Brewery wastes. Strategies for sustainability. A review.

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Summary

Brewery wastes are large in bulk and generally high in moisture. Until recently their major outlet was to agricultural use, particularly animal feed, but also specialised products such as yeast extract. Reductions in dairy farming, restrictions on farm movements due to disease and EU legislation requirements have reduced this avenue leading to a search to broaden options for disposal. Alternative uses have been investigated for some years but require more targeted development to make them accessible to brewers. Encouraging options include anaerobic sludge digestion to release energy, supplementation of food products, mushroom cultivation, incorporation into paper materials and as a substrate for composting, bioremediation and microbial growth. The potential for applications to small scale brewing is good but will require collaboration between innovative biotechnologists and brewers to provide a sustainable result.

Key words. brewery waste, brewers'spent grains, bioremediation.

Introduction

The road to sustainability in the brewing industry has considerable potential due to the high volumes of waste material discharged with every brew. The brewing industry is a major producer of organic waste materials. This review will discuss the options available to manage these wastes and consider how they fit into a sustainable ethos with particular emphasis on small scale production.

What waste is produced?

It is fortunate that the bulk of the organic waste arising as spent malt and hops has traditionally been categorised as food grade so allowing a direct recycling to agriculture, either as animal feed or soil improver. At this level sustainability is high and has been practiced, doubtless since brewing began.

The major challenge is not only the waste products produced but also their bulk. Over 150,000 million litres of beer are produced in the world each year, 5,000 million litres in the UK (Barth Report, 2006).

The range of brewing specific waste materials produced by breweries, over and above standard manufacturing materials such as packaging is listed below (Table 1).

Table 1. Brewery waste products from small scale production.

Material	**Volume per HL 4% abv beer**	**Source / origin**	**Brewing use**	**Destination(s)**	**Difficulties**
Water	3 – 10 HL	Mains or bore hole	Product, cleaning, heating and cooling	Product, Effluent discharge	Chemical composition from acids & alkalis
Spent grain	14 Kg dry wt	Barley and other cereal malts	Source of sugars for fermentation	Agricultural	Hygiene, odour, High BOD
Spent hops	0.166 Kg dry wt	Hop flowers	Bitterness and other flavours	Agricultural	Anti microbial, unpalatable to animals
Trub	0.350 Kg dry wt	Precipitation from wort	Unwanted by product	Effluent discharge	High BOD and TSS
Yeast	3 Kg dry wt	Previous brew	Fermentation	Effluent discharge	High BOD, and TSS
Caustic and acid cleaners		Chemical suppliers	Cleaning	Effluent discharge	Acidity effects on effluent
Waste beer	Variable	Contamination Production errors	Nil	Low value sales or effluent discharge	High BOD

From the above profile it is evident that water and spent malt are the most extensive problems. A typical small brewery brewing 1500 litres three times a week will produce around two tons of spent grain in a week. Large regional breweries producing 1,000HL beer per day will have 40 tons per day to remove.

As a by product of this production around 250 million tons of spent grain and 30,000 tons of waste hops will be available for disposal in the UK. Even small breweries must have careful waste management if only to minimise the potential for spoilage organisms to develop.

Managing this waste has been achievable because of the close connection of the brewing industry with agriculture. Such arrangements were seriously disturbed in 2001 with the outbreak of Foot and Mouth in the UK restricting vehicle movements on farms. Traditional outlets for spent grain were curtailed and alternative sought. Moreover additional difficulties are now in sight with proposals to audit the hygiene of vehicles used to transport grain to farms as specified in EU Regulation 822/2004.

While Table 1 lists the individual waste products of the brewing process the reality on site is simpler because a number are combined into a single waste flow carried by discharge water. Washing water, waste yeast, cleaning chemicals and spoilt beer may all be discharged together and require common processing. While some breweries may route these for local municipal treatment they are often concentrated as a sludge after solids separation. In addition to this outlet stream spent grains and hops may be combined for solid disposal. These two products represent distinct outputs from the brewery and, although both have high BOD levels they also have different implications for processing. Much of the content of brewery waste is organic and digestible. COD levels are generally lower than many waste streams and BOD/COD ratios may be as high as 0.7 (Driessen and Vereijken, 2003).

Taking these outputs in three major areas allows a broad view to be made of the challenges facing breweries and of the often different means of managing each. Before considering solid and liquid brewery wastes it is worth comparing the three major outputs for their chemical nature. Table 2 illustrates these features.

Table 2. Composition summary of brewery wastes.

Waste	Solids (% w/w)	C (% Dry solids)	N (% dry solids)	C/N ratio
Sludge	16	36	7	5
Spent Brewers Grains (BSG)	24	53	2	25
Yeast	10	60	40	1.5

Sludge

Brewery sludge is perhaps the easiest by-product to handle but the most difficult due to its mixed and variable composition. Indeed the output from brewery processing may vary between pH 2 and 10 in only minutes and although a bulk average of pH 6 may be found in collated effluent the variation may impose difficulties in batch consistency and prohibit direct discharge.

Suspended solids vary similarly ranging from near nil to 2,500 mg/L while COD levels may reach 6,000 (Driessen & Verejken, 2003).

A typical system would involve a trickling effluent process with three vessels with an initial screening tank, a bulk settlement tank and an aerobic or anaerobic digester before discharge to mains sewer. Digestion of organic material in the tanks and digester will process soluble material and can lead to an outflow fit for direct discharge. It is the sludge generated in the settlement tanks which requires processing. Typically this consists of a range of heterotrophic microorganisms, organic particles from malt and hops, protein and tannin complexes, precipitated inorganic salts such as carbonates and oxalates and yeast cells. With a BOD of 1200 to 3600 (Driessen & Vereijken, 2003) this has a high demand for treatment but with such a low C/N ratio of 7 is poorly balanced for composting alone.

Generally, brewery sludge has been dumped into landfill, therefore, some environmental and management problems could appear in future. In addition, higher rates of organic wastes may increase salinity, which may be harmful to crops and the environment (Saviozzi *et al.*, 1994). Due to increasing environmental concerns and regulations, there have been attempts to utilise this brewery by product in an environmentally friendly manner (Kanagachandran & Jayaratne, 2006).

A number of studies have investigated the prospect of treatment of brewery sludge with some investigations looking to generate energy (Ince *et al*, 2001, Driessen & Vereijken, 2003, Kanagachandran, 2004; 2005) and others focusing on soil addition or a composting option (Stocks *et al.*, 2002).

A laboratory study carried out to assess the suitability as soil amendment of a sludge obtained through aerobic depuration of wastewaters from a winery (winery-sludge) found that winery-sludge (0.5 – 2.5%) increased the amount of available N, P, K and S, organic and potentially mineralisable carbon, and total microbial activity. In contrast pH, biomass, dehydrogenase activity, decomposition rate, water-soluble sugars, phenolic compounds and chemical oxygen demand (COD) were not affected by the sludge application (Saviozzi *et al.*, 1994). Anaerobic digestion of brewery sludge has the potential to generate up to 0.35m^3 of methane per Kg of COD digested, enough to power all the energy required to process the waste and so incur no additional costs (Ince *et al*, 2001).

Practical considerations of waste water processing for small brewery operations have been discussed in detail by Ockert (2002) who cites a 69% reduction in sewer charges through the installation of a simple pH control system.

Mixing of brewery sludge with agricultural wastes such as cattle dung has allowed systems to produce hydrogen (Fan *et al.*, 2006). Such a system was optimised to produce 43ml of hydrogen per gram of COD. To achieve this, however, the cattle dung required heat treating at 103^{o}C for 24 hours to eliminate methanogenic microorganisms and select for hydrogen-producing *Clostridia*. The economics of energy production from brewery sludge digestion is yet to be guaranteed as a variety of factors will influence the overall balance, not least waste water treatment charges. However, as these are likely to rise in the future the option of treatment on site will become increasingly attractive.

Spent grains

Brewery spent grain (BSG) are the other major brewery by-product with difficulties and potential in disposal. Spent grains are composed by dry weight of dry matter (26.3%): crude protein (23.4%) and crude fibre (17.6%) (Briggs *et al.*, 1996).The treatment of organic solid waste is currently a growing area of investigation as new options are explored. Since BSG is a beverage industry waste having food characteristics, it is thought that this waste can be used in agriculture due to its high organic matter.

While BSG contain significant energy resources from their organic contents they have some major difficulties in a sustainable energy balance as noted below:

High water content

BSG is typically more than 75% moisture. This feature is a major limitation on the energy balance of using spent grains as transport costs will be a dominant part of off site processing.

While drying BSG is energy inefficient and may affect grain character (Prentice & D'Appolonia, 1977) pressing of grains will reduce water content and increase sales and reuse potential by reducing transport costs. Pilot plant studies indicated that moisture levels of 20 – 30% were possible using a membrane filter press (El-Shafey, *et al.*, 2004). However, although commercial systems are available their cost requires continual use and is unlikely to be affordable to small scale brewers.

High nutrient content

High nutrient levels give spent grain flexible options for processing but have the major difficulty in the brewery of encouraging potential contaminants to grow. Spent malt is rapidly colonised with fungi and many bacteria, many able to grow equally well in beer. In addition spent grain encourages pests ranging from flies to rodents, all of which harbour a range of undesirable microorganisms. *Drosophila* flies are particular attracted to fermenting materials as sources of protein and are common in wineries, breweries and associated areas (Hunter *et al.*, 1973; Mckenzie, 1973).

Handling difficulties

Due to its high water content spent grain is denser than dry grain and heavy to move. Smaller breweries typically rely on personal handling with shovels, bags and small trucks greatly increasing the potential for injury. A 25 Kg malt sack filled with spent grain will weigh up to 35Kg, considerably in excess of manual handling regulations for a single person.

For the above reasons the urgency to remove spent grain from brewery areas is high. For larger breweries mechanised systems and bulk carriage achieves this easily and elevates the value of the grain. For smaller breweries urgency reduces bargaining power and spent grain is typically given away free for collection, typically to animal feed. Alternative uses of spent grain from small breweries which benefit from local availability with limited transport costs could contribute significantly to sustainability.

Alternative uses of spent grain are broadly centred on three different targets, food or other supplementation based on residual nutrients, bulking agents based on physical characteristics and composting.

Food or other supplementation

Spent grain contains up to 3% residual sugars in their liquid fraction and around 20% protein as well as a wide range of vitamins and minerals (Mussatto *et al.*, 2006b). In small scale brewing the mashing process only removes 75% of the nutrients in grain as extensive extraction may extract harsh tannins and silicates so affecting flavour (Hornsey, 1999). Spent grains have had a popular history as food for ruminants but with progressive decline in the dairy industry demand has reduced. Alternative feed uses are possible and have included poultry, pigs and fish (Mussatto *et al.*, 2006b).

Given hygienic production and transport it is theoretically feasible to incorporate spent grains into human foods. Biscuits and bread are popular choices and allow for novel flavour characteristics as well as giving a local focus (Finley & Hanamoto, 1980; Huige, 1994; Rich, 1996; Ozturk *et al.*, 2002). However, meat products such as sausages have also benefited from additions of spent grains (Salama, *et al.*,1995). Additions to other food products may also enhance the value of the products. In some cases the grains may affect the production process, for example by limiting the spread of biscuits during manufacture (Finley *et al.*, 1976). In others the grains may enhance dietary fibre (Ozturk *et al.*, 2002). Additions of up to 40% of final composition may be achieved in test systems but palatability as judged by tasting panels indicated that 15% is a suitable maximum for acceptable flavour (Prentice & D'Appolonia*,* 1977).

Alternative additions of spent grains to other products include as an amendment to paper mixtures to make cellulose pulp and paper production (Ishiwaki *et al.*, 2000; Mussatto *et al.*, 2006a) and also in plastics (Georgopoulos *et al.*, 2005).

Soil additions and composting

A broader area of application currently under more extensive investigation is the potential for composting or direct addition to agricultural soils.

Composting provides opportunities for both disposal of waste and for production of a saleable product. Spent grain alone is difficult to compost due to its heavy moisture content. However, mixtures with waste water sludge and bulking agents have been successful (Stocks *et al.*, 2002). Compared to commercial compost such products supported less growth than commercially available composts. This study suggests that further augmentation with other wastes could overcome this to produce a multipurpose compost (Stocks *et al.*, 2002).

Erdem and Ok (2002) found that BSG amended soils demonstrated higher NH_4 –N contents than NO_3 –N contents. Pearson and Adams (1967) found that mineralisation of organic matter in acid soils usually results in higher proportions of ammonium than nitrate because of the sensitivity of Nitrosomonas and Nitrobacter to the high acidity. Moreover, the exchangeable cations (Na^+, Ca^{2+}, Mg^{2+}, K^+) increased with BSG application. During the incubation, BSG application slightly increased the cation exchange capacity (CEC) and values fluctuated around those of control CEC.

Studies at the University of Sunderland have shown that addition of wet spent malt to soil by volume had a slight positive effect on growth of radish plants within 3 weeks but only at high doses when compared to addition of inert vermiculite (Data not shown). In a further study the effect of supplementing wood chips as soil amendments a reduction in 3 week dry weight of radish was evident between the control soil and soil amended with 17.5% fresh wood chip and 3.5% spent grain (Fig 1). This reduction was not maintained at 6 weeks, however, where plants from all treatments including additions of straw and lucerne were of similar mass (Fig 2). Woodchip alone, however, showed a consistent reduction in growth.

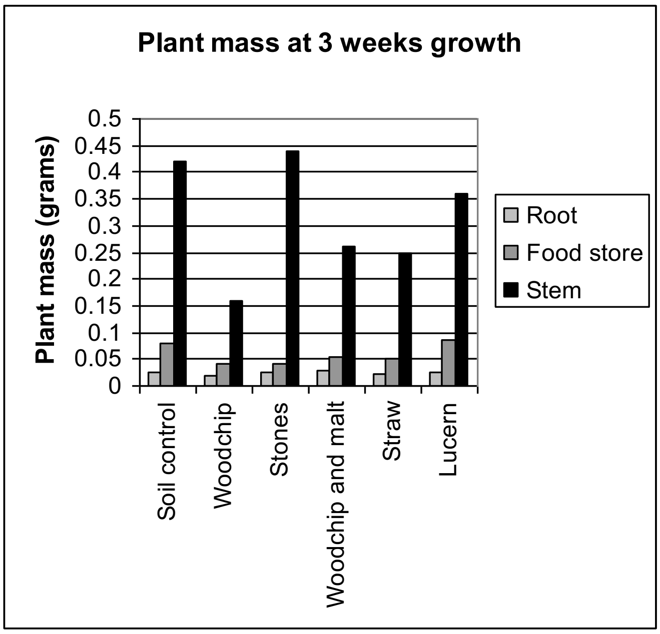


Figure 1. 3 week plant growth in different soil amendments.

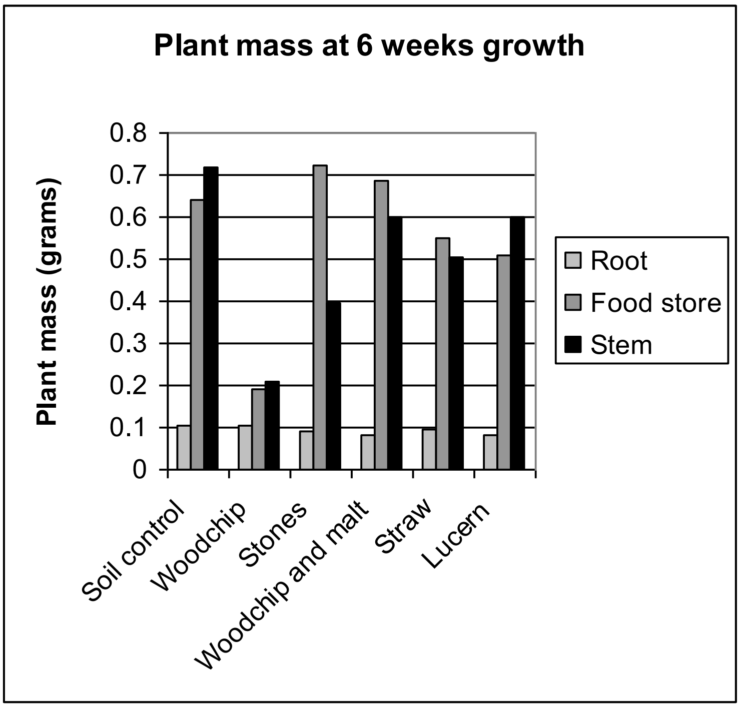


Figure 2. 6 week plant growth in different soil amendments.

The lack of a detrimental effect on plant growth suggests that soil amendment by spent grain may have benefits for brewer and agriculture alike.

Other studies conducted by Stocks *et al*., (2002) revealed that brewery compost from BSG enhanced the growth of plants such as tomato and geranium. Geranium is a horticulture plant, that grows well in the presence of BSG and could be a suitable plant to remediate brownfield sites. High levels of plant nutrients and the availability of 'slow-release' nutrients on degradation of organic material in the brewery compost allowed good growth of mature, well-established plants. This study also showed that the physical property of the compost made using BSG can be improved by the addition of sawdust, green waste or shredded packaging material from the brewery itself. This could improve water retention of the final product, producing a growing media more suitable for young plants and thus producing an added value product.

Gutser *et al*., (2005) also reported the availability of nitrogen content and biodegradability of various nitrogenous materials. The compost made up of BSG could be one of the cheap sources of compost for the application of contaminated soil remediation and could be used for growing bioenergy crops on contaminated lands.

Other positive benefits of BSG addition have been recorded. An antimicrobial effect against *Pythium* infestation of creeping bentgrass was noted for brewery sludge compost (Craft & Nelson, 1996). Its specific effect may have been a result of supporting actinomycete growth with production of antimicrobial compounds. BSG has been more specifically targeted towards supporting fungal growth by its use in mushroom cultivation (Schildbach *et al*., 1992). The ready availability of nitrogen has been implicated in this application (Noble *et al*., 2002), although physical features may also be important (Wang *et al.,* 2001). The practical use of spent grain to produce edible fungi has been promoted by breweries for some time and represents a clear possibility of producing added value out of a waste product.

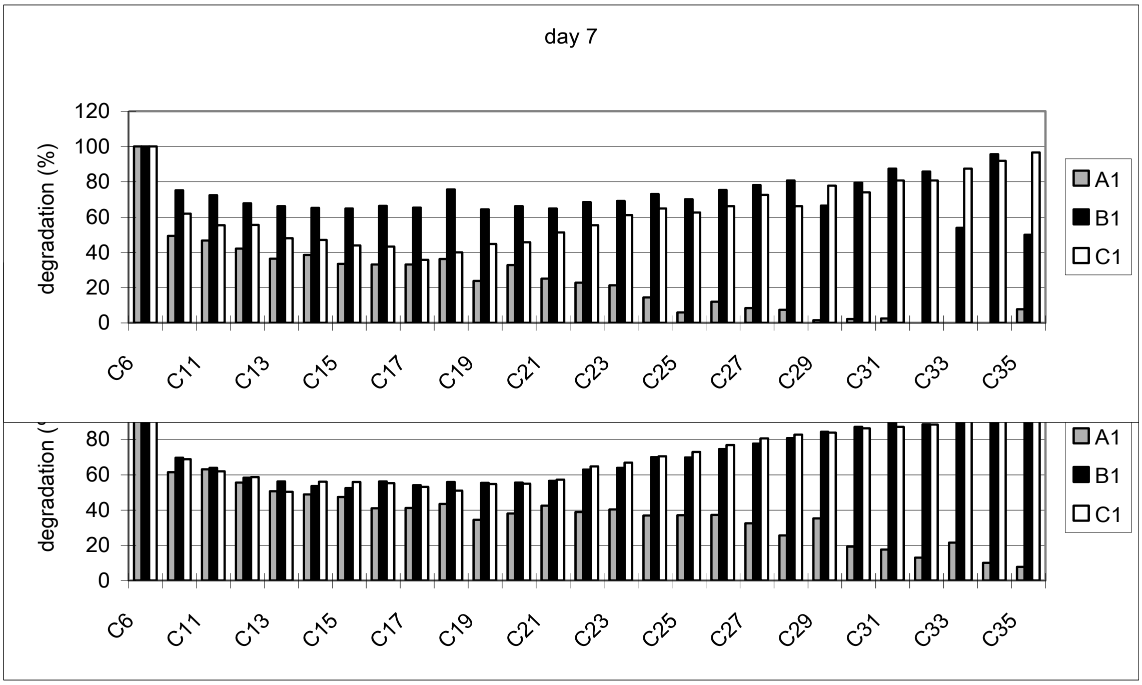
Other value enhancing options are increasingly apparent in the biotechnology industry. Residual liquid from BSG and the solids can support production of biomass or of specialised product in fermentation (Bogar *et al.,* 2002: Sangeetha, *et al*., 2004).

Besides the nutrient rich, residual wort present in BSG the solid residues of malt grains also carry value. Although inert and difficult to digest these particles are rich in sugars which could be extracted (Palmqvist & Hahn-Hägerdal, 2000) or converted into fermentation products such as xylitol and arabitol (Carvalheiro *et al.*, 2005).

A further potential for BSG is as an adjunct in bioremediation whereby grains may provide nutrients to encourage microbial degradation of pollutants and spoilage materials or adjustments to mineral contamination. This is likely to require matching of materials to suit requirements and the augmentation of grains with specialist microorganisms adapted to digest specific pollutants.

Low *et al.*, (2001) studied the sorption of Cr(VI) by BSG. Batch experiments were performed to evaluate the ability of spent grain to remove Cr (VI) from aqueous solution. Parameters investigated include pH, contact time, sorbent dosage, agitation rate, and the presence of other anions. Application of the Langmuir isotherm to the Cr(VI)-spent grain system provided a maximum sorption capacity of 18.94 mg/g. This value compares favourably with other reported values for low-cost materials. The indigenous microflora of spent grains has received limited study although the microbiology of malt is well documented (O'Sullivan, 1999; Papadopoulou *et al.*, 2000). Studies at the University of Sunderland indicate that levels of microorganisms in fresh grain direct from the mash turn are low at around 1,000 CFU per gram but this increased to100,000 CFU per gram after 10 days of incubation at room temperature.

In experiments at the University of Sunderland the effect of BSG on accelerating the degradation of crude oil hydrocarbons has been demonstrated (Fig 3).



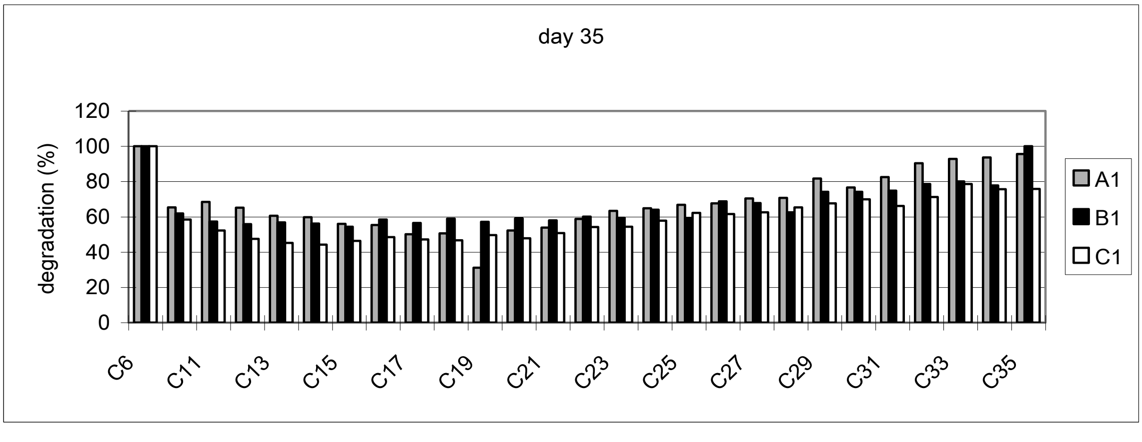


Figure 3. Degradation of hycrocarbons in soil with added spent grain.
A1: crude oil+ sterile soil +bacterial consortium+ biosurfactant
B1: crude oil+sterile soil+bacterial consortium +biosurfactant+BSG
C1: crude oil+sterile soil +biosurfactant+BSG

In this study spent grain was mixed with sterile soil containing 3.2% crude oil with and without an oil degrading microbial consortium and including a biosurfactant. A more rapid degradation of the oil fractions was observed in the presence of BSG at 7 and 21 days of incubation, particularly for higher molecular weight hydrocarbons. By 35 days, however, the degradation of all three treatments were similar.

While specific bioaugmentation is possible selecting organisms from the local environment has been shown to provide optimal bioremediaton (Capelli *et al.*, 2001; Bento *et al.*, 2005). The ability of BSG to enhance this growth is currently under investigation.

In the light of need to diversify the use of brewery waste products a broad range of investigations is warranted. In particular as small breweries become more prevalent in the community locally available materials will allow a range of opportunities for breweries to diversify and for other industries to benefit from co-operation in disposal.

The possibilities for breweries to be a focus of sustainability both for and beyond their own needs is considerable but will require sound knowledge transfer and small scale, targeted innovations. For biotechologists opportunities to promote applications at the local level may be just around the corner and may well start and end with a pint of best bitter.

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