Case Study: The MiniMill Concept
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Abstract
The development of the MiniMill technology has come about as a result of a unique collaboration between environmental organisations and the paper industry. Local production of non-wood pulps provides a solution to the differing problems which these two groups want to solve. Namely, how to reduce the pressure on the World's environment and forests and how to mitigate the unpredictable and unstable economic conditions arising from the need to purchase imported commodity wood pulps.

A survey in 1996 found that current technology did not meet the requirement to produce a hardwood chemical pulp substitute from wheat straw in a clean and economically viable way. With support from the UK Government Department of Trade and Industry and working with industry experts new technology has been developed during 1997- 2000 to produce pulp cleanly on a small–scale (10-100TPD) in an economically efficient manner. The key new features of the MiniMill technology are a method of preparing straw to allow faster and more even pulping. A re-designed twin screw extruder pulping system which has an increased throughput and reduced energy demand, and a new small-scale simple and efficient method of treating black liquor effluent to recover energy and pulping chemicals.

Current projections based on pilot scale laboratory trials and theoretical calculations show that the MiniMill is expected to use less than half the electrical energy of current best available technology at 350kwH per tonne of pulp, be thermal energy self-sufficient - achieving 70% fuel efficiency, recover 85-90% of the pulping chemicals and produce a eucalyptus pulp substitute from straw in 30-40 minutes, ready for bleaching. A predicted green-field pulp mill capital cost of US$10 million for a 10,000TPA mill or $22 million for a 30,000 TPA straw pulp mill means that capital and operating costs are expected to be within or well under industry norms for even larger scale pulp mills.

The next step is to build a 10,000 TPA pilot plant in a two phase development programme. A site in China has been chosen and partners and investors for the majority of the required funding have been found. It is planned that commissioning and pilot trials of the key new parts of the equipment will be carried out in the UK, followed by transfer of the technology and the construction of the complete pulp mill in China.

Although developed for non-woods, we believe that the MiniMill technology could also be used to pulp wood, allowing sustainable harvests from woodlands previously thought too small to supply a traditional large wood pulp mill, such as in Scotland.

A partnership between environmentalists and the paper industry
BioRegional Development Group are an environmental charity, who have initiated a number of practical projects in the UK including local charcoal supply to national retailers and a £10 million eco housing project in south London called BedZED. BioRegional take a market led approach to the use of sustainable local resources to meet more of our needs, with the aim of reducing our collective ecological footprint.

In 1996, concern about the pressure on the world's forests arising from demand for paper led BioRegional Development Group to investigate the use of non-wood fibres for paper. BDG found that in the UK in 1996 we imported 1.6 million tonnes of chemical wood pulp for UK production of paper and 6.6 million tonnes of finished paper and board. This has now risen to 7.5 million tonnes (1). However, the UK has an annual surplus of 4 million tonnes of wheat straw, which could be used to produce 1.6 million tonnes of chemical pulp. This would reduce our demand on forests and also reduce transport of paper products, so cutting our CO_2 emissions. This is not just a UK issue, many other countries, such as China for example, import pulp while disposal of agricultural residues is a problem.

BioRegional first carried out a market study with funds from the World Wide Fund for Nature (WWF) and the UK Government and found a surprisingly high level of support from the UK paper industry for the idea of using local agricultural materials to make paper. In common with the paper industry in many parts of the World, the UK paper industry do not have the resources to vertically integrate their production using traditional large scale (400,000TPA) wood pulp mill technology, neither in terms of raw material supply or capital. Therefore, they are at the mercy of the commodity market in wood pulp, the price of which can vary by over 100%. In addition, imports are subject to exchange rate fluctuations. These two factors mean that the price of their main raw material can vary significantly and makes financial planning for non-integrated papermakers very difficult and risky. Production of a price stable wheat straw pulp to use in a proportion of their paper furnish is therefore extremely attractive. In addition non-wood pulps have interesting properties, which could allow papermakers to develop new products.

A research and development project
Despite this enthusiasm from both the environmentalists and the paper industry it was not possible to go ahead and build a straw pulp mill in the UK. Agricultural crops and residues are bulky and so best pulped locally on a small-scale. Transport of straw over long distances to a large pulp mill is just not economic. However, there has been no small-scale black liquor effluent treatment and a mill could not go ahead without effluent treatment. Led by BioRegional Development Group, a research and development project therefore began. Industry non-woods expert Trevor Dean came up with a new approach to get the best out of straw when making paper and a way of treating the black liquor - the MiniMill concept. WWF International and six UK graphics paper mills (Inveresk plc, Tullis Russell, Sappi, Robert Fletcher, James Cropper plc and Curtis Fine Papers) pledged their support and a company, BioRegional MiniMills (UK) Ltd was established in 1997 to develop the technology and see it established in the UK and elsewhere.

The MiniMill was designed to have the following properties:

- small scale (10 to 100 tonnes per day)
- versatile (able to use a variety of feed sources ie wood or cereal straws etc)
- no or very low environmental impact (use "clean technology")
- largely self-sufficient for energy
- good recovery of process chemicals
- modest capital costs.

Supported by the UK Department of Trade and Industry, and drawing on the expertise of the paper mills and specialist advisers such as the AF Group, the concept has been developed over the last four years to the point that we have established technical proof of principle. A conceptual design and flow sheet has been produced and the economic feasibility established. The next step is to build a pilot scale plant. Although of course as with any new technology, there are risks and certainly some further time and effort will be needed to produce an economic and good quality solution.

The MiniMill innovates in three key areas.

1. Raw material preparation and feed
2. Pulping using a re-designed twin screw extruder
3. Small-scale chemical and energy recovery system for black liquor effluent.

Straw fibre preparation and feed

Using his broad experience gained when working in non-wood pulp mills around the world, industry consultant Trevor Dean came up with a new approach, which aims to get the best out of straw when making paper. Straw has always been chopped before pulping, leaving most of the nodes (nodes are like knuckles in the straw stalk) intact, which has made for uneven pulping. For the MiniMill a new mechanical method has been developed and tested. It opens out the straw stems gently lengthways, preserving the fibre length but also crushing the nodes in the straw. This results in a 70% reduction in visible "shiners" in the paper sheet, due to dispersion of parenchyma cells. The system also led to improved uniformity of cook and measurable improvements in drainage, a higher tensile and tear strength (as there is less fibre damage), a higher pulp yield and a reduced demand for pulping chemicals. A positive feed system attached to the pulper has also been developed. Trials of the new raw material preparation system were carried out at The Wolfson Centre at Brunel University in London in conjunction with trials of the new pulping system.

In the MiniMill design, pulping takes place in a twin screw extruder. These extruders are widely used in many industries such as the plastics and food industry. They provide a compact continuous process with good mixing and fast throughput, operating at high pressures if necessary. When used for paper pulping extruders cut down dramatically on energy, chemical and water demand. Straw, flax and hemp have all been pulped in an extruder in pilot trials carried out at The Wolfson Centre at Brunel University in London.

Engineers discovered that by redesigning the internal screw and barrel system throughput can be increased by up to four times that of twin screw extruders which are currently sold as pulping units. Trials showed that the MiniMill pulping system had a very low energy demand, which at 350Kwh is half that of a traditional system.

It is also very fast, producing a semi-chemical pulp suitable for fluting at 4 bar pressure in 2 minutes. The increased throughput, together with the low pressure required in subsequent digestion when producing a chemical pulp brings down the capital cost considerably and makes the MiniMill an economic reality for commodity grades of pulp.

Tests by STFI on samples produced are found in Tables 1, 2 and 3. To produce a chemical pulp further digestion is required, see table 4.

Analysis of unbleached wheat straw pulp samples
Table 1

Sample	S1	S 2
Kappa No (mg/kg)	57.10	55.70
Dry matter content (%)	17.9	15.9
Somerville shive content (%)	56.9	80.3
Testing of laboratory sheets		
Grammage (g/m²)	70.0	67.5
Zero-span tensile index rewetted	32.8	26.1
CoV%	6.04	10.16

Table 2

Average

Sample	Length (mm)		Width (μm)			Shape factor (%)		
	Arimetic	Length weighted	0.5 - 1.0mm	1.5-3.00mm	Length weighted	0.5-1.00mm	1.5-3.0 mm	Length weighted
Sample 1	0.501	1.199	19.2	28.0	23.0	86.88	78.98	85.41
Sample 2	0.408	0.963	22.3	37.9	26.0	88.13	79.02	87.64

Table 3

Average

Sample	Total no of fibres	No Fibres0.5-1.0mm	No Fibres1.5-3mm	No Particles < 20 um	No Particles 20 - 50 μm	No Particles 50 - 80 μm	No Particles Other
Sample 1	9513	2041	314	3338	9432	5550	488
Sample 2	9382	1580	171	3609	12658	7749	620

Further trials were carried out at Wolfson Centre, Brunel University to assess the potential for a chemical and bleached pulp using the MiniMill technology. Following 2 minutes digestion at four bar pressure in the redesigned twin screw extruder as before, the straw pulp was digested for a further 20-30 minutes at two to four bar pressure. The pulp samples were then sent for testing and bleaching at KCL laboratory in Finland. In sample 1 a brightness of 86 ISO was achieved. The increased brightness achieved in sample 2 was at the cost of reduced tensile strength and other properties. The pulping and bleaching procedure needs to be optimised but it can be seen that it is possible to produce a pulp comparable to a eucalyptus market pulp from wheat straw using the MiniMill process.

Table 4 Wheat straw pulp/lab sheets bleached using DED sequence at KCL

Sample	Sample 1	Sample 2
SR-number, ISO 5267-1:1979	40.0	26.5
Preparation of laboratory sheets (for physical testing), ISO 5269-1:1998		
Grammage, ISO 536:1995, g/m^2	64.1	64.7
ISO-brightness, ISO 2470:1999, %	86.2	90.5
Light-scattering coefficient, ISO 9416:1998, m^2/kg	33.9	46.5
Light-absorption coefficient, ISO 9416:1998, m^2/kg	0.16	0.10
Tensile index, ISO 1924-2:1994, Nm/g	49.8	27.1
Stretch, ISO 1924-2:1994, %	5.1	3.6
TEA index, ISO 1924-2:1994, J/g	2.0	0.8
Modulus of elasticity, ISO 1924-2:1994, N/mm^2	4370	1780

Small scale chemical and energy recovery system for black liquor effluent treatment

The main stumbling block for small graphics pulp mills however is how to treat the black liquor effluent produced. Lack of technically and economically viable small-scale technology has led small mills around the world to be closed down to put a stop to horrendous pollution of watercourses caused by black liquor effluent. In China, where 86% of paper is produced from non-woods, 4,000 small mills have been closed or are threatened with closure in the last five years as the government cracks down on pollution.

Consequently, much of the research effort by the BioRegional MiniMill team has been directed to the search for and development of new technology to deal with the black liquor. The team found that a number of methods are being developed, but not one has been technically and economically proven as yet. In the MiniMill design, a new process making use of existing technology has been designed and tested. It is a chemical process which liberates organic chemicals for use as fuel and recovers sodium hydroxide for re-use in pulping. The process takes place at relatively low temperatures in a type of fluidised bed. This fluidised bed has been on the market for 15 years and is used in many industries including food and industrial waste processing. It avoids the problems with agglomeration associated with previous attempts to use fluidised beds for this purpose as it has a fast throughput, precise temperature control and good mixing.

The process has been tested in a number of pilot scale laboratory trials in the Netherlands. The process does destroy both dilute (10% solids) and concentrated (45% solids) black liquor. Sodium hydroxide and organics were recovered and the process ran cleanly for periods of up to two hours. The next step is to build a dedicated pilot plant with the necessary special gas burner and gas recycling system in order to run for longer periods and maximise the efficiency of the process. A theoretical chemical equilibrium and energy balance has been carried out by an expert in this field from AF-IPK in Sweden. See Table 5.

The energy balance shows that the pulp mill should be thermal energy self-sufficient through this process and that at larger end of the MiniMill scale, of nearer to 100 tonnes of pulp per day it may be economically viable to add a steam turbine to generate electrical energy as well. A high fuel efficiency of 70% is anticipated. Recovery of 85-90% of NaOH is predicted. A second fluidised bed can be installed as a calciner to recover lime used in the process. Calcining takes place at much higher temperatures (around 1,000^{o}C) and so will use a relatively large amount of energy compared to the rest of the process. It also adds to the capital cost. The alternative is to send the lime mud to the local cement factory or brickworks and buy in lime. Local circumstances will probably dictate the best option. Taking all the results into account, the black liquor chemical and energy recovery system has been further developed and re-designed.

Table 5. Tentative energy balance.

Unit GJ/Adt	Wheat straw	Hemp/flax
Input (primary fuels)		
Black liquor (70 % fuel efficiency)	14.5	11.5
Natural gas	0.0	3.0
	14.5	14.5
Consumption		
Fibre line: Digester, washing, screening	4.5	4.5
Bleaching	1.0	1.0
Pulp drying	0.5	0.5
Bleach chem prep/handling	0.1	0.1
Recovery area: BL Evaporation	4.5	4.5
Hot water production, etc	1.0	1.0
Steam for fluidising	2.0	2.0
Misc.	0.4	0.4
	14.5	14.5
		(AF-IPK)

Overall, if it performs as expected the MiniMill will have a low environmental impact. It has a low electrical and heat energy demand and should be thermal energy self-sufficient. Toxic chemicals are recovered for re-use. It has a low water demand with most water being recycled, totally chlorine free bleaching is proposed and 90% of the lime mud will be re-processed. The remaining 10% can be used in cement or brickworks.

Economic analysis
A prototype MiniMill engineering design and cost has been completed by industry consulting engineers, AF-QPS. The 10,000 tpa MiniMill is anticipated to cost US$ 10 million. The cost for a 30,000 tpa pulp mill has been projected at US$ 22 million. A comparison with standard capital and operating costs for new build straw pulp mills in China shown in Table 6 indicates that costs per tonne of pulp produced in small 10,000 –30,000 TPA MiniMills compare favourably with much larger kraft pulp mills.

As shown in Table 6, according to industry consultants Jaakko Poyry, the specific investment requirement for a new straw pulp mill located in China producing 50,000 TPA is USD 1650 per annual tonne of production (t/a).

In contrast, a 30,000 TPA BioRegional MiniMill, if manufactured mainly in China, is projected to sell at USD 22 million, giving a predicted specific investment requirement for a mill producing 30,000 TPA of USD 733 t/a. This can be seen more clearly in Table 6 below. Total projected pulp production cost in the MiniMill also compares favourably.

Table 6 - A Comparison of capital and running costs of MiniMill technology with other technologies on the market
Data from Jaakko Poyry (2) and BioRegional MiniMills Ltd.

Unit	Capacity (tonnes of pulp per annum)	Capital cost (USD)	Capital cost per unit of capacity (USD)	Operating cost per unit of capacity (USD)	Total pulp production cost capital (ex.interest) depreciated 15 yrs (USD)
A New build Kraft straw pulp mill	200,000	200 million	1,000/tonne	200	266 per tonne
B New build Kraft straw pulp mill	50,000	82.5 million	1650/tonne	260	370 per tonne
C (projected) New build straw BioRegional MiniMill	30,000	(projected) 22 million	(projected) 733/tonne	(projected) 193	(projected) 263 per tonne
D (projected) New build straw BioRegional MiniMill	10,000	(projected) 10 million	(projected) 1000/tonne	(projected) 252	(projected) 319 per tonne

First demonstration Mill
There is great interest in the MiniMill concept in China where venture capitalists and customers are ready to invest in our MiniMill technology. Following several visits to China and the ongoing work of our Chinese representative, BRMM have signed a letter of intent with a Chinese city government organisation, who wish to re-open their city pulp mill, which was closed in 1999 due to lack of black liquor effluent treatment. Approval from the environment agency has been obtained and the project has political support. A design study for the application of MiniMill technology on this site has been carried out by AF-QPS. We are in negotiation with a second potential Chinese investor and partner and would like to bring in a further partner who has experience of working in China and a capability in engineering, energy recovery and environmental technologies.

The next step is to build a pilot and demonstration plant in a two phase work programme designed to reduce risk. In the first phase, the new design of feed system and pulping unit, together with the black liquor effluent treatment will be built and run continuously in the UK. Once fully tested this equipment will be shipped to China and a 10,880 TPA commercial demonstration plant with paper making will be constructed around it.

It seemed a simple enough idea when we began in 1996, but developing the MiniMill technology has proved to be a lot of hard work with many twists and turns along the way. With the continued support of the projects many friends we will continue to do our very best to bring this project to a successful conclusion and indeed have a vision for the construction of 100 MiniMills in China and around the World by 2010.

References
(1) Industry Facts 1999, Paper Federation of Great Britain, May 2000
(2) Non Wood Fibre, a competitive component in paper and board. Jaakko Poyry consulting 1998

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