

Cereal Waste Management: Treatment Methods and Potential Uses of Treated Waste

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Introduction

Cereal crops are mostly grasses cultivated for their edible seeds (actually a fruit called a caryopsis). Cereal grains are grown in greater quantities worldwide than any other type of crop and provide more food energy to the human race than any other crop (<http://en.wikipedia.org/wiki/Grains>). Wheat and rice are the most important crops worldwide as they account for over 50% of the world's cereal production. In the UK, wheat is the cereal most commonly used for the manufacture of food products, although many other types of cereals (e.g. maize and barley) are used. The starchy carbohydrates which are provided by cereals are essential in human nutrition. Rice is a staple diet for half the world's population, the remaining half cultivating the other cereals pending on climate and soil (<http://www.geocities.com/napavalley/6454/cereals.html>). Nowadays, cereals provide a very significant proportion of both human and animal diets despite the fact that most grains are, to a greater or lesser extent, deficient in a number of essential nutrients. A primary problem is the low level of essential amino acids such as lysine, methionine and threonine in the major cereal storage proteins (http://www.agrsci.dk/afdelinger/forskningsafdelinger/gbi/grupper/molekylaer_genetik_og_bioteknologi/cereals).

The seven principal cereals grown in the world are wheat, maize, rice, barley, oats, rye and sorghum. Wheat became very popular because of the bread produced. In Europe, rye was very popular for bread-making. Barley was also introduced from Europe and was commonly grown for its high food value for both animals and humans. Oats had a lower food value than barley but they grow well in the damper climate (<http://www.face-online.org.uk/resources/factsheets/discovering/cereals.doc>).

Wheat (*Triticum* spp.) is a grass cultivated worldwide. Wheat is usually ground to flour which is used to produce a wide range of products. The type of flour produced differs according to the rate of extraction. Wheat grain is a staple food used to make flour, livestock feed and for fermentation to make alcohol. Wheat can be fermented to make beer (<http://www.nutrition.org.uk/upload/Cereals%20pdf.pdf>). The husk can be separated and ground into bran. Wheat is also planted as a forage crop for livestock and the straw can be used as a ruminant feed component or construction material (<http://en.wikipedia.org/wiki/Wheat>).

Maize (or corn, *Zea mays*) is a cereal grain that was domesticated in Mesoamerica. It is called corn in the USA, Canada and Australia, but in other countries that term may refer to other cereal grains (<http://en.wikipedia.org/wiki/Maize>). Hybrid maize is favored by farmers over conventional varieties for its high grain yield. It may be processed to make many different ingredients (e.g. high fructose corn syrup which can be used as an alternative to sucrose derived from sugar cane and sugar beet) and food products. Its germ is rich in oil and can be refined to produce corn oil (<http://www.nutrition.org.uk/upload/Cereals%20pdf.pdf>). Finally, maize is one of the first crops for which genetically modified varieties make up a significant proportion of the total harvest.

Rice is a dietary staple of more than half of the world's human population (most of Asia and Latin America), making it the most consumed cereal grain. Rice cultivation is well suited to countries and regions with low labor costs and high rainfall, as it is very labor-intensive to cultivate and requires plenty of water for irrigation. However, it can be grown practically anywhere, even on steep hillsides. Rice is the world's third largest crop, behind maize (corn) and wheat (<http://en.wikipedia.org/wiki/Rice>). Brown rice has its outer husk removed and white rice is milled and polished further to remove the bran and germ.

Barley (*Hordeum vulgare*) is a major food and animal feed crop, a member of the grass family Poaceae (<http://en.wikipedia.org/wiki/Barley>). Barley is mainly sold as pearl barley, which is the whole grain with its husk removed. It is also used in bread (as flour) and ground as porridge in some countries (<http://www.nutrition.org.uk/upload/Cereals%20pdf.pdf>). Barley is used mainly for malting. Malting is the process where the barley grain is germinated thus producing enzymes which convert its starch reserves to sugars, mainly maltose. In animal feed compositions based on barley grain, industrially derived lysine and threonine are added to obtain a balanced nutritional diet. However, the essential amino acids must be added at additional cost. Other non-essential amino acids, such as glutamine and proline, are present in excess in the major storage proteins and create a different problem. These amino acids, when digested by the animal, release non-utilizable nitrogen. This nitrogen is excreted in the urine, creating a significant environmental load, especially on and around pig farms (<http://www.agrsci.dk/afdelinger/>

forskningsafdelinger/gbi/grupper/molekylaer_genetik_og_bioteknologi/cereals). In 2004, barley ranked fourth in area of cultivation of cereal crops in the world (570 000 km²) FAOSTAT (<http://en.wikipedia.org/wiki/Barley>).

Oat (*Avena sativa*) is a species of cereal grain and the seeds of this plant. It is used for food for people and as fodder for animals, especially poultry and horses. Oat straw is used as animal bedding and sometimes as animal feed. Oat straw is also used in corn dolly making and it is the favorite filling for home-made lace pillows (<http://en.wikipedia.org/wiki/Oat>).

Rye is also a crop that has declined in popularity and today is no longer grown on a substantial level. Previously grown as a poor alternative to wheat, its main function was as a fodder crop. The increased production of barley has reduced its importance (<http://www.face-online.org.uk/resources/factsheets/discovering/cereals.doc>). Rye contains a low amount of gluten, thus producing breads with low volume and a dense texture.

The aim of this chapter is to make a comparative and critical presentation of all cereals waste treatment methods in an attempt to disclose the most effective and low cost methods. The treatment methodologies of wheat, corn, rice, barley and oat wastes are summarized in Tables 10.1–10.5.

Treatment methods

Waste treatment techniques are used to alter the physical, chemical or biological character of the waste, to reduce its volume and/or toxicity and to make the waste safer for disposal. Waste treatment may be required for radioactive, hazardous and other Department of Energy (DOE) wastes. However, DOE does not treat all of its wastes. Some solid sanitary waste does not require treatment prior to disposal and hazardous wastes are treated by commercial treatment facilities. Mixed wastes (which contain both hazardous and radioactive components) pose special management challenges since they are difficult to treat with existing treatment technologies (<http://web.em.doe.gov/em30/wasttrea.html>).

Methods of treatment in which the application of physical forces predominate are known as unit operations. Methods of treatment in which the removal of contaminants is brought about by chemical or biological reactions are known as unit processes (Tchobanoglous *et al.*, 2003). The preferred use for surplus straw is as fuel in a suitable on-farm boiler, providing heat for hot water, buildings and grain drying and other operations, thus cutting energy bills and avoiding plowing-in costs. The ash from the boilers can also be used as a fertilizer. Although, there are some problems with drying systems for the straw, control and matching supply and demand. These are not insurmountable and, with current developments in the hardware for drying, the use of straw as a boiler fuel could prove attractive in the future (http://www.biffa.co.uk/files/pdfs/MassBalance_Agriwastes_08_Treatment.pdf). Biological treatment usually involves treatment of waste by bacteria, fungi or algae to remove and degrade the hazardous constituents. A boiler is a type of device that can be used to treat hazardous waste. Boilers use controlled flame combustion and recover thermal energy in the form of steam or heated gases (<http://www.epa.gov/epaoswer/osw/treattech.htm>).

Table 10.1 Treatment methodologies of wheat wastes: parameters, quality control methods and results

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
1	Wheat straw waste	Vermicomposting	The N, P, K content increased during pre-decomposition with bioinoculants	Wheat straw was predecomposed by inoculating it with <i>Pleurotus sajor-caju</i> , <i>Trichoderma harzianum</i> , <i>Aspergillus niger</i> and <i>Azotobacter chroococcum</i> in different combinations	1 Spectrophotometry for total phosphorus (TP) and total potassium (TK) 2 Cellulose, hemicellulose and lignin were determined with Dutta's method	1 TOC content decreased from 30.10% to 26.48% during composting and finally to 12.75% during vermicomposting 2 Both pre-decomposition and vermicomposting resulted in a loss of carbon because of mineralization. Cellulose, hemicellulose and lignin decreased	Anshu <i>et al.</i> , 2002
2	Wheat straw waste	Composting	Temperature, compost pH, weight loss, carbon and nitrogen loss, nitrogen mineralization	Water content was determined by weight loss of compost samples, which were oven dried at 80 °C for 24 h	1 Total N and C were measured by an automated N-C analyzer interfaced with an isotope mass spectrometer 2 Analysis for NH ₄ and NO ₃ content with standard colorimetric methods using flow-injection analysis (FIA) 3 Ammonium with HPLC 4 pH was measured in a solution of compost (20 g fresh weight) and water in a ratio of 1:5	1 pH varied between 7.6 and 8.9 and the highest values were found after 3–4 weeks 2 After 3 weeks of composting, weight losses are decreased 44–45% of initial weight 3 After 7 1/2 weeks weight losses amounted to 61–63% of initial weight 4 %N increased from 2.8% to 4.6%	Dresboll <i>et al.</i> , 2005
3	Wheat straw waste	Composting	C-N dynamics in an arable field amended with three types of UWC (green waste and sludge, biodegradable waste and solid waste)	Three types of UWC were applied: i) a bio-waste compost (BIO) resulting from the co-composting of green waste and the source separated organic fraction of municipal waste; ii) a co-compost obtained from a mix of 70% green waste and 30% sewage sludge, on a dry matter basis; iii) a municipal solid waste compost	1 The CERES model 2 Parameter modeling	1 Simulated N fluxes showed that the organic amendments induced an additional leaching ranging from 1 to 8 kg N/ha/year 2 After 4 years, the composts had mineralized 3–8% of their initial organic N content. Composts with slower N release had higher N availability for the crops 3 CERES could thus be used to aid in selecting the	Gabrielle <i>et al.</i> , 2005

timing of compost application, in relation to its stability, based on both environmental and agronomical criteria

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|---|--------------|--|--|--|--|--|--------------------------------|
| 4 | Wheat straw | Pyrolysis, GC, MS of acid-precipitable polymeric lignin (APPL) | Lignin-carbohydrate-protein complexes, hydroxyphenyl:guaiacyl:syringyl and syringil/guaia-cyl (S/G) ratios, NaOH | Wheat straw transformed by the strains <i>Streptomyces</i> UAH 23, <i>Streptomyces</i> UAH 52 and <i>Streptomyces viridosporus</i> T7 | 1 APPL
2 Pyrolysis
3 GC
4 MC | 1 A large number of compounds derived from phenolic lignin units
2 Replicate analysis resulted in standard deviation of 5–10% range for all compounds | Rodriguez <i>et al.</i> , 1997 |
| 5 | Wheat straw | NMR, conventional pyrolysis and TMAH thermochemolysis | 50:50 cellulose:lignin mixture, ^{13}C | 1 10% H_2SO_4 for 0.5 h at 100°C to remove starch, proteins and sugars
2 4 10^{-2} M KQH for 24 h at room temperature to remove low molecular weight lignin
3 Washing with dilute HNO_3 | 1 Nuclear magnetic resonance (NMR) spectroscopy
2 Pyrolysis without TMAH
3 TMAH thermochemolysis | 1 The acid and base treatments resulted in the elimination of wheat straw components except the ligno-cellulosic ones and LCS is composed of approximately 85% of cellulose and 15% of lignin
2 TMAH thermochemolysis is more efficient than conventional pyrolysis to produce GC compounds via cleavage of cellulose structure | Gauthier <i>et al.</i> , 2003 |
| 6 | Wheat lignin | Pyrolysis, GC, MS | The most noticeable modification was the significant decrease of lignin phenolic content as revealed by Py-GC-MS of methylated straw | Peroxidase is produced by <i>Pleurotus eryngii</i> | 1 Pyrolysis
2 The peroxidase treatment modified the molar H:G:S ratio of the etherified moiety | 1 10 U of peroxidase per mg of straw decreased the amount of phenolic H units from 31% in control to 3% in treated straw, that of G units from 40 to 4% and completely removed the small amount of phenolic S units present in wheat straw
2 The same tendency to decrease lignin phenolic content was observed when lower enzyme doses were used | Camarero <i>et al.</i> , 2001 |

(Continued)

Table 10.1 (Continued)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
7	Wheat straw	Pyrolysis	KCl has a relatively high vapor pressure at the temperature of relevance in combustion	The release of alkali during pyrolysis in the temperature range 25–1060 °C is measured using the sensitive surface ionization technique	Pyrolysis	<ol style="list-style-type: none"> 1 Application of chloride-free fertilizers is concluded to be a simple and efficient way to reduce the alkali release from the fuels 2 The method can easily be combined with other methods in order to improve fuel quality 	Davidsson <i>et al.</i> , 2002
8	Wheat straw	Py-GC:MS	The APPL was precipitated from the supernatants by acidification to pH 1–2 with 12 M HCl	Use of <i>Streptomyces</i> spp. UAH 47	<ol style="list-style-type: none"> 1 Pyrolysis 2 GC 3 MS 	<ol style="list-style-type: none"> 1 Release of ferulic and p-coumaric acid due to respective esterases' action detected with HPLC 2 Straight correlation between the relative areas of the compounds derived from carbohydrates and the pattern of hemicellulolytic and cellulolytic enzymes produced by the strain 	Hernandez <i>et al.</i> , 2000
9	Wheat and corn straw	Pyrolysis	TGA was one of the main techniques for analysis of characteristics of solid fuel volatilization	The heating process consists of fast sample heating (25–70 K/s) to the desired temperature	Pyrolysis kinetics	<ol style="list-style-type: none"> 1 The ratio between the conversion and the heating time varies from a maximum of 10.50 (low temperatures) to a minimum of 65 (high temperatures) with the corresponding solid mass fraction at the beginning of the true isothermal stage equal to 0.99 and 0.75 2 The weight loss curves obtained for corn stalks had the same qualitative behavior as wheat straw 	Lanzetta and Di Blasi, 1998
10	Waste paper and wheat	Pyrolysis	Biomechanical pulps, alkaline salts, H ₂ SO ₄	Biomechanical pulping including solid-state	Pyrolysis procedure	The large variety of lignin-derived products: phenol,	Galletti <i>et al.</i> , 1997

straw pulps	fermentation with the ligninolytic fungi <i>Pleurotus ostreatus</i> and <i>P. floridanus</i>			guaiacol and syringol	
	Pyrolysis	The free phenolic lignin-units were preferentially removed as compared with the etherified ones	Lignin degradation by several white-rot fungi including <i>Pleurotus eryngii</i> , <i>Pleurotus cornuopidae</i> , <i>Pleurotus floridanus</i> , <i>Pleurotus ostreatus</i> , <i>Pleurotus pulmonarius</i> , <i>Pleurotus sajor-caju</i> , and <i>Phanerochaete chrysosporium</i>	1 Analytical pyrolysis 2 GC 3 MS	1 The free phenolic lignin-units (around 50% of the total H and G units and only 6% of S units) were preferentially removed 2 When 50% of wheat lignin degraded by <i>P. eryngii</i> , the relative abundance of aromatic acids was over 15% of the total lignin derived products
11 Wheat lignin degradation					Martinez <i>et al.</i> , 2001
12 The effect of fungal decay on wheat straw lignin	Pyrolysis	The presence of tetramethyl ammonium hydroxide (TMAH)	Fungal degradation by <i>Agaricus bisporus</i>	Pyrolysis, GC, MS in the presence of TMAH is a sensitive method for tracking the oxidative degradation of lignin during the fungal decay of wheat straw	The major TMAH thermochemolysis products from undegraded wheat straw consist of methylated syringyl, guaiacyl and <i>p</i> -hydroxy-phenyl derivatives
13 Wheat straw waste	Combustion	TGA for devolatilization kinetic parameters, chars prepared in a drop-tube were obtained (1273 K, 0% O ₂), particle injection into a stoichiometric air	The temperature is high (ca 1500 °C)	The combustion model for experiment was generated using the FG-DVC pyrolysis model	1 The straw devolatilizes more rapidly, produces a higher yield of volatiles (mostly CO and H ₂) and consequently has a shorter ignition delay 2 Straw burning involves extensive devolatilization and, as a consequence, the char burnout of the residue, which is a small quantity, does not play a significant part of the overall processes
14 Wheat straw waste	Combustion	Silica (76–83 mol%) and K (11–12 mol%) contained small	Air at 1 atm was carried out at temperatures ranging from 500–1200 °C	Combustion of wheat straw	The identification of the probable cause of deleterious effects on the

(Continued)

Table 10.1 (Continued)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
15	Wheat straw waste	Gasification	concentrations (<5 mol%) of Ca, Na, Mg and Al oxides, small amounts of chloride, sulfate and carbonate Use of CO ₂	Temperature 700–900°C	CO ₂ gasification at 700–900°C in a pressurized TGA at 2×10^5 – 2×10^6 Pa	combustion system is an important first step in solving the problems in the combustion of wheat straw 1 The separation effects of total pyrolysis pressure and total gasification pressure were investigated 2 The variation in reactivity among the four biomasses under equal gasification conditions was investigated and analyzed on the basis of their chemical compositions	Illerup and Rathman, 1997
16	Wheat straw waste	Gasification	Use of CO ₂ and H ₂ O	The experimental conditions were 10 and 20 bar total pressure, 0.15–1.5 bar H ₂ O and 0–1.0 bar H ₂ and 750–925°C	Steam (H ₂ O) gasification	The variation in reactivity among the four biomasses under equal gasification conditions was investigated and analyzed on the basis of their chemical compositions	Fjellerup <i>et al.</i> , 1996
17	Wheat straw waste	Gasification	Use of CO ₂ and H ₂ O	The composition of H ₂ was about 40–50% and gas yields were 150–960 ml/g straw, which is dependent on the gasified temperature	Gasification of wheat straw	Wheat straw was gasified in fixed bed reactor at 700–1000°C with steam to investigate the possibility of a process to convert straw to ammonia synthesis gas	Liu <i>et al.</i> , 2000
18	Wheat waste	Roasting of wheat germ	Commercial plant oils, peroxide value, conjugated diene hydroperoxide concentration and atocopherol concentration,	1 Solvents extracts of roasted wheat germ, an actual waste stream of wheat processing, retarded the autocoxidation of corn oil stored at 60°C	1 Wheat germ roasting 2 Accelerated oxidation tests	Presence of classes I and II antioxidants in ethanolic AOE of wheat germ	Krings <i>et al.</i> , 2000

19	Biomass residue	Briquetting pressure	<p>high dosages of 20 and 40% AOE</p> <p>2 Best stabilization of stripped corn oil with ethanolic extract (antioxidative extract, AOE) from wheat germ roasted at 160°C for 20 min</p> <p>The optimum moisture contents and compressive strengths were found to be respectively 22% and 22.4 MPa for wheat straw, and 18% and 32 MPa for a 20% by weight of waste paper and straw mixture</p>	<p>Six different pressures of 300, 400, 500, 600, 700 and 800 MPa</p> <p>Physical parameters such as density, moisture content and compressive strength</p>	<p>1 The density of biowaste briquettes depended on the density of the original biowaste, the briquetting pressure and, to a certain extent, on the briquetting temperature and time</p> <p>2 The effect of moisture content of the briquettes was managed through control over machine and mixture factor. The expression of water during briquette formation and compaction depends upon the draining quality of the feed mixture</p>	Demirbas and Sahin, 1998
20	Waste residues of wheat straw	Adsorption	<p>The reactive dyes were Cibacron Yellow C-2R, Cibacron Red C-2G, Cibacron Blue C-R, Remazol Black B and Remazol Red RB</p>	<p>Temperature (80–120°C)</p> <p>1 Steam pretreatment 2 Alkali pretreatment 3 Ammonia steeping 4 Milling</p>	<p>1 Though the milled, steam and the NaOH treated straw had different Ce values, they had similar dye removal (54%, 56% and 53%, respectively) after 102 h of contact time while the control-substrate removed only 26% of the dyes</p>	Robinson <i>et al.</i> , 2002
21	Wheat straw waste	Composting	<p>NaOH or HCl</p>	<p>Batch tests were carried out to analyze influences of several environmental factors on biohydrogen production from wheat straw wastes</p> <p>1 HCl pretreated wheat straw 2 Composting</p>	<p>1 The maximum cumulative hydrogen yield of 68.1 ml H₂/g TVS was observed at 126.5 h, the value was about 136-fold as compared with that of raw wheat straw wastes</p> <p>2 The pretreatment of the substrate played a key role in the conversion of the</p>	Fan <i>et al.</i> , 2005

(Continued)

Table 10.1 (Continued)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
22	Wheat as generic feedstock	Chemical production	Bioethanol, amino acids and organic acids, ethylene, propylene, butadiene and their derivatives	The world wheat production was evaluated for the production of major bioproducts	Chemical production	<p>wheat straw wastes into biohydrogen by the composts generating hydrogen</p> <ol style="list-style-type: none"> 1 Production of a liquid stream rich in glucose (320 g/l) and one rich in nitrogen (1.5 g/l) 2 Both streams contained phosphorus, vitamins and trace elements necessary for subsequent fermentation processes 3 This versatile fermentation medium was utilized successfully for the production of ethanol, lactic acid, pigment and glycerol 	Koutinas <i>et al.</i> , 2004
23	Wheat straw waste	Biodegradation	The optimum pH for cellulase production was 5.5	<i>Phanerochaete chrysosporium</i> NRRL 6359, <i>P. chrysosporium</i> NRRL 6361 and <i>Coriolus versicolor</i> NRRL 6102	<ol style="list-style-type: none"> 1 Enzyme determination 2 Protein determination 	<ol style="list-style-type: none"> 1 <i>Phanerochaete chrysosporium</i> NRRL 6359 was selected as a better producer for release reducing sugars 2 The highest levels of xylanase, glucanase and cellulase were detected in culture <i>P. chrysosporium</i> in culture after 48 h 	Abd El-Nasser <i>et al.</i> , 1997
24	Wheat straw waste	Combustion	21% O ₂ in a balance of N ₂ , CO ₂ , NO _x , SO ₂	Dried wheat straw was incinerated at 800 °C in a modified muffle furnace	<ol style="list-style-type: none"> 1 GC 2 Combustion 3 MS 	<ol style="list-style-type: none"> 1 The product gas resulting from incineration of wheat straw contained organic as well as inorganic constituents 2 The organic compounds identified in the product gas were benzene, toluene and xylene 	Bubenbeim <i>et al.</i> , 1997

25	Wheat straw waste	Composting	Experiments with ^{15}N -labeled fertilizer showed that wheat was able to utilize the applied N more efficiently when cultivated in the stable compost	The compost was assumed to provide 10% of its total N for plant growth over the growing season	1 Mature composting 2 Immature composting	3 The inorganic components were CO_2 , CO , SO and NO_x 1 When 80% of the N was supplied by the fertilizer and 20% by mature compost, higher yields were produced than with the highest recommended fertilizer N application rate 2 Calculation showed that green waste compost actually released only 2% of its total N content to the following crop, accounting for the low yields	Keeling <i>et al.</i> , 2003
26	Wheat straw waste	Enzymic hydrolysis	1% NaOH for 24 h, 0–3% H_2O_2 for 24 h	The entire process was carried out at low temperature (25–40°C) using a low concentration of chemicals	1 Enzymic hydrolysis 2 Mild alkaline pretreatment 3 Oxidative pretreatment	1 Resulting in relatively low cost and waste liquors containing only trace amounts of dangerous pollutants derived from lignin 2 Recovery of cellulose after the double pretreatment reached 90% of that contained in the starting material, with a concomitant 81% degradation of lignin 3 The action of a commercial cellulase on the cellulose obtained produced syrup with a high concentration of reducing sugars (220 mg/ml), of which a large percentage was glucose	Curreli <i>et al.</i> , 1997
27	Wheat straw waste	Multi-enzyme production	CMCase, Fpase, xylanase, amylase and manganese peroxidase	Two microorganisms identified as <i>Cellulomonas</i> A (yellow color) and <i>Cellulomonas</i> B (white)	Multi-enzyme production	1 To determine the optimal temperature for enzyme activities, assay was performed at 20–90°C,	Emtiaz and Nahvi, 2000 (Continued)

Table 10.1 (Continued)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
				color), isolated from silkworm and rabbit waste		pH 6.0, except for cellobiose assays, which were conducted at pH 5.5 2 Assays for optimal pH were performed at 50 or 45°C for Fpase in the pH range 2.5–9.0	
28	Wheat straw waste	Irradiation and chemical treatment	HBr 47% and NaOH: 0, 3, 6 ml HBr and 3, 6 g NaOH in 25 ml water/100 g DM	1 Samples of wheat straw wastes were dried outdoors for 5 days and then each sample mixed thoroughly 2 Samples were sprayed with different amounts of hydrobromic acid and sodium hydroxide	1 Low gamma irradiation 2 Chemical treatment	1 Chemical treatments increased the <i>in vitro</i> organic matter digestibility (IVOM) and metabolizable energy (ME) values significantly for all samples treated 2 No significant effect of irradiation on IVOMD and ME 3 Combined treatments of irradiation and HBr or NaOH were found ineffective in increasing the IVOMD and ME values	Al-Masri, 2004
29	Wheat straw waste	Enzyme activity	Moisture content of 74%, pH range of 4.5–5.5 on mixed substrate containing wheat straw, wheat bran of 9:1	The organism used in this study was <i>Aspergillus niger</i>	Endoglucanase production	1 An increase in initial moisture content of the substrate from 55 to 74% greatly enhanced the enzymatic activity of the broth 2 It was found that maximum activity was obtained when the initial pH was adjusted to 4.5–5.0 3 The temperature did not affect strongly the enzyme production	Jecu, 2000

Adapted from Arvanitoyannis and Tserkezou, 2007a,b

Table 10.2 Treatment methodologies of corn wastes: parameters, quality control methods and results

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
1	Corn waste	Composting	Changes characterization in C and N isotope during composting	Compost pH measured in 1:2 slurry of 25 g compost and water	Composting	<ol style="list-style-type: none"> 1 Changes in carbon, nitrogen, $\delta^{13}\text{C}$ and $\delta^{14}\text{N}$ content during composting 2 Highly recalcitrant composts with prolonged C storage in non-mineral soil fractions 3 The sensitivity of the natural abundance tracer technique to characterize their fate in soil improves during composting, as a more homogeneous C isotope signature develops, in addition to the relatively large amounts of stable C applied in composts 	Lynch <i>et al.</i> , 2006
2	Corn cob waste	Chemical activation	Chemical activation with ZnCl_2	500°C was found to be the optimal temperature for producing high surface area carbons with ZnCl_2 activation	<ol style="list-style-type: none"> 1 Pyrolysis 2 Zinc chloride activation 	<ol style="list-style-type: none"> 1 Activated carbons yield varied in the range of 27–30.4% 2 The surface areas of the resulting activated carbons, increased rapidly with impregnation ratio of ZnCl_2 3 The ZnCl_2 activation of corn cob was suitable for the microporous activated carbons preparation 	Tsai <i>et al.</i> , 1998
3	Corn stalk waste	Pyrolysis	TGA	Materials were rapidly heated to high temperatures in the absence of air (oxygen)	<ol style="list-style-type: none"> 1 Flash pyrolysis (FP) 2 Plasma heated laminar entrained flow reactor (PHLEFR) 3 Thermolysis 	Yields of volatile pyrolysis products depended on the final pyrolysis temperature and residence time	Shuangning <i>et al.</i> , 2005

(Continued)

Table 10.2 (Continued)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
4	Corn straw waste	Pyrolysis	TGA	The heating process consisted of rapid sample heating (25–70 K/s) to the desired temperature	Pyrolysis kinetics	<ol style="list-style-type: none"> 1 The ratio between the conversion and heating time varied from a maximum of about 1050 (low temperatures) to a minimum of about 65 (high temperatures) with the corresponding solid mass fraction at the beginning of the true isothermal stage equal to 0.99 and 0.75 2 The weight loss curves obtained for corn stalks had the same qualitative behavior as wheat straw 	Lanzetta and Di Blasi, 1998
5	Corn cob waste	Pyrolysis	H ₂ , CH ₄ , CO, CO ₂ and C ₂ H ₂ (for analysis), CH ₄ , C ₂ H ₆ , C ₃ H ₈ and C ₃ H ₆ (for flame ion detector, FID)	<ol style="list-style-type: none"> 1 The corn cob was first placed in the reactor, then nitrogen passed through the reactor with a flow of 80 ml/min 2 The reactor is heated to 110°C at a heating rate of 10 K/min and held the temperature for 1 h in order to remove the water 	<ol style="list-style-type: none"> 1 Pyrolysis 2 GC 3 MS 	<ol style="list-style-type: none"> 1 The experiments showed the higher the temperature, the greater the yield of emitted gases and lesser the amount of the liquid and the solid residue 2 Beyond 400°C, only a part of the components decomposed and exhibited a slower weight loss 	Cao <i>et al.</i> , 2004
6	Corn stover waste	Pyrolysis	Analytical system to determine yield parameters apart from H ₂ O, CO, CO ₂ and H ₂ , the products were divided into paraffins, olefins, alcohols, aromatics etc.	Corn stover, the leaves and stalks usually left in the field after corn harvest, can serve as a representative biomass feedstock	Pyrolysis	ASEM provides a simple and useful way of distilling the essence of the observed thermochemical response of corn stover to temperature and heating rate	Green and Feng, 2006
7	Corn cob waste	Gasification	Activation temperature ranges	True density and porosity increase with	Gasification of corn cob	<ol style="list-style-type: none"> 1 Comparison of physical characterizations of the 	Tsai <i>et al.</i> , 2001

		of 500–800°C with less pollution characteristics of KOH: K ₂ CO ₃) as chemical agents	increase in the activation temperature	carbon products with those of commercial activated carbons indicated that the activated carbons prepared from agricultural waste corn cob by using a cleaner process is an available route for the biomass utilization and bioresource recycling
				2 The high-surface-area carbon products obtained were very promising adsorbents for pollution control and for other applications
8	Corn starch waste	Gasification	<p>The influence of pressure, temperature, residence time, and alkali addition on the gasification of corn starch showed an improvement</p> <p>KHCO₃ was added to the mixture of starch and water before the gel formation</p>	<p>1 Increase in temperature improved the biomass conversion</p> <p>2 Longer residence time in gasification yield until a maximum was reached</p> <p>3 Gas composition changed with residence time and temperature</p> <p>4 Potassium addition affected the gasification yield of corn starch</p> <p>D'Jesus <i>et al.</i>, 2006</p>
9	Corn cob waste	Chemical and physical activation	<p>Subsequent gasification at a soaking period of 800°C</p> <p>KOH and K₂CO₃ were effective activating agents for chemical activation during a period of 10°C/min</p>	<p>The porosity created in acid-unwashed carbon products is substantially lower than that of acid-washed carbon products due to potassium salts left in the pore structure</p> <p>Tsai <i>et al.</i>, 2001</p>
10	Corn waste	Combustion and gasification	<p>Corn refinery industry produces a wide range of products including</p> <p>Removal of carbon from fossil fuels prior to use in energy</p>	<p>1 Green plants developed to produce desired products and energy</p> <p>1 Biomass combustion</p> <p>2 Gasification combustion</p> <p>Chum and Overend, 2001</p>

(Continued)

Table 10.2 (Continued)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
			production is likely to be far less costly than attempting to remove CO from dispersed sources	starch-based ethanol fuels for transportation		could be possible in the future 2 Biological systems can be tailored to produce fuels such as hydrogen 3 Policy drivers for increased use of biomass for energy and biobased products are reviewed for their potential contributions for a carbon constrained world	
11	Corn cob and corn tar waste	Combustion	Engine power performance, fuel consumption and CO ₂ , CO, HC and NO	Temperature range from 110 to 220°C	Combustion	1 No significant difference in performance between diesel fuel and mixed fuel 2 The mixed fuel operation produced low fuel consumption at the various loadings 3 Mixed fuel with 11.7 and 6.6% oil-economizing rate, had better oil-economizing compared to diesel fuel respectively. The mixed fuel showed significant improvement at CO ₂ emissions	Zhang and Wang, 2006
12	Corn waste	Combustion	Calcium, Cu, K, Mg, Na, P, S and Zn were recovered with the bomb washings	The procedure involved sample combustion in commercial stainless steel oxygen bomb operating at 25 bar	1 Combustion 2 Inductively coupled plasma optical emission spectrometry (ICP-OES)	Most of the element recoveries in the samples varied between 91 and 105% and the certified and determined contents exhibited a fair agreement at a 95% confidence level	Souza <i>et al.</i> , 2002
13	Corn stover waste	Combustion	The fertilization consisted of 168 g N and 90 kg each of P ₂ O ₅ and K ₂ O	To minimize the effect of water in the biomass spectra, each sample was air-dried to less than	1 NIR spectroscopy 2 Combustion	1 NIR spectroscopy showed i) a rapid drop in soluble glucan, ii) increase in lignin and iii) increase	Pordesimo <i>et al.</i> , 2005

	equivalents	10% moisture prior to NIR spectroscopic analysis	in xylan	
			2 Since product yield in fermentation-based biomass conversion processes is proportional to the structural carbohydrate content of the feedstock, timing of stover collection and the proportion of anatomical fractions collected affect the quality of corn stover as fermentation feedstock	
14	Corn oil	Biodiesel	Control of HC, CO, NO _x	<p>The engine was fueled with pure marine diesel fuel and blends containing two types of biodiesel, at proportions up to 50%</p> <p>1 Biodiesel</p> <p>1 The two types of biodiesel appeared to have equal performance and irrespective of the raw material used for their production, their addition to the marine diesel fuel improved the particulate matter, unburnt hydrocarbons, nitrogen oxide and carbon monoxide emissions</p> <p>2 The NO_x emissions were reduced in all cases when the two biodiesel containing fuels were used</p> <p>Kalligeros <i>et al.</i>, 2003</p>
15	Corn waste	Ethanol and biodiesel production	Production of 1000 l of ethanol from corn	<p>Under relatively high prices for gasoline the costs for using ethanol and biodiesel were much higher per equivalent liter of gasoline</p> <p>1 Biodiesel 2 Ethanol production</p> <p>Either the costs for generating ethanol or biodiesel have to be reduced substantially, by e.g. technical change or the price for oil has to increase further before ethanol and biodiesel will become economically competitive</p> <p>Wesseler, 2006</p>

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Table 10.2 (Continued)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
16	Corn stover waste	Biodiesel and bioethanol	Soil nitrogen-related burdens (e.g. N_2O , NO_x , NO_3) would be reduced by harvesting corn stover	When corn stover was harvested, ethanol was produced from both corn stover and corn grain and lignin rich fermentation residues from corn stover were utilized to generate electricity and steam, which are used in the ethanol production system	1 Biodiesel 2 Bioethanol	1 Corn stover removal would reduce soil organic carbon accumulation rates, but cultivation of winter cover crops, even with corn stover removal, could increase organic carbon accumulation rates because of increased carbon inputs from winter cover crops 2 Utilization of corn stover and winter cover crops can improve the eco-efficiency of the cropping systems	Kim and Dale, 2005
17	Corn cob waste	Pyrolysis	The gas products were analyzed with GC as CO_2 , CO , H_2 , CH_4 , C_2H_4 , C_3H_6 , C_3H_8 , etc.	The temperature was 350–400 °C	1 Pyrolysis 2 GC 3 MS	1 DTG showed that thermal decomposition process involves two steps 2 The heating rate affected both the activation energy of the decomposition reaction, but also the path of the reaction 3 The maximum rate temperature of the decomposition reaction shifted to a higher temperature and the order and activation energy of the total decomposition reaction decreased	Cao <i>et al.</i> , 2004
18	Corn oil	Chemical method	Diene hydroperoxide concentration and a-tocopherol	Corn oil stored at 60 °C	1 AOE 2 Gas chromatography	1 The stabilization of stripped corn oil, free from any genuine	Krings <i>et al.</i> , 2000

19	Corn waste	Bioremediation	pH was maintained around 7.2-7.5 for 40 days	<i>Mycobacterium smegmatis</i> and <i>M. phlei</i>	<ol style="list-style-type: none"> 1 Anaerobic fermentations 2 Methanogenesis 3 In situ remediation 	<p>antioxidant, proves the occurrence of class I antioxidants generated during roasting</p> <ol style="list-style-type: none"> 2 Protection of genuine a-tocopherol in corn oil indicates the presence of class II antioxidants which are able to protect or to regenerate a-tocopherol 	<ol style="list-style-type: none"> 1 Bioremediation that includes anaerobic fermentations of wastes to produce methane and hydrogen, the genetics of methanogenesis and in situ remediation of contaminated aquifer systems, landfill leachates and industrial effluents 2 Land application of fermentation by-products and their use in animal feeds 3 Biocatalytic studies of transformations of components of corn 4 Separation and recovery of components by membrane technologies 	<p>Montgomery, 2004</p>
					<ol style="list-style-type: none"> 1 Burn-off in gasifying agents at 800 and 900°C 2 Steam activation 	<ol style="list-style-type: none"> 1 BET surface areas of activated carbons after about 71 and 59 wt% burn-off of CO₂ and steam activations at 900°C were 1705 and 1315 m²/g, respectively, indicating high adsorption capacities 2 Production of high quality microporous activated carbon from corn cob agrowaste using 	<p>Chang <i>et al.</i>, 2000</p>	

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Table 10.2 (Continued)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
21	Corn husks waste	Enzyme preparation	The corn husks were passed through a Hobart chopper, blended with 1.25 M NaOH	An enzyme preparation derived from <i>Aspergillus niger</i> and <i>Trichoderma reesei</i>	Enzymatic saccharification of corn husks	<p>N₂ carbonization followed by physical activation with CO₂ or steam</p> <ol style="list-style-type: none"> 1 The products of the enzymatic reaction were identified as glucose, cellobiose, xylobiose, arabinose and xylose 2 Increasing the concentration of corn husks in the reaction mixture adversely affected the production of total and individual soluble sugars 	Hang and Woodams, 1999
22	Corn cobs waste	Enzyme preparation	Pretreated with NaOH, followed by 48 h of reaction at 50°C and pH 5	An enzyme preparation derived from <i>Aspergillus niger</i> and <i>Trichoderma reesei</i>	Enzymatic saccharification of corn cobs	<ol style="list-style-type: none"> 1 The products of the enzymatic reaction were identified as glucose, cellobiose, xylobiose, arabinose and xylose 2 Increasing the concentration of corn husks in the reaction mixture adversely affected the production of total and individual soluble sugars 	Hang and Woodams, 2001
23	Corn cob waste	Biodegradation	Optimum pH for cellulase production was 5.5	<i>Phanerochaete chrysosporium</i> NRRL 6359, <i>P. chrysosporium</i> NRRL 6361 and <i>Coriobolus versicolor</i> NRRL 6102	<ol style="list-style-type: none"> 1 Enzyme determination 2 Protein determination 	<ol style="list-style-type: none"> 1 <i>Phanerochaete chrysosporium</i> NRRL 6359 was selected as a better producer for release reducing sugars 2 The highest levels of xylanase, glucanase and cellulase were detected in culture <i>P. chrysosporium</i> NRRL 6359 after 48 h 	Abd El-Nasser <i>et al.</i> , 1997

24	Corn stover waste	Chemical activation	Corn stover transported by pipeline at 20% solids concentration (wet basis) or higher could directly enter an ethanol fermentation plant	Heat loss in a 1.26 m pipeline carrying 2 Mdry tonnes/year is about 5°C at a distance of 400 km in typical prairie clay soils	Saccharification of corn stover	1 Transport of corn stover in multiple pipelines offers the opportunity to develop a large ethanol fermentation plant, avoiding some of the diseconomies of scale that arise from smaller plants whose capacities are limited by issues of truck congestion 2 Saccharification in the pipeline would reduce the need for investment in the fermentation plant, saving about 0.2 cents/l of ethanol	Kumar <i>et al.</i> , 2005
25	Corn cob waste	Hydrolysis	The enzymatic hydrolysis was carried out using citrate buffer (50 mM, pH 4.5) at 52–53°C for different time intervals	Use of <i>Apergillus</i> spp.	1 Enzymatic hydrolysis 2 The hydrolysis products were analyzed by HPLC	1 Xylose was found to be the major end product with traces of xylobiose and xylotriose at the beginning of hydrolysis 2 Corn cob powder showed lower extent of hydrolysis when treated with higher enzyme concentrations for longer periods of time	Gokhale <i>et al.</i> , 1998
26	Corn stover waste	Radiation	Gamma irradiation of corn stover in combination with sodium hydroxide for bioconversion of polysaccharide into protein by <i>Pleurotus</i> spp.	<i>Pleurotus ostreatus</i> and <i>P. eous</i> are macrofungi which utilize polysaccharides	Gamma radiation	After the heat/radiation treatment, succession of residual microorganism in the compost could influence the bioconversion of the substrate to utilizable nutrients for the mushroom development	Gbedemah <i>et al.</i> , 1998
27	Corn hull and corn stover waste	Physical activation	The usual commercial choices of activation gas are steam, CO ₂ , air or their mixtures. CO ₂ and O ₂	Temperature control for the reactor consisted of a three-zone temperature control system	Physical activation	1 Both surface area and nature of porosity were significantly affected by the conditions of activation,	Zhang <i>et al.</i> , 2004

(Continued)

Table 10.2 (Continued)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
28	Corn cob waste	Chemical activation	Chemically activated method with solution of KOH and soap which acted as surfactant	The temperature varies within 450 and 850°C.	Chemical method	<p>the extent of which depended on the nature of precursors</p> <ol style="list-style-type: none"> 2 The higher the activation temperature, the greater are the surface areas and micropore volumes of the resultant activated carbons 3 Various precursors were affected differently by the duration of activation 4 For oak, the longer the duration of activation, the greater the adsorption capacity of resultant activated carbons, and vice versa for corn hulls and corn stover <ol style="list-style-type: none"> 1 The specific surface area (SSA) of activated carbon from corn cobs reached 2700 m²/g 2 And the addition of the soap as surfactant may shorten the soaking time 3 The structure of the activated carbon prepared had narrow distribution of pore size and the micropores accounted for 78% 4 Easy and feasible method 	Cao <i>et al.</i> ,

Adapted from Arvanitoyannis and Tserkezou, 2007a,b

Table 10.3 Treatment methodologies of rice wastes: parameters, quality control methods and results

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
1	Rice straw	Composting	pH 7, the addition of compost (20–200 g/pot) improved selected soil chemical (increased total N, total C and CEC)	The composts reached maturity in 90 days	Composting	<ol style="list-style-type: none"> 1 Benefit of compost without chemical fertilizer demonstrated the validity and possibility of sustainable agronomic performance of faba bean using locally available recycled organic materials 2 The total organic C concentration declined slightly for all mixtures during composting 3 Compost N increased with increasing amounts of oilseed rape cake and poultry manure in the feedstocks 	Abdelhamid <i>et al.</i> , 2004
2	Rice straw	Composting	TKN, TOC and OM and humic substance (HS)	Psychrophilic and mesophilic microorganisms	Anaerobic composting	<ol style="list-style-type: none"> 1 As a result of biodegradation of organic compounds, the temperature increased and reached 40–50°C 2 pH tended to be stable and appeared to be consistent in all the composts 	Zhu, 2007
3	Rice flakes	Composting	The production media contained 5 g of solid substrate and 10 ml mineral solution containing (mg/gds) (NH ₄) ₂ SO ₄ 4, MgSO ₄ 7H ₂ O 1, FeSO ₄ 7H ₂ O 0.02, K ₂ HPO ₄ 1.4 and KH ₂ PO ₄ 0.6, in 250 ml Erlenmeyer flasks initially maintained at pH 7	<i>Aspergillus</i> spp.	Composting	<ol style="list-style-type: none"> 1 Organic nitrogen supplementation showed a higher enzyme production compared to inorganic source 2 Optimum enzymatic activity was observed at 55°C, pH 5 3 Enzyme activity was enhanced in the presence of calcium, whereas presence of EDTA gave reverse effect 	Anto <i>et al.</i> , 2006
4	Rice straw	Composting	The moisture content (oven dried at 105°C for 24 h), total organic matter (weight loss on ignition at 550°C for 72 h), oxidizable organic carbon (Walkley-Black method) and total	The respiration activity of microorganism was determined on different initial C/N (17, 24 and 40) raw materials	Composting	Straw residues from rice cultivation are rich in organic matter content (80%) and oxidizable organic C (34%) and have a high C/N ratio (very variable and near the average of 50), which means a feasible carbon source for the microorganisms which are able to survive the composting conditions	Iranzo <i>et al.</i> , 2004

(Continued)

Table 10.3 (Continued)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
5	Rice straw	Pyrolysis	nitrogen (Kjeldahl method) were determined Oxygen content of the bio-oils was significantly reduced due to the evolution of catalytic gases such as H ₂ O, CO and CO ₂	Pyrolysis temperature, heating rate and holding time on the yields of pyrolysis products and their chemical compositions	1 Fast pyrolysis 2 GC 3 MS	1 The total yield of liquid products significantly increased when pyrolysis temperature was raised from 400 to 500°C 2 The high water content in the pyrolysis liquid product may be due to the high moisture content in the feeding biomasses and the release of volatile organic products during the preparation of condensed liquid sample	Tsai <i>et al.</i> , 2006
6	Rice husk	Pyrolysis	Weight loss curves for pyrolysis of rice husk under N ₂ and CO ₂ atmospheres	Different levels of temperature	Rice husk pyrolysis	The method predicted satisfactorily the pyrolysis data at different heating rates of rice husk	Sharma and Rao, 1999
7	Rice husk	Pyrolysis	Gravimetric determination of SiO ₂ in solid residue	Non-isothermal heating in air	Pyrolysis	1 The burning of rice husk produces SiO ₂ with globular structure and well developed specific area 2 The pyrolysis in nitrogen medium gave SiO ₂ mixed with carbon	Vlaev <i>et al.</i> , 2003
8	Rice husk	Pyrolysis	The spectrum of catalyzed samples with FeCl ₂ ·4H ₂ O.	Temperature, pyrolysis time, type of catalyst and process atmosphere	Pyrolysis	1 The optimized production process was developed using as a FeCl ₂ ·4H ₂ O catalyst, 1370°C as process temperature, 1.5 l/min argon flow and 40 min residence time 2 Alternative uses for the rice husk were generated as new products that are manufactured from a remainder material	Martinez <i>et al.</i> , 2005
9	Rice straw	Pyrolysis	Nitrogen was used as sweeping gas with the flow rates of either 50, 100, 200 and 400 ml/min and the highest bio-oil yield was	Pyrolysis temperature, particle size, sweeping gas flow rate and steam velocity	1 Pyrolysis 2 GC 3 MS	1 The pyrolysis oils were conducted with H-NMR, oils and aliphatic subfractions with FT-IR 2 The chemical characterization showed that the oil obtained from rice straw may be potentially	Putun <i>et al.</i> , 2004

		obtained when flow rate was 200 ml/min			valuable as fuel and chemicals feedstocks
10	Rice husk and straw	Combustion	The main element in rice husk ash is silicon (87.7% as SiO ₂), followed by potassium (5.4% as K ₂ O) and phosphorus (3.7% as P ₂ O ₅)	Normal temperature	Combustion
					<p>1 The combustion tests using rice husk as fuel were done using different furnace temperatures and fluidization velocities</p> <p>2 The effect of these variables on combustion efficiency, CO emissions and ash characteristics were studied</p> <p>3 The combustion tests were operated in the temperature range of 840–880°C and in the fluidization velocity range of 1–1.2 m/s</p>
					Armesto <i>et al.</i> , 2002
11	Rice husk	Combustion	CO emissions vary from 200 to 800 ppm, SO ₂ ranges from 50 to 100 ppm and NO _x ranges from 150 to 220 ppm	The temperature measuring and gas sampling ports are installed at different heights	Combustion
					<p>1 The experiments showed that CO emissions varied from 200 to 800 ppm, whereas SO₂ ranged from 50 to 100 ppm and NO_x ranged from 150 to 220 ppm</p> <p>2 If the fluidizing velocity grew further, the strong combustion intensity zone will move to the top of the freeboard and increases the losses in unburned combustibles</p>
					Fang <i>et al.</i> , 2004
12	Rice straw	Combustion	K and Cl content of <i>Miscanthus</i> and determined that a substantial decline in K and Cl occurred as a result of over-wintering	The available period for mechanized collection of rice straw after the winter period ranges from 0 to 45 days	Thermal conversion
					<p>1 The moisture contents were similar to those of rice plants just prior to harvest</p> <p>2 Results for the subtreatments showed that shielded stubble had significantly higher concentrations of K and Cl than exposed stubble and loose straw, suggesting that the thatching effect of straw did reduce leaching rate</p>
					Bakkera and Jenkins, 2003
13	Rice husk	Pyrolysis	Using some carbonates like mixture of sodium carbonate and bicarbonate, magnesium carbonate and zinc carbonate	High temperature	Pyrolysis
					<p>1 The drastic weight loss pattern observed between 350 and 400°C was due to the destruction of cellulose and hemicellulose in the original biomass</p> <p>2 Pyrolysis apparently started at 350°C where the volatile</p>
					Maiti <i>et al.</i> , 2005

(Continued)

Table 10.3 (Continued)

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results
14	Rice husk	Combustion	Both fine carbon/silica and pure silica powders were obtained by carbonization of rice husk under non-isothermal conditions	Using heating rates of 5, 10, 15, 20°C/min	1 Combustion 2 Carbonization	<p>matter in the biomass began to vaporize</p> <p>3 The yield became almost constant after this stage, which marked the maximum char yield</p> <p>1 After heating the rice husk in N₂ or air, the impurity content was lower than that in acid-leached sample, indicating that the metals were also probably carried out from the volatiles during thermal decomposition</p> <p>2 By comparing the carbon/silica molar ratio in the carbonized husk, it was found that the carbon/silica molar ratio increased with increasing heating rate</p> <p>Liou, 2004</p>
15	Rice husk	Combustion	Sulfur and nitrogen contained in the liquid fuel are tested to be 0.1% and 0.2% for rice husks	Temperatures between 420 and 540°C	1 Combustion 2 GC 3 MS	<p>1 Experiments showed that a temperature below 420°C was not sufficient for pyrolysis as some rice husks or sawdust were found in the charcoal and ash</p> <p>2 The data showed that: i) the energy cascade is about 49% for liquid fuel and about 86% for all products, ii) the thermal energy contained in the charcoal is more than the energy consumed by electric heating</p> <p>Zheng <i>et al.</i>, 2006</p>
16	Rice straw	Biogasification	Ammonia was used as a supplemental nitrogen source for rice straw digestion	Mechanical, thermal and chemical (ammonia) treatment	1 Biogasification 2 Anaerobic digestion	<p>1 A combination of grinding (10 mm length), heating (110°C) and ammonia treatment (2%) resulted in the highest biogas yield, 0.47 l/g VS-fed, which is 17.5% higher than the biogas yield of untreated whole straw</p> <p>2 Pretreatment temperature had a significant effect on the digestibility of straw</p> <p>Zhang and Zhang, 1999</p>

17	Rice straw	Biogas	Disinfection of straw and manure by means of 0.1% KMnO ₄ plus 2% formalin solution in hot water	<i>Pleurotus sajor caju</i>	Biogas	Supplementation of rice straw with biogas residual slurry manure had strong impact on improving the yield potential, protein and mineral nutrient contents of <i>Pleurotus sajor caju</i> mushroom in Indian subcontinent or similar climatic conditions	Banik and Nandi, 2004
18	Rice husk	Gasification	The infrared band intensity of CO ₂ gas was starting to grow at 200–300°C, indicating an oxidation reaction occurred while CO gas was detected at 450°C	Temperature below 730°C to produce syngases for power generation and to recover valuable amorphous silica materials	1 Pyrolysis 2 Gasification 3 Steam gasification	1 Gasification of rice husk was accompanied by a substantial production of syngas at 450–630°C 2 To generate 10 kW electric power, approximately 28 kg of rice husk must be gasified 3 The rice husk gasification process, in terms of heat requirements, can be self-sustaining	Lin <i>et al.</i> , 1999
19	Rice husk	Gasification	Using a gasifying medium such as air, oxygen, steam	High temperature	Air gasification	1 The higher heating value of the gas obtained at this fluidization velocity and equivalence ratio (3.09–5.03 MJ/Nm ³) compared very well with published data from air-blown biomass gasifiers of similar scale of operation 2 The gas yield and carbon conversion were in the range of 1.30 to 1.98 Nm ³ /kg and 55 to 81%, respectively	Mansarayya <i>et al.</i> , 1999
20	Rice husk	Gasification	CO ₂ was introduced by replacing N ₂ gas	Different levels of temperature	Steam gasification	At the higher temperature of 900°C, the reaction mechanism was not only chemically controlled but also influenced by diffusional resistance	Bhat <i>et al.</i> , 2001

Table 10.4 Treatment methodologies of barley wastes: parameters, quality control methods and results

No	Kind of waste	Treatment	Parameters	Methodology	Quality control methods	Results	References
1	Barley waste	Composting	Total nitrogen content, inorganic nitrogen, potassium, phosphorus	Moisture was determined by drying at 105°C for 24 h, and total organic matter content (TOMC) determined by weight loss on ignition at 540°C for 16 h	1 Composting 2 UV-VIS spectrophotometry 3 Vermicomposting	1 Barley wastes showed a high organic matter content (86.27% on dry weight basis, respectively) and are deficient in nitrogen 2 Available phosphorus increased during the composting	Guerra-Rodriguez <i>et al.</i> , 2000
2	Barley straw waste	Composting	Acid and alkaline phosphomonoesterase (PME) and b-D-glucosidase	A fresh compost sample (0.5 g) was mixed with 2.5 ml of 62.3 mM p-nitrophenyl phosphate or 59.9 mM p-nitrophenyl-b-D-glucopyranoside in a modified universal buffer pH 5.0, 9.0 and 6.0, respectively	Composting	The choice of bulking agent strongly affected the potential capacity for mineralization of organic phosphorus in manure composts, but did not affect glucosidase activity (decomposition of cellulosic plant materials like straw)	Vuorinen, 2000
3	Barley straw waste	Composting	Dehydrogenase activities decreased in mature composts to the final constant level of 4.44–5.43 μM TPF/g (dw) ³ /h	Heterotrophic mesophilic bacteria	Composting	1 During composting, the C/N ratio decreased from 22.6–28.5 to 12.7–13.6 2 Approximately 11–27% of the total C was lost during 7 days active composting and 62–66% during the whole composting time; the respective gaseous losses of N were 13–23% and 23–37% of the total N	Vuorinen and Saharinen, 1997
4	Barley straw waste	Gasification	Use of CO ₂ and H ₂ O	Experimental conditions: L–10 bar total pressure, 0.15–1.5 bar H ₂ O and 0–1.0 bar H ₂ and 750–925°C	Steam (H ₂ O) gasification	The variation in reactivity among the four biomasses under equal gasification conditions was investigated and analyzed on the basis of their chemical compositions	Fjellerup <i>et al.</i> , 1996

5	Barley straw waste	Gasification	Use of CO ₂	Temperature 700–900°C	CO ₂ gasification at 700–900°C in a pressurized thermogravimetric analyzer at 2–20 bar	The separation effects of total pyrolysis pressure and total gasification pressure were investigated	Illerup and Rathmann, 1997
6	Barley waste	Biogas	The pH was adjusted to 7 and 0.75 g NaHCO ₃ /gTS _{initial}	1 The pH adjusted to 7.0–7.2 2 The handheld pressure transducer used measured a pressure change of two atmospheres (0–202.6 kPa) over a range of –200 to +200 mV	1 Biogas 2 Alkaline hydrolysis	1 Co-digestion of the BW with the kitchen waste was beneficial compared to co-digestion with sewage sludge 2 Methane production increased from 25 to 363 LCH ₄ (STP)/kgVS _{initial} and the total and volatile solids reduction increased from 31% to 61% and from 40% to 67%, respectively	Neves <i>et al.</i> , 2006
7	Barley husk waste	Adsorption	The removal of dyes (Cibacron Yellow C-2R, Cibacron Red C-2G, Cibacron Blue C-R, Remazol Black B and Remazol Red RB)	Temperature (80–120°C)	1 Steam pretreatment 2 Alkali pretreatment 3 Ammonia steeping 4 Milling	1 Though the milled, steam and the NaOH treated straw had different Ce values they had similar dye removal (54%, 56% and 53%, respectively) after 102 h of contact time while the control-substrate removed only 26% of the dyes 2 All straw pretreatments were effective at increasing the amount of dye adsorbed per gram of substrate	Robinson <i>et al.</i> , 2002
8	Barley husk waste	Adsorption	At total dye concentrations of 10, 20, 30, 40, 50, 100, 150 and 200 mg/l, experiments were carried out with an artificial effluent of an equal mixture of five textile dyes	Experiments were carried out statically at room temperature, 20 ± 2°C	Adsorption	1 Adsorption of dyes from an artificial effluent onto barley husk was measured for four different initial dye concentrations at an adsorbent dose of 5 g (1 × 4 mm of particle size per 100 ml) 2 Although 5 g of barley husk removed a very high percentage of dyes from the effluent	Robinson <i>et al.</i> , 2002
9	Barley waste	Composting	0.1 M P ₂ O ₇ Na ₄ at pH 9.8 for 24 h	The maximum temperatures reached were 65–68°C and the humidity level was kept at 45–65%.	Composting	The absorption of micronutrients was favored by the lowest doses while doses above 10 mg C/l inhibited it, which was probably one of the causes of the depressed growth observed with the highest doses	Ayuso <i>et al.</i> , 1996

Table 10.5 Treatment methodologies of oat wastes: parameters, quality control methods and results

No	Kind of waste	Treatment	Parameters	Methodology	Quality control	Results methods	References
1	Oat waste	Pyrolysis	The relative compositions of inorganic (Ca, Mg, and K) and organic (C, N and P) elements in plant residues provide a gross estimate of rates of decomposition	The samples were incubated in the dark at 25°C for 15, 30 and 80 days, dried at 65°C for 72 h and weight losses determined	1 Flash pyrolysis 2 GC 3 MS	The weight losses in this experiment were similar to those reported for black oat litter (53% over 70 days)	Franchini <i>et al.</i> , 2000
2	Alkali release from oat straws	Pyrolysis	Use of Al ₂ O ₃ , Cl	The release of alkali during pyrolysis in the temperature range 25–1060°C was measured using the sensitive surface ionization technique	Pyrolysis	1 Application of chloride-free fertilizers is concluded to be a simple and efficient way to reduce the alkali release from the fuels 2 The method can easily be combined with other methods in order to improve fuel quality	Davidsson <i>et al.</i> , 2001
3	Oat waste	Pyrolysis	The clay mineralogy is mostly composed of kaolinite (720 g/kg) and iron oxides (109 g/kg)	The temperature is 600°C	1 Flash pyrolysis 2 GC 3 MS	The main representatives of the phenol-derivatives were phenol, 2-methylphenol and 4-vinylphenol and are commonly identified after Py-GC/MS of plant, soil or humic substances samples	Dieckow <i>et al.</i> , 2006
4	Oat waste	Physical activation	Treatment with 0.2 M HCl	The metal binding ability of oat by-products was calculated from experimental data collected at temperatures of 8, 26 and 54°C and time exposures of 1, 6, 24, 48 and 72 h at each temperature	Physical activation	1 The amount of Cr(III) bound to oat biomass increased as the pH increased with a maximum of nearly 90% binding at pH 6, while the maximum binding of Cr(VI) to the oat biomass was nearly 32% at pH 2 2 Temperature may play an important role in the reduction of Cr(VI) to Cr(III) from contaminated waters	Gardea-Torresdey <i>et al.</i> , 2000

Treatment methods are selected based on the composition, quantity and form of the waste material. Some waste treatment methods are prescribed by regulations and DOE Orders; other treatment methods are being developed for specific wastes. Waste treatment methods being used today include solidification (e.g. calcining and vitrification) and volume reduction (e.g. incineration, compaction and sizing). There are two principal types of biological sewage treatment:

- 1 the percolating filter (also referred to as a trickling or biological filter)
- 2 activated sludge treatment.

Both types of treatment utilize two vessels, a reactor containing the microorganisms which oxidize the biochemical oxygen demand (BOD) and a secondary sedimentation tank, which resembles the circular radial flow primary sedimentation tank, in which the microorganisms are separated from the final effluent (Harrison, 2001).

Chemical reduction uses strong reducing agents (e.g. sulfur dioxide, alkali salts, sulfides, iron salts, etc.) to break down hazardous waste constituents to render them less toxic or mobile. Deactivation is a process that removes the hazardous nature of the waste by neutralizing the characteristics of ignitability, corrosivity and/or reactivity. Carbon adsorption uses activated carbon to adsorb hazardous waste constituents. Gaseous and aqueous waste streams can be treated by carbon adsorption. Chemical oxidation uses strong oxidizing agents (e.g. hypochlorite, peroxides, persulfates, perchlorates, permanganates, etc.) to break down hazardous waste constituents to render them less toxic or mobile (<http://www.epa.gov/epaoswer/osw/treattech.htm>).

Solidification is a method for mixing of cement, fly ash from the incinerator and waste filter cake from the physicochemical treatment to form a virtually insoluble mass (http://www.zazemiata.org/bw/radnevo/resume_ovos_en.pdf). Solidification processes such as calcining and vitrification can be used to treat non-solid radioactive waste. DOE processing plants take liquid waste or semisolid sludge and convert it to a solid waste form that can be safely disposed in a geologic repository (<http://web.em.doe.gov/em30/wasttrea.html>). The advantages of this method are in the use of simple equipment and the very inexpensive and flexible operation. This method allows for a high degree of inertness of the waste (http://www.zazemiata.org/bw/radnevo/resume_ovos_en.pdf).

Incineration is the high temperature burning (rapid oxidation) of a waste, usually at 870–1370 °C. It is also known as controlled-flame combustion or calcination and is a technology that destroys organic constituents in waste materials (<http://www.epa.gov/epaoswer/osw/treattech.htm>). Incineration of some commercial and industrial wastes, which are hazardous and have low throughputs, is a means of disposal and energy recovery is often a secondary objective. Sewage sludge incineration generates heat which is often used to dry the input sewage sludge to levels where the combustion is self-sustaining (Williams, 2005). Airborne effluents are carefully processed and monitored for compliance with environmental regulations and permit conditions to ensure safety (<http://web.em.doe.gov/em30/wasttrea.html>).

The activated sludge process may have up to four phases:

- 1 clarification, by flocculation of suspended and colloidal matter
- 2 oxidation of carbonaceous matter

3 oxidation of nitrogenous matter

4 auto-digestion of the activated sludge (Harrison, 2001).

Neutralization is a process used to treat corrosive hazardous waste streams. Low pH acidic corrosive waste streams are usually neutralized with containing bases. High pH corrosive waste streams are usually neutralized by adding acids (<http://www.epa.gov/epaoswer/osw/treatch.htm>).

An industrial furnace is a type of hazardous waste treatment device that uses thermal energy to recover energy or materials. It includes cement kilns, lime kilns, aggregate kilns, phosphate kilns, coke ovens, blast furnaces, smelting furnaces, etc.

Microencapsulation is a process that coats the surface of the waste material with a thin layer of plastic or resin to prevent the material from leaching hazardous waste constituents (<http://www.epa.gov/epaoswer/osw/treatch.htm>).

Vitrification is a solidification process that combines semi-liquid waste with glass, resulting in a stable glass form. This molten glass is then poured into stainless steel canisters. When the mixture has cooled and hardened into a stable glass the radioactive elements are trapped, thus preventing them from moving through the air or water into the environment (<http://web.em.doe.gov/em30/wasttrea.html>).

The physicochemical treatment plant will neutralize inorganic hazardous waste, including cyanides, chromium waste, waste acids, waste alkalis and heavy-metal containing waste. The main methods used will be cyanide oxidation, chromium reduction with subsequent settling, settling of heavy metals, neutralization of acids and alkalis (http://www.zazemiata.org/bw/radnevo/resume_ovos_en.pdf). Physical removal is a process that removes the hazardous constituents from waste streams by separation techniques such as ion exchange, adsorption, reverse osmosis, chelation, solvent extraction, crystallization, precipitation, distillation, filtration, evaporation, etc. The removed hazardous constituents may require further treatment to make them less toxic.

Steam stripping is a treatment technology mainly applied towards removal of organic compounds from liquid waste streams. The process involves direct application of steam to the liquid and subsequent condensation of the extracted organic compounds. Steam stripping not only removes hazardous constituents from the waste stream but it also can have the added benefit of making the constituents less toxic (<http://www.epa.gov/epaoswer/osw/treatch.htm>). Solid waste reduction, by reducing the volume of waste that requires disposal, means that the DOE can use the existing storage and disposal sites for a longer period of time. Solid waste reduction includes treatment methods that reduce the volume of solid waste such as incineration, compaction and sizing (<http://web.em.doe.gov/em30/wasttrea.html>).

The advantages and disadvantages of the treatment methodologies are given in Table 10.6. A typical wastewater treatment plant flow diagram incorporating flow equalization is presented in Figure 10.1 and from multiple biomass resources to a variety of fuels and energy products in Figure 10.2.

Composting

Composting has long been used for management of manure on farms and is a required practice under organic agriculture production protocols in Canada. The agronomic

Table 10.6 The advantages and the disadvantages of treatment methodologies employed for cereal wastes

Treatment methodologies of cereal wastes	Advantages	Disadvantages
Pyrolysis	<ol style="list-style-type: none"> 1 Uses less oxygen than traditional mass-burn incineration 2 Waste degradation to produce char (or ash), pyrolysis oil and synthetic gas (called syngas) 3 Wastes conversion into energy rich fuels by heating the waste under controlled conditions 4 Oils and solid char from pyrolysis are purified and used as a feedstock for petrochemicals and other applications 	<ol style="list-style-type: none"> 1 High temperature required to break down any waste containing carbon 2 Difficult to transfer heat to feedstock 3 Undermining of recycling 4 Not economically attractive
Gasification	<ol style="list-style-type: none"> 1 Hydrocarbons left into a syngas are broken down using a controlled amount of oxygen 2 Wastes conversion into energy rich fuels by heating the waste under controlled conditions 3 Gasification in conjunction with gas engines obtains higher conversion efficiency than conventional fossil-fuel energy generation 4 Production of nitrogen-free gas 5 Operation at a lower temperature and wider variety of feedstocks than direct combustion systems 	<ol style="list-style-type: none"> 1 High temperatures required to break down any waste containing carbon 2 Not economically attractive 3 Similar to incineration and as a result of negative public perception this can lead to planning problems 4 Gasification may inhibit waste minimization and recycling 5 Small amounts of released tar in the gas coats parts of the pipe or the equipment
Composting	<ol style="list-style-type: none"> 1 Improved soil structure, increased water-holding capacity, improved root and plant growth and reduced wind and water erosion 2 Improvement of manure properties for organic farming 	<ol style="list-style-type: none"> 1 Time-consuming process 2 Nitrogen considered a limiting factor for microbial growth and activity during the decomposition of plant residues
Combustion	<ol style="list-style-type: none"> 1 Combustion in premixed gaseous mixtures often produces interesting structure 2 High softening, hemispherical and flow temperatures are considered to be advantageous 	<ol style="list-style-type: none"> 1 High temperature required high cost 2 High pressure application required high cost
Biogas	<ol style="list-style-type: none"> 1 Biogas is about 20% lighter than air 2 Odorless and colorless gas 	<ol style="list-style-type: none"> 1 Biogas ignition temperature in the range of 650–750°C

value of compost and its beneficial or detrimental effects on soil and the environment are closely linked to the nature and dynamics of its constituent organic matter (Lynch *et al.*, 2006).

Composting is decomposition of the organic, biodegradable fraction of waste to produce a stable product such as soil conditioners and growing material for plants. Composting of garden and food waste has been recommended to home-owners as a direct way of recycling. It has been extended on a larger scale for green waste from parks and gardens and also to municipal solid waste and to sewage sludge. The quality of the compost produced from waste, compared with non-waste sources, has been an issue for waste composting, particularly in the area of contamination (Williams, 2005). Compost was found to improve soil structure and organic matter content and nutrient supply to plants and thus may reduce the input of mineral fertilizers in

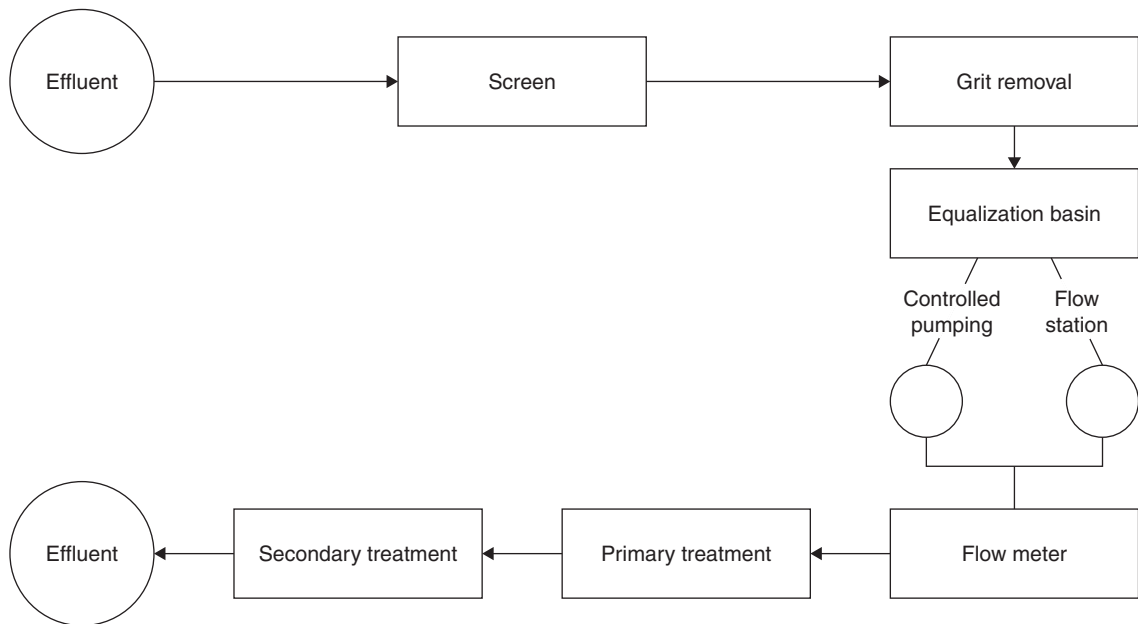


Figure 10.1 Typical wastewater treatment plant flow diagram incorporating flow equalization (adapted from Tchobanoglous *et al.*, 2003)

conventional agriculture and provide a useful nutrient source in organic farming, respectively. To integrate compost into the crop rotation, the availability of the nutrients should be known (Erhart *et al.*, 2005).

The composting process is aerobic and consequently relies on a plentiful supply of oxygen. Regular aeration is required to maintain aerobic conditions. The composting process may be characterized by three stages. The first stage is characterized by increasing temperatures and involves a high rate of microbiological activity. Simple carbohydrates and proteins are readily biologically degraded by mesophilic microorganisms, followed by thermotolerant and thermophilic microorganisms as the temperature rises above 45 °C (Swan *et al.*, 2002). The second stabilization stage involves biodegradation of the waste by thermophilic microorganisms and is an exothermic process where temperature in the compost pile can reach up to 70 °C, so that only the most temperature resistant microorganisms survive. The high temperature stage involves the thermal destruction of weed seeds and pathogenic microorganisms. In the third stage, the material continues to cool and microorganisms begin to compete for the remaining organic material, in turn leading to breakdown of cellulose and lignin in the waste (Harrison, 2001).

Composting is commonly used to improve the properties of manures for organic farming. Available N in raw manure is immobilized during optimal composting allowing more stable slow release of N forms for crops. Nutrient losses during composting can be minimized by good, optimized process handling and use of suitable bulking agents, thus improving the fertilization value of manure. Therefore, during manure

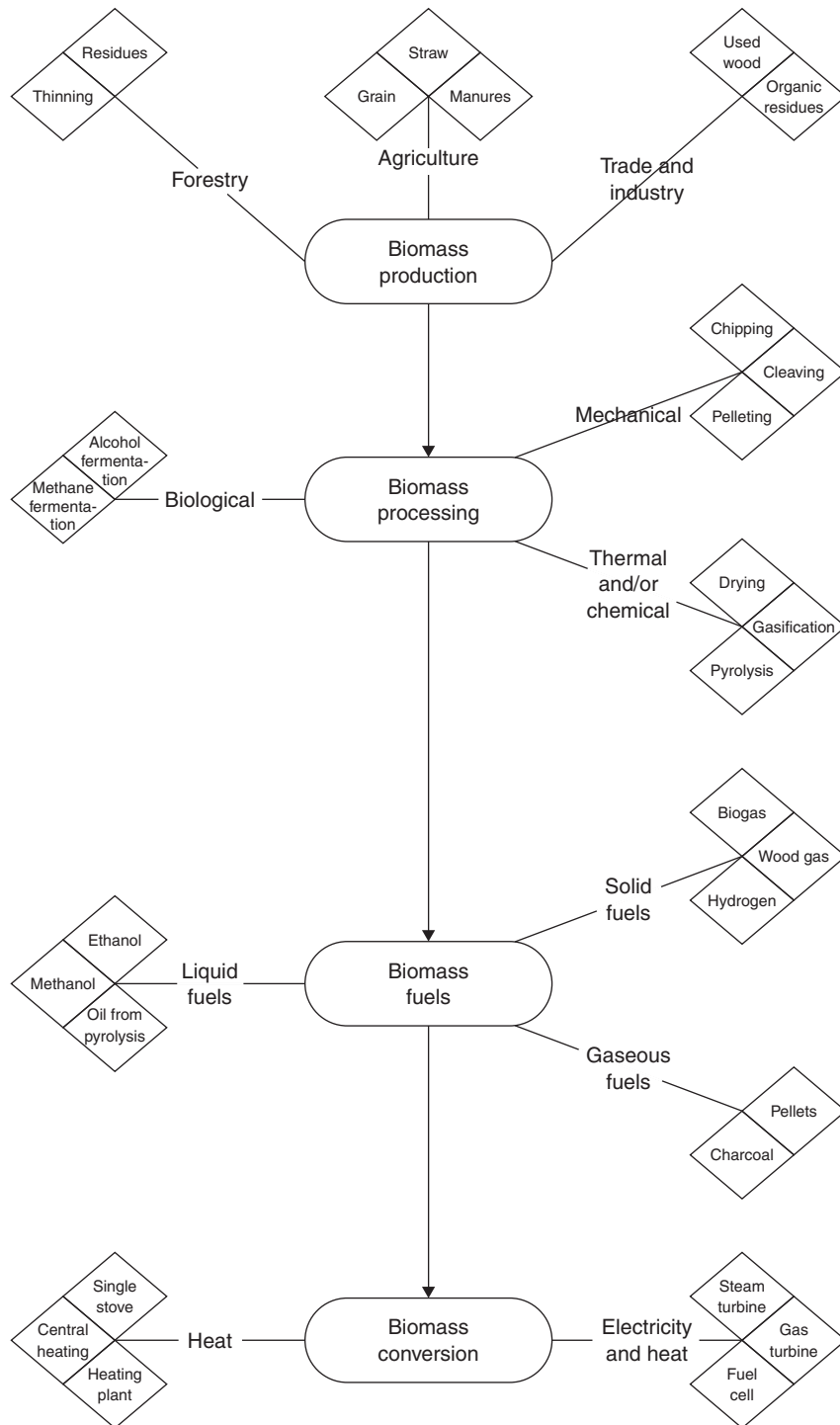


Figure 10.2 From multiple biomass resources to a variety of fuels and energy products (adapted from Chum and Overend, 2001)

composting and application of composted manures, the environmental risks, such as ammonia volatilization and leaching of N and P, may be less than when raw or anaerobically stored manures are handled or during improper handling of manure (Vuorinen Saharinen, 1997). High quality compost is increasingly available and it offers farmers considerable benefits when used on land in a way that other materials, whether conventional fertilizers or wastes such as sludges, do not. Good quality compost is a valuable and safe resource, not a waste product. As a general principle, all material, such as compost that has significant fertilizer value, should be applied only up to the level of crop requirements. However, the way in which compost can be used is different when compared to mineral fertilizers. To identify the use thresholds it is important to understand the nature of compost (http://www.remade.org.uk/organics/organics_documents/compostbenefitsscottishcrops.pdf).

Turning compost is important as it ensures proper mixing, wetting, aeration and decomposition. Materials at the bottom are then placed at the top of the heap. It is recommended to sprinkle 20 liters of water on the heap during turning, particularly when conditions are dry. Compost turning is continued until the heaped materials turn dark gray. Biological activity is periodically monitored by pushing a stick into the middle and sides of the stack. Composting requires 4 to 6 months and, at maturity, about 1900 kg of fortified compost is produced (<http://www.formatkenya.org/orbook/Chapters/chapter9.htm>).

Since much carbon (C) from plant residues such as straw materials is only slowly available to microorganisms, leading to low growth efficiency, a limited amount of nitrogen (N) may be required during decomposition and recycling of N may then be adequate to meet the N requirements. Microorganisms, especially fungi, have a considerable capacity to adapt to N deficient conditions. A large amount of N initially could consequently result in immobilization. This greater N immobilization may depend on:

- 1 synthesis of microbial biomass with a lower C/N ratio
- 2 higher N losses
- 3 reduced N mineralization or re-mineralization, which may have been related to reduced microbial activity (Dresboll and Thorup-Kristensen, 2004).

Amidst the range of waste treatments currently available, incineration and landfilling are the most frequent and are commonly combined to meet the needs of local communities. Composting of urban waste has emerged as a valuable alternative because of the high proportion of organic matter in urban waste. The biodegradable fraction is estimated at about 25% (fresh weight) in France, along with an additional 25% made up of paper and cardboard. Composts have long been used in agriculture and urban waste composts (UWC) may be applied in arable fields as organic amendment to maintain soil organic matter as well as supply nutrients to crops (Gabrielle *et al.*, 2005). Organic wastes make up a large part – up to 40% – of the municipal solid waste stream. Therefore, organic wastes should be recycled from an ecological as well as from an economical point of view. In the late 1980s, composting of separately collected organic household wastes was introduced in Vienna and subsequently a municipal composting plant was set up. Due to extensive quality control measures, all compost lots produced

were suitable for agriculture and 22% even for organic farming. With wheat, a wide range of yield responses to compost fertilization has been recorded. Non-significant wheat yield increases followed the application of 6.9 t/ha biowaste compost on a parabrown soil in Germany (Erhart *et al.*, 2005).

Compost is also likely to contain a wide range of minor plant nutrients and beneficial microbes not normally present in mineral fertilizers. The typical contribution of the long-term application of quality compost has been shown to contribute to the equivalent of less than 5% of pre-existing soil heavy metal level. When considered alongside the constant contribution to soil of airborne dust, high quality compost heavy metals are now widely considered not to be significant. Together these are likely to have an additive positive effect on general soil 'health'. Composts derived from segregated wastes are generally acceptably low in heavy metals and compost complying with an appropriate standard will have data to confirm this (http://www.remade.org.uk/organics/organics_documents/compostbenefitsscottishcrops.pdf).

Availability of nutrients from organic composts is often limited despite a high initial nutrient input and considerable nutrient losses frequently occur during the composting period, primarily due to gaseous emissions. As nutrients are a limited resource in organic production, a more efficient nutrient use is desirable. It was hypothesized that such high efficiency composts could be prepared by splitting the addition of the nutrient rich material during the composting process. The remaining nutrient rich material should be added later in the process when the turnover of the wheat straw would already be proceeding. Decomposition of the newly added material would then result in less N immobilization compared to compost produced by a single addition at the beginning of the process (Dresboll *et al.*, 2004).

Decomposition of plant tissue depends on various factors including temperature, moisture content, oxygen content and residue quality. In general, both resource quality and physiochemical parameters affect the composition and activity of the decomposer communities conducting the mineralization/immobilization processes of decomposition. Thus, when producing plant based compost to be used as growing medium in horticultural productions, choice of plant material is a key factor, as root proliferation and development depend heavily on the physical structure and stability of the medium. The physical properties are mainly dependent on the starting material and are difficult to alter during production (Caron and Nkongolo, 1999).

Nitrogen was often recognized as a limiting factor for microbial growth and activity during the decomposition of plant residues, especially in materials with a high C/N ratio such as wheat straw. However, experiments on the effect of additional N supply on the decomposition of plant residues showed different results, ranging from positive to negative effects on the decomposition rate. Resource quality, microclimatic conditions and decomposer efficiency are major factors regulating composition and activity of decomposer communities and hence the process of decomposition and nutrient release. Thus, the effect of added N on decomposition depended on the plant material as degradation is influenced by nutrient content and anatomical structure of the material (Dresboll *et al.*, 2004).

Organic compost from waste may be used for various purposes, among which are soil recovery, commercial production, pastures, lawns and reforestry and agriculture.

However, the quality of compost determines the plant growth and development of plants. The effect of compost made from urban waste on corn plant (*Zea mays* L.) growth was investigated. Two types of compost were used: the selected compost (SC), produced from organic waste selectively collected; and the non-selected compost (NSC) (Lima *et al.*, 2004).

A series of field and pot trials were carried out to determine the effects of growing wheat and oilseed rape in soils supplemented with green waste composts and additional fertilizers. It was consistently shown that the response of wheat and rape to compost and fertilizer applied together was greater than the responses to the individual additives, but only when very stable compost was used (>10 months processing). Experiments with ^{15}N -labeled fertilizer revealed that wheat was able to utilize the applied nitrogen more efficiently when cultivated in the stable compost. The enhanced growth was also demonstrated in hydroponic culture of oilseed rape with water extracts of green waste compost in the presence of compound fertilizer (Keeling *et al.*, 2003). However, a technical difficulty was the lack of a reliable and inexpensive methodology to examine the fate of compost in soil and to quantify compost effects on soil organic matter (SOM). Organic amendments often supply much greater C inputs to soil than are derived from crop residues. Relatively few studies applied the isotope $\delta^{13}\text{C}$ technique to improve our understanding of the transformation, utilization and stabilization of amendment carbon in soil (Lynch *et al.*, 2006). Composting temperature is influenced by moisture content, degree of aeration, size of the pile and climatic conditions, particularly air temperature and rainfall. The finished compost is friable humus with moisture content less than 40%. Although too low in nutrients to be considered a fertilizer, compost is an excellent soil conditioner (Hammer and Hammer, 2004).

Changes in physicochemical characteristics during composting of tannery effluent, wheat straw and cow manure are given in Figure 10.3. A schematic diagram of the composting process is presented in Figure 10.4.

Pyrolysis

Pyrolysis is the first and most basic thermo-chemical step to convert biomass into gaseous or liquid fuels. However, despite the fact that pyrolysis underlies humankind's oldest technology (the use of fire), it is still not a predictive science (Green and Feng, 2006). Pyrolysis is the decomposition of a complex organic substance to one of a simpler structure by means of heat in the absence of oxygen or any other reagents, except possibly steam. Some polymers will depolymerize in the presence of excessive temperatures, either to polymers of lower molecular weight, or back to the monomers from which they were derived (<http://composite.about.com>).

Pyrolysis typically occurs under pressure and at operating temperatures above 430 °C. In practice, it is not possible to achieve a completely oxygen-free atmosphere. Because some oxygen is present in any pyrolysis system, a small amount of oxidation occurs. If volatile or semi-volatile materials are present in the waste, thermal desorption will also occur (<http://www.cpeo.org/techtree/ttdescript/pyrols.htm>). Pyrolysis is thermal degradation of waste in the absence of air to produce char, pyrolysis oil and syngas,

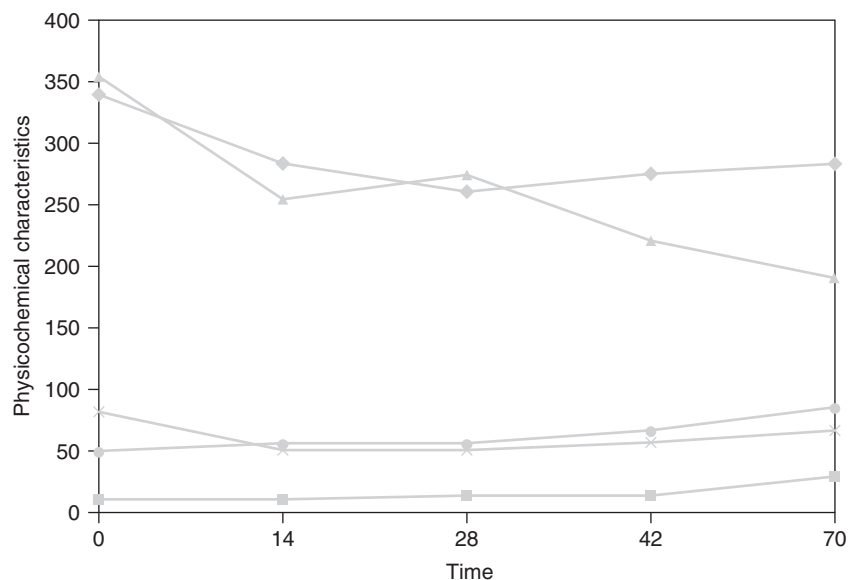


Figure 10.3 Changes in physicochemical characteristics (◆ total carbon, ■ total nitrogen, ▲ lignin, X cellulose and ● ash content) versus composting time of tannery effluent, wheat straw and cow manure (adapted from Conteras-Ramos *et al.*, 2004)

e.g. the conversion of wood to charcoal (http://www.juniper.co.uk/services/Our_services/P&GFactsheet.html). The manner, in which pyrolysis functions offers some advantages over conventional incineration. First, because no air is fed into the combustor, far less waste gases are produced and therefore the gas cleaning system can be smaller and hence less costly. Secondly, the waste itself must be pre-prepared to make it homogeneous and to remove bulky materials. Thirdly, in theory the solid, liquid and gaseous streams can be further processed into useful products and hence there should be less material to discard to landfill (Harrison, 2001). Extreme pyrolysis, that leaves only carbon as the residue, is called carbonization (<http://en.wikipedia.org/wiki/Pyrolysis>).

Organic materials are transformed into gases, small quantities of liquid and a solid residue containing carbon and ash. The off-gases may also be treated in a secondary thermal oxidation unit. Particulate removal equipment is also required. Several types of pyrolysis units are available, including the rotary kiln, rotary hearth furnace or fluidized bed furnace. Pyrolysis is not effective in either destroying or physically separating inorganics from the contaminated medium. By-products containing heavy metals may require stabilization prior to their final disposal (<http://www.cpeo.org/techtree/ttdescript/pyrols.htm>). Flash pyrolysis gives high oil yields but, because of the technical efforts required to process pyrolytic oils, this energy generating system does not seem to be very promising at the present stage of development. However, pyrolysis as a first stage in a two-stage gasification plant for straw and other agricultural feedstocks posing technical difficulties in gasification does deserve consideration. Pyrolysis of biomass generates three different energy products in different quantities: coke, oils and gases (<http://www.tab.fzk.de/en/projekt/zusammenfassung/AB49.htm>).

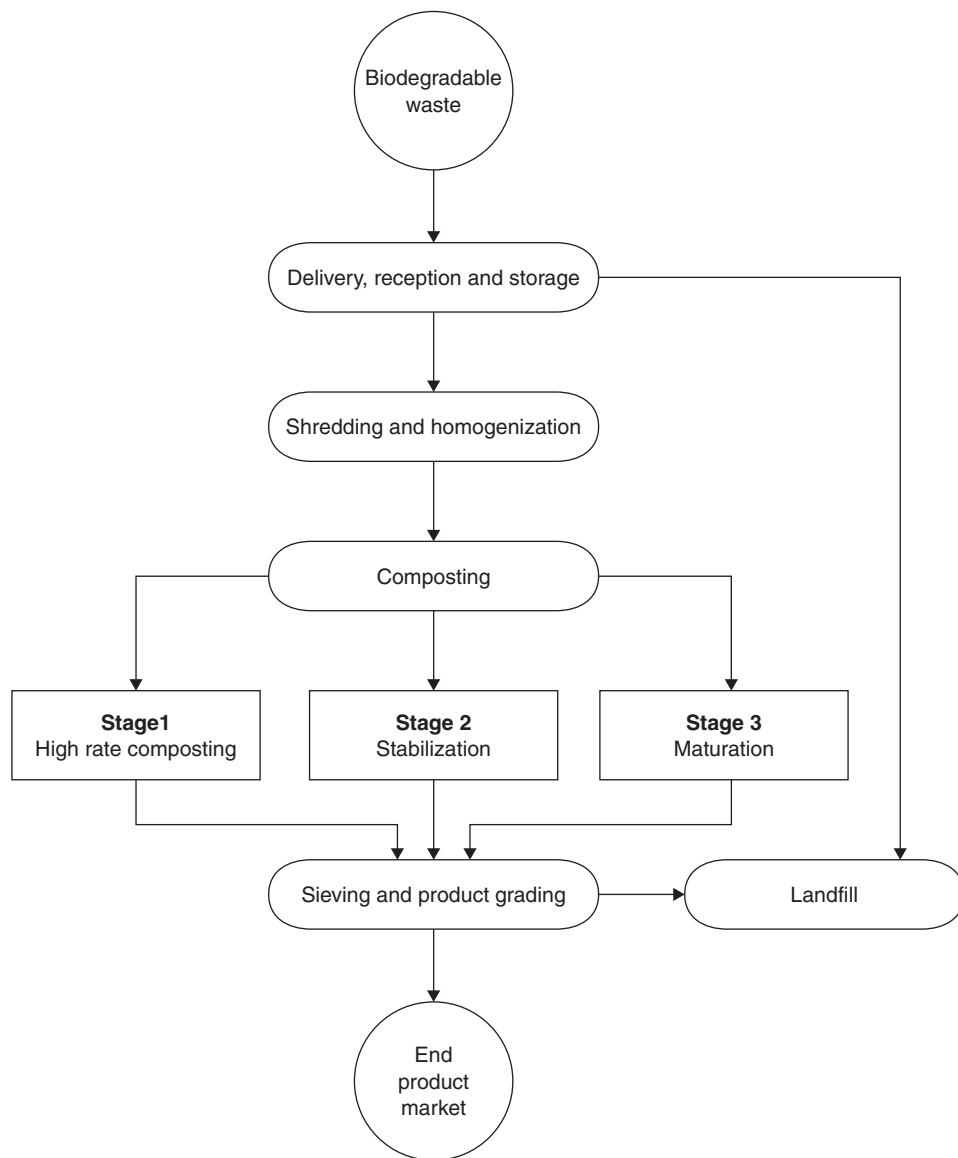


Figure 10.4 Schematic diagram of the composting process (adapted from McLanaghan, 2002; Swan *et al.*, 2002; Williams, 2005)

Anhydrous pyrolysis can be employed to produce liquid fuel similar to diesel from solid biomass. The most common technique applies very low residence times and high heating rates thereby using a temperature between 350 and 500 °C and is called either fast or flash pyrolysis. When burning compact solid fuel, like wood, the flames of a wood fire are due to combustion of gases released by pyrolysis, not combustion of the wood itself. Thus, the pyrolysis of common materials like wood, plastic and clothing is extremely important for fire safety and fire fighting (<http://en.wikipedia.org/wiki/Pyrolysis>).

Pyrolysis (PY) is an interesting degradative technique because it can be easily coupled to gas chromatography (GC), mass spectrometry (MS) or GC/MS, thus allowing the online degradation of polymers and the analysis of their fragments by hyphenated techniques such as PY/GC, PY/GC/MS or PY/MS (Rodriguez *et al.*, 1997). The pyrolysis products identified were mostly related to carbohydrates (furans), proteins (nitriles and pyrroles), chitin (pyridines and pyrazols), lipids (alkanes and derivatives of benzene) and lignin (phenols). The relative yield of all individual pyrolysis products was similar in the samples from the maize (C₄) and control wheat (C₃) soil (<http://dbs.clib-jena.mpg.de/dbs-publ/pubi/bgc/BGC0130.pdf>).

Over the past decade, flash pyrolysis (FP), or thermolysis, became a process in which materials, i.e. biomass, are rapidly heated to high temperatures in the absence of air (oxygen). In this process, the biomass is decomposed into a mixture of solid char, gas, vapors and aerosols. When the components were quenched, the volatile components condensed to bio-oil. It was found that the percentages of these components and product yields were strongly affected by the temperature of reaction and heating rate inside the reactors. Bio-oil is a liquid mixture of oxygenated compounds containing various chemical functional groups, such as carbonyl, carboxyl and phenolic. It can be effectively used as a substitute for fuel (Shuangninga *et al.*, 2005).

Some of the main objectives were to characterize and study the preparation of biomass to meet the necessary specifications to be used for bio-oil production in the rotating cone pyrolysis technology. This included selection of a number of relevant biomass materials based on primary criteria such as their high availability in the EU and low production costs. Biomass materials with certain degree of homogeneity and/or low humidity content were also considered as agro-industrial and agricultural residues produced in Southern Europe and well suited to be utilized in pyrolysis technology. An appraisal of the resource availability and costs was developed in order to assess the selection of the biomass to be studied in detail within the project resulting in selection of twenty substrates (<http://www.biomatnet.org/secure/Fair/F538.htm>).

Bio-oil from fast pyrolysis is, in many ways, different from other liquid fuels (such as rapeseed oil or bioethanol derived) from biomass like. It also differs significantly from diesel fuel in both physical properties and chemical composition. Bio-oil contains water and solids; it is acidic and has a low calorific value. Therefore, the first task was to determine the chemical and physical properties of pyrolysis oil generated using this technology from different feedstocks and compare them with other biofuels and fuels derived from mineral oil. The standard methods developed for petroleum based fuels need to get adapted to bio-oil (<http://www.dynamotive.com/biooil/technology.html>).

The fast pyrolysis process converts forest and agricultural residue (including bark) into liquid bio-oil and char. Bio-oil is a clean burning, greenhouse gas neutral fuel that will initially be used to replace fossil fuels to generate power and heat in stationary gas turbines, diesel engines and boilers and to replace natural gas in the forest industry and to replace another product in the coal industry. The char is a high heating value solid fuel that can be used in kilns, boilers and the briquette industry. Three products are produced: bio-oil (60–75% wt), char (15–25% wt) and non-condensable gases (10–20% wt) (<http://www.biomatnet.org/secure/Fair/F538.htm>).

The fast pyrolysis process is carried out as follows: prepared feedstock (<10% moisture and 1–2 mm particle size) is fed into the bubbling fluid-bed reactor, which is heated to 450–500°C in the absence of oxygen. This is lower than conventional pyrolysis systems and, therefore, has the benefit of higher overall energy conversion efficiency (<http://www.dynamotive.com/biooil/technology.html>).

Thermogravimetric analyzer (TGA) was the main instrument used in analyzing the characteristics of solid fuel volatilization at low-heating rates. The maximum heating rate of TGA could reach as high as 100 °C/min. For years, pyrolysis and combustion reactions of pulverized biomass were investigated in various applications using TGA. Kinetic studies showed a great deal of variations in the measured kinetic parameters of apparent frequency factor and apparent active energy. This could be attributed to the diversity of the biomaterials and experimental conditions. Laminar entrained flowreactor (LEFR) was used to study the chemical characteristics of pulverized coals and other solid fuels in order to provide much higher heating rates and maintain the reaction conditions precisely (Shuangninga *et al.*, 2005). Understanding pyrolysis kinetics is important for the effective design and operation of the thermochemical conversion units, given that solid devolatilization is always a fundamental step. The TGA technique was applied in several cases for such a purpose. Thermogravimetric curves for wheat, barley, oats and rye straw have been measured in both inert and oxidizing atmospheres. Even though TGA studies provided basic information on the kinetics of straw pyrolysis, the results were not readily applicable to practical conversion systems because heating rates were generally much faster. On the other hand, analysis was not carried out on the kinetics of straw degradation under rapid heating (Lanzetta and Di Blasi, 1998).

A special automated feeding system consisting of four supply towers ensures that four boards are introduced simultaneously into the reactor chamber. Ablation rates between 2.0 and 5.5 mm/s have been achieved so far. The pyrolyzer consists basically of a rotating, vertically orientated, electrically heated disk. Solid wood boards with a cross-sectional area of 10 × 47 mm and a length of approximately 350 mm are pressed against the disk by a piston. The pressure ranges between 30 and 50 bar and the heated disk temperature is approximately 700 °C. Gas cleaning and condensation is accomplished with standard techniques such as cyclone, spray tower and electrostatic precipitator (<http://www.pyne2005.inter-base.net/docs/PyNews%2017.pdf>).

The core of the pyrolysis pilot plant is the rotating cone reactor which is a compact high intensity reactor in which biomass of ambient temperature is mixed with hot sand. Upon mixing with the hot sand at 550°C, the biomass decomposes providing 70 weight percent condensable vapors, 15 weight percent non-condensable gases and 15 weight percent char. During the project, BTG and KARA had successfully designed and constructed a fully automated pyrolysis plant with a capacity of 260 kg/h. This was operated over a number of trial periods, during which the following conditions were established as those that gave the highest oil yield and produced the best quality bio-oil:

- 1 reactor temperature of 470°C
- 2 vapor residence time <1 s
- 3 biomass particles <4 mm (<http://www.biomatnet.org/secure/Fair/F538.htm>).

Curie-point pyrolysis-gas chromatography coupled on-line to mass spectrometry (Py-GC/MS) and isotope ratio mass spectrometry (Py-GC/IRMS) were used to determine the individual turnover rate of specific carbohydrates, lignin, lipids and N-containing compounds from French arable soils. Based on the differences in isotopic enrichment of chemical structures after vegetation change, the pyrolysis products could be divided into three groups:

- 1 pyrolysis products with a nearly complete C_4 signal, e.g. phenol, derived from lignin degradation products
- 2 pyrolysis products with an intermediate isotopic enrichment of 6–8 per thousand, most likely to be a composite of remaining fragments derived from both maize and native wheat
- 3 pyrolysis products showing only low enrichments in ^{13}C of 1–3 per thousand.

Most of their precursors were found to be proteinaceous materials. This implied that proteins or peptides were indeed preserved during decomposition and humification processes occurring in the soil. The analyzed soils were cultivated, either continuously with a C_3 plant or transferred to a C_4 plant cropping 23 years ago. Most pyrolysis products identified were related to carbohydrates (furans), lipids (hydrocarbons and derivatives of benzene), proteins (nitriles and pyrrole) and lignins (phenols). The relative yield of all individual pyrolysis products was similar in the samples from the maize and control wheat soil (Gleixner *et al.*, 1999).

An insight into the chemical structure of complex biomacromolecules can be obtained via pyrolytic studies and this technique has been applied to a large range of natural compounds. Among the various methods used for isolating lignin-containing materials from biomass is one yielding the so-called 'ligno-cellulosic substrate' (LCS). This material was obtained from wheat straw by successive acid and base treatments. Wheat straw LCS exhibits a number of interesting features in relation to metal complexation and might be suitable for important applications like metal removal from industrial effluents. This LCS was analyzed with CP/MAS ^{13}C NMR spectroscopy and Py/GC/MS, in the presence and absence of tetramethylammonium hydroxide (TMAH), to derive information on its molecular composition in relation with complexation features (Gauthier *et al.*, 2003). Combined gas chromatography-mass spectrometry of the products from linked synthetic model lignin dimer treated with ^{13}C -labelled TMAH suggested that the ether linkage was cleaved via intramolecular epoxide formation. Pyrolysis in the presence of TMAH was used to analyze phenolic acids, natural resins, resinates, humic acids, asphaltenes, kerogens, lignins and organic matter in near shore marine sediments. Pyrolysis of lignin in the presence of TMAH avoids decarboxylation of polar moieties and yields phenolic derivatives which are not observed during conventional analytical pyrolysis (Vane *et al.*, 2001). Combined pyrolysis/gas chromatography/mass spectrometry (Py/GC/MS) of complex macromolecular materials can provide detailed structural information but suffers limitations for the identification of compounds comprising polar functional groups like carboxylic (COOH) and hydroxyl (OH) groups. This technique was improved by introducing thermochemolysis with TMAH. Thermochemolysis corresponds to a

thermally-assisted chemolytic degradation rather than degradation simply induced by thermal bond cleavage. In addition, *in situ* methylation occurs so that a number of polar products become volatile enough for gas chromatographic analysis (Gauthier *et al.*, 2003).

Analytical pyrolysis is one of the many tools utilized for the study of natural organic polymers. Analytical pyrolysis methodology covers two distinct subjects, the instrumentation used for pyrolysis and the analytical methods that are applied for the analysis of the pyrolysis products. A variety of pyrolytic techniques and of analytical instruments commonly coupled with pyrolysis devices are given at http://www.elsevier.com/wps/find/bookdescription.cws_home/600279/description#description. The term pyrolysis is sometimes used to encompass also thermolysis in the presence of water, such as steam cracking of oil, or more generally hydrous pyrolysis. The applications of analytical pyrolysis included topics such as polymer detection, used for example in forensic science, structure elucidation of specific polymers and identification of small molecules present in polymers (antioxidants, plasticizers, etc.).

Analytical methods based on pyrolysis gas chromatography coupled to mass spectrometry (Py-GC-MS) present great potential due to the small amount of sample required for analysis and the type of information provided. Milled wheat straw was treated with an Mn^{2+} oxidizing peroxidase from *P. eryngii* and the changes produced evaluated by analytical pyrolysis. The results obtained included quantitation of lignocellulose pyrolysis products after peroxidase treatment and information on the action of the enzyme on phenolic and non-phenolic lignin units. The phenolic moiety increased lignin solubility and extractability from lignocellulose and modified the characteristics of lignins as an industrial raw material (Camarero *et al.*, 2001). Analytical pyrolysis was shown to be very effective in the characterization of lignins, where most of the pyrolytic fragments are not secondary rearrangement products, but diagnostic compounds in which the structure of the main building blocks of the macromolecule is preserved. In this way, a semiquantitative assessment of the monomer composition for the different lignin types can be made: in fact, pyrolysis combined with gas chromatography and mass spectrometry proved to be a valuable tool for the analysis of pulp samples (Galletti *et al.*, 1997).

Pyrolysis and gasification are thermal processes that employ high temperatures to break down any waste containing carbon. Pyrolysis was carried out at 600°C for 5 s. Py-GC interface was set at 200°C. The GC column was a SPB-5 and was operated from 50 to 290°C at 5°C/min, holding the initial temperature for 10 min. The injector was set at 250°C in the split mode. Mass spectra were recorded under electron ionization at 70 eV, spectral range from 40 to 450 m/z, 1 scan per second. To optimize Py-GC:MS quantitation of lignin and polysaccharide pyrolysis products, correction factors for the use of 1,3,5-tri-tert-butylbenzene as internal standard were obtained for different phenolic standards (Martinez *et al.*, 2001).

Pyrolysis yields of carbon products prepared from agricultural waste corn cob with chemical physical activation are presented in Figure 10.5 and element analysis of rice husk heat treated under pyrolytic conditions at different temperature is given in Figure 10.6 and Figure 10.7. A system boundary in the various cropping and alternative

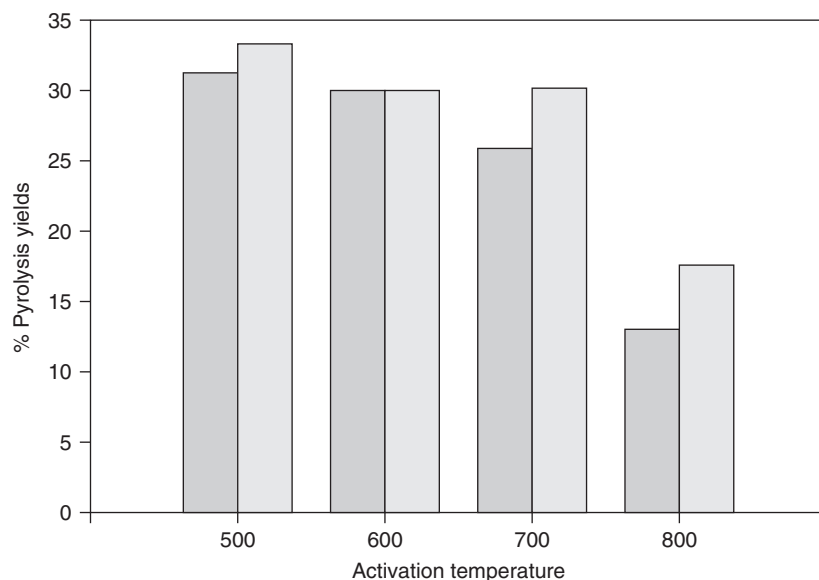


Figure 10.5 Pyrolysis yields of carbon products prepared from agricultural waste corn cob (■ KOH activating agent, ■ K₂CO₃ activating agent) by chemical physical activation (adapted from Tsai *et al.*, 2001)

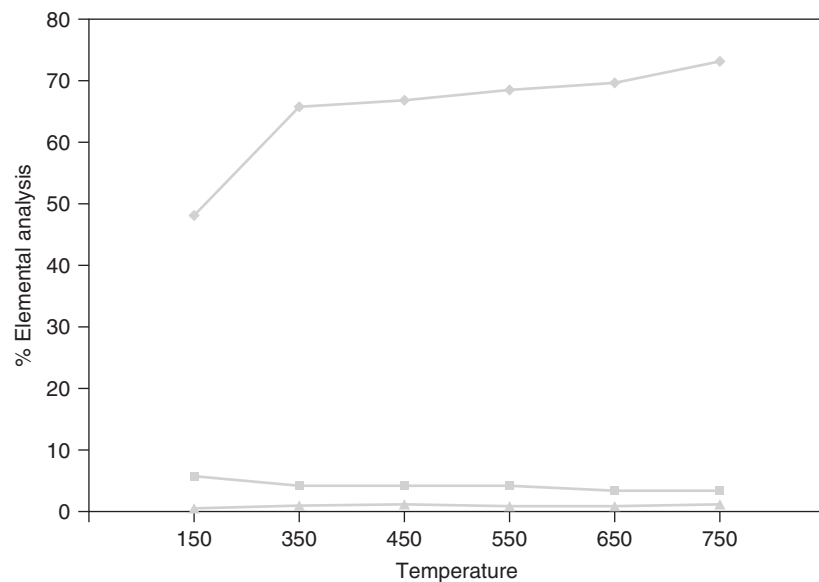


Figure 10.6 Elemental analysis of rice husk heat treated (◆ C, ■ H and ▲ N) under pyrolytic conditions at different temperatures (adapted from Maiti *et al.*, 2005)

production systems is presented in Figure 10.8. Material and energy balances of the rice husk gasification process and flow sheet of rice husk fluidized bed fast pyrolysis and fluidized bed fast pyrolysis catalytic treatment processes are given in Figure 10.9 and Figure 10.10, respectively.

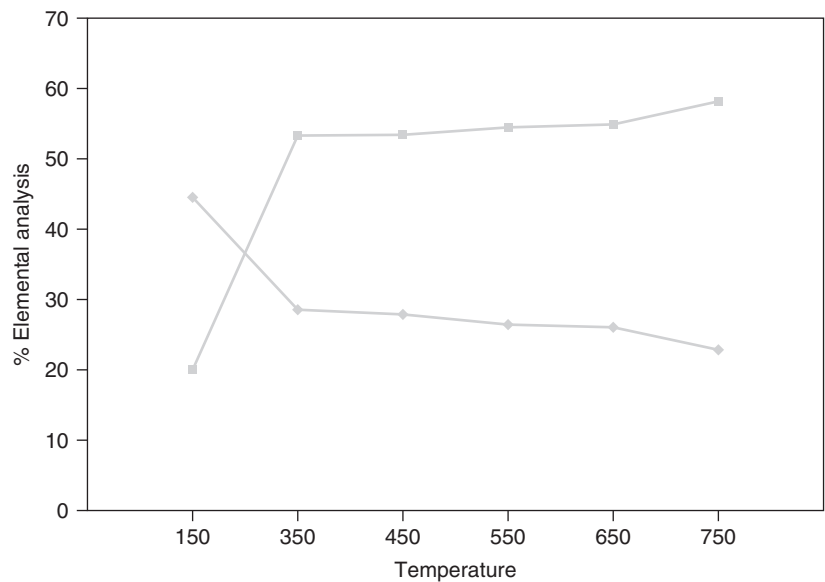


Figure 10.7 Elemental analysis of rice husk heat treated (◆ O-free dry ash and ■ dry ash) under pyrolytic conditions at different temperatures (adapted from Maiti *et al.*, 2005)

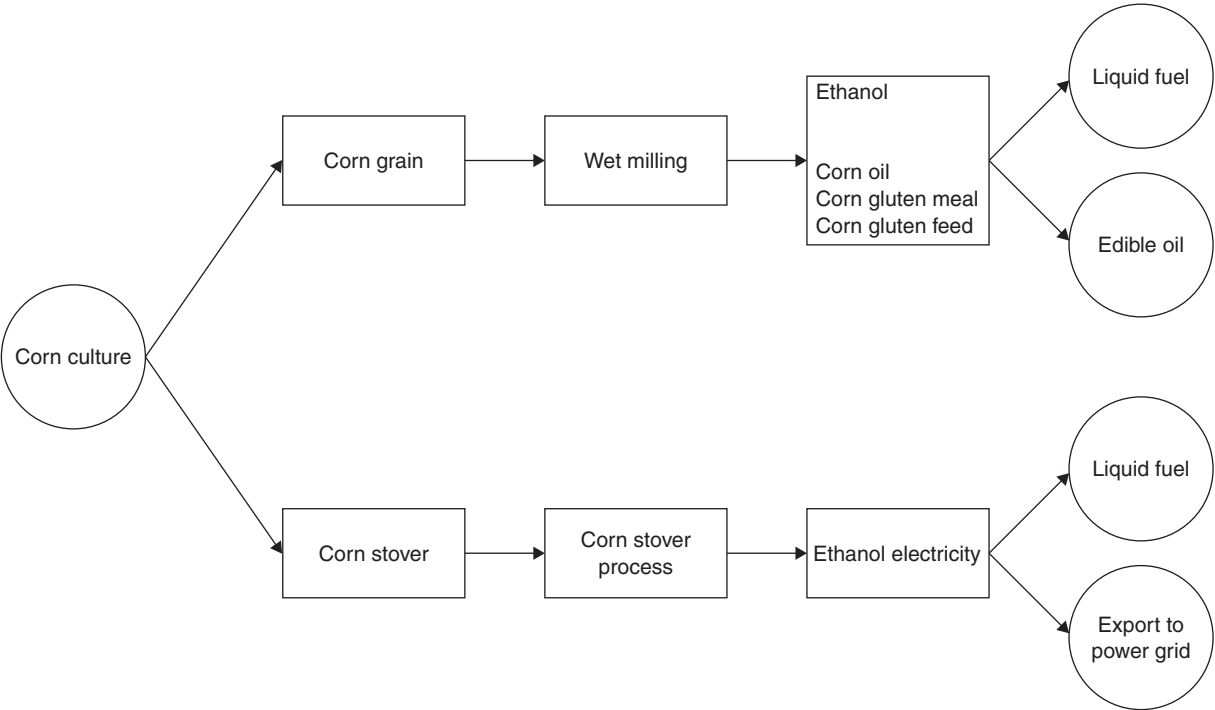


Figure 10.8 System boundaries in the various cropping and alternative production systems (adapted from Seungdo *et al.*, 2005)

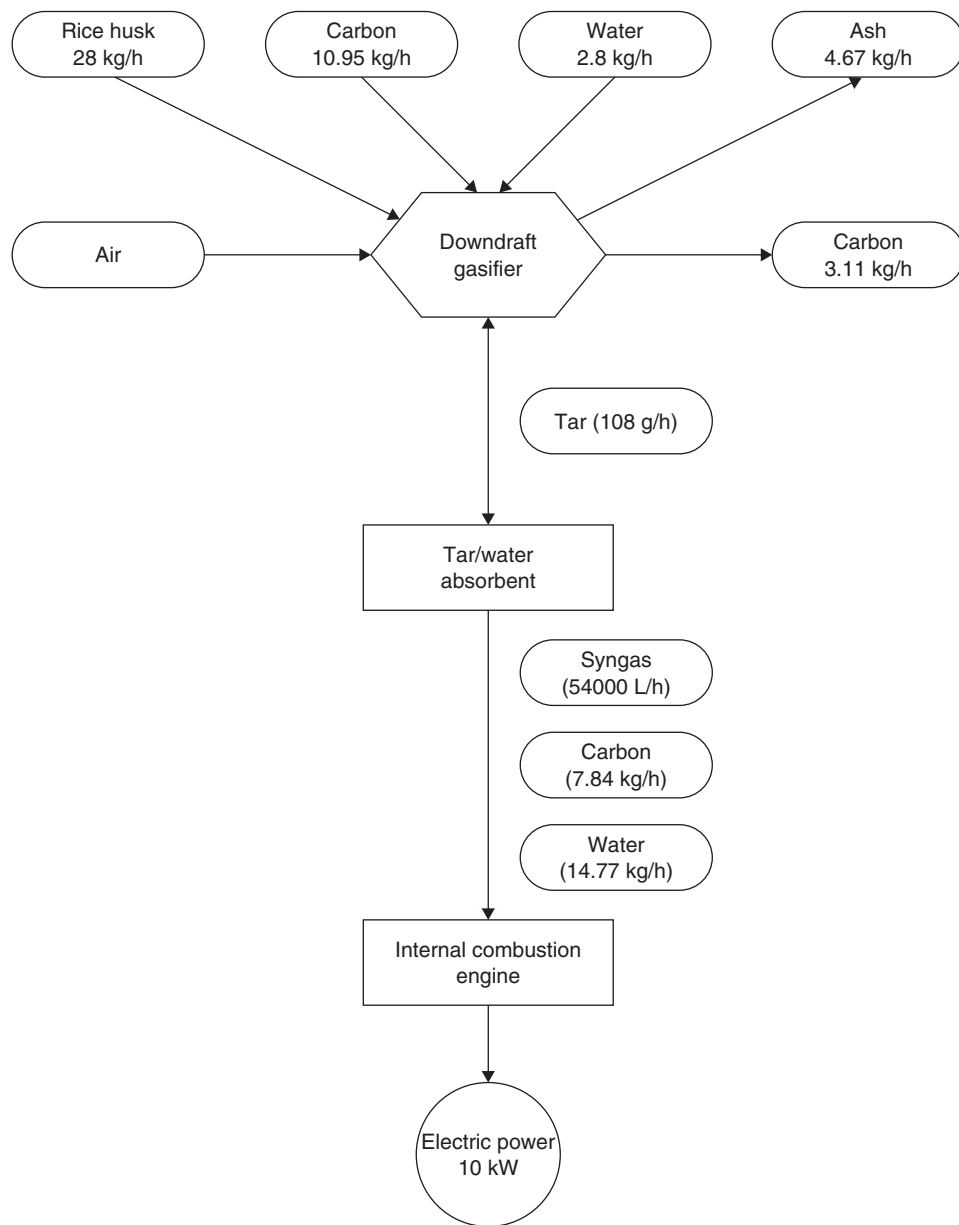


Figure 10.9 Material and energy balances of the rice husk gasification process (adapted from Lin *et al.*, 1998)

Gasification

The gasification process breaks down the hydrocarbons left into a syngas using a controlled amount of oxygen. Gasification and pyrolysis typically rely on carbon-based waste such as paper, petroleum-based wastes like plastics and organic materials such as food scraps. Gasification involves a small amount of oxygen, whereas pyrolysis uses

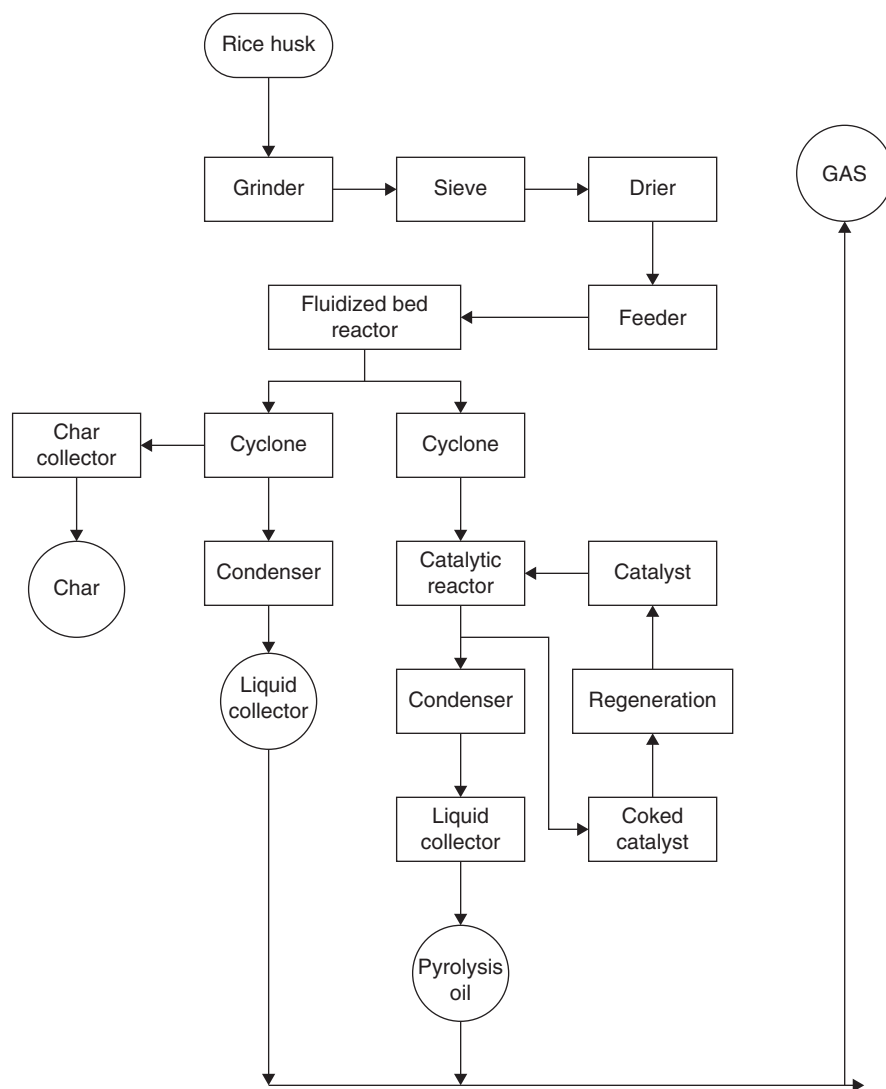


Figure 10.10 Flow sheet of rice husk fluidized bed fast pyrolysis and fluidized bed fast pyrolysis catalytic treatment processes (adapted from Islam *et al.*, 2004)

none (http://www.foe.co.uk/resource/triefings/gasifications_pyrolysis.pdf). Gasification can be used in conjunction with gas engines (and potentially gas turbines) to obtain higher conversion efficiency than conventional fossil-fuel energy generation. By displacing fossil-fuels, waste pyrolysis and gasification can help meet renewable energy targets, address concerns about global warming and contribute to achieving Kyoto Protocol commitments. Conventional incineration, used in conjunction with steam-cycle boilers and turbine generators, achieves lower efficiency (http://www.juniper.co.uk/services/Our_services/P&GFactsheet.html).

Gasification involves subjecting solid biomass to hot steam and air to produce a gaseous biofuel. This gas, often known as ‘synthesis gas’ may be burnt directly for

heating and/or electricity production or may be further converted to act as a substitute for almost any fossil fuel. The advantage of gas, over biomass, is that it is a 'better' fuel, having a higher calorific value and being more easily stored and transported. The gas can often be used to produce electricity directly in CCGT (combined-cycle gas turbine) power stations. This, not new technology, is far more likely to be applied nowadays, to renewable resources, such as wood, from short-rotation coppice or forestry residues (<http://www.ecocentre.org.uk/biomass.html>).

Gasification relies on chemical processes at elevated temperatures $>700^{\circ}\text{C}$, contrary to biological processes such as anaerobic fermentation (digestion) which releases biogas. Gasification is a process that converts carbonaceous materials, such as coal, petroleum, petroleum coke or biomass, into carbon monoxide and hydrogen. The gasification process occurs as the char reacts with carbon dioxide and steam to produce carbon monoxide and hydrogen (<http://en.wikipedia.org/wiki/Gasification>).

The gasification of herbaceous biomass is still at an early stage of research and development. Intensified development efforts on gasification technologies for herbaceous biomass feedstocks are desirable as the potential supply of this group of fuels is comparatively large. Gasification of wood and wood-type residues and waste in fixed bed or fluidized bed gasifiers with subsequent burning of gas for heat production is the current state of the art. The wood gasifiers employed primarily in the Scandinavian countries are used almost entirely for heat generation (<http://www.tab.fzk.de/en/projekt/zusammenfassung/AB49.htm>).

The gasification technologies developed by competing suppliers of gasification power plants are based either on fixed bed gasification or fluidized bed gasification. Two types of fixed bed gasifiers can be principally distinguished by the direction the gasification air and produced fuel gas move through the reactor: updraft and downdraft gasifiers. Updraft gasifiers were more easily scaled up compared to a downdraft gasifier but do produce more undesirable tars (<http://www.ecn.nl/docs/library/report/2000/c00080.pdf>).

The energy efficiency reached 60% without including energy recovery, whereas with energy recovery, the overall energy yield reached 90%. Economical evaluation of this process can also be found in the literature. It was calculated that the cost of the product gas of the supercritical water gasification process is 1.86 times more expensive than city gas in Tokyo (D'Jesus *et al.*, 2006). A wide range of biomass fuels such as wood, charcoal, wood waste (branches, roots, bark, saw dust) as well as agricultural residues – maize cobs, coconut shells, cereal straws, rice husks – were used as fuel for biomass gasification. Theoretically, almost all kinds of biomass with moisture content of 5–30% can be gasified, however, not every biomass fuel leads to successful gasification. The fuel size substantially affects the pressure drop across the gasifier and power that must be supplied to draw the air and gas through the gasifier. Large pressure drops will lead to reduction of the gas load in a downdraft gasifier, thus resulting in low temperature and tar production (<http://mitglied.lycos.de/cturare/fue.htm>).

Compared to other biomass energy conversion technologies, supercritical water gasification (SWG) is the most efficient one for biomass with a high moisture content (40%). In spite of the high pressure and high temperature required for biomass conversion with supercritical water, the process is technically feasible because tubular or slim vessel type reactors can be used (D'Jesus *et al.*, 2006). Excessively large sizes of

particles give rise to reduced reactivity of fuel, causing a start-up problem and poor gas quality (<http://mitglied.lycos.de/cturare/fue.htm#size>).

The influence of process variables like temperature, pressure, residence time and catalyst on supercritical water gasification of model compounds was investigated. The best hydrogen yield for the supercritical water gasification of sawdust and different starches was reached at high temperatures. A similar observation regarding the effect of temperature was reported in other publications (D'Jesus *et al.*, 2006). The pressure had no great effect on the glucose gasification efficiency and the fraction of the gas product. A decrease of pressure led to an increase in hydrogen formation. Carbon conversion did not vary at a longer residence time. The efficiency was observed to be decreased by a shorter residence time (D'Jesus *et al.*, 2006). The moisture content of most biomass fuel depended on the type of fuel, its origin and treatment before it is used for gasification. A moisture content below 15% by weight is desirable for trouble free and economical operation of the gasifier. Higher moisture contents reduced the thermal efficiency of the gasifier and result in low gas heating values (<http://mitglied.lycos.de/cturare/fue.htm#moisture>).

The electric efficiency of a gasification plant is directly related to the cold gas efficiency of the gasifier. This parameter is mainly determined by the carbon conversion, the heat loss of the reactor and the fuel gas temperature leaving the reactor. Fixed bed reactors generally show a lower carbon conversion but also have a lower exit temperature of the gas. The heat loss should be lower since the specific surface (m^2/m^3) is lower (<http://www.ecn.nl/docs/library/report/2000/c00080.pdf>).

Energy content of fuel is determined in most cases in an adiabatic, constant volume bomb calorimeter. Using this method higher heating values were obtained because the condensation heat from water formed in the combustion of fuel was included. Heating values are also reported on moisture and ash basis. Fuel of higher energy content is always better for gasification. Most biomass fuels (wood, straw) have heating values in the range of 10–16 MJ/kg, whereas liquid fuel (diesel, gasoline) display higher heating values (<http://mitglied.lycos.de/cturare/fue.htm#energy>).

Combustion

The combustion of biomass is considered a two-step process: devolatilization to char and volatiles, and combustion of volatiles and char. A number of parameters are required as inputs to existing CFD particle combustion models, such as devolatilization yields and rates, composition of volatiles, amount of char formed and char burning rates (Jones *et al.*, 2000). Although combustion involves complicated chemical reactions and fluid dynamical processes, including the development of instabilities, a high degree of experimental control can be obtained over the combustion and it could be studied in detail by using a two-dimensional chamber that prevented convection. Measurements were taken when the combustion was very slow, i.e. the fuel was smoldering, a non-flaming mode in which the emitted gas did not glow. In this mode, the oxygen interacted with a solid fuel to produce char, gaseous products and the required heat for completion of the process (<http://www.esam.northwestern.edu/~matkowsky/fingering.html>).

The combustion gases typically pass through a boiler system to recover energy. The most flexible means of recovering energy from the hot gases is to produce steam for

direct use or for electricity generation. To generate electricity, superheated steam is passed from the boiler system to a turbine generator (Harrison, 2001). During combustion, all fuel is converted to a hot gas (flue gas), which can be used to generate steam in a boiler and subsequently generate electricity in a steam turbine/generator. The electric efficiency is mainly the result of the efficiency of the steam turbine. Fuel gasification resulted in production of a combustible fuel gas. The gas was combusted in a gas turbine or gas engine. Electric efficiency is the product of the efficiency of the gasifier (approx. 80%) and the turbine or gas engine (30–40%). A steam turbine was coupled to convert 'waste' heat to electricity. For gasifiers, the efficiency was relatively high for small-scale systems. Only below 0.1 Mwe did the efficiency drop due to a lower efficiency of both the gasifier and engine (<http://www.ecn.nl/docs/library/report/2000/c00080.pdf>).

The use of an elevated pressure of oxygen inside a closed metal container in the form of oxygen bomb combustion is an alternative procedure for complete oxidation of biological samples. The sample was burnt using the normal practices involved in determining the calorific value of coal and sulfur was determined with potentiometric titration. An oxygen combustion bomb-ion chromatography (IC) method was reported for elemental analysis of organic compounds, fuel and hazardous wastes with indirect photometric detection. Combustion with oxygen in a sealed bomb was used to convert solid and liquid combustible samples into soluble forms for chemical analysis (Souza *et al.*, 2002). Nitrogen freed by combustion at high temperature in pure oxygen was measured with thermal conductivity detection and converted to equivalent protein by appropriate numerical factor. Any instrument or device designed to determine nitrogen by combustion may be used provided it is equipped as follows:

- 1 furnace to maintain minimum operating temperature of 950°C for pyrolysis of sample in pure (99.9%) oxygen
- 2 system to isolate liberated nitrogen gas from other combustion products for subsequent determination with thermal conductivity detector
- 3 detection system to interpret detector response as % nitrogen (weight/weight).

Other features tentatively included are calibration on standard material, blank determination and barometric pressure compensation (http://www.foragetesting.org/lab_procedure/sectionB/3/part3.3htm). The off-gases containing volatile organic compounds (VOCs) from covered treatment facilities will have to be treated before they can be discharged to the atmosphere. Options for the off-gas treatment include:

- 1 vapor-phase adsorption on granular activated carbon or other VOC selective resins
- 2 thermal incineration
- 3 catalytic incineration
- 4 combustion in a flare
- 5 biofiltration
- 6 combustion in a boiler or process heater (Tchobanoglous *et al.*, 2003).

Worldwide, many regions have experience with alternative fuels other than conventional diesel and gasoline. In Europe, liquefied petroleum gas (LPG), fatty acid methyl

ester (FAME), methanol (M85), biodiesel and bio-compressed natural gas (bio-CNG) have been tested and used in niche markets. Brazil has extensive experience with alcohol (ethanol-program) and palm oil as well as compressed natural gas (CNG). The world has for sometime witnessed growing concern over the environmental impact and/or exhaustion of conventional fossil fuel energy sources. The concern highlighted the need for diversification and prompted research worldwide into potential alternative sources of fuel energy for the internal combustion engine. Environmental well-being requires a modified mix of energy sources to emit less carbon dioxide, starting with a move towards alternative fuels (Zhang and Wang, 2006).

Combustion stabilized in a porous plug burner, in which the flame front is flat, was studied. Ordered states of cellular flames consisting of concentric rings of cells were observed. One or more of the rings of cells drifted in a circular path, speeding up and slowing down. In a solid porous medium, the flow of gas containing oxidizer can react with the reactive component of the porous matrix through which it moves. Such propagation of combustion waves is called filtration combustion. The latter is of great importance because it occurs not only in natural processes such as smoldering and underground fires, but also in coal gasification, the self-propagating high-temperature synthesis of materials, regeneration of coked catalysts, calcination and agglomeration of ores, oil extraction and waste incineration (<http://www.esam.northwestern.edu/~matkowsky/fingering.html>).

Incineration sources of impacts and effects on the environment are shown in Figure 10.11.

Biogas

Biogas technology is a complete system in itself with its set objectives (cost-effective production of energy and soil nutrients), factors such as microbes, plant design, construction materials, climate, chemical and microbial characteristics of inputs and the interrelationships among these factors. Biogas is about 20% lighter than air and has an ignition temperature in the range of 650–750°C. It is an odorless and colorless gas that burns with clear blue flame similar to that of LPG gas. Its calorific value is 20 MJ/m³ and burns with 60% efficiency in a conventional biogas stove (<http://www.fao.org/sd/EGdirect/EGre0022.htm>). High energy yields were obtained from the production of upgraded biogas used for vehicle refueling purposes. Comparisons indicate that energy yields from biogas derived from wheat are twice as high as when wheat is used for ethanol production. As well as economic and air quality benefits, studies also indicated that using biogas for transport, CO₂ emissions could be reduced on a life cycle basis by between 65 and 85% on current fuels, depending on the feedstock used (<http://www.ngvglobal.com/index.php?option=com-content&task=view&id=83&Itemid=2&lang=en>).

Compressed natural gas (CNG) comes primarily from fossil sources, although ‘biogas’, which is very similar to CNG, is produced from renewable sources. Air quality benefits are particularly significant compared with heavy-duty diesel vehicles and it is in these vehicles that CNG tends to be used. CNG engines are also significantly less noisy than diesel engines. Again, this is a particular benefit when CNG is used in heavy-duty vehicles (<http://www.defra.gov.uk/ENVIRONMENT/consult/greenfuel/response/03.htm>).

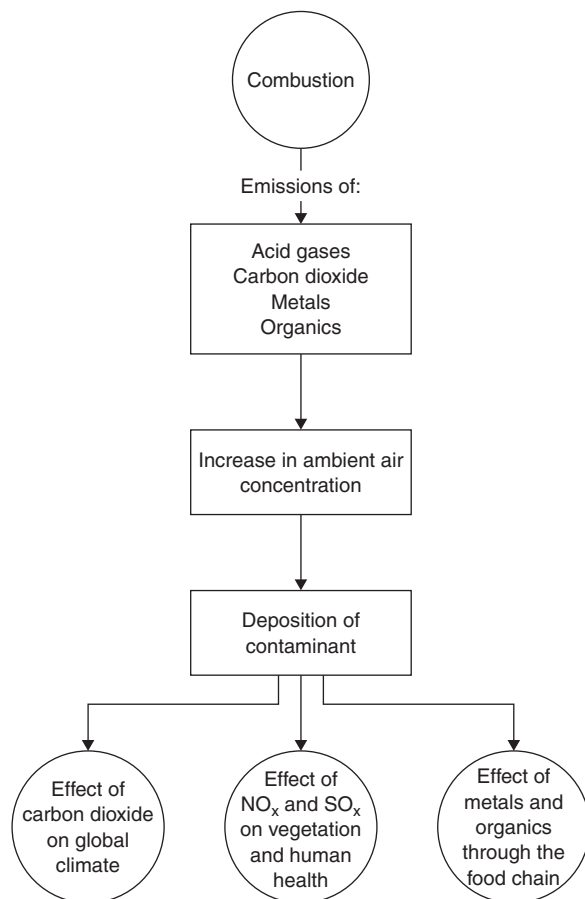


Figure 10.11 Incineration sources of impacts and effects on the environment (adapted from Petts and Eduljee, 1994; Williams, 2005)

Biogas from wheat has the highest energy balance and net energy output per hectare, particularly when straw is collected and converted into transportation fuel. Biogas from ley crops and ethanol from wheat have similar energy balances and net energy output per hectare (about 40 GJ) when the wheat pulp from the ethanol production is utilized for energy purposes (biogas production). When the wheat pulp is utilized as fodder and not for biogas production, the energy balance and net energy output per hectare for the wheat-ethanol alternative are reduced. When both wheat pulp and straw are employed for biogas production, the net energy output per hectare will be higher for the wheat-ethanol alternative than for the ley crop-biogas alternative (<http://www.miljolth.se/svenska/publikationer/visaInfo.asp?ID=>).

Uses of wheat, corn, rice, barley and oat wastes

Agriculture and forest products industries provide food, feed, fiber and a wide range of necessary products like shelter, packaging, clothing and communications. However,

biomass is also a source of a large variety of chemicals and materials and of electricity and fuels (Chum and Overend, 2001). Biomass is considered to be a potential for the renewable energy sources in the future. It already supplies 14% of the world's total energy consumption. Biomass is also a source of a large variety of chemicals and materials. Biomass resources that can be used for energy production cover a wide range of materials such as forestry residues, energy crops, organic wastes, agricultural residues, etc. Agricultural waste, a readily available biomass, is produced annually worldwide and is vastly under utilized (Putun *et al.*, 2004). About 60% of the needed process energy in pulp, paper and forest products is provided by biomass combustion. These processes could be improved to the point of energy self-sufficiency of these industries (Chum and Overend, 2001). The advantages of biomass over conventional fossil fuels are:

- 1 their low sulfur and nitrogen contents
- 2 no net emissions of CO₂ to the atmosphere when biomass production balances consumption.

Using biomass as a renewable energy source is a convenient way to produce energy without contributing to the greenhouse effect. Rice straw is one of the main cereal straws and is created as by-product of the rice milling processes in large quantities worldwide every year (Putun *et al.*, 2004).

Biomass fuels were the first energy source harnessed by mankind. They remain the primary source of energy for more than half the world's population and account for 14% of the total energy consumption in the world. Biomass is the most common form of renewable energy. The use of renewable energy sources is becoming increasingly important when it is considered to alleviate global warming and provide a fuel supply. In the past 10 years, there has been renewed interest, worldwide, in biomass as an attractive alternative to fossil fuels (Cuiping *et al.*, 2004). The reason is that build-up of residual deposits on firesides and heat transfer surfaces in furnaces and boilers are so severe that plants experience rapid decline in efficiency and increasing metal corrosion leading to increasing maintenance costs and reductions in energy revenues (Thy *et al.*, 2006). Modeling and analysis of energy conversion processes require adequate fuel characteristics, especially average and variations in elemental compositions. Knowledge of the concentration and speciation of alkali elements in fuels is useful for studies of BIGCC or other biomass power generation topics (Cuiping *et al.*, 2004). Development of biomass and other renewable power generation has distinct economic and environmental advantages (Thy *et al.*, 2006). Using biomass as a source of fuel has little adverse environmental impact. The combustion of biomass produces significantly less nitrogen oxide and sulfur dioxide than the burning of fossil fuels. Unlike fossil fuel combustions, the use of biomass fuels will not contribute to carbon dioxide levels that cause global warming. However, up to now it has not been extensively used as biomass fuel apart from domestic application (Cuiping *et al.*, 2004).

Fuel ethanol plants are being commissioned and constructed at an unprecedented rate based on this demand, though a need for a more efficient and cost-effective plant still exists. The feasibility of producing these co-products or using new processing steps is currently evaluated by performing calculations that scale-up benchtop or pilot

plant operations (Kwiatkowski *et al.*, 2006). In recent years, research and development efforts directed toward commercial production of fuel ethanol from renewable resources as an alternative transportation fuel have increased. Currently, fuel ethanol is produced almost exclusively from corn starch. The economics of fuel ethanol production is significantly influenced by the cost of raw materials, which accounts for more than half of the cost. Current processes for fuel ethanol production from corn starch have low volumetric productivities and require long fermentation times. However, the development of high-productivity and high-yield processes and reactors can potentially reduce costs (Krishnan *et al.*, 2000). Even the reduction in cost of a few cents per liter of ethanol produced is significant when dealing with the dry-grind process and the ability accurately to predict the costs of production prior to incorporating new technologies is highly desirable (Kwiatkowski *et al.*, 2006).

Today's corn refinery industry produces a wide range of products including starch-based ethanol fuels for transportation. The biomass industry can produce additional ethanol by fermenting some by-product sugar streams. Lignocellulosic biomass is a potential source for ethanol that is not directly linked to food production. Moreover, through gasification biomass can lead to methanol, mixed alcohols and Fischer–Tropsch liquids. Green plants developed to produce desired products and energy could be possible in the future. Biological systems can already be tailored to produce fuels such as hydrogen (Chum and Overend, 2001).

Ethanol is a renewable, bio-based oxygenated fuel. In the USA, the production of fuel ethanol from corn starch reached about 2.81 billion gallons in 2003. Developing ethanol as fuel, beyond its current role as fuel oxygenate, will require developing lignocellulosic biomass as a feedstock because of its abundance and low cost. Previously, corn fiber (obtained from corn wet-milling industries) was targeted as a model substrate for use as lignocellulosic biomass because of its high carbohydrate content (70%) containing 20% residual starch, 15% cellulose and 35% hemicellulose, and low lignin content (>8%) (Saha *et al.*, 2005). The corn dry-grind process is the most widely used method in the USA for generating fuel ethanol by fermentation of grain. Increasing demand for domestically produced fuel and changes in the regulations on fuel oxygenates have led to increased production of ethanol mainly by the dry-grind process. It is currently produced from sugar or starch, raw materials that are relatively expensive. To lower the production cost of bioethanol the cost of the raw material must be reduced and the production process made more efficient (Öhdren *et al.*, 2006).

Ethanol from lignocellulosic biomass is widely recognized as an environmentally friendly and acceptable substitute for gasoline or as an additive to gasoline. This acceptance has triggered increased interest in commercializing technology for production of ethanol from potentially inexpensive cellulosic feedstocks (Schell *et al.*, 2004). The concentration and speciation of heavy-metal elements is related to environment-related topics. With regard to the utilization of biomass as an energy source, the investigation of chemical elemental characteristics of biomass fuels is beneficial for biomass fuels to drive suitable energy conversion technologies and for various energy conversion processes to utilize favorable biomass feedstock (Cuiping *et al.*, 2004). An economic analysis for ethanol production from glucose revealed that cost savings of 6 cents/gal

could be achieved by using technology. These potential cost savings were realized due to higher ethanol yields, lower operating costs and lower capital costs for the continuous FBR process with an immobilized *Z. mobilis* biocatalyst compared with those for a conventional batch process using yeast (Krishnan *et al.*, 2000). Wheat straw contains 35–45% cellulose, 20–30% hemicellulose and 8–15% lignin and can also serve as a low cost attractive feedstock for production of fuel alcohol (Saha *et al.*, 2005).

The production of bioethanol from corn stover using simultaneous saccharification and fermentation (SSF) at high dry matter content addresses both issues. Corn stover is an agricultural byproduct and thus has a low economic value. SSF at high dry matter content results in a high ethanol concentration in the fermented slurry, thereby decreasing the energy demand in the subsequent distillation step (Öhdren *et al.*, 2006). A by-product of the corn wet-milling industry consists of corn hulls and residual starch not extracted by the milling process. Conversion of the starch along with the lignocellulosic components in the corn fiber would increase ethanol yields from a corn wet mill by 13% and is promising if the value of the corn fiber as an animal feed product is not severely affected. Corn fiber was obtained from a local corn wet mill and stored in a refrigerated trailer for no longer than a month. The corn fiber moisture content was 55–60% (w/w) as received (Schell *et al.*, 2004).

Ethanol production was evaluated from wheat straw (WS) hemicellulose acid hydrolysate using an adapted and parent strain of *Pichia stipitis*. The treatment by boiling and overliming with $\text{Ca}(\text{OH})_2$ significantly improved the fermentability of the hydrolysate. Ethanol yield and productivity were increased 2 490 10 and 5 790 24 fold, respectively, compared to neutralized hydrolysate. Adaptation of the yeast to the hydrolysate resulted in further improvement in yield and productivity (Nigam, 2000). The importance of compost to crop productivity has been recognized widely as an alternative nutrient source, but the mechanism of its function has not been elucidated fully. Hence, several studies have been initiated to:

- 1 find out the efficient and rational combination of composting of rice straw with poultry manure and oilseed rape cake
- 2 evaluate the comparative effectiveness of four kinds of rice straw compost on growth and yield of faba bean plants
- 3 assess the properties of soil supplied by different concentrations of straw compost (Abdelhamid *et al.*, 2004).

Wheat is one of the major sources of food in many countries. Average yield per hectare of major crops including wheat is the lowest in the world. Variation in $^{13}\text{C}/^{12}\text{C}$ ratio in C-3 plants occurs during the fixation of CO_2 due to differential stomatal diffusivities of $^{13}\text{CO}_2$ and $^{12}\text{CO}_2$ as the ribulose biphosphate carboxylase enzyme discriminates against the inclusion of the heavier C isotope. The latter study indicated that $\delta^{13}\text{C}$ of plant material depends upon weather and soil moisture conditions experienced by the plant during growth. The variation in fractionation is due to many factors such as plant type, genotypes and environment and has been used to study a variety of issues. The C isotope fractionation by photosynthesis has made it possible to characterize a plant by its C isotope composition ($\delta^{13}\text{C}$) and/or isotope discrimination value (Iqbal *et al.*, 2005).

The traditional disposal method for rice and wheat straw in many parts of the world is burning. The burning of wheat straw is popular in China because of the short turnaround time between the wheat harvest and rice transplanting in rice–wheat rotations. Estimated losses are up to 80% of N, 25% of P and 21% of K in addition to the problem of air pollution. Furthermore, declining or stagnating yields have been observed in rice-based cropping systems. Improvements are therefore required in the management of soil, water and straw (Fan *et al.*, 2005). Wood pellets are a biofuel that is much in demand and increasingly replacing oil and firewood for residential heating and hot water production. Wheat straw and peat are examples of such new raw materials. The availability of wheat straw amounted to 44 million tonnes in Europe and 1.7 million tonnes in Sweden in 2000 (Olsson, 2006). A change from traditional flooding (anaerobic) to non-flooded mulching (aerobic) and the effects of non-flooded mulching cultivation on soil temperature are likely to exert large influences on N forms and availability and N cycling. Return of straw can also lead to temporary nutrient limitation due to microbial immobilization (Fan *et al.*, 2005). Pellet appliances designed to combust a less easily burnt fuel with a higher ash content than wood pellets can be used for peat/wood and straw pellets. There are already pellet burners for straw pellets on the market in Sweden and it has been proven possible to combust wheat straw pellets in adapted residential boilers with low emissions of carbon monoxide and nitrogen oxides and relatively low emissions of sulfur dioxide (Olsson, 2006).

Rice (*Oryza sativa* L.) is an important crop in many areas of the world and yields a large amount of rice straw residue. A major portion of this agricultural waste is disposed by burning or is mulched in rice fields (Abdelhamid *et al.*, 2004). Some potential uses for rice straw have been described. It is a marginal feed that would have to compete with other cereal grain straws such as wheat and barley. Most of the rice straw harvested went to animal feed. The use of agricultural residues, including rice straw, as a source of non-wood fibers has been reviewed. It is most suitable for the production of corrugated medium and newsprint, however, the only commercial pulp mills using straw or bagasse exist in developing countries like India and China. It can be converted through bioconversion to ethanol, which is a clean-burning transportation-fuel oxygenate. Direct combustion of rice straw in a utility boiler of a biomass power plant is also an alternative for utilizing rice straw, but leaching is required to avoid slagging and fouling (Kadam *et al.*, 2000). Preparing compost from rice straw enriched with rock phosphate using cellulose degrading microorganisms and phosphate dissolving ones may not only compensate for the higher cost of manufacturing fertilizers in industry, but also provide the growing plants in alkaline soils with available phosphorus. Use of phosphate dissolving fungi in production of compost offers a solution to the waning interest of farmers in the use of organic phosphatic fertilizers in alkaline soils. The composts obtained were evaluated as organic phosphatic fertilizers in pots cultivated with cowpea plants. The effect of composts on the microbial community structure of rhizosphere soils was also studied (Zayed and Abdel-Motaal, 2005). However, an attractive alternative usage of rice straw is composting. This process has many advantages including sanitation, mass and bulk reduction and decrease of carbon (C) to nitrogen (N) ratio (C/N). Rice straw is rich in C and poor in N. Its C/N can vary from 50 to 150, which limits the composting process. This high C/N can be decreased by

increasing the basal N content of rice straw by adding oilseed rape cake and poultry manure. Mixtures of rice straw and N materials (cow dung + soybean plants) at ratios ranging from 70% to 100% rice straw were compared. The mixture containing 70% rice straw produced the most suitable compost in terms of maturity and nutrients (Abdelhamid *et al.*, 2004).

Rice straw is commonly burnt in many of the developing countries. Burning rice straw has harmful environmental implications through global addition of carbon dioxide, a gas contributing to the greenhouse effect and likely high health costs through increase in respiratory problems in the local population. The conversion of rice straw into value-added compost may have the potential to improve productivity of the crops and reduce environmental pollution. However, rice straw is among certain organic materials which are resistant to microbial attack (Zayed and Abdel-Motaal, 2005). The pyrolysis of rice straw was studied to estimate the effect of pyrolysis conditions on product yields and bio-oil composition when the heating rate was 5 K/min. Liquid products obtained from pyrolysis, inert atmosphere pyrolysis and steam pyrolysis were then fractionated into asphthalenes and maltanes. The chemical characterization has shown that the oil obtained from rice straw may be potentially valuable as fuel and chemical feedstocks (Putun *et al.*, 2004).

The addition of rice straw to wood fuels is expected to decrease both solidus and liquidus temperatures (i.e. the classic freezing point depression), but the magnitude of the depression cannot be predicted based on the available experimental data. It is plausible that typical boiler conditions during combustion are within the melting temperature of slag from blended wood and straw fuel and, therefore, that melt will be present in the slag (Zayed and Abdel-Motaal, 2005).

Bioconversion of waste residues (by-products) from cereal processing industries requires the cooperation of enzymes able to degrade xylanosic and cellulosic material. An enzyme preparation from *Humicola insolens*, Ultraflo, contains feruloyl esterases and glycoside hydrolases capable of solubilizing brewers' spent grain and wheat bran, but total solubilization was not achieved either through steric hindrance or through the lack of certain key activities. *H. insolens* feruloyl esterases released more diferulates from chemically extracted feruloylated arabinoxylan from both cereal sources than from the complex cell wall material, but less monomeric ferulic acid. The 8-*O*-4'-form of diferulic acid was released only from spent grain-derived material, whereas the chemically insoluble residue from wheat bran was more extensively degraded than the corresponding spent grain sample. Arabinoxylans with low amounts of arabinose substitutions were preferentially solubilized. These results showed that some phenolic acids in cereals are less susceptible to enzyme and alkali cleavage than others. The results also revealed that the local environment and molecular arrangement of ferulic and diferulic acids on arabinoxylan chains differ between barley and wheat, thus influencing enzyme hydrolysis (Faulds *et al.*, 2006).

The bioconversion of waste residues (by-products) from cereal processing industries requires the cooperation of enzymes able to degrade xylanolytic and cellulosic material. The type A feruloyl esterase from *Aspergillus niger*, AnFaeA, works synergistically with (1→4)- β -D-xylopyranosidases (xylanases) to release monomeric and dimeric ferulic acid (FA) from cereal cell wall-derived material. The esterase was

more effective with a family 11 xylanase from *Trichoderma viride* in releasing FA and with a family 10 xylanase from *Thermoascus aurantiacus* in releasing the 5,5' form of diferulic acid from arabinoxylan (AX) derived from brewers' spent grain. The converse was found for the release of the phenolic acids from wheat bran-derived AXs. This may be indicative of compositional differences in AXs in cereals (Faulds *et al.*, 2005).

Vidmantienė *et al.* (2006) described a method for hydrolyzing the polysaccharides from cereal-derived waste to yield a sugar feedstock suitable for fermentation into technical ethanol using a complex of amylolytic and hemicellulolytic/cellulolytic enzymes. The enzymatic treatment of raw materials was carried out by liquid concentrated amylase and glucoamylase in combination with xylanase, containing also cellulase and glucanase activities. Gas chromatography was used for qualitative and quantitative analysis of the end products. Apart from ethanol, also methanol, propanol, butanol, isoamyl and amyl alcohols, acetaldehyde, ethyl acetate and methyl acetate were found in the distillate. The optimal composition of amylase, glucoamylase and xylanase was selected, dependent on the raw material. The maximum ethanol concentration reached after fermentation of rye and wheat bran was 44 g/l and for rye and wheat grain it was 73 and 69 g/l respectively. By applying a complex preparation of amylolytic and hemicellulolytic/cellulolytic enzymes to cereal and cereal residues, it was possible to increase the ethanol yield by 20–45%, thereby decreasing the content of higher alcohols by 34% and significantly decreasing the methanol concentration, in comparison with a reference sample without xylanase preparation.

The accumulation of metals by biomass was used for the removal of nickel from aqueous medium (Zafar *et al.*, 2006). The rice bran in its acid treated (H_3PO_4) form was used as a low cost sorbent. The adsorption characteristics of nickel on protonated rice bran were evaluated as a function of pH, biosorbent size, biosorbent dosage, initial concentration of nickel and time. Within the tested pH range (pH 1–7), the protonated rice bran displayed more resistance to pH variation, retaining up to 102 mg/g of the nickel binding capacity at pH 6. Meanwhile, at lower pH values the uptake capacity decreased. The percentage removal of nickel was maximum at 0.25 g of biosorbent dose and 0.25 mm biosorbent size. At the optimal conditions, metal ion uptake was increased as the initial metal ion concentration increased up to 100 mg/l. Kinetic and isotherm experiments were carried out at the optimal pH 6.0 for nickel. The metal removal rate was rapid, with 57% of the total adsorption taking place within 15–30 min. The Freundlich and Langmuir models were used to describe the uptake of nickel on protonated rice bran. The Langmuir and Freundlich model parameters were evaluated. The equilibrium adsorption data were better fitted to the Langmuir adsorption isotherm model. The adsorption followed pseudo second-order kinetic model. The thermodynamic assessment of the metal ion-rice bran biomass system indicated the feasibility and spontaneous nature of the process and ΔG° values were evaluated as ranging from -22.82 to -24.04 kJ/mol for nickel sorption. The order of magnitude of the ΔG° values indicated an ion-exchange physicochemical sorption process.

Treatment methods, physicochemical characteristics, substrate to be applied and final product/uses of corn and rice wastes are given in Table 10.7.

Table 10.7 Treatment methods, physicochemical characteristics, substrate to be applied and final product/uses

No	Substrate to be applied	Treatment methods	Physicochemical characteristics	Final products/uses	References
1	Barley	Composting	<ol style="list-style-type: none"> 1 The final pH of the co-compost was 8.7 and the C/N ratio was 13 2 The percentage of germination obtained using the co-compost varied with the seeds used. It was 186% for ryegrass seeds, 85.74% for wheat seeds and 103% for barley seeds 	Barley wastes and solid poultry manure showed high organic matter content	Guerra-Rodriguez <i>et al.</i> , 2000
2	Barley straw	Composting	<ol style="list-style-type: none"> 1 The acid/alkaline PME/glucosidase ratios dm were 1:4:1 and 3:3:1, in the mature MS and MP composts, respectively 2 The hydrolyzing of organic P to inorganic form in manure composts was affected by the bulking agent 	The mixture of manures was co-composted with chopped barley straw (MS composting) and with <i>Sphagnum</i> peat (MP composting)	Vuorinen, 2000
3	Barley straw	Composting	<ol style="list-style-type: none"> 1 Conductance (1:3 fresh compost/water ratio, w/w) 2 pH (in water and in 0.01 M CaCl₂, 1:3 fresh compost/liquid ratio, w/w) 3 Dry matter content (% fw, 105°C) 4 Ash content (% dw, 480°C, 16 h) were all measured in triplicate 	Cattle and swine manure composted with barley straw	Vuorinen and Saharinen, 1997
4	Barley	Biogas	<p>Strict anaerobic conditions were maintained by using an anaerobic basal medium composed of cysteine – HCL (0.5 g/l), NaHCO₃ (3 g/l), with the pH adjusted to 7.0–7.2</p>	Methane production from an industrial waste composed of 100% barley	Neves <i>et al.</i> , 2006
5	Wheat straw, corn cobs, barley husks	Adsorption	<p>Use of chemical (NaOH and NH₄OH) and physical treatments (steam and milling) to help break down the complex lignin complex in order to improve the performance of the substrates</p>	Soil conditioner or fertilizer	Robinson <i>et al.</i> , 2002
6	Corn cob, barley husk and wheat	Adsorption	Experiments were carried out statically at room temperature, 20 ± 2 °C	Soil fertilizer	Robinson <i>et al.</i> , 2002
7	Barley	Composting	<ol style="list-style-type: none"> 1 The Indore composting system was used, an open-air pile being turned 7 times during the composting phase of 105 days 2 The maximum temperatures reached were 65–68 °C and the humidity level was kept at 45–65% 	Fertilizer	Ayuso <i>et al.</i> , 1996

8	Corn stalk and fresh wheat straw	Pyrolysis	<p>3 The compost was then left untouched for 3 months to allow the organic matter to stabilize</p> <p>1 Pyrolysis temperature 2 Residence time</p>	Bio-oil	Shuangninga <i>et al.</i> , 2005
9	Corn straw and wheat straw	Pyrolysis	At low temperatures (400 K), only equilibrium moisture content and presumably extractives are released, even for very long residence times of the solid	Gas and volatile	Lanzetta and Di Blasi, 1998
10	Corn oil and wheat germs	Chemical method	<p>Use of different antioxidants</p> <p>1 Ascorbyl palmitate (0.02% w/w) 2 BHA 3 Tert-butyl-4-hydroxyanisole (0.02% w/w) 4 Different amounts of solvent extracts, to 25 g of stripped corn oil or plant oils</p>	Edible products as corn oil	Krings <i>et al.</i> , 2000
11	Corn cob and wheat straw	Biodegradation	Xylanase, glucanase, cellulase, <i>Phanerochaete chrysosporium</i> NRRL 6359, <i>P. chrysosporium</i> NRRL 6361 and <i>Coriolus versicolor</i> NRRL 6102	Production of enzymes	Abd El-Nasser <i>et al.</i> , 1997
12	Wheat straw	Vermicomposting	Wheat straw was pre-decomposed by inoculating it with <i>Pleurotus sajor-caju</i> , <i>Trichoderma harzianum</i> , <i>Aspergillus niger</i> and <i>Azotobacter chroococcum</i> in different combinations	Fertilizer	Anshu <i>et al.</i> , 2002
13	Wheat straw waste	Composting	Total C and N of the materials were determined, the wheat straw having a C/N ratio of approximately 100 kg/kg and the clover-grass hay a C/N ratio of 15 kg/kg	Fertilizer	Dresboll <i>et al.</i> , 2004
14	Wheat straw	Composting	<p>1 pH 6.9 2 Negligible CaCO₃ content 3 An organic carbon content of 11.0 g C/kg dry soil</p>	Soil conditioner or fertilizer	Gabrielle <i>et al.</i> , 2005
15	Wheat straw	Pyrolysis, gas chromatography, mass spectrometry of acid-precipitable polymeric lignin (APPL)	Air dried for 24 h at 50°C	The main product of solubilization of lignocellulose by different <i>Streptomyces</i> strains	Rodriguez <i>et al.</i> , 1997

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Table 10.7 (Continued)

No	Substrate to be applied	Treatment methods	Physicochemical characteristics	Final products/uses	References
16	Wheat straw	NMR spectroscopy, conventional and pyrolysis TMAH thermochemolysis	<ol style="list-style-type: none"> 1 pH 4.5 2 Treatment with 10% H₂SO₄ for 0.5 h at 100°C to remove starch, proteins and sugars 3 Alkaline treatment, using a concentration of acid-treated material of 20 g/l with KOH for 24 h at room temperature 4 Washing with dilute HNO₃ <p>pH optimum 5</p>	Production of lignocellulosic material	Gauthier <i>et al.</i> , 2003
17	Wheat straw	Pyrolysis, gas chromatography, mass spectrometry (Py-GC-MS)		Polysaccharide and lignin content of straw	Camarero <i>et al.</i> , 2001
18	Wheat and oat straw	Pyrolysis	Temperature range 25–1060°C for straw	Chloride rich fertilizer	Davidsson <i>et al.</i> , 2002
19	Wheat straw	Pyrolysis, gas chromatography, mass spectrometry (Py-GC-MS)	<ol style="list-style-type: none"> 1 Air-dried for 24 h at 60°C 2 12 M HCl 	Compost in soil	Hernandez <i>et al.</i> , 2001
20	Wheat straw	Pyrolysis	<p>Treatment with 7%w NaOH at 95°C for 3 h</p> <p>2.5% w H₂SO₄ for 3 h at 90°C</p>	Fertilizer for production of <i>Pleurotus</i> spp.	Martinez <i>et al.</i> , 2001
21	Wheat straw	Combustion	<ol style="list-style-type: none"> 1 1273 K, 0% O₂ 2 Temperature about 1500°C 	Fuel	Jones <i>et al.</i> , 2000
22	Wheat straw	Combustion	<ol style="list-style-type: none"> 1 Temperatures ranging from 500 to 1200°C 2 Large concentration of silica (76–83 mol%) and potassium (11–12 mol%) 3 Small concentrations (<5 mol%) of calcium, sodium, magnesium and aluminum oxides as well as small amounts of chloride, sulfate and carbonate 	Renewable fuels	Blander and Pelton, 1997
23	Wheat straw	Chemical production	Bioethanol, amino acids and organic acids	Generic feedstock and fuels	Koutinas <i>et al.</i> , 2004
24	Wheat straw	Combustion	<ol style="list-style-type: none"> 1 SO₂ (1–25 µmol/mol range) 2 NO (0.5–10 µmol/mol range) 3 Temperature was held constant at 23°C 4 350 µmol/mol CO₂ 5 21% O₂ 	CO ₂ rich gas resulting from the incineration of plant biomass can be used to support photosynthesis in closed systems	Bubenbeim <i>et al.</i> , 1997

25	Wheat straw	Composting	The compost was assumed to provide 10% of its total N for plant growth over the growing season	Additional fertilizer	Keeling <i>et al.</i> , 2003
26	Wheat straw	Enzymatic hydrolysis	1 1% NaOH for 24 h 2 0–3% H ₂ O ₂ for 24 h 3 Low temperature (25–40°C)	Enzymatic production of reducing sugars	Curreli <i>et al.</i> , 1997
27	Wheat straw	Multi enzyme production	1 Wheat straw 10.0 g/l 2 Peptone 0.5 g/l 3 KH ₂ PO ₄ 2.0 g/l 4 (NH ₄) ₂ SO ₄ 1.4 g/l 5 MgSO ₄ ·7H ₂ O 0.3 g/l 6 CaCl ₂ 0.3 g/l 7 FeSO ₄ ·7H ₂ O 0.005 g/l 8 pH 7.0	Enzymatic production of sugars	Emtiaz and Nahvi, 2000
28	Wheat straw	Irradiation and chemical treatment	Treatments of irradiation and HBr or NaOH	Ruminant feeding	Al-Masri, 2005
29	Wheat straw	Enzyme activity	1 Moisture content of 74% 2 pH range of 4.5–5.5	Excellent carbon source	Jecu, 2000
30	Oat waste	Pyrolysis	The temperature is 600°C	Fuels	Dieckow <i>et al.</i> , 2006
31	Corn	Composting	The temperature of the mixture rose to >40°C within one week of the onset of composting of CSC and thermophilic phase (>40°C) temperatures were sustained for the first 7 months of the 9 month composting period	Composting has long been used for management of manure on farms	Lynch <i>et al.</i> , 2006
32	Corn cob	Chemical activation and pyrolysis	1 Impregnation ratio of 20–200 wt% 2 Heating rate of 10 K/min 3 Pyrolysis temperature of 673–1073 K 4 Soaking time of 0.5–4.0 h	Raw materials for preparing activated carbons or adsorbents to apply in the removal of some organic and inorganic compounds from liquid and gas phases	Tsai <i>et al.</i> , 1998
33	Corn cob	Pyrolysis	The temperature was at 350–400°C	1 Xylan from corn cob is an additive in papermaking, textile printing and the pharmaceutical industry 2 Low-grade fuels	Cao <i>et al.</i> , 2004
34	Corn stover	Pyrolysis	High levels of temperature	Biomass feedstock	Green and Feng, 2006
35	Corn cob	Gasification	Temperature ranges of 500–800°C with less pollution characteristics of potassium hydroxide: potassium carbonate (KOH:K ₂ CO ₃) as chemical	Raw material for the preparation of activated carbon	Tsai <i>et al.</i> , 2001

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Table 10.7 (Continued)

No	Substrate to be applied	Treatment methods	Physicochemical characteristics	Final products/uses	References
36	Corn starch	Gasification	agents and subsequent gasification at the soaking time of 1 h The influence of process variables like temperature pressure, residence time and catalyst on supercritical water gasification of model compounds has been investigated	Feedstock	D'Jesús <i>et al.</i> , 2006
37	Corn cob	Chemical and physical activation	1 Chemical activation with potassium salts 2 Physical activation with CO ₂	Renewable source for energy production	Tsai <i>et al.</i> , 2001
38	Corn	Combustion and gasification	Carbon, hydrogen and mixed alcohols	Renewable fuels	Chum and Overend, 2001
39	Corn cob and corn tar	Combustion	Temperature range from 110 to 220°C	Burning oil of biomass (BOB)	Zhang and Wang, 2006
40	Corn	Combustion	Combustion was carried out in a high-pressure stainless steel oxygen bomb with a capacity of 340 ml	Renewable fuels	Souza <i>et al.</i> , 2002
41	Corn stover	Combustion	To minimize the effect of water in the biomass spectra, each sample was air-dried to less than 10% moisture prior to NIR spectroscopic analysis	Fuel or industrial feedstock	Pordesimo <i>et al.</i> , 2005
42	Corn oil	Biodiesel	The engine fueled with pure marine diesel fuel and blends containing two types of biodiesel, at proportions up to 50%	Alternative fuels	Kalligeros <i>et al.</i> , 2003
43	Corn	Ethanol and biodiesel production	Under relatively high prices for gasoline the costs for using ethanol and biodiesel are much higher per equivalent litre of gasoline	Alternative liquid fuels and ethanol production	Wesseler, 2006
44	Corn stover	Biodiesel and bioethanol	When corn stover is harvested, ethanol is produced from both corn stover and corn grain	Biofuels	Kim and Dale, 2005
45	Corn cob	Pyrolysis	Pyrolytic temperatures below 600°C	Liquid products of biomass	Cao <i>et al.</i> , 2004
46	Corn	Bioremediation	1 Varying pH (4.5–7.5) 2 Temperature between 35 and 55°C	1 Methane and hydrogen 2 Biofuels	Montgomery, 2004
47	Corn cob agrowaste	Chemical activation	1 Physical activation involves the carbonization of a carbonaceous precursor followed by	Renewable source for energy production	Chang <i>et al.</i> , 2000

48	Corn husks	Enzyme preparation	gasification of the resulting char in the presence of suitable oxidizing gasifying agents such as CO ₂ and steam at high temperatures 2 Chemical preparation with ZnCl ₂	1 pH 5.0 2 Temperature 50°C	Enzymatic production of soluble sugars	Hang <i>et al.</i> , 1998
49	Corn cobs	Enzyme preparation	1 Pretreated with NaOH 2 Followed by 48 h reaction 3 Temperature 50°C 4 pH 5.0	Enzymatic production of reducing sugars	Hang and Woodams, 2001	
50	Corn stover	Chemical activation	Heat loss in a 1.26 m pipeline carrying 2 M dry tonnes/year is about 5°C		Production of ethanol and sugars	Kumar <i>et al.</i> , 2005
51	Corn stover	Radiation	Gamma irradiation of corn stover in combination with sodium hydroxide for bioconversion of polysaccharide		Fertilizer for the production of <i>Pleurotus</i> spp.	Gbedemah <i>et al.</i> , 1998
52	Corn hull and corn stover	Physical activation	Temperatures around 800°C		Activated carbon	Zhang <i>et al.</i> , 2004
53	Corn cob	Chemical activation	Many chemicals can be used as activators such as ZnCl ₂ , H ₃ PO ₄ , KOH, K ₂ CO ₃ , water vapor, CO ₂		Renewable fuels	Cao <i>et al.</i> , 2006
54	Rice straw	Composting	EC, pH were measured in the aqueous extracts of rice straw, oilseed rape cake, poultry manure and compost in a solid:distilled water of 1:20 (w/v dry weight basis)		Composting of rice straw with oilseed rape cake and poultry manure effects faba bean (<i>Vicia faba</i> L.) growth and soil properties	Abdelhamid <i>et al.</i> , 2004
55	Rice straw	Composting	1 Temperature, aeration, moisture and nutrients should be appropriately controlled 2 C/N ratio at 25–30 is the initial optimum ratio for composting		The mixture of swine manure with rice straw is used as fertilizer	Zhu, 2007
56	Rice flakes	Composting	1 (NH ₄) ₂ SO ₄ 4 mg/gds 2 MgSO ₄ · 7H ₂ O 1 mg/gds 3 FeSO ₄ · 7H ₂ O 0.02 mg/gds 4 K ₂ HPO ₄ 1.4 mg/gds 5 KH ₂ PO ₄ 0.6 mg/gds 6 pH 7		Edible products	Anto <i>et al.</i> , 2006
57	Rice straw	Composting	1 The C/N ratios were the lowest (17–24) 2 A temperature of 62°C during 48 h removed pathogenic microorganisms from rice straw		Paper production, construction materials, incorporation in soil, compost, energy source, animal feed, etc.	Iranzo <i>et al.</i> , 2004

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Table 10.7 (Continued)

No	Substrate to be applied	Treatment methods	Physicochemical characteristics	Final products/uses	References
58	Rice straw	Pyrolysis	1 Moisture 13.6% wt 2 Pyrolysis temperature of 400–800°C	Fuel gases, liquids and solids	Tsai <i>et al.</i> , 2006
59	Rice husk	Pyrolysis	Temperature 250–550°C	Source of thermal energy	Sharma and Rao, 1999
60	Rice husk	Pyrolysis	Temperature 1300–1500°C	Fuel gases	Martinez <i>et al.</i> , 2005
61	Rice straw	Pyrolysis	Moisture 7.1%wt	1 Raw material for paper industry, or as animal feed sources 2 Bio-oils	Putun <i>et al.</i> , 2004
62	Rice husk and straw	Combustion	The influence of different variables such as temperature, fluidization velocity on the combustion efficiency and CO emissions was investigated	Fuels	Armesto <i>et al.</i> , 2002
63	Rice husk	Combustion	1 Moisture 16.9%wt 2 Temperature is 340°C	Renewable fuels	Fang <i>et al.</i> , 2004
64	Rice straw	Combustion	Temperature 575°C	Fuel	Bakera and Jenkins, 2003
65	Rice husk	Pyrolysis	The optimum temperature is 400°C	Fodder for livestock and industrial fuel for boilers	Maiti <i>et al.</i> , 2005
66	Rice husk	Combustion	1 Temperature ranging between 300 and 700°C 2 pH about 7	Renewable source of thermal energy	Liou, 2004
67	Rice husk	Combustion	Temperature range of 450–550°C	Liquid fuel	Zheng <i>et al.</i> , 2006
68	Rice straw	Biogas	1 2% formalin 2 0.1% KMnO ₄	Fertilizer for production of <i>Pleurotus sajor caju</i>	Banik and Nandi, 2004
69	Rice husk	Gasification	1 High moisture content (10.0% wt) 2 Low heating value (HHV 3450 kcal/kg)	Renewable source of energy	Lin <i>et al.</i> , 1999
70	Rice husk	Gasification	Temperature range of 200–1372°C	Fuel gas	Mansaraya <i>et al.</i> , 1999

References

Scientific references

- Abdelhamid, M.T., Horiuchi, T. and Oba, S. (2004). Composting of rice straw with oilseed rape cake and poultry manure and its effects on faba bean (*Vicia faba* L.) growth and soil properties. *Bioresource Technol* **93**, 183–189.
- Abd El-Nasser, N.H., Helmy, S.M. and El-Gammal, A.A. (1997). Formation of enzymes by biodegradation of agricultural wastes with white rot fungi. *Polymer Degrad Stabil* **55**, 249–255.
- Al-Masri, M.R. (2005). Nutritive value of some agricultural wastes as affected by relatively low gamma irradiation levels and chemical treatments. *Bioresource Technol* **96**, 1737–1741.
- Anshu, S. and Sharma, S. (2002). Composting of a crop residue through treatment with microorganisms and subsequent vermicomposting. *Bioresource Technol* **85**, 107–111.
- Anto, H., Trivedi, U.B. and Patel, K.C. (2006). Glucoamylase production by solid-state fermentation using rice flake manufacturing waste products as substrate. *Bioresource Technol* **97**, 1161–1166.
- Armesto, L., Bahilloa, A., Veijonenb, K., Cabanillas, A. and Oteroa, J. (2002). Combustion behaviour of rice husk in a bubbling fluidised bed. *Biomass Bioenergy* **23**, 171–179.
- Arvanitoyannis, I.S. and Tserkezou, P. (2007a). Wheat, barley and oat waste: a comparative and critical presentation of methods and potential uses of treated waste. *Int J Food Sci Technol* (in press).
- Arvanitoyannis, I.S. and Tserkezou, P. (2007b). Corn and rice waste: a comparative and critical presentation of methods and current and potential uses of treated waste. *Int J Food Sci Technol* (submitted).
- Ayuso, M., Hernández, T., Garcia, C. and Pascual, J.A. (1996). Stimulation of barley growth and nutrient absorption by humic substances originating from various organic materials. *Bioresource Technol* **57**(3), 251–257.
- Bakkera, R.R. and Jenkins, B.M. (2003). Feasibility of collecting naturally leached rice straw for thermal conversion. *Biomass Bioenergy* **25**, 597–614.
- Banik, S. and Nandi, R. (2004). Effect of supplementation of rice straw with biogas residual slurry manure on the yield, protein and mineral contents of oyster mushroom. *Indust Crops Prod* **20**, 311–319.
- Bhat, A., Bheemarasetti, J.V.R. and Rao, T.R. (2001). Kinetics of rice husk char gasification. *Energy Conversion Manage* **42**, 2061–2069.
- Blander, M. and Pelton, A.D. (1997). The inorganic chemistry of the combustion of wheat straw. *Biomass Bioenergy* **12**(4), 295–298.
- Bubenbeim, D.L., Patterson, M., Wignarajah, K. and Flynn, M. (1997). Incineration of biomass and utilization of product gas as a CO₂ source for crop production in closed systems: gas quality and phytotoxicity. *Adv Space Res* **20**(10), 1845–1850.
- Camarero, S., Bocchini, P., Galletti, G.C., Martinez, M.J. and Martinez, A.T. (2001). Compositional changes of wheat lignin by a fungal peroxidase analyzed by pyrolysis-GC-MS. *J Analyt Appl Pyrolysis* **58–59**, 413–423.

- Cao, Q., Xie, K.C., Bao, W.R. and Shen, S.G. (2004). Pyrolytic behaviour of waste corn cob. *Bioresource Technol* **94**, 83–89.
- Cao, Q., Xie, K.C., Lv, Y.K. and Bao, W.R. (2006). Process effects on activated carbon with large specific surface area from corn cob. *Bioresource Technol* **97**, 110–115.
- Caron, J. and Nkongolo, V.K.N. (1999). Aeration in growing media: recent developments. *Acta Hortic* **481**, 545–551.
- Chang, C.F., Chang, C.Y. and Tsai, W.T. (2000). Effects of burn-off and activation temperature on preparation of activated carbon from corn cob agrowaste by CO₂ and steam. *J Colloid Interface Sci* **232**, 45–49.
- Chum, H.L. and Overend, R.P. (2001). Biomass and renewable fuels. *Fuel Process Technol* **71**, 187–195.
- Conteras-Ramos, S.M., Alvarez-Bernal, D., Trujillo-Tapia, N. and Dendooven, L. (2004). Composting of tannery effluent with cow manure and wheat straw. *Bioresource Technol* **94**, 223–228.
- Cuiping, L., Chuangzhi, W., Yanyongjie and Haitao, H. (2004). Chemical elemental characteristics of biomass fuels in China. *Biomass Bioenergy* **27**, 119–130.
- Curreli, N., Benedetta Fadda, M., Rescigno, A. *et al.* (1997). Mild alkaline/oxidative pretreatment of wheat straw. *Process Biochem* **32**(S), 665–670.
- Davidsson, K.O., Pettersson, J.B.C. and Nilsson, R. (2002). Fertiliser influence on alkali release during straw pyrolysis. *Fuel* **81**, 259–262.
- Demirbas, A. and Sahin, A. (1998). Evaluation of biomass residue 1. Briquetting waste paper and wheat straw mixtures. *Fuel Process Technol* **55**, 175–183.
- Dieckow, J., Mielniczuk, J., González-Vila, F.J., Knicker, H. and Bayer, C. (2006). No-till cropping systems and N fertilisation influences on organic matter composition of physical fractions of a subtropical Acrisol as assessed by analytical pyrolysis (Py-GC/MS). *Geoderma* **135**, 260–268.
- D'Jesus, P., Boukis, N., Kraushaar-Czarnetzki, B. and Dinjus, E. (2006). Gasification of corn and clover grass in supercritical water. *Fuel* **85**, 1032–1038.
- Dresboll, D.B. and Thorup-Kristensen, K. (2005). Delayed nutrient application affects mineralisation rate during composting of plant residues. *Bioresource Technol* **96**, 1093–1101.
- Emtiazi, G. and Nahvi, I. (2000). Multi-enzyme production by *Cellulomonas* sp. grown on wheat straw. *Biomass Bioenergy* **19**, 31–37.
- Erhart, E., Hartl, W. and Putz, B. (2005). Biowaste compost affects yield, nitrogen supply during the vegetation period and crop quality of agricultural crops. *Europ J Agron* **23**, 305–314.
- Fan, M., Jiang, R., Liu, X. *et al.* (2005). Interactions between non-flooded mulching cultivation and varying nitrogen inputs in rice-wheat rotations. *Field Crops Res* **91**, 307–318.
- Fang, M., Yang, L., Chen, G., Shi, Z., Luo, Z. and Cen, K. (2004). Experimental study on rice husk combustion in a circulating fluidized bed. *Fuel Process Technol* **85**, 1273–1282.
- Faulds, C.B., Mandalari, G., Lo Curto, R.B., Bisignano, G., Christakopoulos, P. and Waldron, K.W. (2006). Synergy between xylanases from glycoside hydrolase family 10 and family 11 and a feruloyl esterase in the release of phenolic acids from cereal arabinoxylan. *Appl Microbiol Biotechnol* **71**, 622–629.
- Faulds, C.B., Mandalari, G., Lo Curto, R.B., Bisignano, G. and Waldron, K.W. (2006). Influence of the arabinoxylan composition on the susceptibility of mono- and

- dimeric ferulic acid release by *Humicola insolens* feruloyl esterases. *J Sci Food Agricult* **86**, 1623–1630.
- Fjellerup, J., Gjernes, E. and Hansen, L.K. (1996). Pyrolysis and combustion of pulverized wheat straw in a pressurized entrained flow reactor. *Energy and Fuels* **10**(3), 649–651.
- Franchini, J.C., Gonzalez-Vila, F.J. and Rodriguez, J. (2000). Decomposition of plant residues used in no-tillage systems as revealed by flash pyrolysis. *J Analyt Appl Pyrolysis* **62**, 35–43.
- Gabrielle, B., Da-Silveira, J., Houot, S. and Michelin, J. (2005). Field-scale modelling of carbon and nitrogen dynamics in soils amended with urban waste composts. *Agricult Ecosyst Environ* **110**, 289–299.
- Galletti, G.C., Bocchini, P., Guadalix, M.E., Almendros, G., Camarero, S. and Martinez, A.T. (1997). Pyrolysis products as markers in the chemical characterization of paper-boards from waste paper and wheat straw pulps. *Bioresource Technol* **60**, 51–58.
- Gardea-Torresdey, J.L., Tiemann, K.J., Armendariz, V. *et al.* (2000). Characterization of Cr(VI) binding and reduction to Cr(III) by the agricultural byproducts of *Avena monida* (Oat) biomass. *J Hazard Mater* **B80**, 175–188.
- Gauthier, A., Derenne, S., Largeau, C. *et al.* (2003). Comparative study of ligno-cellulosic material from wheat straw and of pure and mixed standard compounds via solid state ^{13}C NMR spectroscopy, conventional pyrolysis and TMAH thermochemolysis. *J Analyt Appl Pyrolysis* **67**, 277–293.
- Gbedemah, C.M., Obodai, M. and Sawyerr, L.C. (1998). Preliminary investigations into the bioconversion of gamma irradiated agricultural waste by *Pleurotus spp.* *Radiat Phys Chem* **52**, 379–382.
- Gleixner, G., Bol, R. and Bolesdent, J. (1999). Molecular insight into soil carbon turnover. *Rapid Commun Mass Spectrom* **13**(13), 1278–1283.
- Gokhale, D.V., Patil, S.G. and Bastawde, K.B. (1998). Potential application of yeast cellulase-free xylanase in agrowaste material treatment to remove hemicellulose fractions. *Bioresource Technol* **63**, 187–191.
- Green, A.E.S. and Feng, J. (2006). Systematics of corn stover pyrolysis yields and comparisons of analytical and kinetic representations. *J Analyt Appl Pyrolysis*, **76**, 60–69.
- Guerra-Rodriguez, E., Vazquez, M. and Diaz-Ravina, M. (2000). Co-composting of barley wastes and solid poultry manure. *Bioresource Technol* **75**, 223–225.
- Hammer, M.J. and Hammer, M.J. Jr (2004). *Water and wastewater technology*, 5th edn, p. 437. Pearson Educational International, New Jersey, USA.
- Hang, Y.D. and Woodams, E.E. (1999). Enzymatic production of soluble sugars from corn husks. *Lebensm-Wiss u-Technol* **32**, 208–210.
- Hang, Y.D. and Woodams, E.E. (2001). Enzymatic production of reducing sugars from corn cobs. *Lebensm-Wiss u-Technol* **34**, 140–142.
- Harrison, M.R. (2001). *Pollution causes, effects and control*, 4th edn, pp. 121, 129, 396, 398. Royal Society of Chemistry, London.
- Hernandez, M., Hernandez-Coronado, M.J., Montiel, M.D. *et al.* (2001). Pyrolysis: gas chromatography: mass spectrometry as a useful technique to evaluate the ligninolytic action of streptomycetes on wheat straw. *J Analyt Appl Pyrolysis* **58–59**, 539–551.
- Illerup, J.B. and Rathmann, O. (1997). CO_2 gasification of wheat straw, barley straw, willow and giganteus. *Fuel Energy Abstr* January.

- Iqbal, M.M., Akhter, J., Mohammad, W., Shah, S.M., Nawaz, H. and Mahmood, K. (2005). Effect of tillage and fertilizer levels on wheat yield, nitrogen uptake and their correlation with carbon isotope discrimination under rainfed conditions in north-west Pakistan. *Soil Tillage Res* **80**, 47–57.
- Iranzo, M., Canizares, J.V., Roca-Perez, L., Sainz-Pardo, I., Mormeneo, S. and Boluda, R. (2004). Characteristics of rice straw and sewage sludge as composting materials in Valencia (Spain). *Bioresource Technol* **95**, 107–112.
- Islam, M.N. and Ani, F.N. (2000). Techno-economics of rice husk pyrolysis, conversion with catalytic treatment to produce liquid fuel. *Bioresource Technol* **73**, 67–75.
- Jecu, L. (2000). Solid state fermentation of agricultural wastes for endoglucanase production. *Indust Crops Prod* **11**, 1–5.
- Jones, J.M., Pourkashanian, M., Williams, A. and Hainsworth, D. (2000). A comprehensive biomass combustion model. *Renewable Energy* **19**, 229–234.
- Kadam, K.L., Forrest, L.H. and Jacobson, W.A. (2000). Rice straw as a lignocellulosic resource: collection, processing, transportation, and environmental aspects. *Biomass Bioenergy* **18**, 369–389.
- Kalligeros, S., Zannikos, F., Stournas, S., Lois, E., Anastopoulos, G., Teas, C. and Sakellaropoulos, F. (2003). An investigation of using biodiesel/marine diesel blends on the performance of a stationary diesel engine. *Biomass Bioenergy* **24**, 141–149.
- Keeling, A.A., McCallum, K.R. and Beckwith, C.P. (2003). Mature green waste compost enhances growth and nitrogen uptake in wheat (*Triticum aestivum* L.) and oilseed rape (*Brassica napus* L.) through the action of water-extractable factors. *Bioresource Technol* **90**, 127–132.
- Kim, S. and Dale, B.E. (2004). Global potential bioethanol production from wasted crops and crop residues. *Biomass Bioenergy* **26**, 361–375.
- Kim, S. and Dale, B.E. (2005). Life cycle assessment of various cropping systems utilized for producing biofuels: bioethanol and biodiesel. *Biomass Bioenergy* **29**, 426–439.
- Koutinas, A.A., Wang, R. and Webb, C. (2004). Evaluation of wheat as generic feedstock for chemical production. *Indust Crops Prod* **20**, 75–88.
- Krings, U., El-Saharty, Y.S., El-Zeany, B.A., Pabel, B. and Berger, R.G. (2000). Antioxidant activity of extracts from roasted wheat germ. *Food Chem* **71**, 91–95.
- Krishnan, M.S., Taylor, F., Davison, B.H. and Nghiem, N.P. (2000). Economic analysis of fuel ethanol production from corn starch using fluidized-bed bioreactors. *Bioresource Technol* **75**, 99–105.
- Kumar, A., Cameron, J.B. and Flynn, P.C. (2005). Pipeline transport and simultaneous saccharification of corn stover. *Bioresource Technol* **96**, 819–829.
- Kwiatkowski, J.R., McAloon, A.J., Taylor, F. and Johnston, D.B. (2006). Modeling the process and costs of fuel ethanol production by the corn dry-grind process. *Indust Crops Prod* **23**, 288–296.
- Lanzetta, M. and Di Blasi, C. (1998). Pyrolysis kinetics of wheat and corn straw. *J Analyt Appl Pyrolysis* **44**, 181–192.
- Lima, J.S., De Queiroz, J.E.G. and Freitas, H.B. (2004). Effect of selected and non-selected urban waste compost on the initial growth of corn. *Resources Conservat Recyc* **42**, 309–315.
- Lin, S.H. and Lan, W.J. (1998). Treatment of waste oil/water emulsion by ultrafiltration and ion exchange. *Water Research* **32**(9), 2680–2688.

- Lin, K.S., Wang, H.P., Lin, C.J. and Juch, C.I. (1999). A process development for gasification of rice husk. *Fuel Process Technol* **55**, 185–192.
- Lin, Y.F., Jing, S.R. and Lee, D.Y. (2001). Recycling of wood chips and wheat dregs for sludge processing. *Bioresource Technol* **76**, 161–163.
- Liou, T.H. (2004). Evolution of chemistry and morphology during the carbonization and combustion of rice husk. *Carbon* **42**, 785–794.
- Liu, Y., Shengwei, Z. and Haoquan, H. (2000). Gasification of wheat straw for ammonia synthesis gas. *Coal Conversion* **23**, 92–95.
- Lynch, D.H., Voroneyb, R.P. and Warmanc, P.R. (2006). Use of ^{13}C and ^{15}N natural abundance techniques to characterize carbon and nitrogen dynamics in composting and in compost-amended soils. *Soil Biol Biochem* **38**, 103–114.
- Maiti, S., Dey, S., Purakayastha, S. and Ghosh, B. (2005). Physical and thermochemical characterization of rice husk char as a potential biomass energy source. *Bioresource Technol* **97**, 2065–2070.
- Mansaraya, K.G., Ghalya, A.E., Al-Taweelb, A.M., Hamdullahpurc, F. and Ugursal, V.I. (1999). Air gasification of rice husk in a dual distributor type fluidized bed gasifier. *Biomass Bioenergy* **17**, 315–332.
- Martinez, A.T., Camarero, S., Gutierrez, A., Bocchini, P. and Galletti, G.C. (2001). Studies on wheat lignin degradation by *Pleurotus* species using analytical pyrolysis. *J Analyt Appl Pyrolysis* **58–59**, 401–411.
- Martinez, V., Valencia, M.F., Cruz, J., Mejia, J.M. and Chejne, F. (2005). Production of β -SiC by pyrolysis of rice husk in gas furnaces. *Ceramics Int* **32**, 891–897.
- McLanaghan, S.R.B. (2002). Delivering the landfill directive: the role of new and emerging technologies. *Industrial Ecology*, Penrith, UK.
- Migliore, L., Brambilla, G., Casoria, P., Civitareale, C., Cozzolino, S. and Gaudio, L. (1996). Effect of sulphadimethoxine contamination on barley (*Hordeum distichum* L., Poaceae, Liliopsida). *Agricult Ecosyst Environ* **60**, 121–128.
- Montgomery, R. (2004). Development of biobased products. *Bioresource Technol* **91**, 1–29.
- Neves, L., Ribeiro, R., Oliveira, R. and Alves, M.M. (2006). *Enhancement of methane production from barley waste*. Elsevier, London.
- Nigam, J.N. (2000). Continuous ethanol production from pineapple cannery waste using immobilized yeast cells. *J Biotechnol* **80**, 189–193.
- Öhgren, K., Rudolf, A., Galbe, M. and Zacchi, G. (2006). Fuel ethanol production from steam-pretreated corn stover using SSF at higher dry matter content. *Biomass Bioenergy* **30**, 863–869.
- Olsson, M. (2006). Wheat straw and peat for fuel pellets – organic compounds from combustion. *Biomass Bioenergy* **30**, 555–564.
- Petts, and Eduljee (1994). *Environmental Impact Assessment for Waste Treatment and Disposal Facilities*. John Wiley and Sons Ltd. West Sussex, England, p. 485.
- Pordesimo, L.O., Hamesb, B.R., Sokhansanjc, S. and Edens, W.C. (2005). Variation in corn stover composition and energy content with crop maturity. *Biomass Bioenergy* **28**, 366–374.
- Putun, A.E., Apaydin, E. and Putun, E. (2004). Rice straw as a bio-oil source via pyrolysis and steam pyrolysis. *Energy* **29**, 2171–2180.

- Robinson, T., Chandran, B. and Nigam, P. (2002). Effect of pretreatments of three waste residues, wheat straw, corn cobs and barley husks on dye adsorption. *Bioresource Technol* **85**, 119–124.
- Rodriguez, J., Hernandez-Coronado, M.J., Hernandez, M., Bocchini, P., Galletti, G.C. and Arias, M.E. (1997). Chemical characterization by pyrolysis/gas chromatography/mass spectrometry of acid-precipitable polymeric lignin (APPL) from wheat straw transformed by selected *Streptomyces* strains. *Analyt Chim Acta* **345**, 121–129.
- Saha, B.C., Iten, R.B., Cotta, M.A. and Wu, Y.V. (2005). Dilute acid pretreatment, enzymatic saccharification and fermentation of wheat straw to ethanol. *Process Biochem* **40**, 3693–3700.
- Schell, D.J., Riley, C.J., Dowe, N. *et al.* (2004). A bioethanol process development unit: initial operating experiences and results with a corn fiber feedstock. *Bioresource Technol* **91**, 179–188.
- Seungdo, K. and Dale, B.E. (2005). Environmental aspects of ethanol derived from no-filled corn grain: nonrenewable energy consumption and greenhouse gas emissions. *Biomass Bioenergy* **28**, 475–489.
- Sharma, A. and Rao, T.R. (1999). Kinetics of pyrolysis of rice husk. *Bioresource Technol* **67**, 53–59.
- Shuangning, X., Weiming, Y. and Li, B. (2005). Flash pyrolysis of agricultural residues using a plasma heated laminar entrained flow reactor. *Biomass Bioenergy* **29**, 135–141.
- Singh, A. and Sharma, S. (2002). Composting of a crop residue through treatment with microorganisms and subsequent vermicomposting. *Bioresource Technol* **85**, 107–111.
- Souza, G.B., Carrilho, E.N.V.M., Oliveira, C.V., Nogueira, A.R.A. and Nobrega, J.A. (2002). Oxygen bomb combustion of biological samples for inductively coupled plasma optical emission spectrometry. *Spectrochim Acta Part B* **57**, 2195–2201.
- Swan, J.R.M., Crook, B. and Gilbert, E.J. (2002). Microbial emissions from composting sites. *Issues Environ Sci Technol* **18**, 73–102.
- Tchobanoglous, G., Burton, F.L. and Stensel, H.D. (2003). *Wastewater engineering treatment and reuse*, 4th edn. Mc Graw Hill, New York, USA.
- Thy, P., Jenkins, B.M., Leshner, C.E. and Grundvig, S. (2006). Compositional constraints on slag formation and potassium volatilization from rice straw blended wood fuel. *Fuel Process Technol* **87**, 383–408.
- Tsai, W.T., Chang, C.Y. and Lee, S.L. (1998). A low cost adsorbent from agricultural waste corn cob by zinc chloride activation. *Bioresource Technol* **64**, 211–217.
- Tsai, W.T., Chang, C.Y., Wang, S.Y., Chang, C.F., Chien, S.F. and Sun, H.F. (2001). Cleaner production of carbon adsorbents by utilizing agricultural waste corn cob. *Resources Conservat Recyc* **32**, 43–53.
- Tsai, W.T., Chang, C.Y., Wang, S.Y., Chang, C.F., Chien, S.F. and Sun, H.F. (2001). Preparation of activated carbons from corn cob catalyzed by potassium salts and subsequent gasification with CO₂. *Bioresource Technol* **78**, 203–208.
- Tsai, W.T., Lee, M.K. and Chang, Y.M. (2006). Fast pyrolysis of rice straw, sugarcane bagasse and coconut shell in an induction-heating reactor. *J Analyt Appl Pyrolysis* **76**, 230–237.
- Vane, C.H., Abbott, G.D. and Head, I.M. (2001). The effect of fungal decay (*Agaricus bisporus*) on wheat straw lignin using pyrolysis–GC–MS in the presence of tetramethylammonium hydroxide (TMAH). *J Analyt Appl Pyrolysis* **60**, 69–78.

- Vidmantienė, D., Juodeikienė, G. and Basinskiene, L. (2006). Technical ethanol production from waste of cereals and oats products using a complex enzyme preparation. *J Sci Food Agricult* **86**, 1732–1736.
- Vlaev, L.T., Markovska, I.G. and Lyubchev, L.A. (2003). Non-isothermal kinetics of pyrolysis of rice husk. *Thermochim Acta* **406**, 1–7.
- Vuorinen, A.H. and Saharinen, M.H. (1997). Evolution of microbiological and chemical parameters during manure and straw co-composting in a drum composting system. *Agricult Ecosyst Environ* **66**, 19–29.
- Vuorinen, A.H. (2000). Effect of the bulking agent on acid and alkaline phosphomonoesterase and β -D-glucosidase activities during manure composting. *Bioresource Technol* **75**, 133–138.
- Wesseler, J. (2006). *Opportunities (costs) matter: ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower*. Elsevier, London.
- William, P.T. and Bagri, R. (2004). Hydrocarbon gases and oils from the recycling of polystyrene waste by catalytic pyrolysis. *Int J Energy Res* **28**, 31–44.
- Williams, P.T. (2005). *Waste treatment and disposal*, 2nd edn. John Wiley & Sons, Ltd, Chichester.
- Zafar, M.N., Nadeem, R. and Hanif, M.A. (2006). Biosorption of nickel from protonated rice bran. *J Hazard Mater* (in press).
- Zayed, G. and Abdel-Motaal, H. (2005). Bio-active composts from rice straw enriched with rock phosphate and their effect on the phosphorous nutrition and microbial community in rhizosphere of cowpea. *Bioresource Technol* **96**, 929–935.
- Zhang, H. and Wang, J. (2006). Combustion characteristics of a diesel engine operated with diesel and burning oil of biomass. *Renewable Energy* **31**, 1025–1032.
- Zhang, R. and Zhang, Z. (1999). Biogasification of rice straw with an anaerobic-phased solids digester system. *Bioresource Technol* **68**, 235–245.
- Zhang, T., Walawendera, W.P., Fana, L.T., Fanb, M., Daugaard, D. and Brown, R.C. (2004). Preparation of activated carbon from forest and agricultural residues through CO₂ activation. *Chem Engin J* **105**, 53–59.
- Zheng, J., Zhu, X., Guo, Q. and Zhu, Q. (2006). Thermal conversion of rice husks and sawdust to liquid fuel. *Waste Manage* **26**, 1430–1435.
- Zhu, N. (2007). Effect of low initial C/N ratio on aerobic composting of swine manure with rice straw. *Bioresource Technol* **98**, 9–13.

Electronic sources

<http://en.wikipedia.org/wiki/Grains>
<http://www.nutrition.org.uk/upload/Cereals%20pdf.pdf>
<http://www.face-online.org.uk/resources/factsheets/discovering/cereals.doc>
<http://www.historyworld.net/wrldhis/PlainTextHistories.asp?historyid=ab56>
<http://en.wikipedia.org/wiki/Wheat>
<http://en.wikipedia.org/wiki/Maize>
<http://en.wikipedia.org/wiki/Barley>
<http://en.wikipedia.org/wiki/Oat>
<http://en.wikipedia.org/wiki/Rice>

<http://www.geocities.com/napavalley/6454/cereals.html>
http://www.agrsci.dk/afdelinger/forskningsafdelinger/gbi/grupper/molekylaer_genetik_og_bioteknologi/cereals
<http://web.em.doe.gov/em30/wasttrea.html>
<http://www.epa.gov/epaoswer/osw/treattech.htm>
http://www.biffa.co.uk/files/pdfs/MassBalance_Agriwastes_08_Treatment.pdf
http://www.zazemiata.org/bw/radnevo/resume_ovos_en.pdf
<http://www.cpeo.org/techtree/ttdescript/pyrols.htm>
http://www.juniper.co.uk/services/Our_services/P&GFactsheet.html
<http://en.wikipedia.org/wiki/Pyrolysis>
<http://www.tab.fzk.de/en/projekt/zusammenfassung/AB49.htm>
<http://dbs.clib-jena.mpg.de/dbs-publ/pubi/bgc/BGC0130.pdf>
<http://www.biomatnet.org/secure/Fair/F538.htm>
<http://www.dynamotive.com/biooil/technology.html>
<http://www.pyne2005.inter-base.net/docs/PyNews%2017.pdf>
http://www.elsevier.com/wps/find/bookdescription.cws_home/600279/description#description
http://www.foe.co.uk/resource/triefings/gasifications_pyrolysis.pdf
<http://www.compost.org/pdf/ccr.rs.testing.compost.PDF>
http://www.remade.org.uk/organics/organics_documents/compostbenefitsscottishcrops.pdf
<http://www.formatkenya.org/ormbook/Chapters/chapter9.htm>
http://www.juniper.co.uk/services/Our_services/P&GFactsheet.html
<http://www.ecocentre.org.uk/biomass.html>
<http://en.wikipedia.org/wiki/Gasification>
<http://www.tab.fzk.de/en/projekt/zusammenfassung/AB49.htm>
<http://mitglied.lycos.de/cturare/fuel.htm>
<http://www.ecn.nl/docs/library/report/2000/c00080.pdf>
<http://mitglied.lycos.de/cturare/fue.htm#size>
<http://www.ecn.nl/docs/library/report/2000/c00080.pdf>
<http://mitglied.lycos.de/cturare/fue.htm#moisture>
<http://mitglied.lycos.de/cturare/fue.htm#form>
<http://mitglied.lycos.de/cturare/fue.htm#energy>
<http://www.esam.northwestern.edu/~matkowsky/fingering.html>
<http://www.eeci.net/archive/biobase/B10367.html>
<http://www.fao.org/sd/EGdirect/EGre0022.htm>
<http://www.ngvglobal.com/index.php?option=com-content&task=view&id=83&Itemid=2&lang=en>
<http://www.defra.gov.uk/ENVIRONMENT/consult/greenfuel/response/03.htm>
<http://www.miljolth.se/svenska/publikationer/visaInfo.asp?ID=222>
<http://www.fao.org/sd/EGdirect/EGre0022.htm>