in the sector are:

1) Low carbon energy supplies
2) Online moisture measurement
3) Optimised dryer operation
4) Hot press

The carbon and financial benefits from these opportunities at the 52 sites that make up the sector are summarised below:

	Challenge	Project Cost	Maximum Sector CO_2 savings	CO_2 saving after 10 years	Cost of CO_2 £ per tonnes saved/year	Payback Time years	Lifetime	IRR
1	Low carbon energy supplies	£500k - £2 million	200,000	50,000	£10	5.56	25	30%
2	Online moisture measurement	£600,000	65,600	19,600	£12.60	2.31	5	33%
3	Optimised dryer operation	£500k - £1.5 million	110,000	55,000	£6.40	2.86	10	33%
4	Hot press	£2 million	230,000	68,000	£7.50	3.08	25	32%

A fifth project was considered but eventually rejected by the sector. Heat recovery from dryer exhaust has the potential to contribute some energy savings, but the recoverable heat is a small percentage of the total heat content of the dryer exhaust as the bulk of this energy is in the form of latent heat. Significant recovery of this energy stream requires a very low temperature heat sink, e.g., underfloor heating for a large office complex, a swimming pool or a major greenhouse complex.

The IRR estimate is for a pilot scale, demonstration project. Once the technology is proven the investment case should be stronger.

Table of contents

1 Introduction

1.1 Carbon Trust & Industrial Energy Efficiency Accelerator (IEEA)

The Industrial Energy Efficiency Accelerator (IEEA) is a major part of the current programme of work being undertaken by Carbon Trust. The purpose of the IEEA is to identify and accelerate the take up of innovations by industry to reduce CO2 emissions.

The focus for the IEEA is to collaborate with industrial sectors to identify low carbon innovations that go beyond “good practice”, which require support for their implementation and roll out. To achieve this, the IEEA is split into three stages: Investigation and Solution Identification;, Implementation; and Replication. The three stages are summarised below in Figure 2.

Figure 2 *Overview of IEEA Stages*

Examination of specific processes to understand energy use and interfaces with other systems.
This involves collecting information from process operators, equipment manufacturers and the actual equipment in use at a representative group of sites.

The opportunities identified at this stage fall in to 3 themes:

- Product Strategy: Concerning the raw materials, product mix and the supply chain
- Processes: How processes configuration could be improved
- Equipment: Upgrades or new technologies to replace existing equipment

Gathering evidence to support a business case for implementing energy-efficiency opportunities.
In this stage projects are funded to demonstrate and deploy innovative low carbon technologies in the areas identified in stage 1

The aim of each project is to provide the evidence for the whole sector to implement changes

Promoting the uptake of demonstrated solutions in partnership with the relevant trade associations

The IEEA commenced in 2008 and to date has worked with 14 sectors:

- Aggregates
- Animal Feed
- Blow Moulding
- Industrial Bakeries
- Brewing
- Brick Manufacture
- Catering
- Confectionery
- Dairies
- Laundries
- Maltsters
- Microelectronics
- Paper
- Metal Forming

The Stage 1 work looks to identify the main carbon and cost saving opportunities, including opportunities from operational improvement, innovation in process control and use of innovative equipment and products.

1.2. Paper sector IEEA

The Paper sector was identified by the Carbon Trust as a major emitter of CO2. The sector is represented by the Confederation of the Paper Industry (CPI) and the Paper Industry Technical Association (PITA). Both were instrumental in getting agreement for the sector to participate in Stage 1 of the IEEA programme commencing in February 2010. To deliver the Stage 1 project, SKM Enviros were engaged in March 2010.

1.3. Overview of the paper sector and initial engagement

The Paper sector is generally subdivided into 6 main subsectors:

- **Print and Write** – white or coloured papers used in the commercial sector. Typically, Print and Write papers are coated with clay or other minerals to give good surface properties.
- **Newsprint** - Newsprint is that quality of paper used chiefly for the publication of newspapers and which has a basis weight of 40 - 57 grams. Other properties correspond to the EU harmonized definition, with brightness up to and including 59 ISO.
- **Packaging** – Packaging papers have higher basis weights and may be coated to improve strength or to provide other desirable properties such as moisture or oil resistance.
- **Corrugating Materials** – These are the fluting and liner boards that together are used to make corrugated packaging which are mainly used in the Fast Moving Consumer Goods (FMCG) sector – for food and beverages – with the remainder used in consumer durables and industrial sectors.
- **Household and Industrial Tissues** – Tissues are papers with the lowest basis weights.
- **Speciality** – speciality papers are designed for specific purposes such as currency, filter papers, wallpapers etc. and hence come with a variety of basis weights, finishes and surface properties.

Within Europe, Packaging (an amalgam of packaging and corrugating materials) accounted for 43% of the output in 2009, with Print and Write 35%, Newsprint 11% and sanitary and household (mainly tissue) 7%.

At a single site there may be one or more paper types being manufactured: e.g. packaging and corrugating materials or Print and Write with speciality grades. Newsprint as a global commodity is manufactured in dedicated mills, Tissue plants are also most likely to be dedicated to a single paper type.

Initial engagement with the paper sector undertaken through the CPI/PITA and Carbon Trust identified Print and Write and Packaging as the focus sectors for the IEEA programme. Together these account for nearly 88% of the European production output. The Tissue subsector declined to participate – this is a highly competitive subsector and with energy costs being the second highest variable production cost (after raw materials) they perceived a potential risk through participation due to the need to share information. The newsprint sector is poorly represented in the UK with only three mills in operation – with the third mill – Palm in Kings Lynn only having been in operation since August 2009.

Due to confidentiality concerns from the sector the CPI has only been able to provide limited data concerning the energy consumption profile for the sector. Thus, with the exception of the data obtained from the monitored sites, the data used in this report has been used has been derived mainly from publicly available sources.

1.4. Key activities

The Stage 1 project included the following key activities:

1) Identify key carbon emission hotspots from the Sector;
2) Identify potential "black boxes" (those processes / plant where energy efficiency is not clearly understood) and further investigation is required to confirm and quantify potential carbon savings;
3) Define and implement energy and production data collection methodology for "black boxes";
4) Develop prioritised list of opportunities for energy savings and categorise these as good practice actions or innovations;
5) Recommend key innovations that require intervention / support to accelerate their take-up and where Carbon Trust can add maximum value.

For reference, good practice actions are those which the sector can take forward now and further support from the IEEA is not required. For example, this would include improvements delivered through better operator practices and utilising well documented, often generic technology improvements; such as compressed air, lighting, space heating, energy efficient motors, insulation etc. Innovations are opportunities that provide an additional step change in carbon savings of particular relevance to the Paper sector. Transport related emissions are excluded from IEEA.

This report presents the findings and recommendations from completing the Stage 1 works.

2 Paper sector background

2.1. Focus for the paper sector IEEA

The focus for the IEEA project is the Print and Write and the Packaging subsectors.

- **Print and Write** is a diverse sector whose products include: art papers; banknotes and other high security papers; document papers; tinted, coated and copier papers together with papers for inkjets and laser printers; printing board and paper.
- **Packaging** comprises core papers and boards, foil laminating bases, gift wraps, Kraft and imitation Kraft papers with a variety of finishes.

The IEEA project focuses on these two subsectors given the importance of these subsectors to the overall production of the European paper industry and the similarity of the technologies employed. This should ensure that the IEEA achieves good sector coverage.

In terms of the paper machines themselves, those used for newsprint will be similar in concept – tissue machines differ in that they use Yankee dryers (hot air impingement dryers) in addition to cylinder drying.

2.2. The paper making process

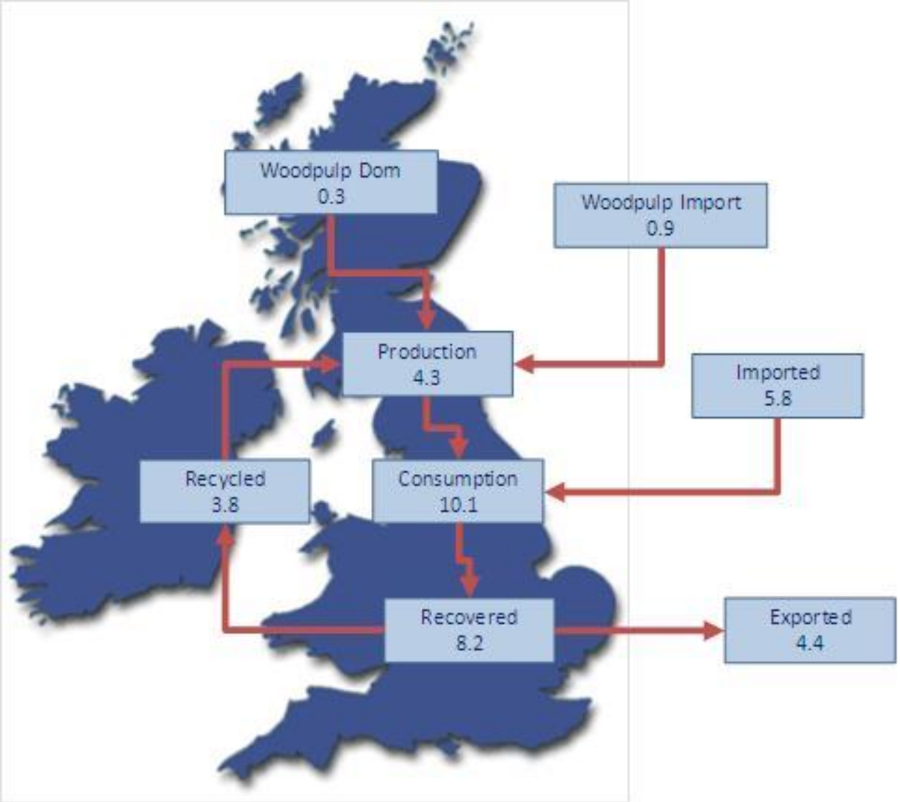
2.2.1. Raw materials

The main sources of fibres for the paper making process are either wood chips or recycled paper. Figure 3 is a representation of flows for the UK paper industry in 2009 in millions of tonnes. The key features to note are:

- Production meets 43% of domestic consumption;
- 81% of domestic consumption is recovered;
- Of the recovered paper 46% is recycled to UK production;
- Woodpulp is 24% of the material flows into production;
- Domestic woodpulp makes up only 6% of the material flows into production.

In addition to fibre the sector will also consume minerals and chemicals – the minerals are used as fillers for the paper to improve its opacity, chemicals are used throughout the production process – for example starch which is used as a size, dyes for tinting the paper, surfactants in deinking etc.

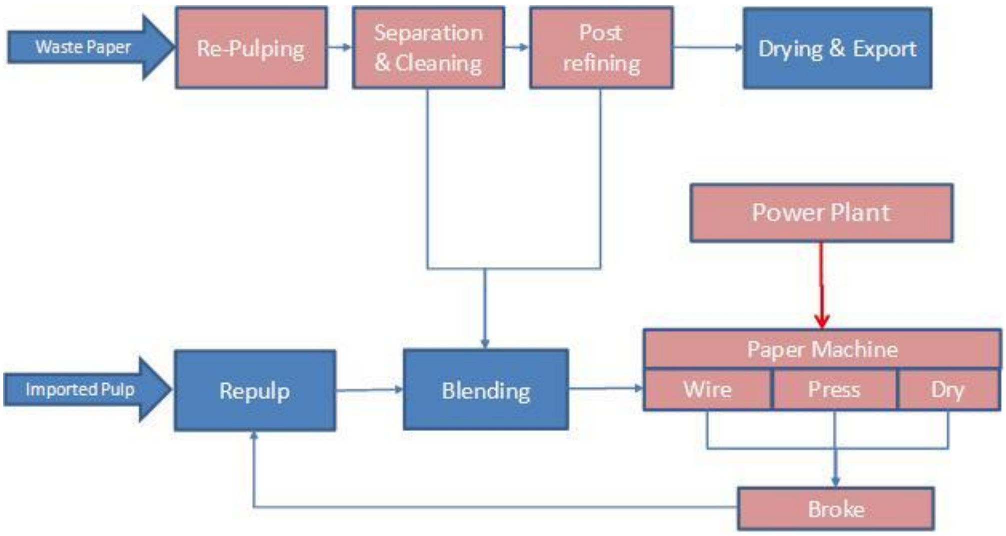
Figure 3 Mass flows for production and consumption



2.2.2. Paper production process

Figure 4 below shows a simplified flowsheet for the production of paper – the pink stages are the most energy intensive.

Figure 4 Simplified production process



The main stages are:

Repulping – Recovered paper – whether from the skips seen in supermarket car parks or from commercial collections is transported to waste paper merchants who sort the paper into different grades. The sorted paper is then baled and transported to the paper mills. At the mill the bales are loaded into a pulper where it is mixed with water and repulped. Devices are fitted to the pulpers to remove unwanted materials such as staples, wire bands and plastics. The pulpers are driven by high horsepower electric motors through reduction gearing.

Separation and Cleaning – this stage comprises a large number of process steps. The main objective is to clean the fibres of all inks and other non-desirables. The process steps included will comprise centrifugal screen, dissolved air floatation tanks, dewatering processes, redispersion and bleaching. To achieve high levels of fibre cleanliness it may be necessary to have multiple stages of cleaning each including the process steps described. The separation and cleaning processes are predominately electricity driven processes although in there is also a demand for hot water. Through the separation and cleaning process there will be buffer tanks to balance process flows and pumps for materials transfer. The buffer tanks will contain agitators to ensure that the consistency of the pulp remains uniform. The output of the cleaning processes will be pulp that is ready for the paper machine.

Paper Machine Wire Section – The stock flows from the headbox onto the wire – this is a woven plastic conveyor belt – the headbox is designed to ensure an even distribution of fibres across the width of the paper machine. As the wire moves away from the headbox water drains from the stock initially by gravity and then assisted via vacuum pumps. At the end of the wire section there is a mat of moist fibres. This section is a large consumer of electricity – for machine drives, vacuum pumps and water pumps to return the drained water to the fibre recovery processes.

Paper Machine Press Section – At the end of the wire section the web may pass under a dandy roll this applies the watermark. After the wire section the web is carried via felts through a number of heavy rollers where more water is squeezed out of the paper. This dewatering process is also assisted by vacuum pumps. The pores of the felts will get blocked by fibres reducing the effectiveness of the vacuum pumps – the felts are continuously cleaned using sprays and may be intermittently cleaned using chemicals.

Paper Machine Dryer Section – The paper then passes over a large number of steam heated cylinders which heat up the paper to evaporate the moisture. The steam cylinders are typically boxed in and hot air is passed over the cylinders to remove the evaporated moisture. Pocket ventilation is also used to ensure an effective removal of evaporated water. The paper is carried through the dryer section on synthetic fibre felts. There may be a size press part way down the dryer – in the size press a starch solution is sprayed onto the paper which improves the surface properties for printing. After the size press there will be more steam heated cylinders to dry the size. The dryer section is a significant consumer of energy in the form of heat (in steam for the cylinders and hot air for the dryer hood) and electricity for machine drives, for ventilation and for exhaust fans.

Paper Machine – Calendars – After the dryer the paper may be calendared – this involves passing the paper across heated and polished rollers mounted one above the other. This smoothes the surface of the paper in a process similar to ironing. After the calendars the paper is wound onto reels. The Calendars may use direct gas firing to heat the cylinders or they will use superheated steam.

Power Plant – Given the high use of heat and electricity the sector is characterised by the high uptake and use of combined heat and power plants. These can be high pressure steam boilers and steam turbines or gas turbines with waste heat recovery boilers and/or supplementary steam boilers and steam turbines.

2.3. The UK paper industry

The paper sector features a mix of globally active companies and UK based independent mills. Overall, the sector consumed approximately 19,200 GWh of fossil fuel and imported electricity in 2008, in producing over 5 million tonnes of product. An overview of key figures is as follows:

Table 1: *UK paper production and energy use, 2008*[1]

Production			
Printings and Writings	(tonnes)	1,040,070	
Packaging Boards	(tonnes)	330,285	
Newsprint	(tonnes)	1,100,038	
Speciality and Other	(tonnes)	552,413	
Tissue	(tonnes)	825,810	
Corrugated Case Materials	(tonnes)	1,329,262	
Total	**(tonnes)**	**5,177,878**	
Energy Use			**CO_2e**
Total fossil fuel	(GWh)	16,718	3,344
Total imported electricity	(GWh)	2,512	1,356

The major operating companies in the sector are listed in **Error! Not a valid bookmark self-reference.** below.

Table 1 *UK Paper Industry*

Company Name	No. Mills	Sector	Company Name	No Mills	Sector
Huhtamaki	1	Moulded Pulp	Whatman	1	Specialities
Vernacare	1	Moulded Pulp	Carleson Filtration	1	Speciality
Aylesford Newsprint	1	Newsprint	De La Rue	1	Speciality
Palm	1	Newsprint	Hollingsworth	1	Speciality
UPM-Kymmene	2	Newsprint	Weidemann Whiteley	1	Speciality
Iggesund	1	Packaging	James Cropper	1	Speciality
Romiley Preston Board	1	Packaging	Disley Tissue	1	Tissue
Smurfit	2	Packaging	Fourstones paper	1	Tissue
Sonoco	1	Packaging	Georgia Pacific	2	Tissue
St Regis	4	Packaging	Intertissue	1	Tissue
Billerud Beetham	1	Packaging / Speciality	Kimberley Clark	3	Tissue
Arjo Wiggins	3	Print	LPC	1	Tissue
Devon Valley	1	Print	NTG	1	Tissue

[1] These figures include everything currently in the CPI database rather than representing the CCA sector as reported (see Table 3). The variance is because mills that closed during 2008 are included up to their last download rather than being removed from the Milestone as in CCA. Furthermore, Carlson was not in the 2008 CCA sector but is in the database courtesy of retro-data. Waste, even if fossil-derived in content, has not been included because we do not know the fossil content of waste. However gas for 3rd party CHPs has been included. Source: CPI. The impact of this is that the primary energy consumption is 4490 kWhp/tonne compared to a CCA reported and verified amount of 3940 kWhp/tonne. Fossil fuel factor ~0.2 kg/kWh to allow for some liquid fuel usage.

Inveresk	1	Print	Peter Grant	1	Tissue
Tullis Russell	1	Print	SCA	4	Tissue
Glatfelter	1	Print / Speciality	Union Papertech	1	Specialities

Following discussion with the sector and initial site visits, four sites were selected for monitoring both to identify opportunities and to supply the evidence base to allow a business case for technology innovation to be defined. Ultimately three of the companies progressed to a monitoring programme.

2.4. Equipment suppliers

The supply chain for paper manufacturing is dominated by a very small number of key players who are based in Germany, Scandinavia and North America.

The large players in the market are:

- ABB (Swiss/Swedish)
- GL & V – Canada
- Metso Paper Inc. (Finland)
- Allimand (France)
- Mitsubishi Heavy Industries (Japan)
- Voith Paper – Germany
- Over Meccanica - Italy

The major equipment suppliers have large and expert development departments and are engaged in continual process improvement. Although these big suppliers remain important for identifying suitable innovations it is also clear that having UK based technology providers that can innovate and adapt quickly is equally important.

A second tier of equipment suppliers exist who focus on specific processes within paper making. These companies are members of the BPMSA – the British Paper Machinery Suppliers Association:

- Compact Engineering Ltd : Delivers energy efficient solutions for the pulp and paper sector, specifically in the field of electric infrared.
- Deublin Ltd : Precision rotating connections for steam and water used in the dryers to deliver steam to the cylinders. This is the UK entity of this US company.
- Gardner Denver Nash Ltd: Major player in the vacuum pumps market.
- Industrial Automation & Control Ltd: Electrical systems and controls providing DC Drives, AC Drives, Soft Starts, AC Regulators, PLC Control, Motor Control Centres (MCC), SCADA, Motion Control, Distribution Boards and Instrumentation.
- Jarshire Ltd: Supplier of ancillary equipment – limited manufacturing capability for slitting systems, unwind and rewind stands.
- Kadant UK Ltd: UK end of a US corporation, Kadant specialises in stock preparation systems, fluid handling systems, doctoring and water management systems.
- Parsons Reiss: Process engineering company now supplying engineering services and specialist machinery to the international tissue, board and paper industry.
- Pilz Automation Technology: UK subsidiary of German company specialising in controls and communications technologies.

- PMT Industries Ltd: Manufacturer of Papermaking Machinery, and Ferrous Castings for the non-papermaking sectors, for customers worldwide. A subsidiary of PMT Italia SpA. Main products are Paper Dryers and Rolls with the niche product being the Yankee Dryer.
- Poole Projects Ltd: An independent consultant engineering company specialising in the design, manufacture and installation of machinery and process systems, primarily for the Pulp and Paper industry.
- Spooner Industries Ltd: Process solutions for the contact-less drying of paper - air flotation and impingement dryers, industrial coolers, Air Turns and web stabilisers are manufactured. Forced air convection drying using air flotation bars and air flotation nozzle systems allows the web to dry without contact.
- Walmsleys Ltd: A consulting, technical engineering and service company which through a network of manufacturing partners can provide equipment and engineering services for machine rebuilds and upgrades.
- William Kenyon (Ropes & Narrow Fabrics) Ltd: Carrier ropes and rope threading equipment.

2.5. Energy consumption and carbon emissions for the sector

2.5.1. Sector emissions in the EU-ETS

In the verified emissions for 2008, the UK paper industry accounted for 1,877,681 tonnes of CO2. Since then approximately 200,000 tonnes of emissions have been lost through mill closures (the most important of which was International Paper's site at Inverurie in Aberdeen which alone accounted for 126,000 tonnes.

The sector has also seen the construction of the Palm Paper site at Kings Lynn in Norfolk that has a newsprint output of 400,000 tonnes of paper per year.

2.5.2. Sector emissions covered by the CCA

The sector consumption reported by CPI under the Climate Change Agreement with DECC are shown in Table 3.

Table 3 Sector *performance - CCA*[2]

	Equivalent baseline (1990)			Performance		
	Energy(kWh)	Production (t)	SEC (kWhp/t)	Energy (kWh)	Production (t)	SEC (kWhp/t)
TP1 (2002)	25,902,356,203	3,939,080	6,576	28,595,774,290	6,388,404	4,476
TP2 (2004)	25,902,356,203	3,939,080	6,576	27,216,229,382	6,358,595	4,280
TP3 (2006)	25,902,356,203	3,939,080	6,576	22,856,344,695	5,630,279	4,060
TP4 (2008)	25,902,356,203	3,939,080	6,576	20,696,540,994	5,253,107	3,940

[2] Source: Climate Change Agreements - Results of the Fourth Target Period Assessment. AEAT/ENV/R/2758/Issue 1

2.5.3. Energy balance for paper making

Data has been reported for the UK paper industry which indicates that on average the energy consumption is 4MWh/tonne. There are however substantial variations in energy intensity. Table 4 shows the range of performance for different grades of paper.

Table 4 Energy *consumption in Paper Making*

Paper Type	Energy Consumed
Packaging Board	2 – 3 MWh / tonne
Newsprint	3 – 4 MWh / tonne
Tissue	5 – 7 MWh / tonne
Fine Paper	4 – 8 MWh / tonne
Speciality Papers	Up to 20 MWh/tonne
UK Average	**4 MWh / tonne**

Benchmark data has been obtained from Natural Resources Canada on for pulp and paper making. While the pulp making data is not directly comparable – the majority of pulping in Canada is either TMP or Kraft whereas the UK either recycles fibres back into pulp using deinking processes or purchases virgin pulp – the data for the paper machines is comparable.

Table 5 shows the energy consumption for each of the main stages broken down into heat consumption and electricity consumption.

Table 5 Energy *consumption by process area*[3]

Process Area	Median		Range (Upper Quartile/Lower Quartile)	
	Thermal energy consumption GJ/ADt*	Electrical energy consumption kWh/ADt	Thermal	Electrical
Recycled Pulping	0.11	344.2	+300%/-75%	+/- 25%
Paper Machine – Newsprint	5.36	565.2	+23%/-11%	+/-10%
Paper Machine – Printing and Writing	6.32	662.5	+31%/-9%	+/- 7%
Paper Machine – Kraft Papers	9.1	1021.5	+0.1%/7%	+/-10%
Board Machine	6.94	555.0	+3.5%/-0.2%	+/-15%
Converting	0	87.2	-	+/-30%
Water treatment	0	29	-	+100%/-50%
Effluent treatment		49.4	-	+60%/-30%
General / Buildings	0.04	14.4	+75%/-100%	+300%/-50%

* ADt – Air Dried tons

[3] Source: Benchmarking Energy Use in Canadian Pulp and Paper Mills – Natural Resources Canada (2006)

The energy consumption for recycled pulping has been validated against data obtained directly from Voith[4] for stock preparation which gives the energy consumption (electrical) for a 500 tonnes per day (tpd) process as 175 MWh/day i.e. 350 kWh/ADt.

2.6. Impact of carbon legislation

The Climate Change Levy (CCL) is charged on non-domestic energy bills for both electricity and selected fossil fuels including natural gas. The CPI manages the sector Climate Change Agreement (CCA), which is a sector level umbrella agreement with associated energy performance targets. These targets need to be achieved, or carbon purchased if they are exceeded, if the Levy rebate is to be maintained. The CCA provides a significant financial benefit to the Sector through Levy rebate and is therefore a significant driver for energy efficiency. The average Levy rebate per site (assuming the maximum rebate is achieved by all sites) would be approximately £1.0 million[5] per year based on the Sector energy use presented in Section 2.5.1.

The beneficial effect of CCAs on energy performance is difficult to quantify in isolation. The paper industry has had a CCA since 2001 and this will continue until 2012 with the potential for this to be extended to 2017. The extension to CCAs is under review by Government.

The other major direct carbon regulation which impacts on the paper industry is the EU Emissions Trading Scheme (EU-ETS). The larger mills will be direct participants in the EU--ETS and hence will need to manage their CO2 emissions within the annual allocations. Even where mills are not direct participants they will be indirectly impacted by the EU-ETS due to the knock on effect of this scheme on electricity generators and hence whole sale electricity prices. The other impact on the electricity generation industry which will be passed through to customers is the Renewables Obligation (RO) which requires suppliers to provide increasing amounts of renewable electricity. The cost of the RO will again impact on the costs for electricity supply (new infrastructure and cost of incentive). The EU-ETS and RO are examples of mechanisms to support the move to a low carbon economy that will result in the "cost of carbon" increasing through direct compliance requirements. These costs will be passed through by electricity suppliers and will impact on cost of raw materials. However, for organisations that are proactive in reducing carbon emissions there is opportunity to mitigate cost impacts and also benefit through carbon trading.

With the high volumes of raw materials derived from recycled paper the industry generates significant volumes of waste fibres which are unable to be reprocessed and deinking wastes. New technologies offer the possibility to convert this waste into clean energy which could provide benefits to the sector under the renewable heat incentive.

2.7. Progress on improving energy performance

Sector interest in energy efficiency has always been high driven predominately by cost control but more recently by compliance and to a lesser extent corporate responsibility.

The sector as a whole has achieved a 12% reduction in specific energy consumption between the first and fourth target periods within the Climate Change Levy agreement. While some of this improvement may be down to less efficient mills closing, some of the improvement will be due to technological and energy management

[4] Reducing energy costs – A challenge in stock preparation – Voith Technology (www.voithpaper.com/media/03_Energie_FS_E_72dpi.pdf)
[5] 16720GWh Fossil Fuel, 2512 GWh imported electricity, 80% rebate

improvements. Past focus appears to have been on good practice actions particularly on primary plant services. For example actions include:

- Increasing press dryness (for example through the use of shoe presses);
- Improvements to press and dryer fabrics;
- Addressing machine efficiencies – reducing sheet break and grade change times;
- Improving chest agitation;
- Improving pumping systems through elimination of excessive safety factors in design, improving control regimes (avoidance of throttling flows and recirculation lines);
- Increasing consistency in recycled fibre systems to reduce hydraulic volumes;
- Progress towards closing water loops;
- Maximising stock temperatures through heat recovery into whitewater;
- Maximising the shower water temperatures;
- Reducing heat losses from the dryers;
- Monitoring and targeting/benchmarking of steam consumption;
- Avoidance of steam venting;
- Improving control systems for paper machines and utility systems.
- Conventional improvements to utility systems e.g. compressed air, steam traps, steam leak reduction.

2.8. Business drivers

The paper industry presents many of the features typical of a commodity market with little evident differentiation between products from competing suppliers and customers rewarding those suppliers who can sell product of a sufficient quality at the lowest price. Where customer influence has an effect it is focused more on recycled content and the sustainability of the virgin fibre sources than on either the energy consumption or carbon emissions associated with the paper manufacturing process.

What is also apparent is that the market demand for certain categories of paper is changing as more information is accessible via the internet, for example, the online editions of magazines and newspapers and the arrival of e-books.

To add to the challenges facing the industry papermakers have also to face the impacts of globalisation with manufacturers located in China, Russia and Latin America able to deliver pulp to the American and European markets for the same cost as domestic suppliers. Whilst the pulp market itself is changing the global demand for pulp is still rising, thus pulp prices remain firm. High raw material costs coupled with weak product values is squeezing producer margins and focusing attention on cost reduction although reduced margins also mean that capital availability for investment is constrained.

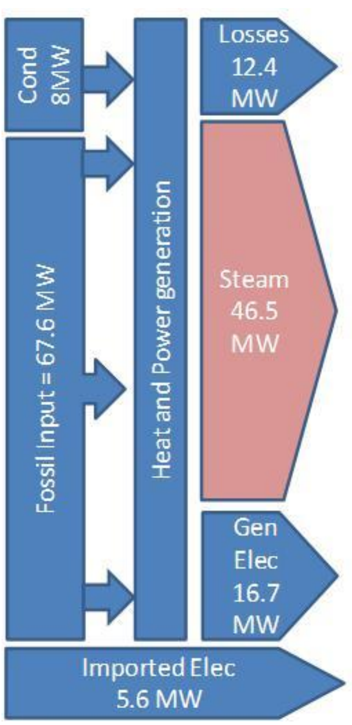
The sector has expertise in the processing of biomass – one possible vector for the industry could be diversification into bioproducts with higher value added than paper.

3 Methodology

3.1. Overview of the process

The objective of Stage 1 of the IEEA work is to identify the technological opportunities to deliver carbon savings though innovation in the paper making process. To aid this process a generic energy consumption model for a paper mill has been created which allows the allocation of consumption and associated carbon emissions to key stages of the process. With the sector being an advanced user of combined heat and power systems, the model includes embedded CHP with the CO2 emissions allocated to end use on an energy content basis. Figure 5 below shows the model of the paper mill.

Figure 5 *Generic Energy Balance for a Paper Mill*



Area	Electricity	Steam
Stock preparation	3.79	
Vacuum Systems	3.57	
Wire Section	1.56	
Press Section	2.01	6.51
Dryer Section	2.90	31.61
Calendar	0.22	1.39
Runnability/Ventilation	2.01	3.72
Compressed air	0.89	
Water systems	1.12	2.32
Hydraulic/Lubrication	0.89	
Broke Systems	0.89	
Others	2.45	0.93
Total	22.30	46.48

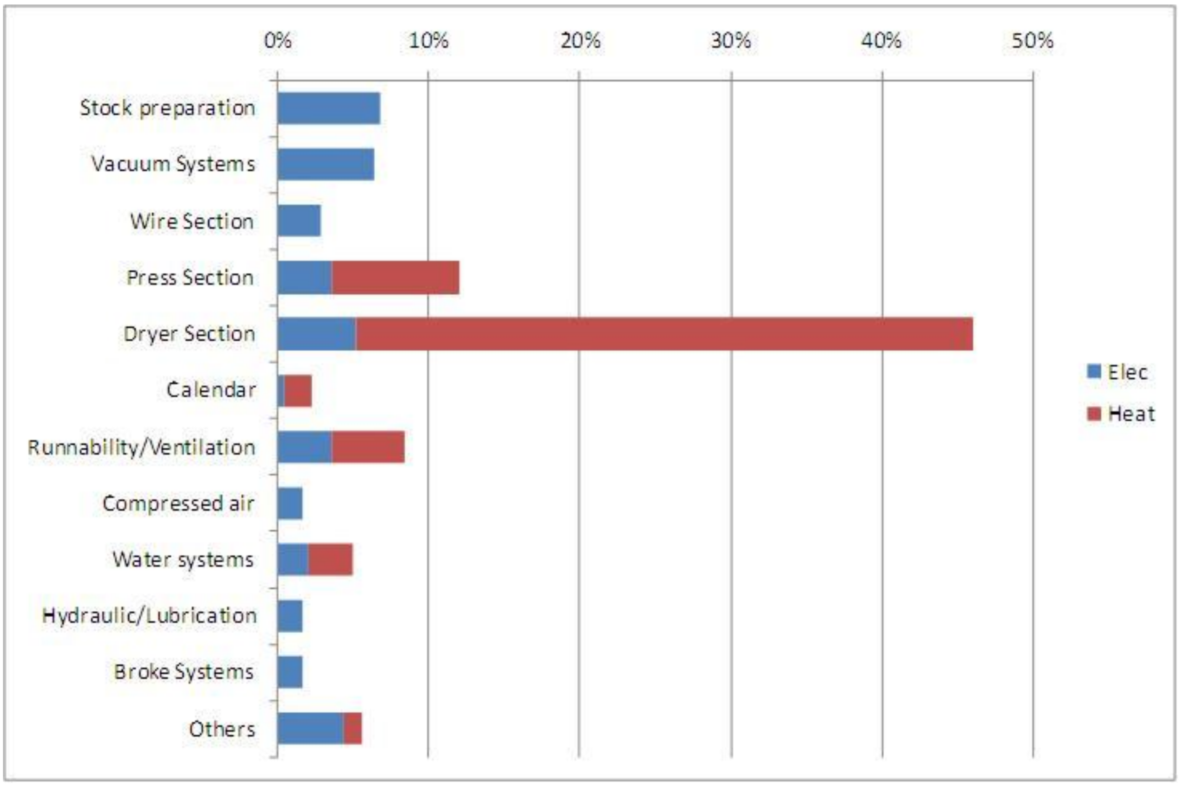
*** Cond – Condensate recvcled**

This model has been calibrated to the CCA data for the sector and gives agreement in terms of the specific energy consumption – at 3940 kWhp/ADt. The model has also incorporated data from the NRCan[6] benchmarking study and specific technical papers from Voith[7] and Metso[8] .

To arrive at this model requires steam consumption in the dryer of 1.84 kg/kg water evaporated (See Appendix A) and hence implies a dryer efficiency of 48%. These values are to be compared against measured data from the monitoring sites.

Taking the date from Figure 5 above it is possible to map the carbon emissions for the production process, as shown in Figure 6.

Figure 6 *Sources of carbon emissions for a Paper Mill*



3.2. Energy costs

For a paper mill producing on average 500 ADt/day the annual emissions would be 127,000 tonnes of CO_2 and using typical energy costs of 2.5p/kWh for fossil fuels and 4.5p/kWh for electricity the annual energy spend would be £15.5 million per year. Of this value the paper machine (i.e. Vacuum Systems, Wire/Press/Dryer, Ventilation/Operability, Calendar and Broke) will represent 76%.

[6] Benchmarking energy use in Canadian Pulp and Paper Mills

[7] Reducing energy costs – A challenge in stock preparation - Werner Brettschneider – Voith Paper

[8] Paper machine air systems as tools for improving energy efficiency – Petri Norri - Metso Paper – COST paper

The paper machine is a continuous process. Exact operating regimes for paper mills vary in terms of total operating hours but for a highly utilised plant it will run for 24/7 with short gaps every couple 2 weeks for simple maintenance, a day down every 4-6 weeks for routine maintenance. There will also be production stoppages due to paper breaks. Overall the best practice mills will be aiming for uptime of 90% and upwards therefore for highly utilised plant energy demands are reasonably constant.

3.3. Monitoring strategy

3.3.1. Participating sites

Site visits were undertaken to four mills with the primary purpose to define the information required to characterise the energy consumption profiles of the manufacturing process in terms of gas usage and electricity usage. The visits demonstrated that there was significant diversity in terms of energy supply and that substantial investment in metering would be needed to provide a full picture of energy consumption at the sites. This was not going to be possible within the scope of the budget allowed for the project hence there was a need to prioritise the monitoring programme to focus on the key areas of energy consumption in paper making.

From the site visits three of the four sites were taken through into the detailed monitoring programme where additional metering was installed. The primary criteria for selecting the sites were:

- There was an enthusiastic management team in place keen to make their plants more efficient;
- That with the monitoring installed the main energy consuming stages of the process could be addressed;
- The plants should be producing the main products – printing and writings and/or packaging;
- The production lines should be well metered as possible –enabling access to process data; and
- Meter installation could be achieved at reasonable cost with no serious health and safety issues.

The sites selected for the monitoring programme have the following characteristics:

- Site A. A speciality paper maker producing a range of coloured papers. This site has the peculiarity that it is in operation only 5 days per week and shuts down most weekends. Given the broad range of products this site has frequent grade and colour changes. This site has a heat recovery system on the hood exhaust which was considered as quite advanced.
- Site B. Also active in the print and write sector this site manufactures fine papers. The site has a gas turbine CHP plant with waste heat recovery steam generator and steam turbine. The site has 4 paper machines. The paper is manufactured from imported pulp, there are no paper recycling facilities on site.
- Site C. Active in the packaging sector this site produces test liner and waste based fluting. The site has a single paper machine and a recycling facility.

3.3.2. Monitoring requirements

To characterise and quantify carbon emissions from the sector a detailed monitoring strategy was defined. This included collection of key energy flows to the plants (electricity, steam) alongside production and control parameters. Given the scale and complexity of the plants the monitoring strategy had to focus on key process steps which were felt to offer the greatest potential for eventual technology projects. The areas of focus for monitoring were:

- **Air flow in the paper machine hood**. The objective is to understand the energy balance around the hood – heat is recovered from the exhaust from the hood and used to heat air entering the paper machine hall and in some cases water for space heating. Air for the paper machine is drawn from inside the hall. The measurements of interest were flow-rates, temperatures and relative humidities (or dewpoints) in the exhaust ducting and temperatures / flow-rates of the air entering the paper machine hoods.

- **Vacuum Systems**. In the sites visited a significant energy demand is accounted for by the vacuum systems. Whilst the electricity for vacuum and the vacuum level is well known and monitored the measurement of the vacuum air flows is not. One potential opportunity exists through optimisation of the vacuum systems and hence understanding how the air flows vary through the lifetime of the felt and how the vacuum systems are controlled is important. Equally there are different configurations of vacuum systems – some have pumps dedicated to specific parts of the process, others use common headers.
- **Energy generation** – The use of energy is one part of the equation – paper mills have quite complex energy generation plant often comprising CHP plants with both gas turbine generators and steam turbine generators working in parallel to supplementary boilers and in some cases waste to energy plants. Paper breaks cause havoc with energy generation, when breakages occur on the paper machine steam demand falls abruptly and the energy generation system has to cope with this sudden change in demand, hence the objective is to monitor the energy generation plant over a period (gas turbine and supplementary boilers, steam turbine if present, steam pressures and steam flows, gas flows) to understand the scale of the opportunity for steam accumulation or improved control system. Optimisation of the energy generation system is thus also an area of opportunity.

To provide the context for the monitoring process measurements were also taken:

- Production rates and grades (grammages)
- Moisture content
- Water removal rates
- Steam pressures.

The data collection was to a large extent dependent on the site process data collection systems in place – although it was possible within the scope of the project to test new microwave moisture measurement equipment.

High frequency data were collected – for the production data a 2 minute data frequency was defined – the energy monitoring was also configured to provide high frequency data.

3.4. Engagement with the sector

The project has proceeded with the involvement of the sector, in particular Steve Freeman from the CPI and Barry Read from PITA. This has been achieved by a regular dialogue with the sector through the CPI and PITA and also a series of sector workshops.

- 26th March 2010 - This workshop was used to bring forward ideas for key technologies for Stage 2 of the Accelerator programme and to discuss criteria for sector interest (i.e. what factors would lead the sector to engage in Stage 2). The workshop culminated with a discussion of the supply chain for the industry.
- 12th October 2010 – The installation and commissioning of the monitoring equipment took a considerable amount of time. This workshop was held after the PITA annual meeting and had the objectives of reporting back to the sector on the progress that had been made and in addition to start the process to distil the long list of technologies identified in the first sector workshop down to a shorter list of priority technologies for the sector.
- 7th December - the priority technologies were presented to the Process Issues Committee of the CPI.
- 15th February – discussion on the draft report and consensus on the project's recommendations.

In addition to the sector workshops two articles have been written for Paper Technology, the PITA magazine.

This engagement with the sector has had three key objectives:

1) To identify and prioritise potential innovations that will deliver a step change in CO2 emissions from the sector

2) To identify the barriers to the adoption of innovations

3) Ultimately to promote partnering between organisations, in particular technology suppliers or researchers and paper manufacturers.

3.5. International perspective

From a European standpoint three countries – Germany, Finland and Sweden account for 47.9% of paper production, the next major producers are Italy (9.5%) and France (9.4%). These countries are also home to the most vibrant machinery manufacturers and service suppliers to the sector. Outside of Europe there are also centres of technological excellence in Canada and the USA. One of the key market trends is the emergence of China and Latin America as major sources of paper.

The paper industry is global and the equipment manufacturers also operate globally. Whereas in other sectors which are more regionalised innovation occurs in the main centres and then ripples out, in the paper industry the main opportunities for innovation are in new builds and in major refits which can happen anywhere in the world but are now more focussed in the developing countries.

The main focus for innovation within the industry has been defined in terms of increased speed, increased productivity, increased specialisation and better production quality. The innovations have tended to be evolutionary rather than revolutionary – the design of a modern paper machine is not too dissimilar from those from the 1950s or 1960s – the major changes are in:

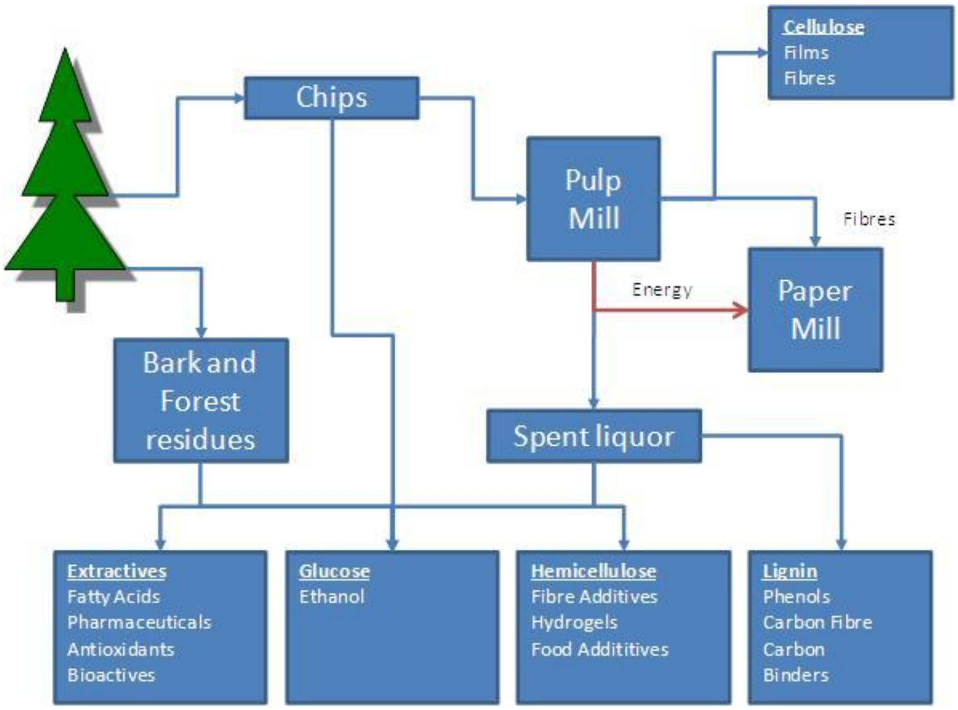
- Automation and controls that allow the paper machine to operate faster;
- The width of the web – the newest machine in the UK – at Palm Paper in Kings Lynn has a width of 10.63 metres and runs at speeds of up to 2000 m/min;
- Better felts which improve drainage and heat transfer;
- The integration of heat recovery into the machines – for example through use of thermo-compressors which utilise motive steam to recompress blow-through steam and reuse it in the same dryer section; cascade systems which reuse flash and blow-through steam in different dryer sections that operates at a lower temperature and pressure; hood heat recovery which captures heat from the humid hood exhaust and uses it to preheat the air for the dryer hood and for the machine room;
- Use of gas turbines as part of the energy generation mix at the paper mills – the sector has always been a user of CHP – initially in the form of central steam boilers and pass out steam turbines to generate electricity and to provide steam at the different pressures required – the adoption of gas turbines has continued this trend but increased the percentage of on-site power generation;
- Recycling – the optimisation of paper recycling facilities which have led to increased fibre recovery and improvements in recovered fibre quality.

The international research activities within the pulp and paper sector have been reviewed as part of this project - Appendix B and Appendix C summarise the relevant research activities or objectives of the EU and US Forest products industries. In both instances the industries incorporate both pulp making and paper making and hence research activities address both elements of the overall paper making process. Appendix D presents the technologies developed by Paprican – the Canadian research and development organisation for the pulp and paper sector. Appendix E provides high level information about the technology route map agreed for the Netherlands paper industry (the Energy Transition Programme) – which shares many characteristics with the UK industry – e.g. high reliance on recycling for raw materials.

The common research and development themes that emerge from this analysis are:

- Where industries are vertically integrated (pulp making and paper making) there is a repeated emphasis on the “bio-refinery” concept. Biorefineries would typically integrate several biomass raw materials to produce different biomaterials and bioproducts – i.e. integrating forestry wastes and other sources of biomass, separating the fibres for paper production and converting the wastes into value added chemicals. Even outside of vertically integrated mills, it should be recognised that the biorefinery concept could be applied to process wastes, potentially augmented by other biomass (e.g. agricultural wastes).

Figure 7 *Biorefinery Concept*



- Black liquor gasification is also of considerable interest and is similar to the biorefinery concept. With Black liquor gasification, in place of combustion the black liquor will be chemically processed and will undergo a series of reactions to extract chemicals of value. Process stages envisaged include thermal reforming, hydrocracking and distillation to convert the lignins and hemicelluloses into gases, naphthas and diesels.
- Closing the water cycle. Water is used as a carrier liquid within the pulp and paper making processes. Reduction of the water consumption of the industry will lead to both environmental and economic benefits (lower capital costs of treatment processes). In order to reduce the water consumption requires increasing of the amounts of water recycled which will require the integration of a range of treatment techniques into the process water recovery streams, for example membrane filtration, ozonation and evaporation to remove those chemicals which impact negatively on the paper quality.
- Need to increase solids entering dryers. The dryer is the key energy consuming step of the paper making process using 68% of the heat and an estimated 13% of the total electricity. To reduce the heat demand the solids content of the web at the dryer entry needs to be higher. A 5% reduction of the water content entering the dryer would lead to a 10% reduction in drying energy requirement. This will require innovation in wire and press design together with improvements to the vacuum systems. Since wire and press are mechanical dewatering processes, operating parameter changes to improve drainage are also relevant – i.e. the "hot press" programme which seeks to increase the energy content of the web at the dryer entry.

- More novel approaches also consider replacement of water as a carrier material with either liquid CO2 or (bio-) ethanol. (E.g. Energy Transition Programme NL). This would radically change the energy consumption profile for the paper industry through reducing the energy needed for evaporation. Clearly use of different carrier fluids has impacts on the design and layout and operating parameters of the paper making process.

3.6. Business drivers and barriers

The key barriers to innovation were identified through engagement with the sector – these are summarised below and were incorporated in the evaluation of opportunities which are discussed in Sections 4 and 5.

1. Cost Effectiveness. As identified in Section 2.8 Business Drivers one of the major challenges to the sector is increasing competition driven by imports and overcapacity. This has reduced the margins available to the manufacturers and has limited capital availability for investment. Paybacks on investment of 12 months were mentioned as being the hurdle in the current business climate.
2. Conservatism. Participants in the sector have stated that ideally they would like to be second or third to implement a technology – i.e. there is a degree of risk aversion in the sector. Given the nature of the sector with high capital intensity, high volumes and low margins this is understandable – technological failures would have a significant impact on business performance. For the IEEA programme this would imply that the technologies to be demonstrated will need to be evolutionary rather than radical, or will need to have been established in other sectors.
3. Operability. If any technology contains uncertainty regarding the impact on machine operability this would be a major barrier to its adoption – however the converse also holds – any technology that both reduced energy consumption and improved operability would be perceived as offering additional benefits to the sector.
4. Operational Costs. The sector is under severe pressure on margins, while low carbon technologies should reduce operational costs this should not be accompanied by increases in maintenance costs for the equipment installed – if the maintenance needs are onerous in comparison to the benefits then the equipment will be mothballed – this has been the case with some heat recovery systems.
5. Business Case. This will need to be robust, i.e. savings must be deliverable and all financial savings and costs captured. The Sector would like to see all potential benefits captured, e.g. could a carbon reduction measure also help deliver productivity improvements or reduce maintenance requirements.

4 Key findings

In this section we describe the key findings from the monitoring carried out at the host sites and discuss what the data tells us about the opportunities for reducing energy consumption in the sector. The analysis of the data from each site is presented separately and then common themes are discussed in the summary to this section.

Note that not all measurements were eventually used in the analysis and not all the data collected during the course of the project have been included in this report. However, all data collected and associated spreadsheets have been supplied to the Carbon Trust as part of the complete project record.

4.1. Site A – air flows / humidities in machine hoods

At one site the focus of the Accelerator project was to understand better the heat balance around the paper machine dryer – in particular the relative humidity of the dryer hood. To ensure that the readings were consistent monitoring was proposed that would enable the construction of a heat/mass balance of the moisture flows in the paper machine. Site A was used as the host site for this monitoring. Site A is a speciality paper producer, manufacturing a wide range of products with varying quality and colour. A mid-sized paper mill, it processes around 40,000 tonnes of pulp per annum and is a stand-alone business with interests in paper converting and retailing as well as paper manufacture.

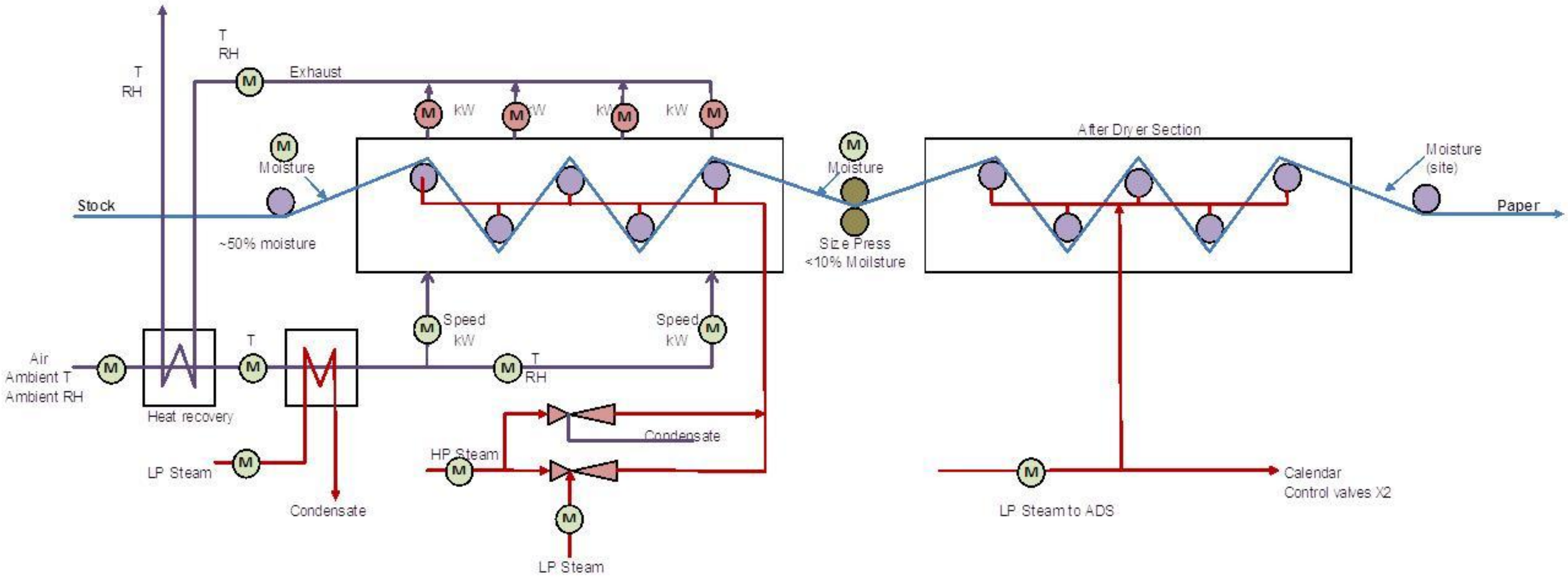
Site A has a number of paper machines of varying sizes and capabilities and the machine chosen for the project also had several heat recovery technologies in place – most notably air to air heat exchange to preheat the air to the dryer and flash steam recovery from condensate, both of which should reduce the demand for primary steam. A schematic of the dryer is shown below in Figure 8.

The selected paper machine was fitted with a number of new instruments as well as connecting existing steam meters to an automatic data collection system. The dryer itself was not well monitored – steam flows and machine speed were the only process parameters routinely recorded by the plant.

To increase the understanding of the process heating efficiency, additional measurement points were installed to monitor air flow, temperature and humidity as well as an additional steam meter in the air preheater. Of great interest to the site, and to the sector in general, was the demonstration of two microwave instruments for on-line continuous moisture measurement and whether they could be used for control purposes.

The site also installed a local workstation to see real-time process measurements and conduct trials during the monitoring period. This has proved highly beneficial in a number of ways and is to be commended for future projects of this nature.

Figure 8 *Schematic of meter system, Mill A*



4.1.1. Moisture measurement

As noted above, one of the trials during this period was the use of continuous on-line moisture measurement of the paper at various stages of the process. This was achieved using two microwave moisture measurements supplied and installed by Invista Ltd. The sensors were installed at the inlet to the dryer after the press rollers and at the outlet of the dryer before the size press. The sensors take spot measurements at a single point on the sheet, so may not be fully representative of the average moisture content of the sheet.

Experience of the data output has been mixed, with some concerns over sensor calibration, location and sensitivity. However, for much of the trial the monitors did yield credible data, indicating the moisture content of the sheet at the inlet and outlet of the dryer.

The following chart show that the dryer does achieve a consistent product quality across the hood, with input moistures varying between 200 – 550 g/m².

Figure 9 *Dryer Inlet and Outlet Moisture content (2 minute readings, zeros and blanks removed)*

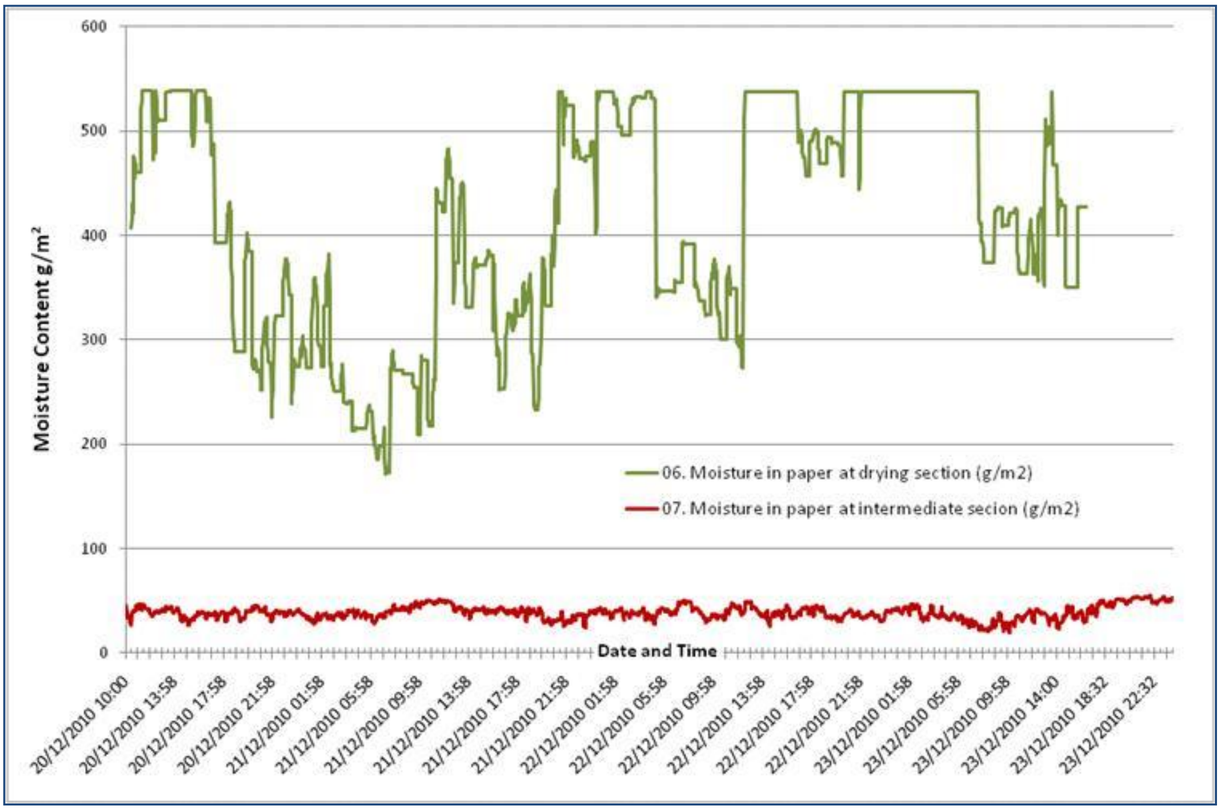


Figure 9 shows the 2-minute readings for the inlet and outlet moisture meters for a 4-day period (20-23 December 2010). This shows that the moisture level of the feed from the press varies considerably, while the moisture content of the product is much more consistent.

Figure 10 *Dryer Inlet and Outlet Moisture content (by paper grade)*

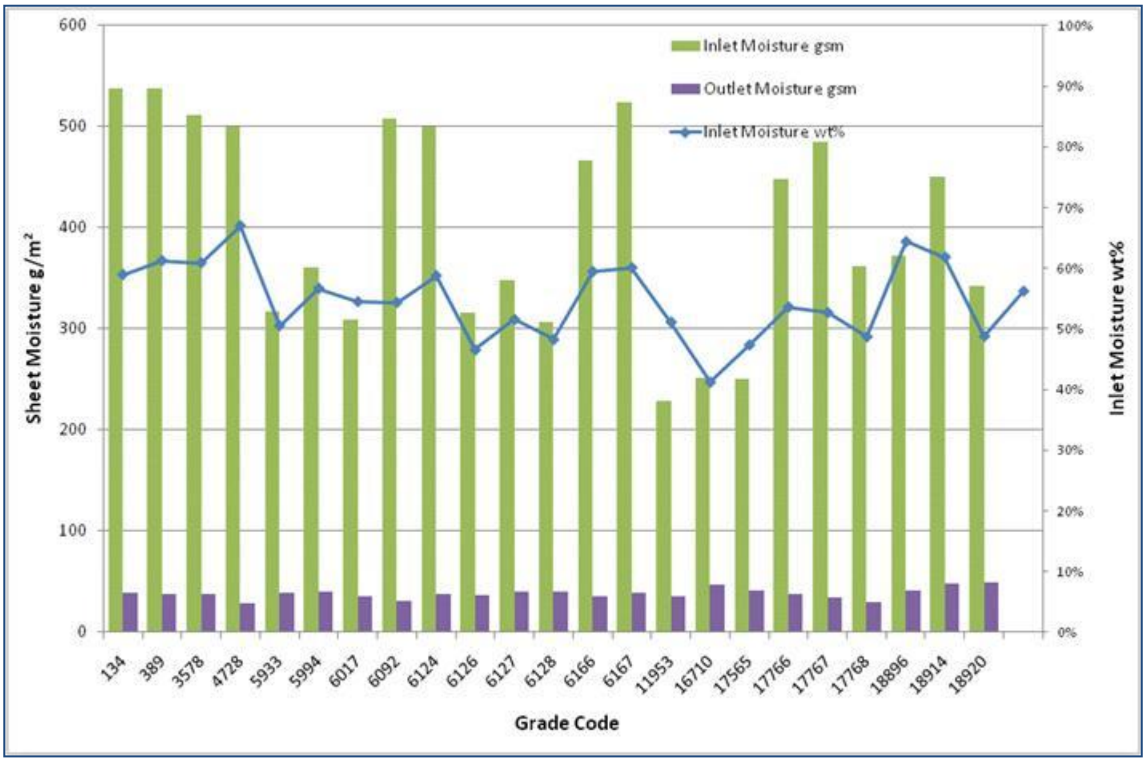


Figure 10 is the same data, grouping performance by product grade. There is a significant variation between the inlet composition of the sheet depending on the grade of paper in production, but the outlet content remains consistent. The line on the chart is the moisture content of the feed expressed as weight% moisture and this shows a less pronounced variation, between 40% and 65%.

The outlet moisture content of around 30 gsm is actually equivalent to around 2% by weight. This seems low, as the end product typically has a moisture content of around 7%. This suggests that the paper is being over-dried before size is applied.

With more confidence in the moisture sensors it should be possible to fine tune the performance of the dryer. To be fully effective, these measurements must traverse the whole sheet rather than take spot measurements, so further development of these sensors would be a valuable application of additional R&D funds.

Key Finding

On-line moisture measurement. The experience of using the microwave moisture measurement has been a mixed success. On the one hand the microwave meters do appear to provide a good indicator of changes in sheet composition; on the other hand the absolute values appear to be open to question and the difference between the two measurements across the dryer does not reflect the volume of moisture removed from the sheet during drying.

The plant in question appears to be over-drying by about 5%. This is equivalent to around 2,800 tonnes of steam per annum at this plant (say 2,500 MWh of primary fuel) and, if replicated across the industry for 6 million tonnes per annum production the energy penalty of this is 312,500 MWh, or £6.25 million per annum and 57,800 tonnes of CO_2 per annum.

4.1.2. Dryer air humidity

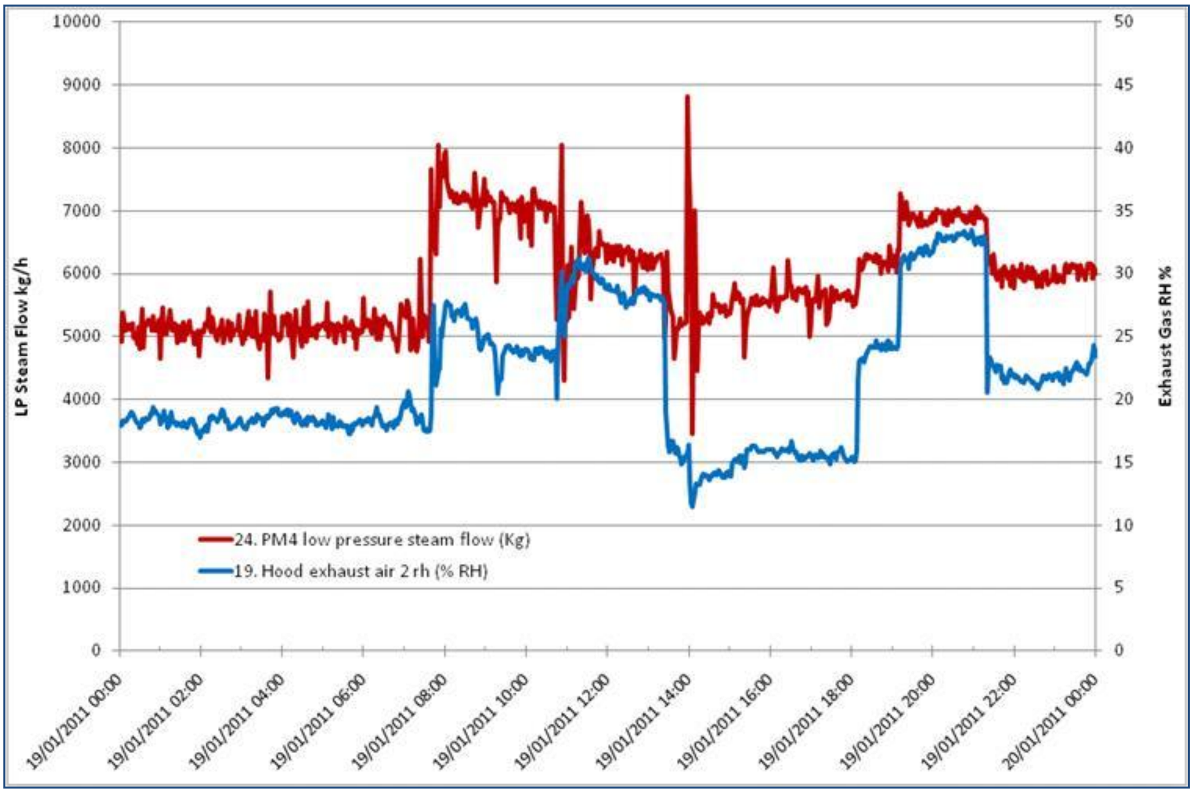
Another way of monitoring dryer performance is to track the humidity of the exhaust air. The capacity of air to absorb moisture increases significantly with temperature – at 20 °C air is saturated at 17 g/m³, while at 60 °C the saturation point is 130 g/m³. So, at the typical exhaust gas temperature of the dryer (70 °C), the air should be able to carry away over 200 g/m³. With an air flow relatively constant of around 85,000 m³/h the capacity of the air to remove water is equivalent to a drying rate of 17,000 kg/h.

In fact the drying rate required by the machine is, at typical production rates, around 4,000 kg/h. Therefore, the relative humidity measurements (i.e. expressing water content as the % of saturation concentration) of around 25-30% are consistent with the plant operation.

Humidity measurement in the exhaust air has proved problematical. In particular, the RH meter on the dryer exhaust has failed several times due to condensation on the sensor during the weekend shut-down periods. This has the effect of pushing the reading to several hundred percent – clearly an impossible result – over a short period of time and the sensor take some time during the start-up period until the reading settles back to a credible value.

A typical RH profile during operating hours is shown in Figure 11. There is no obvious correlation of other process parameters to the variation in exhaust gas RH. Possibly the closest linkage is with LP steam, as shown by the following chart:

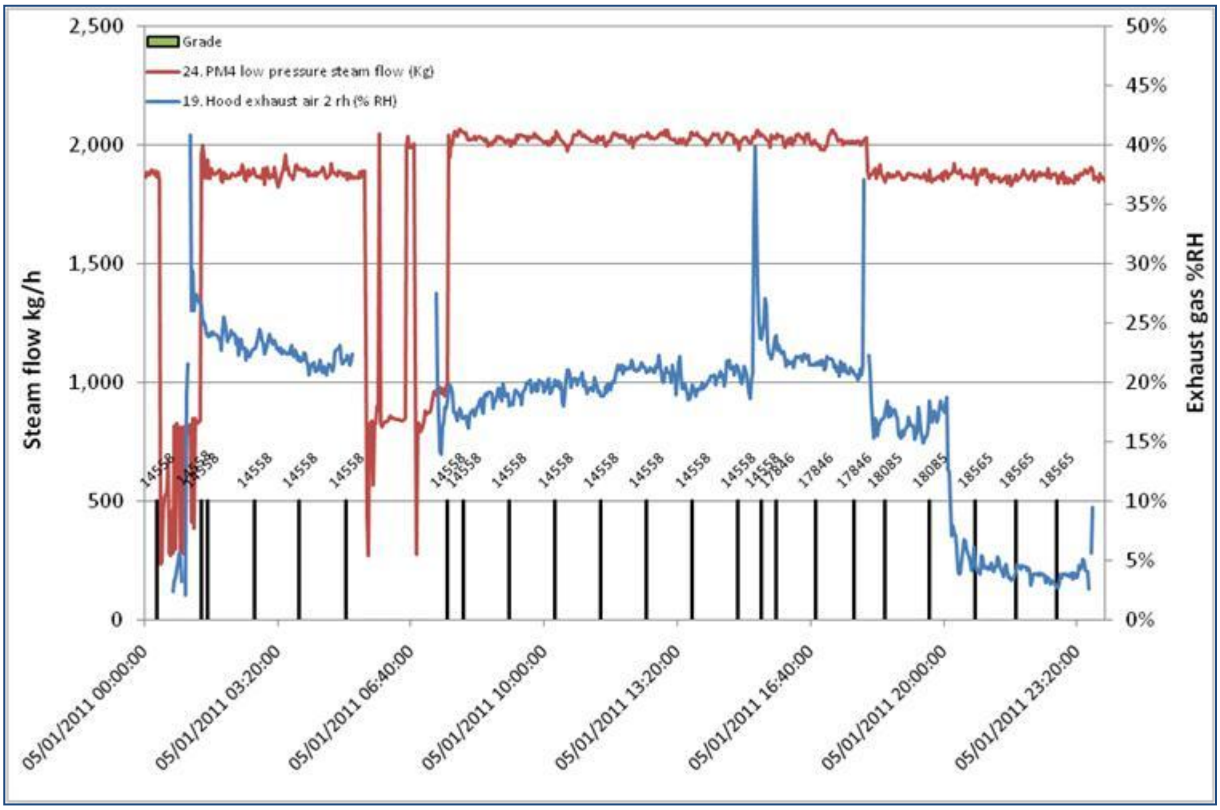
Figure 11 *Exhaust Gas RH and LP Steam Flow – 19 Jan 2011*



This suggests that the steam flow is driving the evaporation rate, whereas ideally it should be the required evaporation rate that should determine the steam flow. This can be achieved through the use of the RH measurement in a control loop to set the required steam flow (possibly coupled with the signal from the incoming stock water content).

Another day's data is shown in the following chart. This is a plot of the exhaust gas RH and steam flow, on which we have also noted time-stamped events, i.e. reel and/or grade changes. The black vertical lines show the event and the grade label. In this case the same grade was run for a considerable proportion of the day, so not surprisingly the RH trace and steam flow are relatively constant during these periods, although there is a number of missing data points.

Figure 12 Exhaust *Gas RH and LP Steam Flow – 19 Jan 2011*



At 70 °C, 20-25% RH represents a moisture content of 47-59 g/m³. The inlet air flowrate is estimated to be around 80,000 – 90,000 m³/h (from fan speed measurements) so this would imply a moisture removal rate of around 4,500 kg/h (say 90,000 m³/h of air @ 50 g/m³). This is consistent with the estimated moisture content of the stock entering the dryer at around 55% w/w moisture (See Section 4.1.1) and leaving at less than 10% w/w, given the reported production rates of between 4 and 5 tons per hour for most grades of product. Calculating water removal via this route does actually give a more plausible figure than the calculation of drying capacity from the two microwave measurements.

Clearly, uncontrolled air ingress through leakage is an issue that needs to be addressed through plant maintenance and operational discipline. However this is not the only story and it should be possible to operate at much higher RH levels without compromising product quality.

The dryer is equipped with two main air supply fans. These fans are fitted with variable speed drives (inverters) but the inverters are not used in a control mode. Using the RH signal to control the fan speed could help to reduce the volume of air required. This in turn should reduce the steam demand and, with higher exhaust temperatures, increase the performance of the heat recovery plant.

Key Finding

Control of Exhaust Moisture Content. As noted above, using the Relative Humidity signal to control fan speed to a set point of, say, 50% should result in reduced energy consumption in the dryer as well as delivering additional power savings in the operation of the fans.

4.1.3. Heat recovery

The initial assessment of dryer efficiency suggests it is much lower than the "typical" 1.6-1/8 kg steam/kg water suggested by the theoretical model. However, it has not proved possible to completely validate the performance, owing to discrepancies between the two methods of moisture measurement. Discussions with site suggest that there are still some discrepancies in the steam metering that they need to address but that they accept it is not the most efficient of dryers. There is significant air leakage (which will affect the heat balance shown in Figure 13).

This dryer is equipped with a heat recovery system that preheats incoming fresh air using the exhaust gas from the dryer. A simple schematic is shown below (Figure 13), using average process measurements for the period 20-23 December. The average value for each parameter is based on 2-minute readings with zeros and negative readings (i.e. false records) removed.

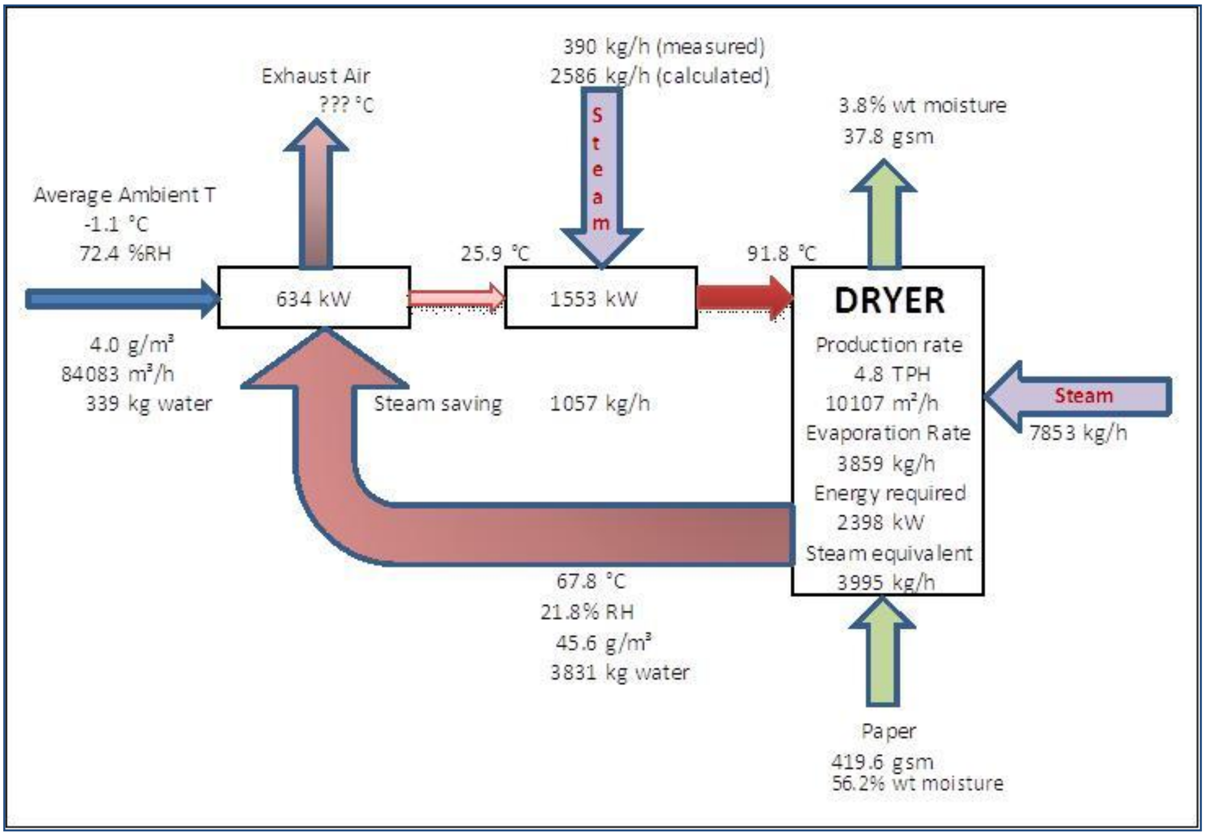
The air preheater provides about 30% of the air preheat to the dryer as calculated from the temperature rise of the air across the heater. We cannot check this against the exhaust outlet conditions as they were not measured.

This is clearly a valuable contribution to the overall heat balance. However, as we can also see, the steam being used to dry the paper in the hood is around 2.4 times the amount of evaporation. This is well in excess of the theoretical figure of 1.2 kg/kg and still well above the industry norm of 1.8 kg/kg.

Discussions with the site suggest that the heat exchanger is not in a good state of repair. It is a glass tube exchanger, which is prone to breaking tubes through thermal shock, particularly on plants that are frequently subject to start-up and shut-down heating fluctuations. It has not been inspected in several years so broken tubes are likely, which will reduce the heat transfer surface area and result in leakage from exhaust gas to inlet air, or vice versa.

It is possible that this specific technology was chosen for ease of cleaning, but this requires frequent inspections so it is likely that the remaining surfaces are fouled.

***Figure 13** Schematic of dryer heat balance showing heat recovery*



Key Finding

Exhaust Air heat recovery. There is obviously some benefit in recovering heat from the dryer exhaust, as it contributes around 30% of the air reheat duty. The limitation on heat recovery from the exhaust air into the feed air for the hood is the relative humidity of the exhaust air – an air to air heat exchanger will typically operate 'dry' i.e. the minimum temperature of the exhaust air at the exit of the dryer will be above the dew point. The monitoring shows that there is unexploited potential for recovery – with the exhaust air relative humidity only at 22% and a minimum approach temperature of 40°C.

Equipment selection is key – using a robust exchanger that can operate with a partially condensing exhaust gas stream without a significant corrosion risk is the most appropriate solution. While a glass-tube exchanger may have this anti-corrosion capacity its relative fragility probably makes it unsuitable for this application.

For further information on energy balances around dryers, see Appendix A.

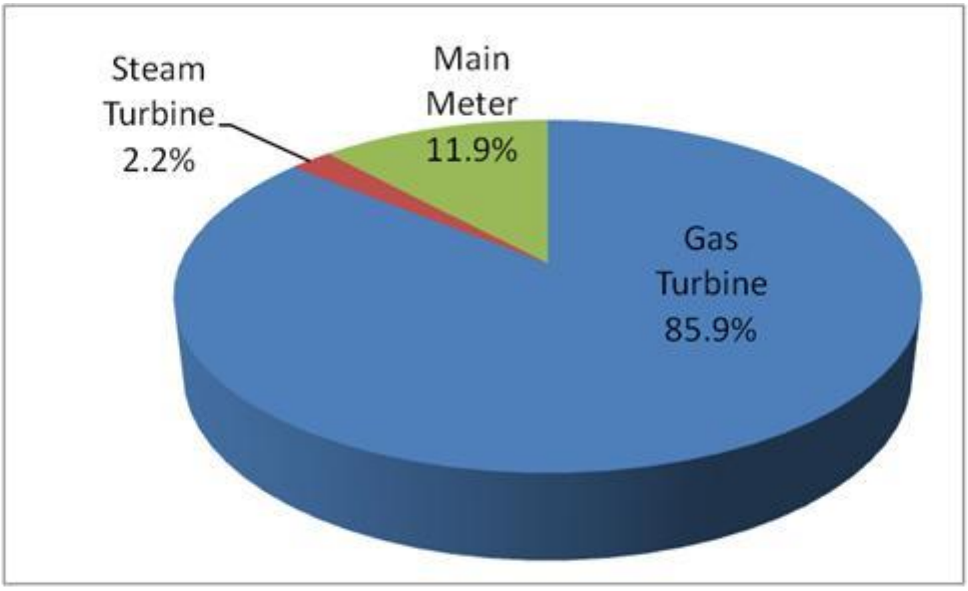
4.2. Site B – heat and power generation

Site B is a speciality paper producer operating in a similar market to Site A. This mill is entirely dependent on a single source of steam – a gas turbine (GT) with auxiliary-fired waste heat boiler (WHB). Additional power is generated by passing the high pressure steam from the WHB through a steam turbine (ST) to supply the site process steam demand. Any disruption to the operation of the power station causes a significant risk to production as there is no back-up steam supply.

The focus of the monitoring was to investigate the response of the power station to changes in production patterns, particularly when paper breaks occurred during production. Paper breaks cause steep reductions in steam demand – if the power generation system is unable to respond to the sudden changes is demand, steam venting can occur which is wasteful of energy. Similarly when the paper machine restarts the demand on the power generation system is also high which leads to issues with pressure control. Advanced control systems offer the potential to improve the response characteristics of the power generation systems in paper mills.

As shown in the charts below, the site is very dependent on power generation from the boilerhouse. Under normal operation there is a small export of surplus power to the grid, but this can change suddenly if steam demand is affected by a process change.

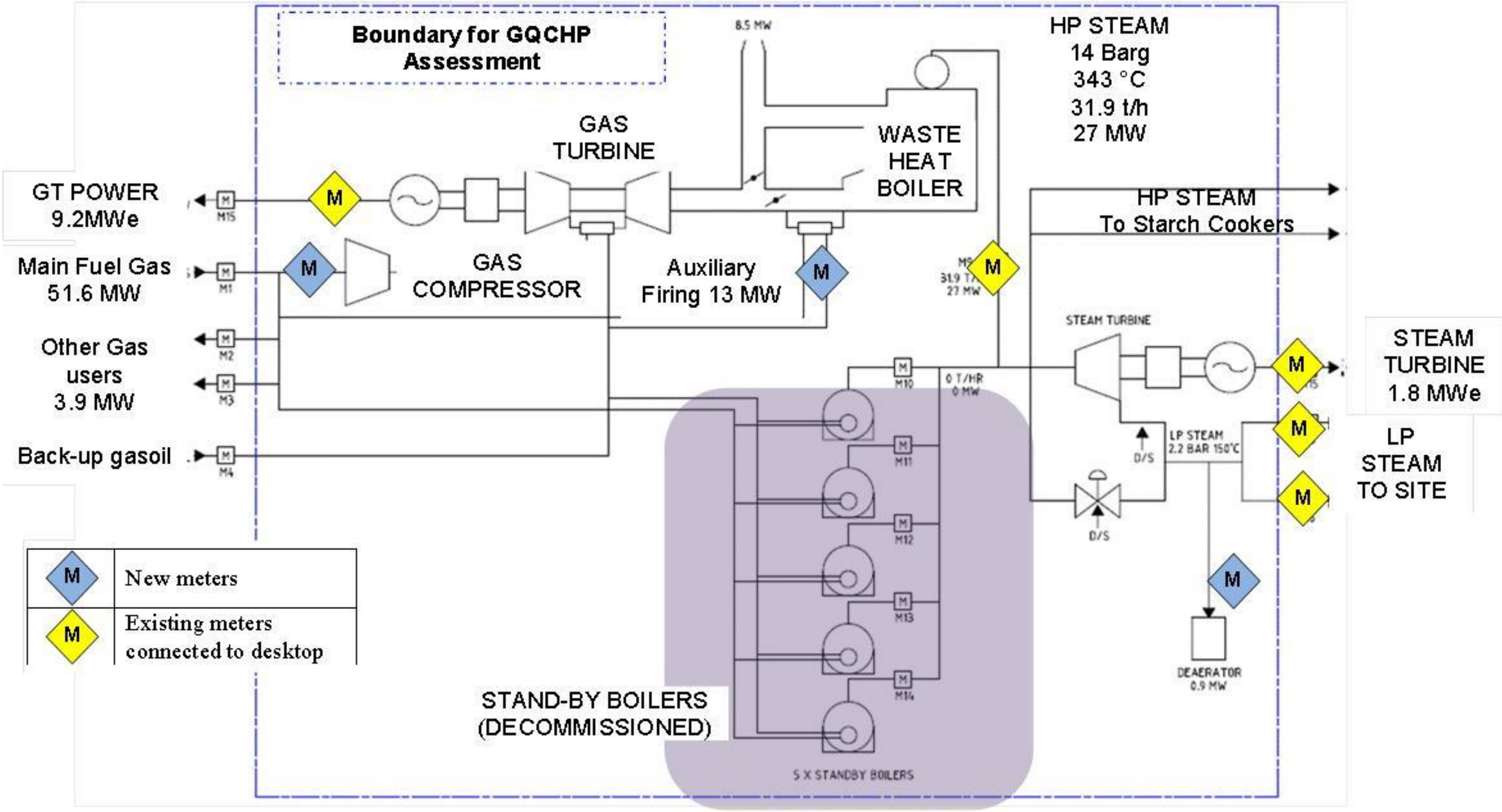
Figure 14 *Site B – Source of Electricity*



The power station in this instance is already relatively well metered to enable the site to report on its Good Quality CHP Index for the purpose of validating climate change levy rebates. However, there was no separate measurement of gas flow to the GT and WHB. The power station configuration is shown below.

`

Figure 15 *Schematic of Power Station, Mill B*



Most of the monitoring programme involved the connection of existing meters to the data capture system. However, in parallel with this exercise, Site B also installed around 30 new electricity meters to enable them to monitor energy use in specific parts of the mill.

Steam use at this plant is as expected, dominated by the 4 paper machines. However, the relationship between steam use and total production is not well-defined as shown by the regression plot (Figure 17).

Figure 16 *Site B, Steam use*

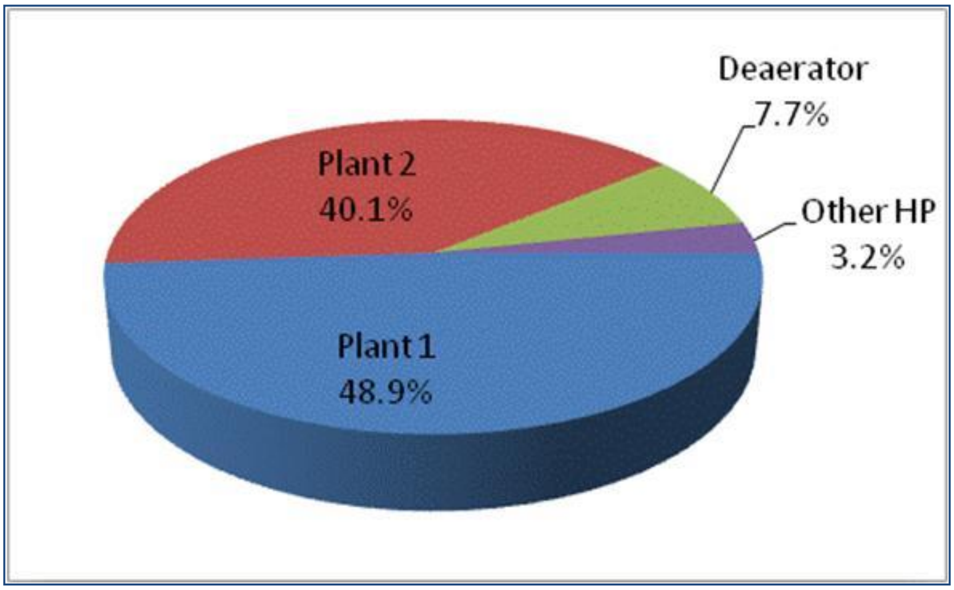
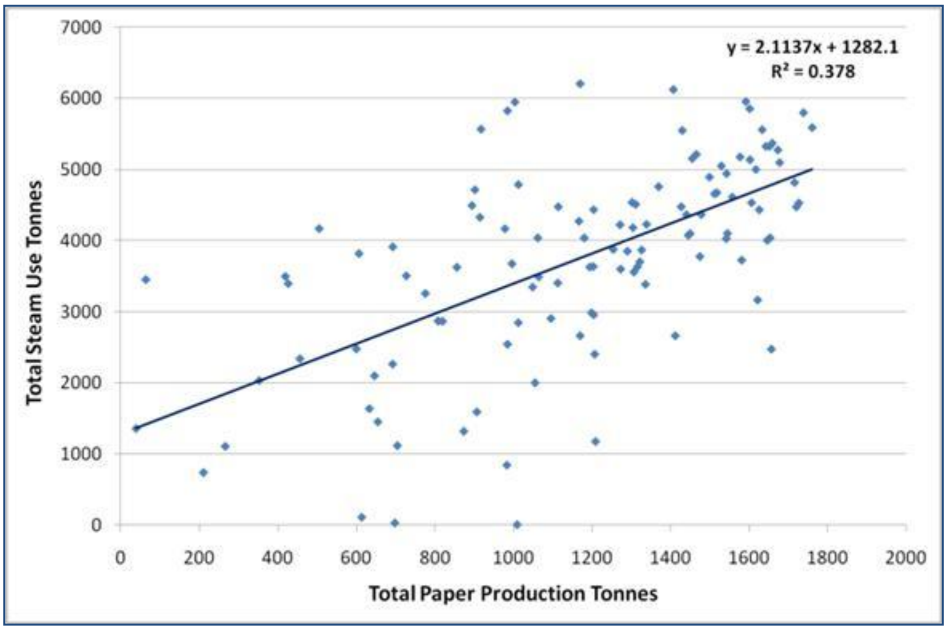


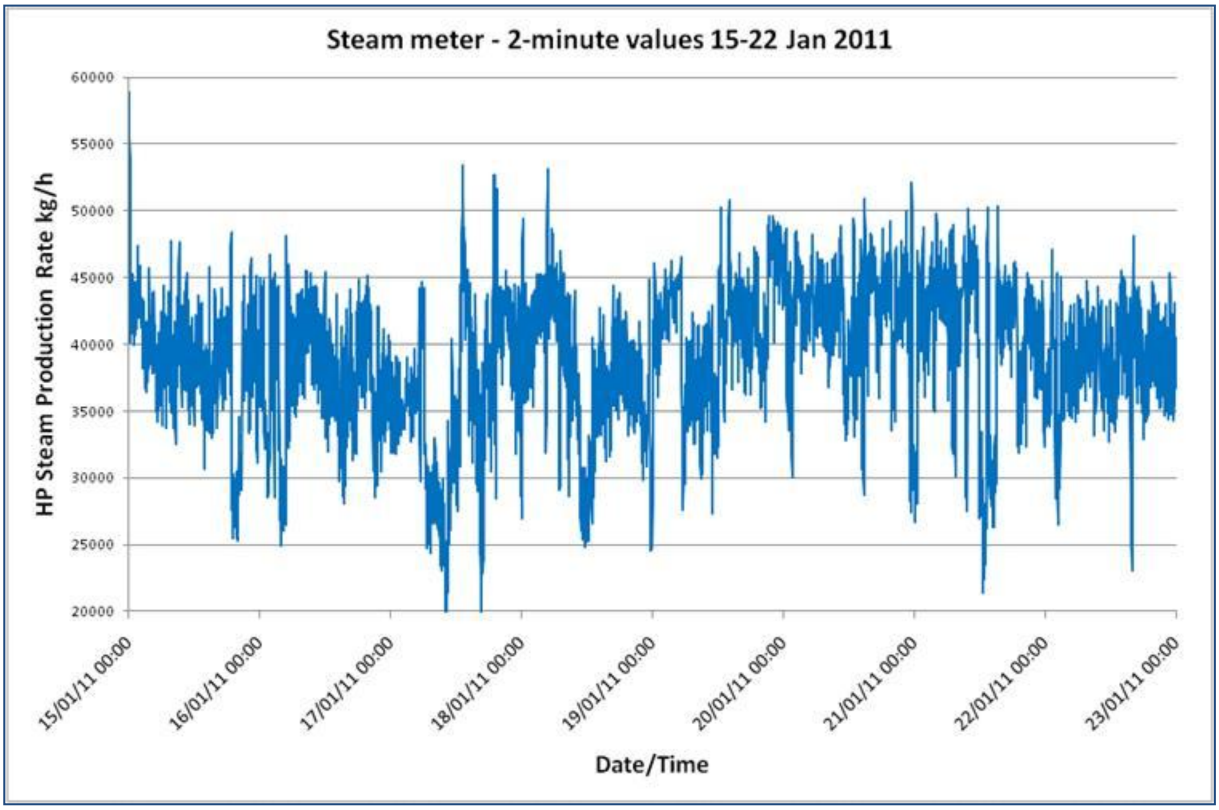
Figure 17 *Regression plot for Production vs. Steam*



This plot, based on weekly production figures and total steam use for 2008 and 2009, suggests that steam usage is not well controlled and that product mix probably plays an important part in determining the site energy needs. None of the paper machines show a particularly good correlation between product throughput and steam consumption, based on the site's existing steam meters.

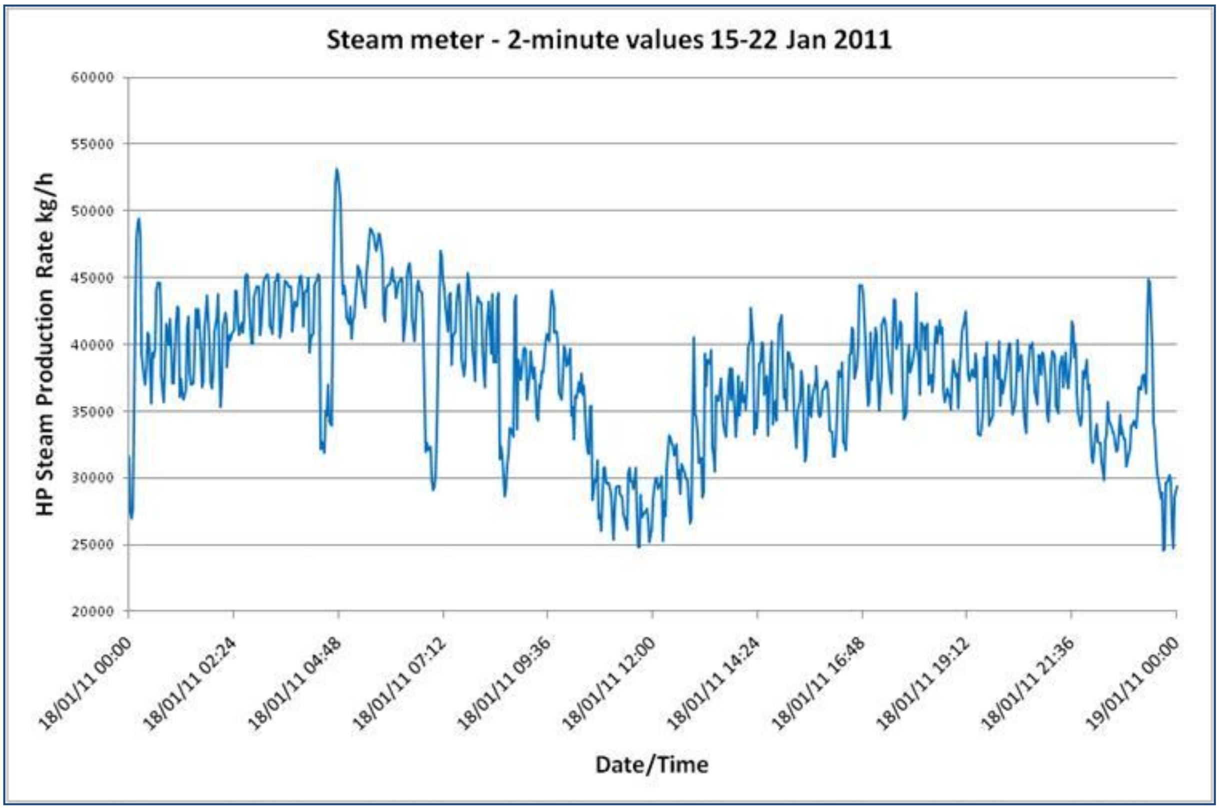
Looking at the site steam usage over an extended period shows that there are significant demand variations over a short timeframe. The following figure shows a plot of 2-minute values for a period of approximately 1 week, 15-22 January.

Figure 18 *HP steam production, 2-minute values*



Looking at a single day, we can still see significant variations, as shown by the next chart.

Figure 19 *HP steam production, 2-minute values over 1 day*



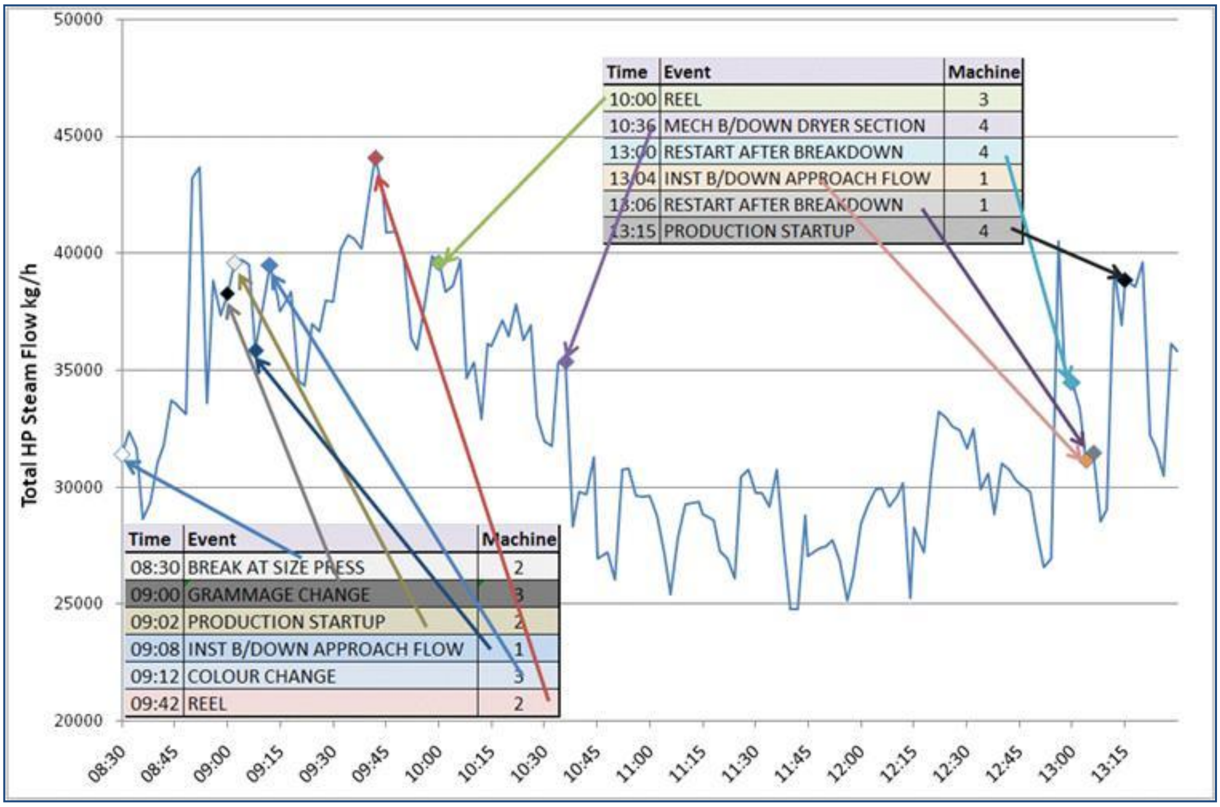
During this period all 4 paper machines were operational, with each experiencing between 8 and 22 operational changes.

Taking a 5-hour period, between 0830 and 1330, there were ten logged event changes on the four paper machines (other than reel changes for the same product grade), as shown on the following chart. Looking at 2-minute intervals, we can see some sudden changes in HP steam demand in both directions – up and down.

For example, after the size press break on Line 2 at 0830 there is a loss in demand of about 3,000kg/h, while after a breakdown on Line 4 the steam make drops by around 7,000 kg/h. Interestingly, there is no up-turn in steam demand immediately after a machine start-up.

The short-term swings in HP steam demand during "normal" operation must have an impact on power generation efficiency so this should be the subject of further investigation. Perhaps one important consideration is the capacity and potential inertia in the steam distribution system, which should provide some buffer storage to absorb some of the swings in demand. Perhaps using a steam accumulator by each paper machine would assist in smoothing out the boiler response requirement.

Figure 20 *HP steam production and event log*



4.2.1. Power balance

For this mill the power balance is a very important driver in minimising operating cost and a process upset leading to a sudden loss of steam demand can result in a sudden increase in imported power, which could impact maximum demand charges at certain times of the year as well as possibly resulting in a short term need to vent steam if the power station cannot follow the load change at the same rate.

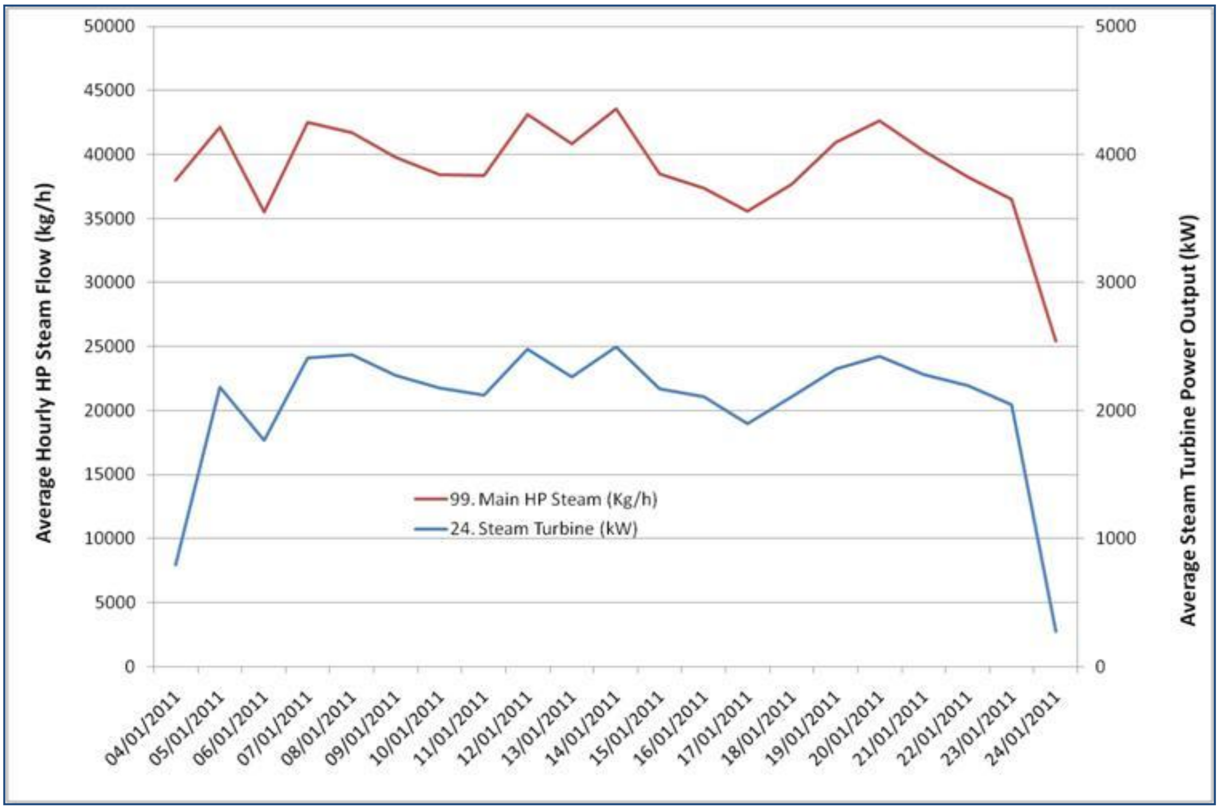
4.2.2. Steam turbine

The steam turbine is a central feature of the power station energy balance, taking HP steam at 14 barg/343 °C from the boiler and passing steam out at 2.2 barg/150 °C to the mill. The load varies according to the site steam demand but typically the demand is of the order of 30 tons/hour, delivering around 1.8 MW of electrical power.

From the figures below, however, it is apparent that there are substantial variances from this norm. HP steam production varies from 20 to 45 tons/h, as shown by the following chart, with “normal” operation at maximum site activity ranging from 35 to 45 tons/h.

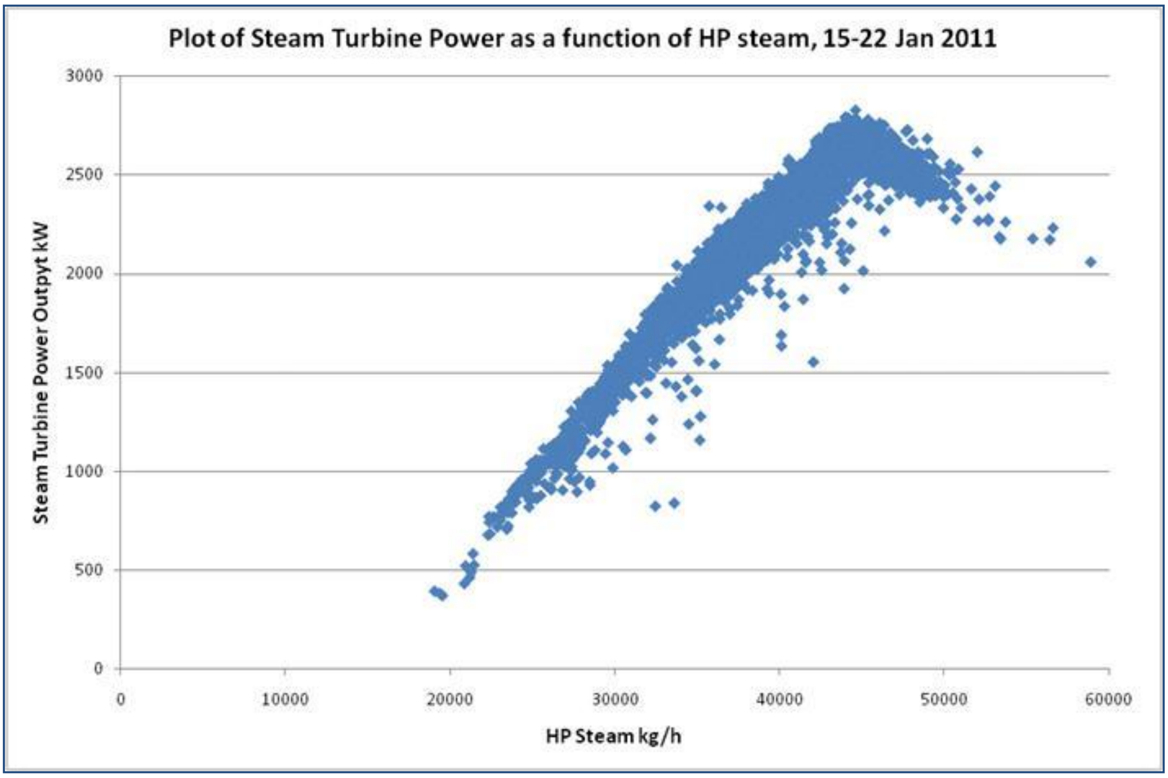
The power output associated with this steam flow is typically in the range 2 – 2.5 MW. Both these figures are substantially higher than the expected power station values.

Figure 21 *HP steam production and steam turbine power output, daily average expressed as kg/h, January 2011*



However, when we look at the specific power output, or the relationship between power output and steam flow, we get an interesting figure that shows that at high steam loads the plant is effectively choking the turbine, leading to reduced power output and efficiency at higher steam flows (Figure 22). This shows that the optimum operating point for the turbine is about 45,000 kg/h, when the power output is expected to be around 2.6 MW. Higher steam flow results in the power output dropping below this maximum. This is typical of any pump, compressor or turbine in that if flows are pushed beyond a certain critical point, efficiency drops off considerably.

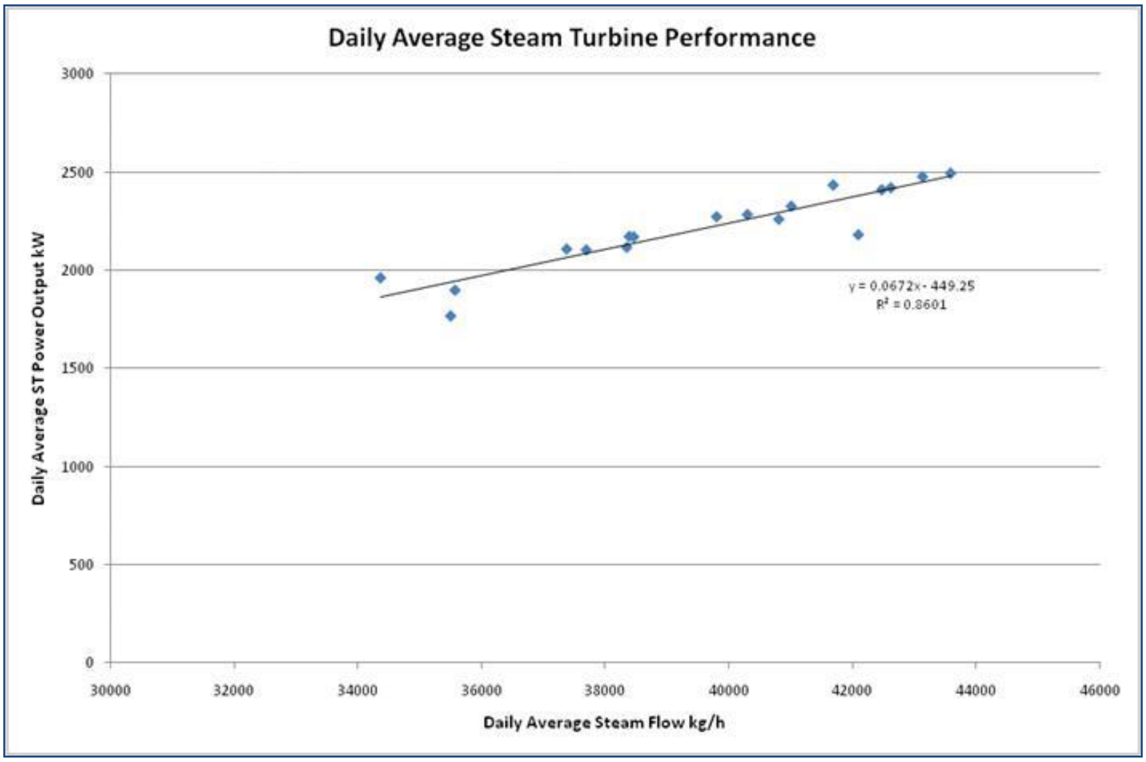
Figure 22 2-minute values for power output v steam flow

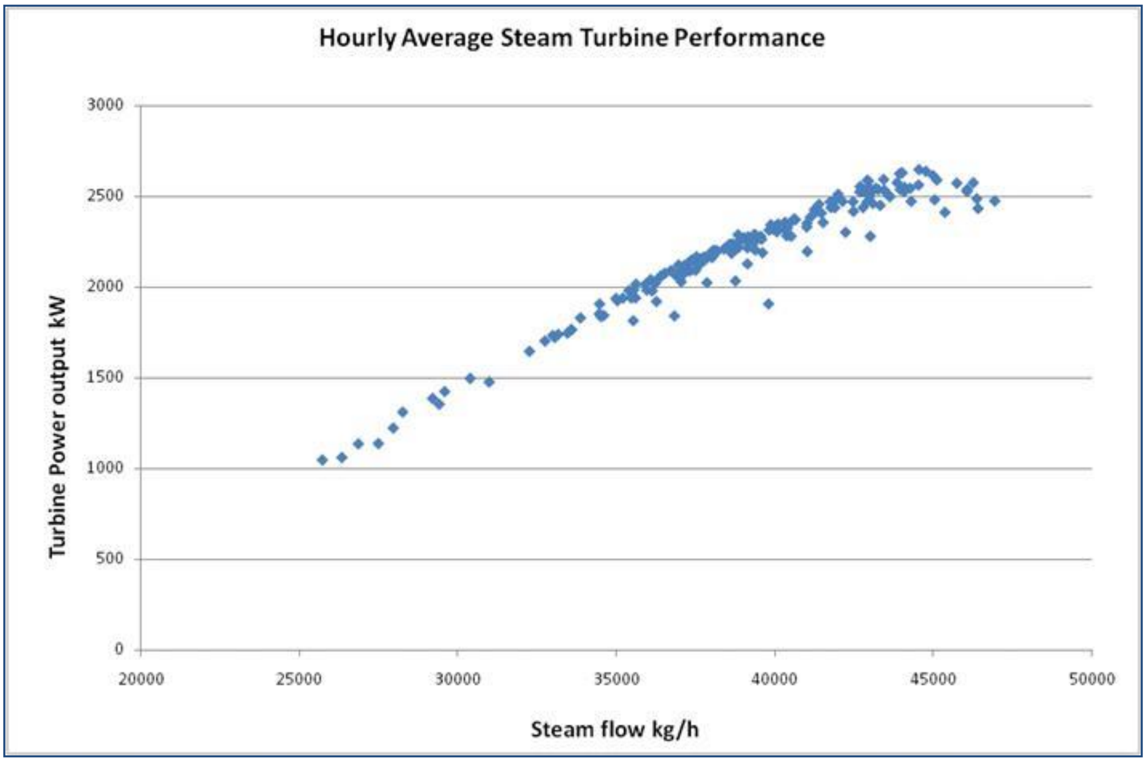


It is unlikely that this issue would have been highlighted by daily monitoring, and even hourly reporting might not have been sufficient to identify this trend, if carried out over a relatively short time period. The following charts in Figure 23 show that for daily averages, there is a clear straight-line relationship between power output and steam throughput, while only in the hourly data is it possible to see the pattern of a fall-off in turbine performance. Real-time monitoring and performance reporting is therefore critical to ensuring the maximum power output from the power station at all times.

Subsequent discussions with site engineers revealed that there is a flow limit built into the turbine control; however this limit would appear to have been over-ridden during a period of poor turbine operation and had not been re-instated following recent turbine repairs. This has now been corrected and the turbine should now operate up to the maximum steam throughput but not beyond it.

Figure 23 *Hourly and daily averages, power output v steam flow*





Key Finding

Steam Turbine Control. At this site there is the potential to improve operation of the steam turbine through introduction of a flow limiter so that the HP steam flow cannot exceed 45,000 kg/h. At this point, if the site needs more process steam, it should be met by letting HP steam down to LP steam through the desuperheater. If similar issues exist in other paper mills then it represents an opportunity for the sector through advanced controls on the power generation plant.

4.2.3. Boiler performance

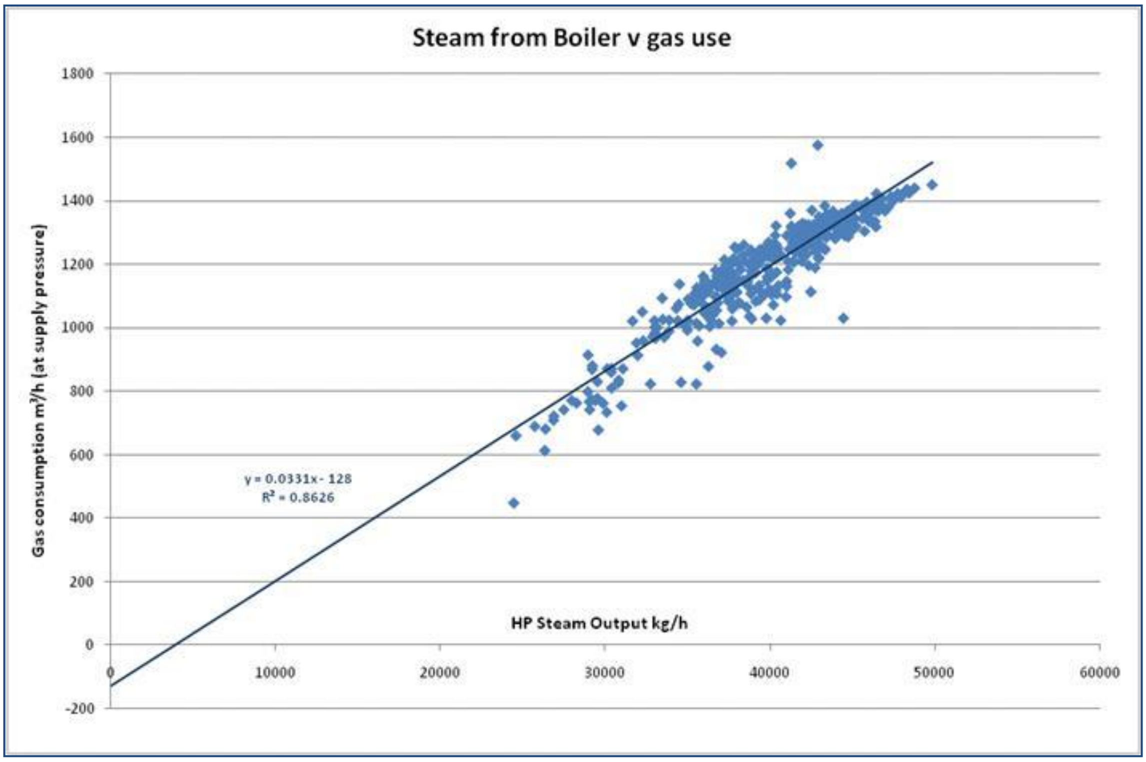
Steam is generated from a waste heat boiler that has supplementary fuel firing capability to manage peak demands. The boiler is designed such that the auxiliary fuel firing rate can double the steam output.

We would therefore expect to see periods of operation when the boiler would not call for supplementary fuel, during periods of relatively low steam demand (e.g., when half of the mill is shut down).

Because of a failure of the boiler gas meter (at the end of October) there is limited data available to test this thesis. However, during January there is no evidence of the boiler running without supplementary firing. This may be a function of the site having to run hard to make up for lost production time during the severe cold weather experience in December when the interruptible gas supply was cut off for 4 days, leading to a sudden unplanned shutdown that was not fully recovered until the New Year.

The relationship between steam output and fuel input is shown below.

Figure 24 *Relationship between steam and boiler gas use*



The intercept on the X-axis is such that this could be the base load steam generated by the waste heat alone. However, this figure (around 4,000 kg/h) is not consistent with the available heat in the gas turbine exhaust. Further investigation of the boiler performance is recommended, as the base load performance of the boiler without supplementary firing is supposed to be of the order of 15 tonnes/h. Part of this assessment should be to check the calibration of the HP steam meter, as there is some concern over the age and condition of this meter.

4.2.4. Gas turbine

The gas turbine generally runs at constant output, delivering around 9 MW from a fuel input of around 180 m³/h at supply pressure. As pressure compensation was not implemented on the installed meter we have to make some assumptions about line conditions to estimate energy input. (Fortunately, Flow variations were small and rare, so this is a reasonable assumption to make for this analysis.) Taking a supply pressure of around 20 bar and a gross calorific value of natural gas of 38.5 MJ/Nm³, this equates to an energy input of approximately 38.5 MW gross and a generation efficiency of around 23.4%.

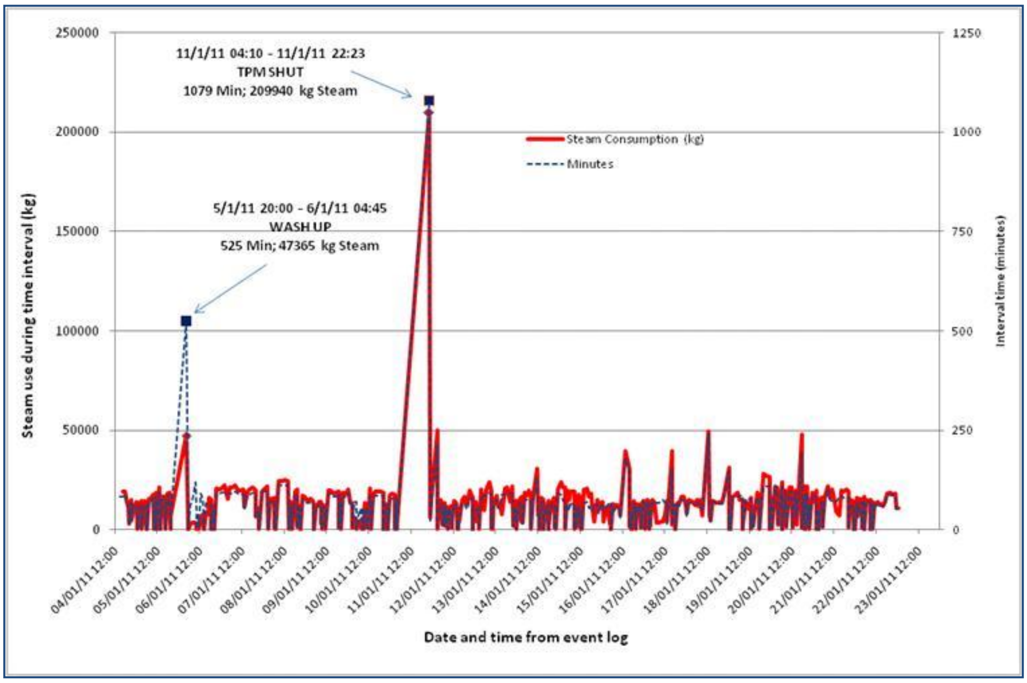
To generate 1 tonne of HP steam from hot well temperature (60 °C) requires around 800 kWh of energy. Up to 60% of the residual heat in the turbine exhaust gases is recoverable in a well-designed waste heat boiler with economiser, so the base load capacity of the boiler should be around 18 tonnes/h. (residual heat ~ 29.5 MW, 50% of this ~ 14.75 MW /0.8 = 18.4 tph). So there should be no supplementary fuel requirement (other than pilot light) below a steam load of least 15 tonnes/h. This not the case at Site B.

4.2.5. Paper machine steam use

One of the questions relating to this site was the impact of machine shut-down – planned or otherwise – on power station operation. To examine this we have looked at one paper machine, which has a meter that is reporting at 2-minute intervals rather than 15-minutes as is the case with the other machine steam meters.

The first step was to extract steam meter data and align it with the machine event log. This gave steam usage for each period recorded in the event log. Data were collated for 20 days following the plant start-up in January 2011. During this period the machine produced a total of 460,866 kg of product and date- and time-stamped 525 distinct events. The steam consumption plot broken down by event is shown in Figure 25.

Figure 25 *PM steam consumption, Jan 2011*



Typical events are reel run, reel change etc. The first thing to note is that there is relatively little variation in steam consumption per event and most event intervals are of a similar duration – 30-60 minutes is typical. Most events represent reel runs, with an event noted at reel change, grade or colour change. Two points on the chart stand out, however:

- A wash up exercise on the night of 5/6 Jan lasting almost 9 hours, with a recorded steam flow of used 47 tonnes. The site believes that this is a genuine steam use during a major clean-down procedure.
- A planned shutdown on 11 Jan lasted for almost 18 hours with a recorded steam flow of over 200 tonnes of steam. The site disputes this figure and suggests that this is an effect of the Annubar steam meter, which is vulnerable to significant errors at low flow rates.

Other production breaks shows little in the way of steam flow reduction. The average steam flowrate during production is around 12,900 kg/h. Only when there was a mechanical breakdown in the calendars did steam usage drop significantly below this rate. Significantly, it is disturbing to see shut-down periods or stand-by periods (e.g. waiting for starch) where the steam flowrate has apparently not changed at all from the production demand.

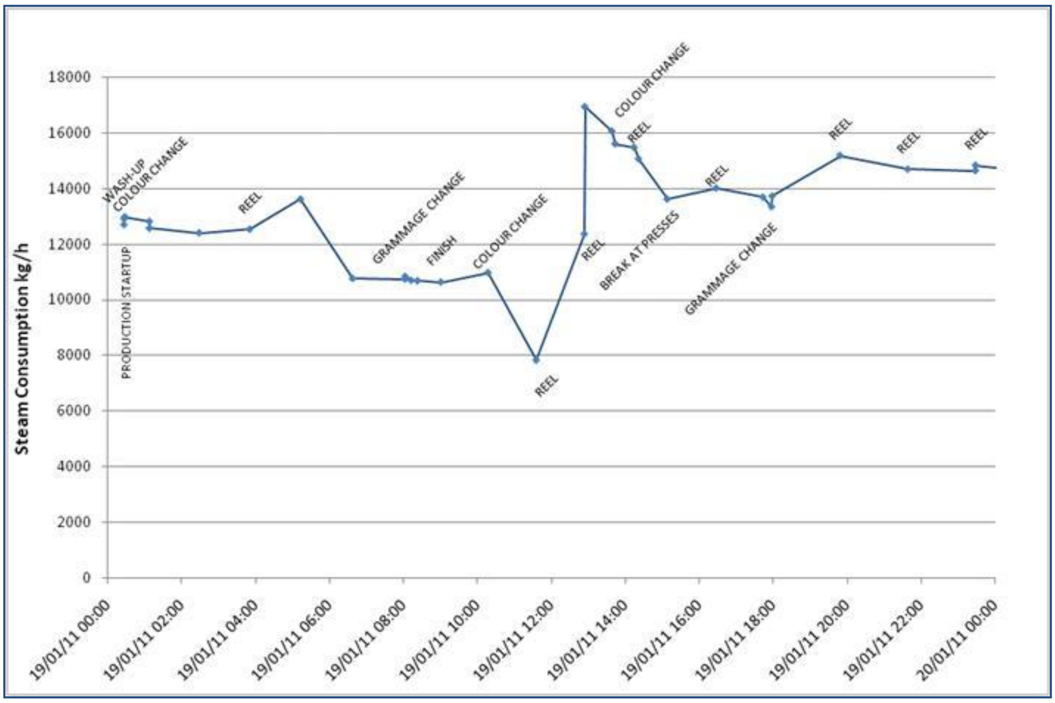
Non-productive run time accounted for about 25% of the total run-time for the period in question, which is consistent with Site A.

Looking at a shorter time-period in more detail, the extent of the steam demand swings are shown in greater detail. The following chart shows the main events on the machine for 19 Jan.

It is difficult to see clear pattern from this record. Only one instance of colour change is followed by a significant change in steam demand, while grammage change seems to have no effect whatsoever. The largest step change is after a couple of reel changes around noon, yet a break at the press section seems to have had hardly any impact.

Coupled with the event observations documented in Section 4.2 these data suggest that the HP steam load does not swing quite as suddenly as might have been expected. This in turn suggests a significant inertia in the site steam distribution network that helps to dampen out the effect of a sudden change.

Figure 1 *PM steam consumption, 19 Jan 2011*



Key Finding

Machine Steam Control. At least one of the paper machines at Site B has little real control of steam use. When the machines are not producing, particularly for long periods during planned shut-down periods, steam flow should be switched off if possible, or at the very least set to a minimum flow. However, this may also be a function of inaccurate steam measurement.

4.3. Site C – vacuum systems

Vacuum systems are used as part of the process for dewatering the web prior to thermal drying. Vacuum systems are significant electricity consumers. At one site detailed monitoring of the vacuum system was proposed to understand how these systems are operated and controlled. In particular vacuum systems are normally controlled on the basis of the vacuum level in the suction pipework of the pump. This suction will be a function of the pressure loss across the felt – i.e. the amount of blockage of the felt, as the felt blinds the airflows will reduce. Since water removal is proportional to air velocities through the vacuum slots there may be an opportunity to control vacuum using air flow measurement in the suction pipework rather than on the vacuum generated.

Site C was interested in hosting this aspect of the sector monitoring strategy. Site C is active in the packaging sector and has one production line with an output of approximately 500 tpd. The paper machine incorporates a size press and hence the drying process comprises: initial drying; rewetting with size; final drying to achieve the desired dryness in the final product.

4.3.1. High level performance

Figure 27 below shows the trends in production and steam to the dryer over a period of three weeks. To facilitate the graphing the raw 2 minute data has been averaged over 30 minutes. What is seen is a period of near continual production with occasional paper breaks – with the exception of the Christmas shutdown the machine achieved uptime of 87% for the period. The majority of the paper breaks are resolved within one hour however there was a longer shutdown on the 28/11 which lasted 12 hours.

When the machine is in production there is a close correlation between the steam consumption and production.

The regression equation is:

Steam (TPH) = 13.67 + 1.335 x Prod (TPH)   R2 = 0.83

Figure 27 Steam Flow and Production (19/11-06/01)

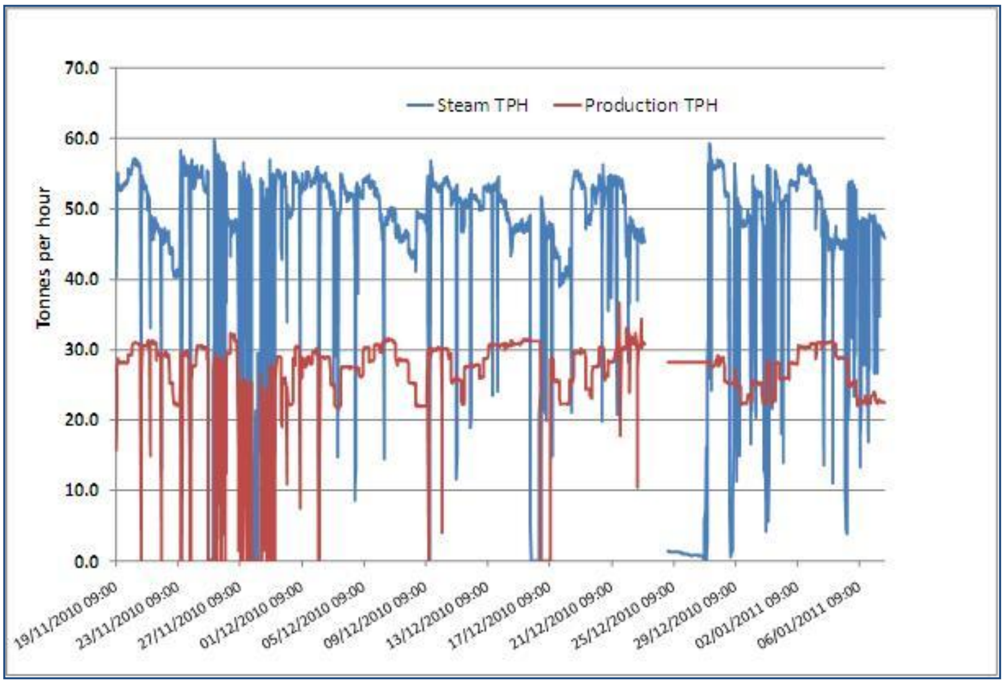


Figure 28 looks at a small part of this data and uses 10 minute averaging; in addition this graphic includes the steam to evaporation ratio which gives a measure of the dryer efficiency.

Figure 28 Steam to production ratio

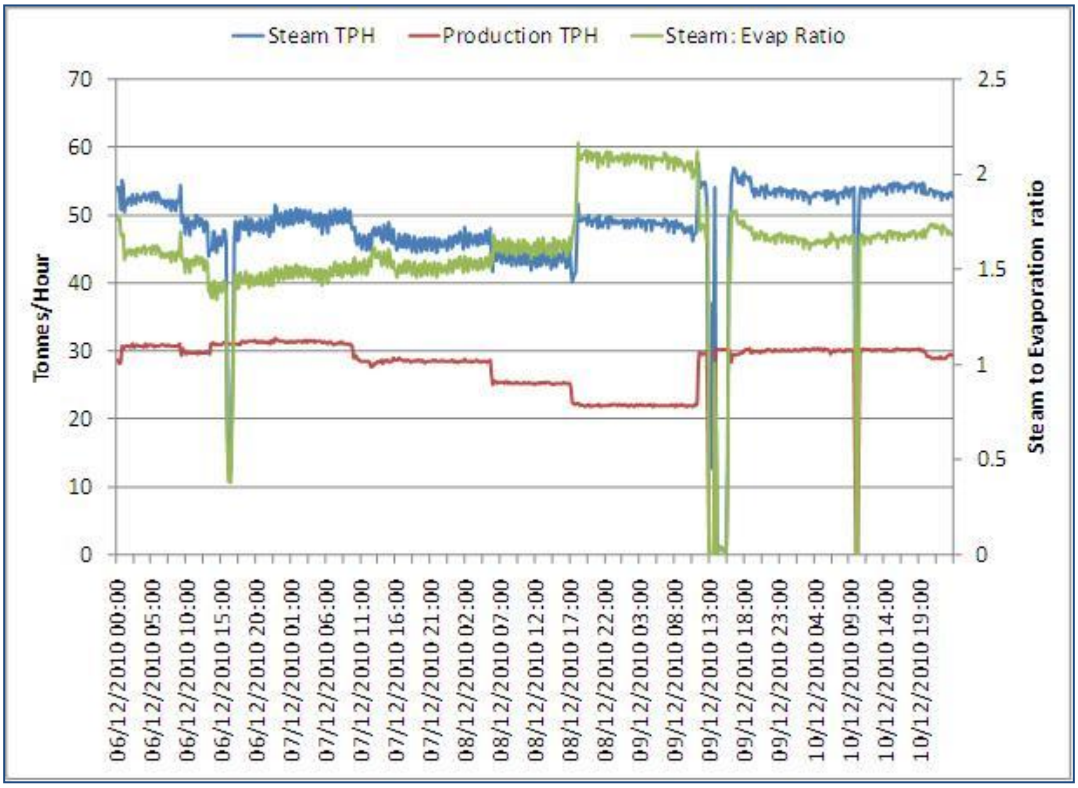
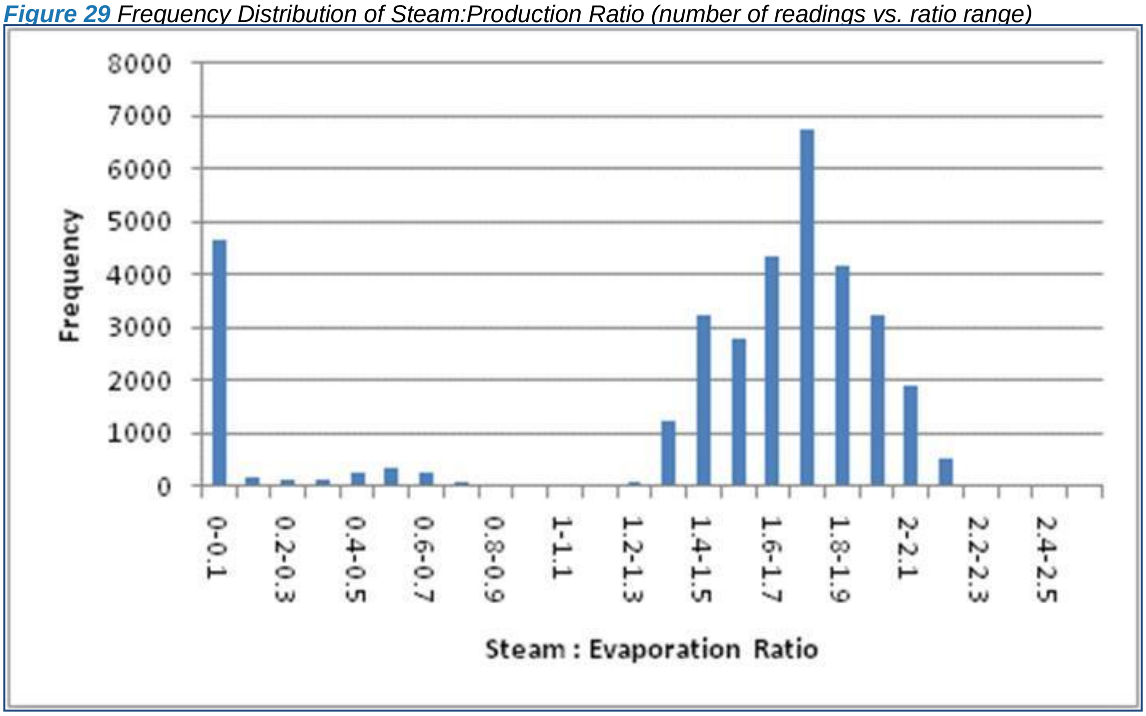


Figure 28 demonstrates that production is set at fixed speeds – the steam consumption shows short term variability which may be an indication of issues with control loop tuning and thermal inertia in the system. In this figure the steam to evaporation ration varies between 1.5 and 2.3.

The steam to production ratio is a clear indication of dryer efficiency. Figure 29 investigates this in more detail. The majority of the values lie between 1.7 and 2.0 – outliers coincide with breaks in production. Note that this ratio translates to 1.6 - 1.9 when considered on a steam to evaporation ratio. This is higher than the TAPPI recommended value of 1.2. The high value is related to the presence of a size press which increases the drying duty.

Figure 29 *Frequency Distribution of Steam:Production Ratio (number of readings vs. ratio range)*



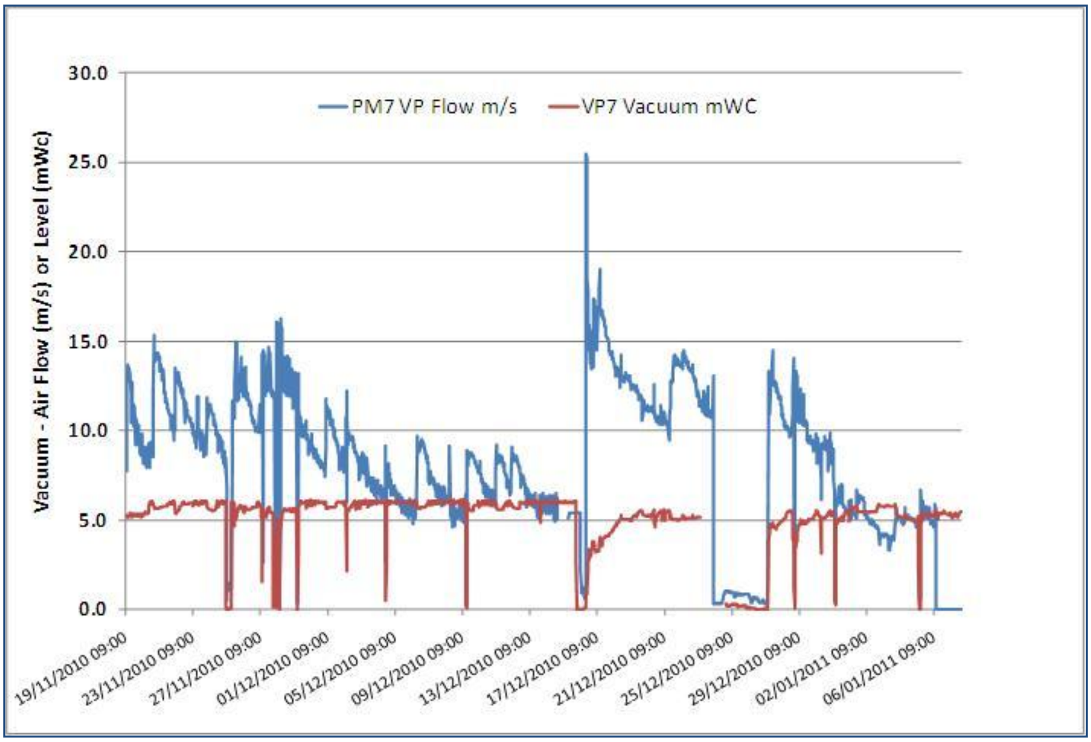
4.3.2. Vacuum system performance

The monitoring at this site looked at the vacuum system and comprised the installation of a vacuum flow meter within the suction duct of one out of the 8 vacuum pumps.

Figure 30 below shows the vacuum level in the suction duct – which is the normal parameter to operate and control on - and the flow in the vacuum duct. What is seen is that the vacuum flows follow a “saw tooth” pattern – as the felt blinds the resistance increases and the flow falls for a constant vacuum level in the suction duct. The sudden increases in flow are associated with activation of the felt cleaning systems.

On 17/12/2010 the felt was replaced and one can see an immediate increase in the air velocity – at the same time the vacuum level is reduced. The data for the 17&18/12 shows the new felt bedding in and from then on vacuum levels are maintained more or less constant. Over a period of 15 days the air flow falls from 15 m/s down to 5m/s.

Figure 30 *Vacuum Flow and Vacuum Level*



The data for the 17&18/12 (Figure 31) shows the new felt bedding in and from then on vacuum levels are maintained more or less constant. Over a period of 15 days the air flow falls from 15 m/s down to 5m/s.

Figure 31 *PM7 Flow and vacuum, 17-23 Dec*

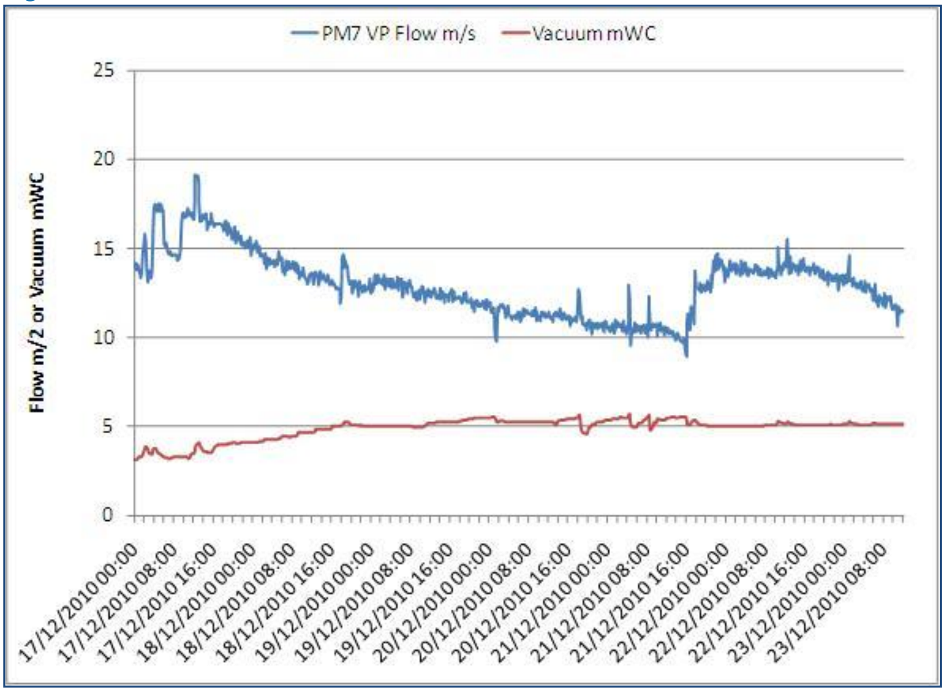


Figure 32 compares the vacuum flow and vacuum level with the power consumption of the vacuum pump. What is seen is that there is little change in the power consumption of the vacuum pump even as the amount of flow declines and the vacuum level remains more or less stable. The control strategy of the vacuum pump is to open a bypass vent – this redirects exhaust air from the pump back to the inlet thereby controlling the suction level.

Figure 32 *Vacuum Pumps Amps – with flow/level*

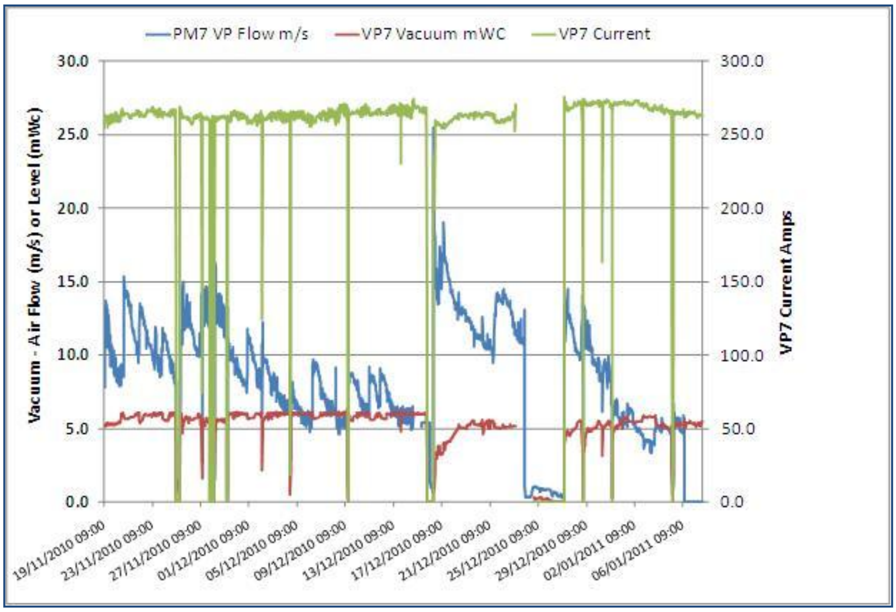
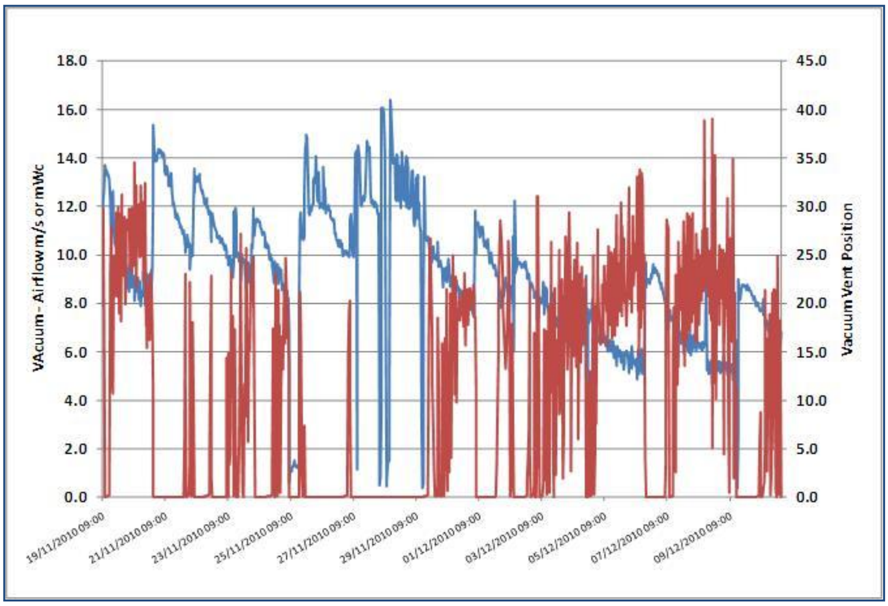


Figure 33 shows the position of the vent valve in relation to the flow in the vacuum line – the vent is typically used when the vacuum flow drops below 8-9 m/s – whilst the vent was used only intermittently in the early part of the data set it is in use almost continuously in the latter part of the data set. The vacuum pump is drawing 275A which is equivalent to a power consumption of 200 kW. This is one of 8 vacuum pumps in the wire/press section.

Figure 33 *Vacuum vent position*

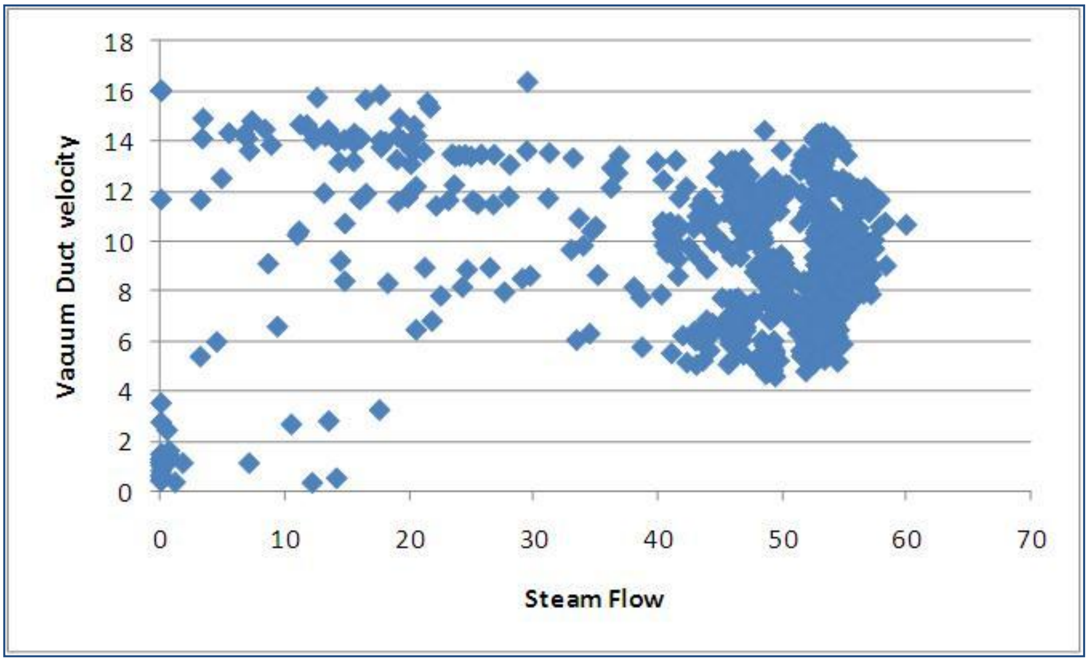


Key Finding

Control of Vacuum Levels. Control of vacuum levels through bypass valves is inherently wasteful of energy – measurement of vacuum flows appears to offer an alternative control algorithm is more relevant to the function since it will be directly related to the amount of air flow through the felt.

With the velocity and hence volume flow in the vacuum duct reducing in the recent part of the data set, the expectation could be that the web is wetter on the entry to the dryer and hence steam consumption in the dryer would increase. Figure 34 compares the velocity in the vacuum duct and the steam consumption in the dryer - There does not appear to be any relation between the vacuum velocity and the steam consumption – however it is important to recognise that this is for one out of 8 vacuum pumps – a relationship is expected between the amount of mechanical dewatering and the heat requirement of the dryer.

Figure 34 *Vacuum flow vs. steam flows in dryer*



Key Finding

Control of Vacuum Flows. Control of vacuum flows offers an opportunity for improvement provided that the moisture level in the web at the end of the press section can be measured robustly and accurately – there is a dominant view in the paper industry that “one can never have too much vacuum” and there is a tendency to over apply vacuum – this could have detrimental effects on operation with high levels of vacuum leading to faster blinding of the felt and a reduction in dewatering performance.

4.4. Summary of key findings

1) On-line moisture measurement. The experience of using the microwave moisture measurement has been a mixed success. On the one hand they do appear to provide a good indicator of changes in sheet composition; on the other hand the absolute values appear to be open to question and the difference between the two measurements across the dryer did not reflect the volume of moisture removed from the sheet during drying. There is plainly scope for development and demonstration of online moisture measurement as a key contributor to paper machine control.

2) Control of Exhaust Moisture Content. Using a Relative Humidity signal to control exhaust fan speed to a set point of, say, 50% should result in reduced energy consumption in the dryer as well as delivering additional power savings in the operation of the fans. Again the reliability of sensors has been brought into question although in this case it may be due to the particular operating regime of the paper machine (i.e. with frequent shutdowns). In other subsectors where the machines have far higher uptimes (e.g. newsprint, packaging) relative humidity control would be more reliable.

3) Exhaust Air heat recovery. There is obviously some benefit in recovering heat from the dryer exhaust, as it contributes around 30% of the air reheat duty. The limitation on heat recovery from the exhaust air into the feed air for the hood is the relative humidity of the exhaust air – an air to air heat exchanger will typically operate ‘dry’ i.e. the minimum temperature of the exhaust air at the exit of the dryer will be above the dew point. The monitoring has shown that there is unexploited potential for recovery – with the exhaust air relative humidity only at 22% and a minimum approach temperature of 40°C.

4) Management of product changeover. One site experiences frequent product changes. This site has to operate in response to market demand and endeavours to plan its production schedule to meet those demands at optimum efficiency – i.e. minimising the amount of down time. There appears to be scope at this site to improve through review of change-over procedures to reduce down-time even more than the current regime.

5) Steam Turbine Control. Where the power generation system was monitored there was potential to improve operation of the steam turbine through introduction of a flow limiter to limit HP steam flow. If similar issues exist in other paper mills then it represents an opportunity for the sector through advanced controls on the power generation plant.

6) Machine Steam Control. At least one of the paper machines monitored has little real control of steam use. When the machines are not producing, particularly for long periods during planned shut-down periods, steam flow should be switched off if possible, or at the very least set to a minimum flow. Again this is an indicator of limitations in the existing control systems.

7) Control of Vacuum Levels. Control of vacuum levels through bypass valves is inherently wasteful of energy – measurement of vacuum flows appears to offer an alternative control algorithm which is more relevant to the function since it will be directly related to the amount of air flow through the felt.

8) Control of Vacuum Flows. Control of vacuum flows offers an opportunity for improvement provided that the moisture level in the web at the end of the press section can be measured robustly and accurately – there is a dominant view in the paper industry that “one can never have too much vacuum” and there is a tendency to over apply vacuum – this could have detrimental effects on operation with high levels of vacuum leading to faster blinding of the felt and a reduction in dewatering performance.

5 Opportunities

5.1. Introduction

Low carbon and energy efficiency opportunities that can be applied to the paper sector have been identified from references to a number of sources:

- Through the monitoring that has been undertaken as part of Stage 1 of the Accelerator project;
- Through reference to the TAPPI Technical Information Publication "Paper Machine Energy Conservation" first issued in 2003 and revised in 2006 and other published literature concerning energy efficiency in the paper industry.
- Through a literature review of the international research community to determine the key areas of focus for the forest products and / or paper sectors especially as they relate to energy consumption.
- Via consultation with the industry and its supply chain.

In total over 52 distinct opportunities have been identified and these have been characterised into two main areas:

- **Opportunities that can be implemented now without any further support**. These will include technologies and actions considered best practice but also some of the new technologies with no adoption barriers such as LED lighting or new generation motors and drives. We describe these as best practice opportunities and they represent a valuable list of actions that organisations can adopt to reduce their energy costs.
- **Opportunities where barriers exist** for their adoption for which additional intervention is required to enable or accelerate deployment. We describe these as innovations. Within this category is a subset of opportunities which, although they require support for deployment in the sector, are covered by other Carbon Trust programmes.

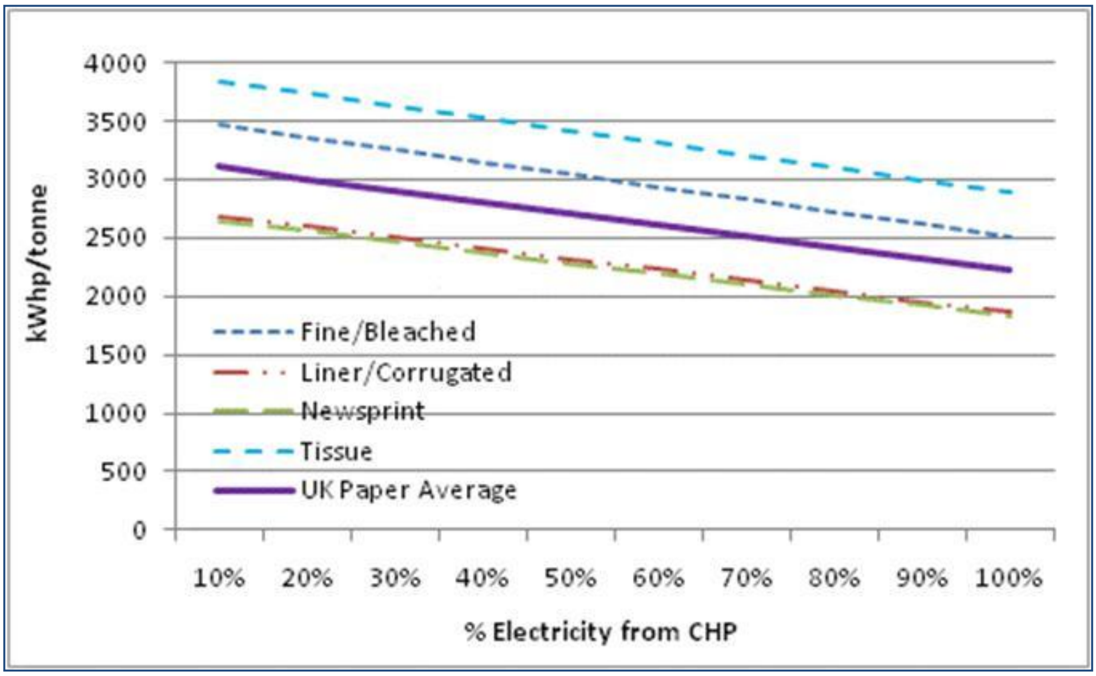
The two sets of opportunities are set out in the sections below along with an estimate of their costs to implement, their payback and the CO2 reduction potential for the sector. In the case of the innovations we have also included a short analysis of the barriers for their deployment.

5.2. Best practice opportunities

The opportunities listed below represent opportunities for paper manufacturers to reduce energy consumption that are readily available and have already been deployed and proven within the sector or within other sectors.

The majority of paper mills will have already implemented some if not all of the following technologies. It is important therefore to get a measure of the residual potential that remains from best practice opportunities. Our approach to this estimate has been to take the best practice benchmarks for paper machines from the recent TAPPI Technical Information Paper[9] and then calculate the equivalent primary energy consumption based on varying amounts of the electricity consumption provided by CHP. The outputs are provided in Figure 35 below.

Figure 35 *Primary Energy consumption for best practice*



The next stage is estimation of the relative proportions of each product group in the overall output the estimates we have used are based on production data from CPI (see Table 1):

- Newsprint - 21%
- P&W - 31%
- Packaging - 32%
- Tissue - 16%

With these proportions the best practice specific primary energy consumption of the UK paper sector as a whole should range between 3105 kWhp/tonne at 10% CHP and 2221 kWhp/tonne at 100% CHP.

We estimate that 75% of the electricity is provided by CHP hence best practice consumption is 2466 kWhp/tonne. As a comparison – the UK paper industry reported a specific energy consumption of 3940 kWh/tonne at the last target period assessment within the CCA programme suggesting that there is theoretical 38% potential from best practice.

[9] TAPPI TIP 0404-63 – Paper Machine Energy Conservation 2006 revision

Key Finding

If the best practice potential is 38% and the annual emissions of the Paper industry in the UK are approximately 4.7 million tonnes of CO_2 (based on Fossil Fuel of 16718 GWh and 0.2 t CO_2 /MWh and imported electricity of 2512 GWh and 0.54 T/MWh) then the reduction potential from the sector would be **1,780,000 tonnes**.

It is evident that not all of this potential is genuinely available – opportunities within the sector to attain best practice can in some instances only be taken when the paper machines are rebuilt – but the value serves as a medium to long term objective.

Table 7 highlights some of the best practice opportunities – these have been drawn mainly from the TAPPI TIP and augmented with insights derived from the monitoring programme. This bottom up assessment of available potential gives a reduction of 490,000 tonnes – approximately 10% of the estimated sector total emissions and 25% of the theoretical potential.

The trajectory already demonstrated by the industry within the framework of the CCA programme gives an annual saving varying between 1.5% and 2.5% per year (see Table 6Table 6) with the lowest figure covering the most recent target period. To achieve 38% reduction would imply another 16 years at current rates assuming no increase in production.

Table 6 *Annual reduction in specific energy consumption*

TP End Year	SEC kWhp/tonne	Reduction compared to previous TP	Annual reduction equivalent
2002	4,476		
2004	4,280	4.4%	2.2%
2006	4,060	5.1%	2.5%
2008	3,940	3.0%	1.5%

Table 2 *Best practice opportunities*

	Process	Opportunity	Sector Costs to Implement	Payback (years)	% of Sector Where Applicable	Total CO_2 Saving by Sector
1	Compressed air	Regular review of system layout to eliminate dead legs	100,000	1	25%	500
2	Compressed air	Review of system pressures to ensure system is operated at the lowest allowable pressure	100,000	1	35%	900
3	Compressed air	Regular programme of leak detection and repair	100,000	0.5	25%	1,300
4	Compressed air	Implement an appropriate control strategy for multiple compressor systems	300,000	1.5	25%	1,300
5	Compressed air	Use variable speed compressors for variable loads	800,000	3	30%	2,400
6	Dryer	Keep the system 'tight" - reduce air infiltration	26,700,000	3	35%	71,100
7	Dryer	Efficiently utilise flash steam from high pressure condensate	6,100,000	4	15%	12,100
8	Dryer	Maximise the hood humidity consistent with no condensation in the hood	38,200,000	5	45%	60,900
9	Dryer	Optimise differential pressures for condensate evacuation and blow through flows	2,600,000	2.5	20%	8,100
10	Dryer	Felt design to optimise uniformity of sheet contact with dryer surface	5,100,000	2.5	40%	16,200
11	Dryer	Avoid steam venting during normal operation, close separator tank drain valves	600,000	2	15%	2,000
12	Dryer	Maximise heat recovery from dryer hood into supply air, machine room air and warm / white water	19,100,000	5	45%	30,400
13	Dryer / Steam Systems	Use Low pressure steam in place of high pressure steam where possible	6,800,000	5	20%	10,800
14	Dryer / Steam Systems	Maximise condensate recovery and flash steam recovery	7,200,000	3	35%	18,900
15	Dryer / Steam Systems	Automate warm up, shut down and break recovery response to minimise steam losses.	6,100,000	3	40%	16,200
16	Press	Shoe pressing increases dryness potential	3,400,000	4	25%	6,700

	Process	Opportunity	Sector Costs to Implement	Payback (years)	% of Sector Where Applicable	Total CO_2 Saving by Sector
17	Press	Steam Boxes increase sheet temperature and increase exit dryness and can improve profile. Use LP or vented steam for boxes and showers	5,100,000	3	20%	13,500
18	Press	Felt and belt design optimisation	2,100,000	3	35%	5,500
19	Press	Minimise re-wet (sleeve doctors, double doctors, air doctors, catch pans etc.)	3,200,000	2.5	25%	10,100
20	Press	Check nip profiles and optimise crowns	3,900,000	3	25%	10,100
21	Press	Monitor press performance - water flows, CD/MD, fabric permeability, moisture, temperature.	2,400,000	4	25%	4,900
22	Press	Turn off or reduce steam flow when grades that are not drying limited are produced	1,500,000	2	30%	5,900
23	Pumps and Motors	Avoid controlling flows by throttling or recirculation - either resize pump or install frequency inverters	13,500,000	3.5	60%	36,100
24	Pumps and Motors	Match pumping capacity to duty in multi pump systems	5,200,000	4	30%	12,000
25	Pumps and Motors	In batch operation ensure pumps are switched off when not needed.	1,000,000	1.5	30%	6,000
26	Pumps and Motors	Equalize flows using surge vessels	300,000	2	15%	1,200
27	Pumps and Motors	Avoid tanks where possible and design for continuous flows	10,300,000	4	60%	24,100
28	Pumps and Motors	Do not rewind motors, replace with high efficiency models	1,800,000	4	25%	4,000
29	Pumps and Motors	Switch motors off when not needed	2,200,000	2	50%	10,000
30	Stock preparation	Reduce pulp and water volumes and increase consistency as much as possible to reduce hydraulic volumes	1,700,000	3.5	40%	4,500
31	Stock preparation	Use latest development machinery to increase overall efficiency	6,100,000	5	50%	11,300
32	Tank Agitation	Consider variable speed or two speed agitators	400,000	3	25%	1,200
33	Tank Agitation	Only operate the number of agitators needed	100,000	1	25%	800
34	Tank Agitation	Use zone agitation where complete mixing is not needed	200,000	3	25%	400

	Process	Opportunity	Sector Costs to Implement	Payback (years)	% of Sector Where Applicable	Total CO_2 Saving by Sector
35	Tank Agitation	Slow down agitator if consistency varies from design.	200,000	3	25%	400
36	Tank Agitation	Avoid excessive agitation	200,000	2	25%	800
37	Vacuum Systems	Control vacuum to balance steam penetration, sheet temperature and air infiltration	3,500,000	3	50%	10,700
38	Vacuum Systems	Use turbocompressors in place of vacuum pumps for high vacuum duties - as well as offering lower consumption discharge is at higher temperature	11,400,000	5	50%	21,400
39	Vacuum Systems	Use fans or blowers in place of vacuum pumps for low vacuum applications such as foils	5,200,000	5	30%	9,600
40	Vacuum Systems	Provide water/air separation ahead of vacuum pump	600,000	3	25%	1,600
41	Vacuum Systems	Check internal clearances and capacity annually - rebuild pumps operating at less than 80% of design capacity	1,400,000	2	30%	6,400
42	Vacuum Systems	Reduce pressure loss in suction and discharge ducting	1,400,000	4	30%	3,200
43	Vacuum Systems	Take unnecessary vacuum pumps out of service	1,400,000	2	30%	6,400
44	Wire	Operate headbox within design flow ranges	100,000	1	20%	700
45	Wire	Improve moisture profile to allow maximum possible moisture content at the reel	600,000	3	30%	1,600
46	Wire	Maintain cleanliness for efficiency	200,000	2.5	20%	700
47	Wire	Match hardware to drainage needs	200,000	1	25%	1,100
48	Wire	Graduate vacuum down the table to reduce drag and provide good sheet consolidation	800,000	3	25%	2,300
49	Wire	Manage temperatures for impact on drainage and solids	300,000	3	20%	900
50	Wire	Avoid couch re-wet (double doctors, air doctors)	400,000	4	20%	900
51	Wire	Optimise performance through choice of fabrics	500,000	5	20%	900
	TOTALS		**212,700,000**			**491,000**

5.3 Opportunities from Innovation

Table 3 lists innovative energy efficiency and low carbon opportunities identified by the sector during the engagement process. Within the table we have indicated the priority the sector placed on the technologies and the perception of maturity, i.e. how close the technology is to being commercialised with low being assigned to the technologies furthest from being a commercial solution. The highlighted opportunities are those that the industry itself considers to be high priority for further research and assistance.

Table 3 *Energy Efficiency and Low Carbon technologies*

Technology	Priority / Maturity	Comments
Stock Preparation		
Better segregation	Low / Med	Possible partnering with Local Authorities to deliver non-comingled waste. Some sites are taking alternative route of building mixed waste sorting plants. Technically mature - innovation would be in systemic approach to problem.
Advanced conditioning (Enzymatic, chemical, etc.)	Low / High	Regarded as generally adopted and thus current known advances need to diffuse before new ones developed
Pumping optimisation	Med / Med	The individual elements of pumping optimisation (pump selection, motor selection, low friction coatings, impeller design, system layout, variable speed, controls etc.) are mature. Issue is need to balance pumping and mixing performance.
High consistency processing	Low / High	Can already take place at 15-20%
Online Fibre analysis (high frequency)	Low / Med	Demonstration in Canada, didn't create much interest in UK Industry
Recycled mineral fillers (RMF PCC)	Low / Low	Very little interest/discussion - felt that it was moving carbon emissions and not eliminating them.
Pulping Optimisation	**High / Med**	**New pulpers are being introduced by manufacturers and hence could be considered as commercial technology.**
Wet End		
Use of other carrier liquids	Low / Low	No interest , too immature
Advanced controls including moisture measurement	**High / Med**	**Perhaps the most interest here (a common theme in all areas)**
Dry forming	Low / Low	Not much interest
Vacuum optimisation	**High / Med**	**A lot of interest - this is as much about control of vacuum systems as it is about new technology in vacuum pumps**
Advanced felts	Low / Med	Not much interest but only because it is easy to do. Perhaps shouldn't be dismissed but made part of other project ideas
Press configuration	Med / Med	Hot pressing. Main issue here is difficulty and cost. There appears to be a limit on the maximum temperature possible in pressing - while higher temperatures reduce water viscosity and improve drainage they also have an impact on fibre strength. Needs to be considered further. Dennis Jewitt of Metso expressed an interest.
“Double” Doctors	Low / High	Rejected as already commercially available.

Technology	Priority / Maturity	Comments
Impulse Drying	**High / Low**	**Applying heat and pressure for dewatering before drying. Regarded as a good innovation but doubts expressed about performance of impulse dryers - R&D papers do not provide unequivocal basis for improvement.**
Dryers		
Advanced heat recovery (Heat pumps, Chemical heat transformers – upgrade waste heat)	Low / Med	The main interest here is either to generate electricity from the waste heat or to upgrade the heat with a "heat amplifier".
Advanced heat recovery – better integration (reuse either in plant or outside)	Low / Med	Could be stand alone as a PINCH software solution for the sector or as part of a new technology. Integration is also about linking paper industry with symbiotic industries (i.e. needing low grade heat) or with district heating.
Advanced controls	**High / Med**	**Considerable interest in better humidity and mass flow control. Barrier was mentioned of better sensors capable of operating reliably at temperatures and relative humidities expected in hoods. Would facilitate operation with lower air flows and higher relative humidities at exhaust - this would upgrade quality of heat in exhaust stream (higher specific enthalpy)**
Hood segregation – air flow management	**High / Med**	**Linked to above**
"Condebelt" dryers	Low / Low	Rejected - although innovative not considered as a viable future technology path
Other heat technologies (e.g. Microwave, IR, etc.)	Med / Med	Apply heat to web prior to dryer using IR - so dryer cylinders used for evaporation and not heating. Offset new carbon emissions for IR vs. reductions in steam consumption.
Power Generation		
Biogas from recycling wastes	Low / High	Regarded as demonstrated (which is a surprise); main industry interest is in partnering with 3rd party energy from waste operators, i.e. mass burn incineration with CHP.
Advanced predictive controllers for central energy plants	Med / Med	Good interest here again with a control project. Aylesford Newsprint have a neural net based system for their boiler
Steam accumulation	Low / High	Linked with advanced controls – as a way of damping changes in the steam system
Steam system optimisation – cascade systems	Low / High	Recovery and reuse of flash steam in the dryer sections
Voltage optimisation	Low / High	Rejected as commercial technology

From the above list and in conjunction with industry representatives we have highlighted five technology challenges for the industry. They are:

1. **Low carbon energy supplies** – biomass or waste to energy boilers, anaerobic digestion of effluent, wind or other renewable electricity supplies. Biomass boilers can be a useful addition to a paper mill that produces significant volumes of sludge from de-inking or recycling processes as well as providing a potential community resource for waste management.
2. **On-line moisture measurement** at various stages in the press/dryer cycle, which could help to control stock composition and dryer settings.
3. **Process control of dryers**, which accounts for around 50% of a mill's energy use. This would involve optimisation of heat supply to the cylinders, management of air flows and heat recovery from dryer exhaust.

4. “**Hot Press” systems**, currently being trialled in Holland. This involves feeding stock to the wire at higher temperatures, which can improve dewatering on the wire and in the press and therefore increases the solids content of the paper as it enters the dryer.
5. **Heat Recovery and Integration**. This could be a combination of re-visiting process integration analysis of the heat flows within the mill to identifying neighbouring heat sinks. This is a continuing technical challenge to all sectors of industry and there could be significant opportunity for the application of heat pump or organic Rankine cycle power generation technologies in this environment. However, without a significant continuous low temperature heat sink in close proximity to the low grade heat sources in a paper mill and the difficulties in harnessing such low temperature energy sources we have discounted this topic in our final recommendations for further investigation.

6 Next Steps –the business case

In this section we have prepared business cases for four of the five main technology challenges identified in section 5. Each business case is constructed in the same format containing the following information:

- A description of the concept and the CO2 emissions it is addressing;
- The benefits of its development, why it represents an advance for the sector;
- One or more potential approaches or projects that would deliver the benefits;
- An estimate of the projects costs and an estimate of the cost of the developed solution;
- An estimate of the CO2 reduction for a site and for the sector; and
- Any key risks or barriers that may prove difficult to get over.

We have summarised the key numbers in the table below

	Challenge	Project Cost	Maximum Annual Sector CO_2 savings	CO_2 saving after 10 years	Cost of CO_2 £ per tonnes saved/year	Payback Time years	Lifetime	IRR
1	Low Carbon Energy supplies	£500k - £2 million	200,000	50,000	£2.5 - £10	5.56	25	30%
2	Online moisture measurement	£600,000	65,600	19,600	£9.212	2.31	5	33%
3	Optimised Dryer Operation	£500k - £1.5 million	110,000	55,000	£4.5 - £13.56	2.86	10	33%
4	Hot press	£2 million	230,000	68,000	£8.77	3.08	25	32%

Note: A fifth project was considered but eventually rejected by the sector. Heat recovery from dryer exhaust has the potential to contribute some energy savings, but the recoverable heat is a small percentage of the total heat content of the dryer exhaust as the bulk of this energy is in the form of latent heat. Significant recovery of this energy stream requires a very low temperature heat sink, e.g., underfloor heating for a large office complex, a swimming pool or a major greenhouse complex.

The IRR estimate is for a pilot scale, demonstration project. Once the technology is proven the investment case should be stronger.

6.1 Low carbon energy supplies

Title: Low carbon energy supplies	
Development	
Description	Through PITA the sector has indicated that low energy supplies are a key area of focus. Biomass or waste to energy boilers and anaerobic digestion of effluent have had some uptake within the sector. Energy from waste via gasification of process wastes (“deinking sludges”) potentially coupled with other recovered papers which are unable to be reprocessed would however be innovative. In the paper recycling process waste paper is received and deinked prior to the recovery of the fibre. During the deinking and cleaning process a fibre sludge is generated which contains fibres that are too short to be converted into a finished paper product, the sludge will also contain the chemical wastes and extractives from the deinking and cleaning processes. Historically the sludges were sent to landfill, more recently paper makers have been investing in waste combustion plants to reduce the amount of landfill and to generate heat which can be used back in the process thereby reducing fossil fuel demands. Fossil fuels remain the dominant energy source for the sector (CPI data shows that 93% of the energy input to the sector is in the form of fossil fuels) – these are combusted within conventional boilers to generate steam and electricity or are combusted in gas turbines again for heat and power. The introduction of waste gasification technology to provide a feed gas for the existing power plants should therefore be technically possible since gasifiers are currently available but within the UK the market for them is still immature and their use still non-existent in the paper sector. If the gasifier creates syngas (a mix of CO and H_2) then the existing heat and power generation equipment should be able to be used with minimal modifications, this would then leave the project as one of integrating gasification into the paper plant, although dealing with tar in the gas stream and the impact that would have on the power generation equipment would also need to be examined.. In the consultation this subject received some support and there is a keen interest to explore this technology further. It does present some challenges: • The process wastes have a high ash and moisture contents – a critical concern will be the net energy generation from gasification once parasitic losses through sludge drying have been addressed; • Waste gasification plants have been laid open to criticism due to the fear that they divert wastes that should be recycled or composted – by embedding the gasification plant within the paper recycling process there is a reduced risk that the operator will sacrifice fibre recovery for energy generation; • The advantages of gasification over conventional incineration will need to be explored. The scale of the combustion plant in a typical paper mill means that replacement of the fossil fuel supply by syngas would need to pilot a small to medium sized gasifier and then co-fire the syngas produced.

Title: Low carbon energy supplies	
Technology maturity and need for support	The concept seeks to take small scale existing gasification technology and link it to a combustion system currently deployed in the sector. This has not been done in the UK before and no case studies exist elsewhere in the world As a response to adding value to process wastes gasification is in direct competition with conventional combustion – and with the proposal seeking to combust the syngas the end result is ultimately the same. The reason gasification should be supported is that integration of gasification into the process is a first step in the longer term objective of integrating paper making with bio-refineries. Support is needed to demonstrate the use of gasification and to address the marginal costs of a gasification system over and above a conventional combustion based system. Large scale bio-mass gasification is a relatively immature market in the UK and therefore some development of the technology may be required for its integration into power generation, the starting point however should be existing technology. There is considerable expertise in the UK in waste gasification and combusting syngas and thus this technology is fairly mature, no-one however has put these systems together as an integral part of the heat and power generation in the paper industry. The complexity of the team required to deliver this project and the development costs make it a project that is unlikely to proceed from the sector itself without support.
Possible project approach	This concept has quite a narrow scope and the project approach is likely to involve all of the following: • Selection and construction of gasifier to run off process wastes potentially augmented with recycled materials that are unable to be reprocessed due to fibre contamination and the non-recoverable materials such as plastics found within recycled paper bales. The gasifier would supply a syngas for one or two burners in the steam generation boiler; • Modification of the existing combustion system to accommodate the properties and combustion characteristics of the syn-gas • The integration of the gasifier and new combustion system into boiler operation • Dealing with potential problems such as “tar” in the syngas, residual char, controls. The project would need a host site willing to provide significant space labour and process time to the project; an engineering company to provide and commission the gasifier; a combustion engineer to modify the existing burner system. The sector already has the networks in place for the provision of the raw materials
Estimated project cost	A 500ADt/day mill operating with 100% recycled pulp and 7% rejects from the deinking process will generate approximately 12 000 ADt/year of process wastes with a moisture content of 40-50% and a lower calorific value of 7000-8000 kJ/kg – this implies a heat generation potential of approximately 5MW. A 5MW gasifier would have capital costs of approximately £10 million to £15 million. We propose a project in the 250 – 500kW range – i.e. sufficiently large to demonstrate the technology and to provide a scalable result. Capital costs are likely to fall in the £500.000 - £2 million range. The project would also be eligible for support at a European level within 7FP.
Payback to project host site	If a 500kW unit was installed it would receive a RHI of 2p/kWh and would generate annual income of £80,000. In addition it would offset a further £100,000 of fossil fuel consumption and cost savings from the avoidance of on-site waste disposal. A conservative estimate of avoided costs would be £50/tonne, or £120,000 per annum for a demonstration unit of this size (avoiding the disposal of 2,400 tpa of waste).
Dissemination	
Cost of technology (once mature)	For small scale units capital costs of £1500 - £2000/kW are anticipated – for larger units the capital cost/kW will be lower potentially between £1200 - £1500/kW. Note that the paper industry is in a good position to exploit this technology because the ‘biomass’ is a waste product from the process.

Title: Low carbon energy supplies	
Saving	The saving is dependent on: • The level of the RHI; • The value of fossil fuel alternatives; • Disposal costs for wastes
Payback once mature	4-5 years
Project persistence	10 years
CO_2 saving per site	A 5MW installation would save 8000 tonnes of CO_2 per year (assuming 0.2 t/MW for fossil fuel.
Sector CO_2 saving potential	The sector potential is 200,000 tonnes per year however this is based on the use of gasification for syngas production and reliance on process wastes alone. As mentioned the technology is the first stage in a longer terms objective of integrating paper making into biorefineries.
Market penetration	Market penetration depends on the evolution of the papermaking industry among many other factors – a working estimate would be 10% after 5 year and 25% after 10.
Forecast CO_2 saving	20,000 tonnes after 5 years 50,000 tonnes after 10 years
Barriers to adoption	i) The high capital costs in comparison to waste combustion; ii) The increased management control and maintenance required to run a duel fuel system;
Risks	i) The high temperature of the generated syngas may make the modification of the burner pipe work system more difficult than anticipated. ii) The lack of gasifier expertise/resources may be difficult to secure.

6.2 On line moisture measurement

Title: On line moisture measurement	
Development	
Description	The vast majority of the energy used within the UK paper industry is consumed in removing water from the stock – our estimation suggests that 80% of the total energy is used for this purpose. The water removal follows three stages: drainage, pressing and drying. While most manufacturers have moisture measurement at the exit of the dryer and measure the consistency at the headbox, intermediate measurement of moisture is off line and often through grab sampling which carries with it a risk of sheet breakage. Mechanical dewatering is far more efficient than thermal dewatering (i.e. through evaporation) although there are limits as to how much moisture can be removed by mechanical means. The project concept is to integrate online moisture measurement through the length of the paper machine to underpin the control of the wire, press and dryer sections, including the vacuum systems, with the objective of: • Maximising the amount of water removal by mechanical means (i.e. through vacuum assisted drainage or pressing) • Minimising the thermal load on the dryer for evaporation; • Optimising the energy performance of the mechanical dewatering section of the paper machine through application of an appropriate level of vacuum as and when it is needed. • Placing the whole under automatic control; The project will therefore increase the amount of online monitoring of moisture and using the data obtained within control algorithms to optimise the energy performance. During the monitoring programme a moisture sensor using microwave rather than infrared sensing technology was introduced to the paper machine at one of the host sites prior to the dryer. The results obtained were mitigated, however this may be due to the sensor positioning rather than to intrinsic faults in the sensor technology. It is evident however that moisture sensor technology needs to be robust to operate in a production environment. In addition to moisture measurement we also advocate the inclusion of vacuum air flow sensors. The project seeks to take existing state of the art monitoring technologies (for moisture) and to integrate them within an advanced control strategy to reduce energy consumption. It is expected that energy consumption will be reduced in both the mechanical stages and the thermal stages.
Technology maturity and need for support	A variety of moisture sensor technology exists using both infra-red and microwaves. These have been applied to the paper machines before but typically operate at the reel end where the moisture levels are around 5-8%, the project will require the moisture sensor to operate between the press and the dryer (typical moisture 55%), between the wire and the press (typical moisture 75%). Equally if sensors could be sourced that could operate within the dryer to control the drying profile (i.e. steam supply) along the length of the dryer that would also be a significant innovation. Advanced control systems are also 'mature' technology – as far as any technology that is under a constant state of development can be termed mature. The innovation is in integrating continuous moisture sensing into a control algorithm to control, the operation of the wire, press and dryer sections. The project presents a high risk of failure due to the difficult operating conditions found in the process.

Title: On line moisture measurement	
Possible project approach	The concept has quite a broad approach and will require capabilities in: • Sensor technology – especially online moisture measurement; • Advanced control systems The approach is likely to involve the following: • Selection of a sensor technology which can operate in the normal production environment found in a paper machine (i.e. temperature, humidity, sheet speeds); • Modification of the paper machine to provide adequate positioning for the moisture sensors which do not impact on the operation or maintenance of the paper machine; • Implementation of the control system and design of the algorithms to optimise the control of the various elements of the dewatering system. The project would need a host site willing to allocate time and resources to the project, sensor suppliers and controls suppliers working together to introduce the monitoring equipment. This in addition to sufficient downtime on the machine to install the monitoring equipment.
Estimated project cost	The total project cost will depend on the scope of the monitoring foreseen. This is likely to be a project requiring £600,000 and between 12 months and 18 months to implement.
Payback to project host site	If successful the host site could expect to attain savings of £260,000 / year giving a payback of 2.5 years for the full project cost.
Dissemination	
Cost of technology (once mature)	There will be limited cost reductions available once the project has been demonstrated since the control system integration will be bespoke for each site.
Saving	The project should deliver annual operational savings of £260,000 for a typical site.
Payback once mature	The likely payback will remain at 2.5 years
Project persistence	A controls system project will have a lifetime of 5 years as sensor replacement needs to be factored in.
CO_2 saving per site	At a typical site manufacturing 500 tpd the annual savings would be 2600 tonnes per year.
Sector CO_2 saving potential	The sector potential is 65,600 tonnes
Market penetration	The market penetration will depend on the energy savings made in the pilot site which in turn is dependent on the current sophistication of their control strategy. If the pilot project is a success then we would expect penetration of 15% within 5 years and 30% after 10 years.
Forecast CO_2 saving	10,000 tonnes after 5 years 19,600 tonnes after 10 years
Barriers to adoption	1) Concerns regarding the long term durability of the sensor technologies deployed; 2) Impacts on quality during commissioning and control loop tuning; 3) Inherent conservatism of industry
Risks	Project persistence less than anticipated due to sensor reliability.

6.3 Optimised Dryer operation

Title: Optimised Dryer operation	
Development	
Description	The dryer is the most energy intensive section of the dewatering system. Dryers typically will reduce the web from a moisture content of 55% water down to the final product moisture of between 5 and 8% moisture. In addition where coatings are foreseen in the product specification the dryer can comprise two or more drying sections – initial drying / wet coating and then final drying. The TAPPI Guidelines suggest that for an optimum dryer (single stage drying / no coating) the steam to evaporation ration should be close to 1.2:1. The moisture evaporated is removed by a hot air stream – there is the possibility of heat recovery into fresh air and into white water (the water that is recycled in the process). Our monitoring programme has shown that the relative humidity of the air stream is low (15% to 25% at Site B) although background research indicates a best practice value of 38-40%. The project concept is technological modification to the hood air system to permit operation at higher levels of absolute (as distinct from relative) humidities. Increasing the moisture content of the exhaust gas will reduce the ratio of air to humidity thereby reducing the air flow rates; To attain this objective means being able to effectively control the relative humidity in the hood and hence a determinant is the reliable measurement of relative humidity at elevated temperatures. Other technology innovations could be included within the scope of this project: • Hood segregation – i.e. hoods are currently large plenums, hood segregation would permit management of the air flows through the hood to optimise evaporation – potentially with internal recirculation; • Increased heat recovery from the hood exhaust (potentially with condensation) to recover water; • Control of steam supply to the cylinders in each dryer zone to the absorption rate of the air stream.
Technology maturity and need for support	The sector is aware of the potential from better management of the hood air flows however there remains inertia in the sector due to fears of moisture condensation in the hood and the impacts of drips onto the paper. There are also concerns about the long term reliability of humidity sensors hence it has proved easier for the sector to operate at temperatures and air flow rates which result in low levels of relative humidity and minimise the risks of condensation. Changes to the hood are a major engineering challenge and present a significant risk of failure – for this reason the industry has not progressed this technological route in the past.
Possible project approach	There are a number of technologies and approaches that could meet the requirement for optimised dryer performance. A good project application would need to include: • A willing host site; • A paper machine manufacturer or engineering company with experience in air management in the hood; • Access to expertise in moisture sensors. Depending on the scope of the project it may also need skills in heat exchange design and engineering.
Estimated project cost	The project costs will depend on the overall scope of the project and the approach of the project team but could range from £500,000 for integration of relative humidity control into the air flow control strategy to £1.5 million if substantial changes to hood designs are required to attain 50%RH.

Title: Optimised Dryer operation	
Payback to project host site	1.5 to 4.5 years Increasing the relative humidity from 38% to 50% would reduce air flow rates by 30% with an associated reduction in electricity consumption of an estimated 50% (higher due to friction effects). On a typical paper mill this would lead to cost savings of £350,000 / year.
Dissemination	
Cost of technology (once mature)	Paper machines are to a great extent bespoke designs thus the opportunities for declining costs with increased market penetration are limited. In all cases the costs will be project specific.
Saving	Assuming the air flow rates can be reduced in each case by 30% this should continue to deliver approximately 1MW of electricity consumption. This will be from imported electricity with a value of approximately £350,000 / annum.
Payback once mature	1.5 to 3.5 years
Project persistence	10 years
CO_2 saving per site	4300 tonnes
Sector CO_2 saving potential	Using the model generated for this project we estimate the annual emissions from the ventilation systems associated with the paper machines as 220,000 tonnes (note that this assumes that savings will be solely derived from imported rather than own generated electricity) hence the saving potential is 110,000 tonnes
Market penetration	The market penetration will depend on the energy savings made in the pilot site. If the pilot project is a success then we would expect penetration of 20% within 5 years and 50% after 10 years.
Forecast CO_2 saving	22,000 tonnes after five years 55,000 tonnes after ten years
Barriers to adoption	1. Concerns regarding the long term durability of the sensor technologies deployed; 2. Downtime necessary for major hood engineering changes 3. Impacts on quality during commissioning and control loop tuning.
Risks	Project persistence less than anticipated due to sensor reliability (condensation in sensors leading to inaccurate readings).

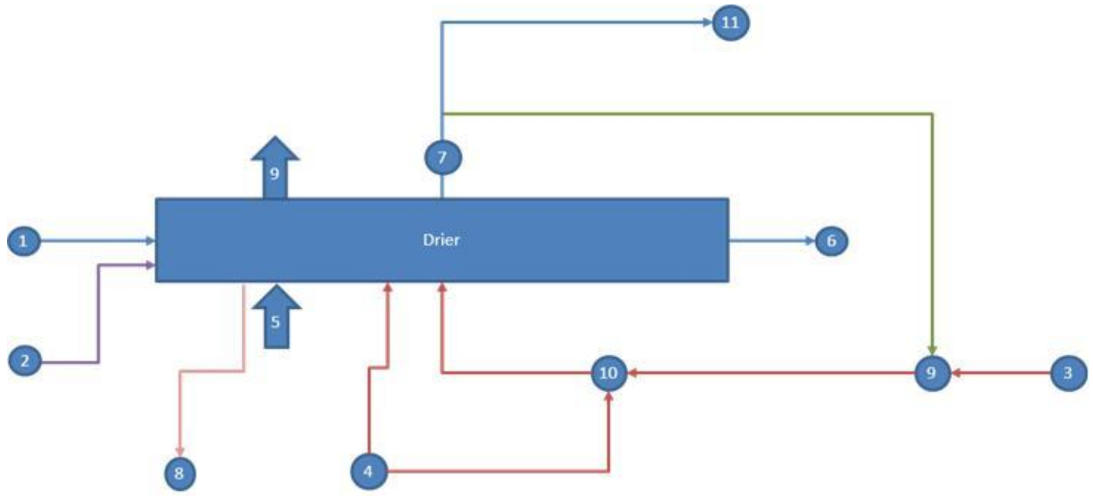
6.4 Hot Press

Title: Hot Press	
Development	
Description	In reducing the stock from 4% solids to 45% solids mechanical drainage removes 95% of the total moisture content of the stock at an estimated energy performance of 0.03MWh/tonne of moisture removed (note that the dryer removes the remaining 5% at an energy performance of 1.8MW/tonne moisture). Mechanical dewatering is therefore considerably more effective than thermal dewatering. The "hot press" concept seeks to increase still further the effectiveness of mechanical dewatering. The critical process parameter for mechanical dewatering is the kinematic viscosity of water – operating with a reduction in viscosity would lead to increased mechanical dewatering for the same energy input (thus reducing the load on the dryer) or a reduction in the energy input into the mechanical dewatering stages. The papermakers would exploit this opportunity to get increased mechanical dewatering and would thereby be able to increase throughputs in the dryers. There are two process "levers" available to papermakers to reduce viscosity – temperature and chemical addition – of these two temperature rise is the most sustainable – a 20°C rise in temperature from 50°C to 70°C will reduce the viscosity by 25%. There is sufficient available heat in the dryer exhaust to raise the temperature of the fresh water to the stock preparation system up to 50°C (see Section 6.4 above), marginal heating of fresh water up to 70°C would be needed (potentially higher to offset increased heat losses in the stock preparation system). Reducing dryer entry moisture from 55% down to 50% would reduce the dryer energy consumption by approximately 25%. 80% of the saving comes from reducing the amount of evaporation required in the dryer, the remaining 20% comes from reducing the amount of air flow required for a given exhaust relative humidity. The challenge therefore looks to demonstrate the opportunity from changing the operating parameters of the wire and press and hence the knock on effects on changes to operation of the stock preparation system from higher recycled water temperatures.
Technology maturity and need for support	The main technological changes required to operate at higher web temperatures are: • Preheating of fresh water additions to the water cycle; • Modifications to the wire/press to enable operation at higher temperatures – typically this will involve increasing safety measures to reduce the risk of contact between the hot web and individuals working in the vicinity; The uncertainty with hot pressing is the impact of higher operating temperatures on fibre surface properties and the ultimate impact on the mechanical and finish properties of the final product.
Possible project approach	A good application would need to include: • A paper manufacturer; • A paper machine manufacturer also with competence on stock preparation
Estimated project cost	In the absence of detailed information from the sector as to the actual technological changes required to operate with higher temperature web we are assuming an implementation cost of £2 million of which we would expect the site to contribute £1.5 million and the Carbon Trust to contribute £500,000.
Payback to project host site	1.5 – 3 years
Dissemination	

Title: Hot Press	
Cost of technology (once mature)	Paper machines are to a great extent bespoke designs thus the opportunities for declining costs with increased market penetration are limited. In all cases the costs will be project specific.
Saving	Assuming in each case that the dryer inlet moisture can be reduced from 55% down to 52% this should deliver savings which average 45,000MWh/year of fossil fuels. This has a value of £1.1 million.
Payback once mature	1.5 to 3.5 years
Project persistence	10 years
CO_2 saving per site	9,000 tonnes of CO_2.
Sector CO_2 saving potential	The potential from the sector is 230,000 tonnes
Market penetration	If the demonstration project pr9oves successful then one can estimate a market penetration of 15% within 5 years and 30% in 10 years
Forecast CO_2 saving	34,000 tonnes in 5 years 68,000 tonnes in 10 years
Barriers to adoption	The uncertainty with hot pressing is the impact of higher operating temperatures on fibre surface properties and the ultimate impact on the mechanical and finish properties of the final product.
Risks	Amount of moisture reduction at the dryer inlet is less than anticipated.

Appendices

Appendix A: Heat and mass balance for a dryer



Production	500	ADt/d
	20.83	ADt/h
Paper Moisture at press exit	55%	
Paper Moisture at Dryer Exit	8%	
Dry Fibre	19.17	ADt/h
Moisture at entry	23.43	tph
Moisture at Exit	1.67	tph
Evaporation	21.76	tph
[TAPPI Guidelines	1.2	kg/kg evaporated]

Assumptions:		
Steam	11	bar
Fresh Air : Dry Fibre	7.5	
Air	10	g/kg Dry Air (42% RH)
Leakage Air : Fresh	0.5	
PM	76%	Total Steam
Required Steam	1.86	kg/kg evaporated

Heat and Mass Balance

	Flows In	Flow	Flow	Temp	Enthalpy	Heat Flux	
		TPH	KG/S	DegC	kJ/kg	kW	
1	Dry Fibre	19.17	5.32	50	70	373	
1	Moisture in Paper	23.43	6.51	50	208.75	1358	
2	Leakage Air	71.875	19.97	28	53.62	1071	
2	Moisture in Leakage Air		0.20	28			
3	Dry Air to heat recovery	143.75	39.93	28	53.62	2141	
3	Moisture in HR Air		0.40	28			
4	Steam	40.53	11.26	188	2780	31299	11 bar abs - Sat
5	Fans + Electricity					2899.3	
	Flows Out						
6	Dry Fibre	19.17	5.32	90	126	671	
6	Moisture in Paper	1.67	0.46	90	375.75	174	
7	Dry Hood Air - Exhaust		59.90	83	466.17	27922	35% RH
7	Moisture in Hood Air - Exhaust		6.64	83			
8	Condensate		11.26	100	640	7205	5 bar abs
9	Other Losses					3172.0	
	Total Mass / Heat In		83.58	kg/s		39141	kW
	Total Mass / Heat Out		83.58	kg/s		39144	kW
9	**Heat recovery**						
	Exhaust In DA		59.90	83	466.17	27922	
	Exhaust In Moisture		6.64	83			
	Fresh Air In DA		39.93	28	53.62	2141	
	Fresh Air In Moisture		0.40	28			
	Exhaust Air Out DA		59.90	68.8	447.65	26812	63% RH
	Exhaust Air Out Moisture		6.64	68.8			
	Fresh Air Out - DA		39.93	55	81.4	3250	
	Fresh Air Out - Moisture		0.40	55			
	Heat transfer					**1109**	**kW**
10	After Steam Battery						
	Fresh Air Out - DA		39.93	95	122.84	4905	
	Fresh Air Out - Moisture		0.40	95			
	Heat from Steam		0.79	150		1655	kW
	Evaporation Duty		**6.04**	**83**	**2441.25**	**14755**	**kW**
	Efficiency (Evap/Steam)					**47%**	

Appendix B: EU research project summary

Project Title	Host organisation, Country	Research Area	Description
Expansion of process and property space through novel paper chemistry	STFI-Packforsk Sweden	RA 1-8 Pulp, energy and chemicals from wood bio-refinery, RA 2-2 More performance from less inputs in paper products, RA 2-3 Reducing energy consumption in pulp and paper mills, RA 2-1 Reengineering the fibre-based value chain	Surface modifications of fibres promise to expand the property space of paper and board materials, decrease the resource use and improve the productivity of paper/board machines. This will be explored together with the practical utilisation of the nanostructure of cellulose and of nanoparticles in papermaking.
Tools for Sustainability Impact Assessment of the Forestry-wood Chain	The Forestry Research Institute of Sweden Sweden	RA 5-1 Assessing the overall performance of the sector	The objective of EFORWOOD is to develop a quantitative decision support tool for Sustainability Impact Assessment of the European Forestry-Wood Chain (FWC) and subsets thereof (e.g. regional), covering forestry, industrial manufacturing, consumption and recycling. The objective will be achieved by: a) defining economic, environmental and social sustainability indicators ,b) developing a tool for Sustainability Impact Assessment by integrating a set of models ,c) supplying the tool with real data, aggregated as needed and appropriate, d) testing the tool in a stepwise procedure allowing adjustments to be made according to the experiences gained, e) applying the tool to assess the sustainability of the present European FWC (and subsets thereof) as well the impacts of potential major changes based on scenarios, f) making the adapted versions of the tool available to stakeholder groupings (industrial, political and others).The multi-functionality of the FWC is taken into account by using indicators to assess the sustainability of production processes and by including in the analysis the various products and services of the FWC. Wide stakeholder consultations will be used throughout the process to reach the objective. EFORWOOD will contribute to EU policies connected to the FWC, especially to the Sustainable Development Strategy. It will provide policy-makers, forest owners, the related industries and other stakeholders with a tool to strengthen the forest-based sectors contribution towards a more sustainable Europe, thereby also improving its competitiveness. To achieve this, EFORWOOD gathers a consortium of highest-class experts, including the most representative forest-based sector confederations. EFORWOOD addresses with a high degree of relevance the objectives set out in the 3rd call for proposals addressing Thematic Sub-priority 1.1.6.3 Global Change and Ecosystems, topic V.2.1. Forestry/wood chain for Sustainable Development

Project Title	Host organisation, Country	Research Area	Description
New eco-efficient process technology for papermaking from recycled fibres	STFI-Packforsk AB Sweden	RA 2-3 Reducing energy consumption in pulp and paper mills, RA 3-3 Streamlined paper recycling, RA 2-1 Reengineering the fibre-based value chain	EcoFracSmart develops three innovative process concepts, collectively named “EcoFracSmart”, which address the main operations for recycling mixed recovered fibre streams into new paper products: extracting fibres from recycled paper, separating impurities and preparing for production of new paper. The new ideas originate from a Swedish SME technology developer and are designed for papermaking SMEs. The driving force behind the EcoFracSmart project is the conviction that today’s technology for brown and grey recycled paper grades is unduly complex and energy consuming. In spite of their technical complexity, modern recycled fibre lines have significant negative effects on the fibre raw material. The basic idea of the new concept is to separate impurities in the earliest stage of the process, where impurities are large and easy to remove. Thereby one can simplify the subsequent process stages and design a compact process with fewer unit operations then in a conventional solution, and which is less capital intensive, easier to control and more energy-efficient. Thereafter, hydrocyclone fractionation separates fibres in sub-streams with different papermaking properties and potential to give strength to the final product. Thus, energy-intensive fibre treatments can be limited only to the sub-streams that need it. The flexibility of the concept will allow papermakers to improve product evenness when feeding the paper mill with mixed recovered fibre sources. Earlier assessments suggest that the system has a potential energy saving of 30-40% as compared to a traditional concept for stock preparation of recovered fibres or a saving of 100-130 kWh/ton for a typical recovered paper mill. The concept will be demonstrated through pilot scale studies and industrial tests using the raw materials and products of the SME participants. In particular, the RTD activities will focus on assessing whether EcoFracSmart can improve the papermaking yield of the raw material mixtures for the business cases of three European SME mills.

Project Title	Host organisation, Country	Research Area	Description
Pre-treatment of cellulose based pulp	Karlstad University Sweden	RA 1-8 Pulp, energy and chemicals from wood bio-refinery, RA 1-9 Green speciality chemicals	The project, which is a continuation of an on-going research project at our university, is to use an enzyme pre-treatment of the original pulp to improve the following process steps in the preparation of cellulose based derivates including viscose products. So far we have shown that the enzyme pre-treatment can improve considerably the reactivity of the pulp for viscose preparation with reduced chemical demand and reduced environmental impact if done in industrial scale in the following process steps. However, now we would like to continue these studies to preparation of other derivatives like CMC, cellulose acetates etc. The benefit we hope to achieve is reduced chemical demand, reduced costs and indirectly reduced environmental impact. We also hope to get a better understanding of the actual chemical mechanisms in the preparation of cellulose derivatives. We believe that these types of products will play a greater role in the future when oil based products have to be phased out.

Project Title	**Host organisation, Country**	**Research Area**	**Description**
Advanced Quality Prediction Tool for Knowledge-Driven Packaging Design and Manufacturing in European SMEs (030299)	AIDIMA Spain	RA 1-1 A new generation of functional packaging, RA 2-1 Reengineering the fibre-based value chain, RA 3-3 Streamlined paper recycling	The MODELPACK project aims at improving the international competitiveness of European corrugated board industries, which are mainly SMEs and of related sectors by an integrated, transnational research approach. Research will be carried out by RTD performers in order to expand the knowledge base and improve the overall competitiveness of participating SMEs. It shall enable SMEs to increase their added-value in producing corrugated board, being one of the most valuable packaging materials, from alternative resources with high proportion of recycled fibres. For the European corrugated board industry the variability in raw materials (packaging grade papers) with increasing percentages of recycled fibres is a very common technical problem. This is due to the restrictions in availability of forest based raw materials along with favourable environmental policy (EU Packaging Directives). The difficulty of predicting the properties of paper products produced from heterogeneous sources puts several limitations, which therefore lead to severe economic losses and only a comprehensive characterisation will enable their better utilization. The project work will start with an international survey on existing definitions and grading of raw materials and end products relevant for the project. The overall scientific and technical objectives of the project are: 1. To create a database of information on raw materials (grade papers and corrugated board) available for packaging companies throughout Europe 2. To classify packaging grade papers into well-defined categories according to their basic properties and production methodologies 3. To investigate and to identify the lower tolerance limits of the properties of grade papers that ensure high performance of selected semi-elaborates (corrugated boards) and final products (package boxes) according to their specific use 4. To filter and prioritise by the use of statistical analysis the paper characteristics (crucial industrial relevant properties) those mostly affect corrugated boards and boxes properties, considering SMEs practises (production, practical measurements, practical quality control) 5. To develop appropriate quality prediction systems and explore new decision possibilities for both cost reduction and quality increase in packaging design and manufacturing 6. To train the staff of the group of participating SMEs and IAGs and disseminate the results to interested packaging industrial SMEs by organising seminars, by publications in practical journals and brochures and by using the internet The integrated results to predict the quality of packaging from alternative raw materials with special regard to feasibility, risks, costs, profit and energy input will be disseminated to a large number of SMEs and other interested bodies in Europe

Project Title	Host organisation, Country	Research Area	Description
Chemical and energy recovery in the kraft pulp mill	STFI-Packforsk AB Sweden	RA 1-8 Pulp, energy and chemicals from wood bio-refinery, RA 2-3 Reducing energy consumption in pulp and paper mills	The over-all aim of the research work within the area of inorganic process chemistry is to gain such process knowledge that is necessary when handling process problems caused by NPEs (non-process elements), and in the development of a simulation tool for the industry with which it is possible to predict process problems of NPEs and thus increase the productivity and energy efficiency
White Biotechnology for added value products from renewable plant polymers: Design of tailor-made biocatalysts and new Industrial bioprocesses	Centro de Investigaciones Biológicas, CSIC Spain	RA 1-9 Green speciality chemicals, RA 1-10 New generation of composites, RA 2-1 Reengineering the fibre-based value chain, RA 1-8 Pulp, energy and chemicals from wood bio-refinery, RA 2-3 Reducing energy consumption in pulp and paper mills, RA 2-2 More performance from less inputs in paper products	Plant polymers are the main source of renewable materials in Earth. The use of biotechnology will permit to develop new routes for cellulose and lignin-based added value products, including speciality paper products and surfactants. The industrial utilization of cellulose includes pulps for the paper industry. However, its characteristics permits to use cellulose for speciality products whose potential is still to be fully investigated. Lignin is a heterogeneous aromatic polymer, highly recalcitrant towards degradation. Most industrial uses of cellulose require the previous removal of lignin, which is generally burnt at the mill. However, the chemical nature of lignin makes this polymer an interesting source of aromatic chemicals. Oxido-reductases are involved in both lignin biosynthesis and biodegradation. Therefore, they have the highest potential for modification of lignocellulosic materials and isolated lignins. Some oxido-reductases have been extensively investigated in terms of structure-function relationships. This will allow a new approach based on tuning their catalytic and operational properties using protein engineering tools (such as forced evolution and site-directed mutagenesis) to obtain industrial biocatalysts. The applications of tailor-made enzymes will include among others: i) increase of strength and other properties of cellulose fibres, and improve refining; ii) production of lignin-free cellulose for high-quality products; and iii) production of lignin-based surfactants (as dispersants and nano-emulsifiers) and adhesives. In this way, the IP will contribute to maintain the EU leading position in the market of industrial biotechnology. The potential impact is illustrated by the turnover of the EU Paper-Forest cluster that attains 400 000 million euro/year. In this way, the IP will contribute to transform a part of the EU chemical sector to more sustainable and eco-friendly manufacturing processes
Briljant	Kenniscentrum Papier en Karton Netherlands	RA 2-2 More performance from less inputs in paper products	The project focuses to a minimisation of the amount of water introduced after the press section to the web that has to be removed in the drying section. Major driver is energy reduction; however product quality is an important boundary condition. Partners are Smurfit-Kappa Roemond Papier, Coldenhove Papier, Solidpack Loenen and EsKa Board as paper / board mills, ABEKO as additive supplier, Bumaga as sensor supplier, WUR A&F and KCPK as knowledge providers.

Project Title	Host organisation, Country	Research Area	Description
Process Chemistry in Closed Papermaking Systems	STFI-Packforsk AB Sweden	RA 2-3 Reducing energy consumption in pulp and paper mills	The aim is to reduce the amounts of dissolved and colloidal material in the white water system, thus lowering the cost for papermaking additives, increasing the productivity and giving a more uniform product. New papermaking additives that function well in such systems will also contribute to these benefits.
Tailor made cellulose pulps with specific compositions	Karlstad university (KaU) Sweden	RA 1-1 A new generation of functional packaging, RA 1-10 New generation of composites, RA 1-9 Green speciality chemicals, RA 1-8 Pulp, energy and chemicals from wood bio-refinery	The project, which is a continuation of an on-going research project at our university, will use kinetic studies to determine the dissolution of different components from the wood chips during pulping and further refining. The intention is to end up with a cellulose material with specific composition with regard to different wood components with specific characteristics and to be able to tailor make different types of cellulose materials which can be used as a component in other materials. The intention is to study different types of wood raw materials and one possibility is to combine this study with the bio-refinery concept where the project starts after the elimination of low molecular weight carbohydrates that can for example be used for chemical or fuel purposes. The project will also increase our knowledge of how much that be expected from new bio-refinery processes and establish limits for the possibility to extend the range for material properties based on traditional wood processes. Our studies have been going for a few years and we have equipment and knowledge for a quick start. The vision is to obtain better products based on biological material that can help in replacing oil based products
Recovered paper SORTing with Innovative Technologies	Papiertechnische Stiftung Germany	RA 3-3 Streamlined paper recycling, RA 2-1 Reengineering the fibre-based value chain, RA 2-3 Reducing energy consumption in pulp and paper mills, RA 2-2 More performance from less inputs in paper products	The SORT IT project aims at developing new sensors for better identification of components in recovered paper streams. These sensors will be integrated into new sorting concepts and implemented into industrial sorting installations. The resulting sorted recovered paper mixes will be characterised in industrial recycled paper mills (both in packaging materials and deinking mills). The benefits in terms of recovered paper yield and quality, as well in resulting recycled paper quality, process conduct, reject rate, energy consumption, side-costs, etc. will be fully assessed. The overall environmental benefit will be assessed using life cycle studies. The project includes the valorisation of non-paper components (in particular plastics) in recovered material streams containing paper (not sorted at source). The focus of the project is to maximise yield and quality of sorted materials in order to facilitate recycling in comparison to energy recovery

Project Title	Host organisation, Country	Research Area	Description
Production of fuel ethanol from biomasses	STFI-Packforsk AB Sweden	RA 1-7 Moving Europe with the help of bio-fuels	The main objective of the EUROETHANOL project is to: Supply Europe with industrially applicable technologies for sustainable production of ethanol from lignocellulosics as a fuel for transportation. The project thus considers the interdependencies between: the biomass raw materials; the process technologies for their pre-treatment, hydrolysis and fermentation into ethanol; the recovery of spent liquids and solids; the generation of bio-products; and the supply of heat and energy for the process. The heart of the project is to develop processes, with a focus on the pre-treatment process as a part of a process system, for the conversion of selected lignocellulosic biomasses into fuel ethanol. This will be accomplished by extensive laboratory work and the demonstration of at least one of the laboratory technologies in a pilot plant trial in the SEKAB E-Technology "Ethanol Pilot" in Sweden. A bio-product such as ethanol from biomass requires sustainable technologies. This is accomplished by process integration enabled by comprehensive system analyses. The development and selection of efficient recovery technologies allowing for the generation of heat and power and the production of valuable bio-products will i.a. be assessed by employing a patent-protected process for the extraction of lignin. Hemicelluloses, such as polymeric xylan, will also be a target for the separation and a source for the generation of valuable bio-products from the process. The results from each work package in this project; Biomass raw materials, Pre-treatment & processing - Laboratory investigations, - Pilot trials and Recovery & bio-products will continuously be put together and evaluated as a process system by means of System Analysis
Optimal Mechanical Dewatering	STFI-Packforsk Sweden	RA 2-3 Reducing energy consumption in pulp and paper mills	The overall objective of this project is the improvement of mechanical dewatering processes in papermaking, such as suction dewatering in the wire section and wet pressing. Suction dewatering in the wire section will be improved by the implementation of the membrane-assisted dewatering process. Wet pressing will be improved by focusing on better wet press felts and an optimization of the wet pressing process for given operating conditions. An additional focus of the project is, that the improvements will not lead to a deterioration of the paper properties which would be an obstacle to the introduction of the improvements

Source: www.ftpdatabase.org – These projects are returned with the search item energy and reflect the Research Area 2-3: Reducing energy consumption in pulp and paper mills

Appendix C: USA forest products industry technology roadmap

Strategic Objectives:

The US Forest products industry working with the US department of Energy – Industrial technologies programme has published the Industry technology roadmap setting out the objectives for research, development and demonstration against six key strategic objectives:

- Reduce Carbon Emissions and Energy Consumption
- Reduce Fresh Water Use by 50%
- Increase Biomass Supply
- Increase Value from Biomass
- Enable New Products and Product Features
- Increase Recovery and Recycling of Waste Products

The US industry is different from the UK industry in that it is based on vertically integrated mills and organisations – i.e. single companies having ownership or stewardship of the forests and having integrated pulp and paper mills. With chemical pulping the pulp process can be a net energy generator – from combustion of the black liquor and the heat and power can be used in the paper mill. Even with Thermomechanical pulping – which is a highly intensive electricity consumer; there is significant generation of waste heat which can be recovered and used in paper machines.

What this means is that not all of the objectives highlighted will be shared with UK industry. In the tables following we have highlighted those objectives which would be shared by UK industry

C1 Strategic Objective - Reduce Carbon Emissions and Energy Consumption

Objectives	R&D Needs
Generate Power and Energy More Efficiently with 25% Lower GHG Emissions	• High temperature operation of steam generating boilers (especially recovery boilers) • Improve energy efficiency of recovery boilers • Significantly improve fluidized-bed boilers to achieve high steam values and power values • Develop and deploy practical, cost effective black liquor gasification • **Develop advanced gasification combined-cycle technologies for black liquor and solid forest-based biomass. (ndlr – in UK – gasification of wastes from paper making)** • Generate more by-product electric power
Reduce Energy Intensity in Manufacturing by 25%	• **Deliver a dryer sheet (55–65% moisture) to the paper machine dryer section** • Reduce energy for black liquor concentration by 50%—including reducing pulp washing water usage • Increase pulping consistency to 30% from current levels of 15%–16%) • **Better recover and utilize waste heat** • Develop a next generation refiner to achieve more efficient mechanical pulping • Reduce energy intensity of refining and fibre preparation for papermaking • **Use steam more efficiently in manufacturing processes** • Use steam more efficiently in combined heat & power (CHP) systems yielding more cogeneration of electric power • Improve lime kiln efficiency • Develop alternative way to change sulfate to sulfide • Reduce energy use in chemical pulping—including pumping pulp and chemicals • Dry wood more efficiently • Reduce process water needs to that which enters with wood (Overlaps Water) • **Reduce fibre in products to enable the product’s intended function and require lower energy input**

	(Overlaps - Product Features) • Optimize the integration of new processes such as bio-refineries into pulp and paper mills
Eliminate Use of Fossil Fuels	• **Use biomass to replace fossil energy—renewable source for nonsteam thermal demand** • Eliminate fossil fuel use in lime kiln • Better utilize lignin as an energy source • Find waste streams that can be sources of energy • Use internally generated solid waste streams as fuel • Develop waste water treatment as an energy source—recover VOCs
Reduce CO_2 Emissions with Novel Mill-Based Capture Techniques	• Recover CO2 from lime kiln stack and use it synergistically in mill • Grow algae or other biomass as fuel with CO2 feed

C2 Strategic Objective – Reduce Fresh Water use by 50%

Objectives	R&D Needs
Reduce Fresh Water Used in Pulping and Papermaking by 50%	• Remove non-process elements (NPEs) from chips prior to pulping (e.g., hemicellulose extraction, segregation in bleach plant, water treatment) • Reduce fresh water used in pulp washing, including alternative washing processes and pressurized washing (Overlap with need in Carbon and Energy) • Develop trees engineered to avoid calcium and barium • Build on existing work on chip leaching and hemicellulose extraction to remove metal ions • Develop a better understanding of how metals become fixed in wood • Improve process modelling tools for engineering studies, including chemical equilibrium for ion tracking and lifecycle analysis on chemical inputs
Develop Technologies to Treat and Reuse Process Water in Plants	• **Separate dilute contaminants (both organic and inorganic) from reusable water streams** • **Remove ions from filtrate to enable reuse as fresh water**

	• **Avoid scaling issues associated with process water** • **Develop heat recovery systems to better recover waste heat from water**
Develop Closed-Loop Water Systems	• **Develop testing protocol for in-plant evaluation of process water streams and to evaluate new technologies** • **Separate contaminants and useful components from water-based process streams** • **Survey mills on waste-water management to determine feasibility of totally closing mill water systems** • **Apply biological treatments in waste water streams earlier than at central waste-treatment plant at end of mill** • **Understand and learn from past efforts at achieving 100% closed water systems in paper mills**

C3 Strategic Objective – Increase Recovery and Recycling of Waste Products

Objectives	R&D Needs
Improve Sorting of Recovered Wood and fibre	• **Develop certified document destruction processes which maintain fibre integrity and reduce contaminants** • **Improve sorting in recycle paper mills to better separate grades and contaminants** • Detect, sort, and remove wood that contains heavy metals
Enable Recycled Fibres to have Operability Equivalent to Virgin Fibres	• **Develop new techniques that enable recycled fibres to have first grade production rate (Operability) equivalent to virgin fibres—machine design, water, fibre modification, nanotechnology** • **Develop improved process control technologies for contaminants** • **Increase fibre yield during paper recycling** • **Optimize paper machine water use and quality**
Use Non-Fiber Components of Recovered Materials More Effectively	• **Develop separation techniques to remove filler from recycling mill wastes and ways to reuse the recovered filler** • **Identify approaches for beneficial reuse of paper recycle mill residue such as sludge** • **Develop process to transform recovered filler into useful or saleable product**
Enhance Availability and Use of Recovered Biomass for Energy	• Recover urban wood wastes (e.g., from construction and clearing) for energy • Recover paper recycle mill ash and separated sludge for energy or chemicals • **Recover energy from pulp/paper mill heavy rejects**
Design Products for Deconstruction or Recycling	• Identify methods and materials for systems approach to wood product design • **Incorporate product end-of-use recovery into design of wood products and paper, paperboard, and packaging**

Appendix D: Canada – research, development and demonstration

Paprican (FP Innovations) is the Canadian research and development organisation for the Forest products industry. Like the USA the Canadian paper industry is vertically integrated and incorporates virgin pulp making as well as paper making.

For Pulp and Paper, FP Innovations separates its activities into two main areas:

- Consortium Research where the research programs are driven by the high-priority technical issues of the industry such as product quality and value, cost competitiveness, environment and sustainability.
- Transformative Technologies. In an environment of changing markets, global competition, new technology and new opportunities are reshaping the forest sector, both in Canada and worldwide. The industry has to look beyond its traditional products and markets, and be a leader in the emerging bioeconomy. Through a series of consultations with industry, academia and government, FPInnovations has developed a Transformative Technologies portfolio of five research programs, to generate the knowledge needed to develop new products and processes for a rejuvenated Canadian forest products sector.

The areas covered by consortium research are:

- Fibre Supply and Quality: Capturing more value from fibre resources and enhancing performance of market pulps.
- Chemical Pulping: Producing superior kraft pulps and the next generation of bleaching technologies.
- Mechanical Pulping: Developing the next generation of superior-performance thermomechanical pulps.
- Papermaking: Improving wet-end chemistry, designing and developing highly-filled printing papers.
- Product Performance: Delivering state-of-the-art end use properties from advances in surfaces, coatings and web structures.
- Environment and Sustainability: Minimizing environmental impact, reducing atmospheric emissions, optimizing energy and resource recovery and the development of new forest-derived products.

The five areas of focus for transformative technologies are:

- Next Generation Pulps and Papers: creating new value-added pulps and papers

- Energy and Chemicals from Forest Biomass: producing new fuels and chemical intermediates
- Novel Bioproducts: high value products based on nanocrystalline cellulose and other new bio-materials
- Integrated Value Maximization: linking the fibre resource to the product attributes demanded by customers
- Next Generation Building Solutions: creating innovative and sustainable building solutions

FP Innovations is also active in the development of technologies which they then licence to equipment manufacturers and pulp/paper makers.

The technologies and associated licensees are as follows:

1) Advanced Control of TMP Refiner Operations
- Metso Automation USA Inc, Norcross GA
- Metso Automation Oy, Helsinki FIN
- Metso Automation Canada Ltd., Field Systems Division - Pointe-Claire QC

2) Fibre Surface Development Sensor - Posidex
- OpTest Equipment Inc., Hawkesbury ON

3) Applications of Eco-Tec Fixed Resin Bed Technology to Chemical Pulp Mill System Closure
- ECO-TEC Inc., Head Office/Pickering Ontario

4) Lime Kiln and ClO_2 Generator
- TEXO Consulting & Controls Inc, Baie d'Urfe Qc

5) Autofeeder for FQA
- OpTest Equipment Inc., Hawkesbury ON

6) AutoSpeck
- Technidyne Corporation, Indiana
- Technidyne Inc., Dorval

7) Automated Pulp Kappa Number Measurement
- Mandel Scientific Company Inc., Guelph Ontario

8) FPInnovations highly filled paper technology without latex
- Specialty Minerals Inc., Bethlehem PA

9) $C10_2$ Generator Control
- TEXO Consulting & Controls Inc, Baie d'Urfe Qc

10) FTIR Analyzer
- ABB Inc., Quebec Qc
- ABB Inc., St-Laurent QC
- FITNIR Analyzers Inc, Richmond BC

11) Crepe Sensor Technology

12) Gas Content Sensor

- CapStu Inc., Pointe Claire Qc

13) Felt Permeability Tester
- Lorentzen & Wettre, Sweden
- Lorentzen & Wettre Canada Inc., Laval PC

15) Fiber Wall Thickness (FWT) Determination Technology
- Eurocon Analyzer AB, Sweden

- Process Measurement & Controls Inc, Connecticut USA

14) Improved PEO Retention Aid System
- Kemira Chemicals Canada Inc., Pointe Claire Qc

16) Lime Kiln
- TEXO Consulting & Controls Inc, Baie d'Urfe Qc

Appendix E: Netherland innovation programme

Original	Translation
Van eerste ideeën tot 5 innovatieprogramma's Doelstelling van de Energietransitie Papierketen is een halvering van het energieverbruik voor eindproducten papier en karton in 2020. Hiertoe heeft de sector de Strategische Innovatie Agenda opgesteld. Hierin is de innovatieroute opgenomen die is verdeeld over 5 innovatieprogramma's. De Strategische Innovatie Agenda zal worden gecoördineerd door branchevereniging Koninklijke VNP en het Kenniscentrum Papier en Karton.	**From concept to five innovative programs** Objective of the Paper Chain Energy is to halve the energy consumption for end-products of paper and cardboard in 2020. To this end, the sector has established the Strategic Innovation Agenda. It is recognized that the innovation route is divided into five innovation programs. The Strategic Innovation Agenda will be coordinated by the association and the Royal VNP Competence Paper and Board
1 - Energy Management 'Energy Management' is gericht op een directe en versnelde energiebesparing in de papier- en kartonfabrieken. Hiervoor zijn 3 pijlers opgesteld. Een daarvan omvat het branchebreed uitwisselen van best practices voor energiebesparingen in de fabriek. Daarnaast worden energietargets opgesteld op verschillende niveaus (branche, bedrijf, afdeling en proces). De derde pijler is het veranderen van de mindset in de fabrieken; het creëren van energiebewustzijn bij alle medewerkers in de fabrieken. 'Energy Management' is begin 2006 gestart en zal blijvend de aandacht krijgen. Doel van dit programma is om energie als integraal onderdeel van de bedrijfsvoering bij alle Nederlandse papier- en kartonfabrieken te implementeren.	**1 - Energy Management** "Energy Management" is aimed at an immediate and accelerated energy saving in paper and paperboard. There are three pillars established. One branch includes the wide exchange of best practices for energy savings in the factory. In addition, energy targets established at different levels (industry, company, department and process). The third pillar is to change the mindset in the factories, the creation of energy awareness among all employees in the factories. "Energy Management" in early 2006 and will continue to receive attention. The objective of this program is to energy as an integral part of its operations in all Dutch paper and board to implement.
2 - Energy Neutral Paper Papier- en kartonfabrieken beschikken over een aantal nevenstromen die te beschouwen zijn als 'potentiële energiebronnen' die beter benut kunnen worden. Hierbij valt te denken aan delen in het oudpapier die niet geschikt zijn voor recycling, componenten in het afvalwater en restwarmte. Het accent in het programma 'Energy Neutral Paper' ligt op het ontwikkelen en implementeren van nieuwe technologieën die deze potentiële energie converteren naar elektriciteit, bruikbare warmte-energie en andere energiedragers. Tevens wordt de mogelijkheid van alternatieve energiebronnen onderzocht. Het doel is om te komen tot een papier- en kartonsector die onafhankelijk is van fossiele brandstoffen.	**2 - Energy Neutral Paper** Paper and cardboard have a number of side streams that can be considered as potential sources of energy that can be utilized more. This could include parts of scrap paper unsuitable for recycling, and wastewater components in the residual heat. The emphasis in the program "Energy Neutral Paper" is on developing and implementing new technologies that convert potential energy into electricity, useable heat energy and other energy carriers. It also examined the possibility of alternative energy sources. The goal is to create a paper and cardboard sector independent of fossil fuels.
3 - Supply Chain of the Future	**3 - Supply Chain of the Future**

De Nederlandse papierketen kent een sterke verpakkingsketen en een sterke grafische keten . Voor beide ketens zijn de partners bij uitstek in Nederland te vinden. Het programma 'Supply Chain of the Future' is gericht op het opzetten van partnerships tussen papierfabrieken en andere partners. Dit omvat zowel bekende partners in de papierketen als ook partners in nog niet eerder verkende sectoren. Doel van dit programma is het realiseren van een papierketen die verder aansluit op de wensen van de eindconsument, zodat nog meer toegevoegde waarde wordt gecreëerd. Bij deze nieuwe samenwerkingsvormen wordt gewerkt aan het optimaliseren van deze ketens, waardoor verbetering in energie-efficiency en materiaalefficiency bereikt kan worden. Tevens kan samenwerking tot geheel nieuwe producten leiden.	The Dutch paper chain has a strong chain and a strong graphic packaging chain. Both ranges are the ideal partners in the Netherlands found. The program "Supply Chain of the Future is aimed at creating partnerships between paper mills and other partners. This includes both well-known partners in the paper chain as well as partners in areas not previously explored. The objective of this program is to create a paper chain that go in line with the wishes of the end consumer, so that even more value is created. These new forms of cooperation is underway to optimize these chains, thereby improving efficiency in energy and materials efficiency can be achieved. Operation can also lead to entirely new products.
4 - Bio-refinery In Nederland liggen mogelijkheden om grondstoffen optimaal te benutten met een bio-refinery, maar dan met een innovatief karakter; bio-refinery. Dit is een concept waarbij zowel hout als oudpapier, agrarische grondstoffen en andere nevenstromen gecombineerd verwerkt tot een groot scala aan nieuwe producten. Hierbij valt te denken aan pulp, bio-chemicaliën, bio-ethanol, bio-energie en nutriceuticals. Het doel is om maximale waarde te creëren uit houtvezels en agrarische producten. De papiersector onderzoekt de mogelijkheden om dit concept in een alliantie met verwerkers van agrarische grondstoffen vorm te geven.	**4 - Bio-refinery** In the Netherlands there are ways to maximize resources with a bio-refinery, but with an innovative, bio-refinery. This is a concept where both wood and waste paper, agricultural commodities and other secondary flows combined processed into a wide range of new products. This could include pulp, bio-chemicals, bio-ethanol, bio-energy and nutriceuticals. The goal is to maximize value from wood and agricultural products. The paper industry is examining possibilities for this concept into an alliance with processors of agricultural commodities.
5 - Without Water Voor de productie van papier wordt veel water ingezet om houtvezels op te lossen tot zogeheten papierpulp. Bij het proces waar de pulp weer gedroogd wordt, wordt de meeste energie verbruikt. Als papier met minder water kan worden geproduceerd, kan dus veel energie worden bespaard. In de papierindustrie worden nu diverse mogelijkheden zichtbaar om bij het droogproces energie te besparen. Toekomstige stappen zijn de vervanging van alle energie-intensieve procesonderdelen, waaronder de vervanging van water door bio-alcohol of zelfs door superkritische CO_2. In het programma 'Without Water' wordt gezocht naar doorbraaktechnologieën en de haalbaarheid daarvan voor de Nederlandse papier- en kartonindustrie.	**5 - Without Water** For the production of paper is water used to resolve to wood pulp known. In the process where the pulp is dried again, the most energy. If the paper can be produced with less water, so much energy could be saved. In the paper are now several possibilities to see in the drying process to save energy. Future steps include the replacement of all energy-intensive process steps, including the replacement of water by bio-alcohol or even by supercritical CO_2. In the program "Without Water" is looking for breakthrough technologies and their feasibility for the Dutch paper and board industry.

The Carbon Trust receives funding from Government including the Department of Energy and Climate Change, the Department for Transport, the Scottish Government, the Welsh Assembly Government and Invest Northern Ireland.

The Carbon Trust is a company limited by guarantee and registered in England and Wales under Company number 4190230 with its Registered Office at: 6th Floor, 5 New Street Square, London EC4A 3BF.

Published: August 2011