Green Waste As a Resource for Value Added Product Generation: A Review

Vivek P. Bhange[a,*], SPM. Prince William[b], A.N.Vaidya[b], A.R.Chokhandre[d]

[a,d]Department of Biotechnology, Priyadarshini Institute of Engineering & Technology, Nagpur-19 (MS) INDIA.

[b]Solid Waste Management Division, National Environmental Engineering Research Institute, Nehru Marg, Nagpur-20 (MS) INDIA

[*]Corresponding Address:

vivek_bhange@yahoo.co.in

Review Article

Abstract: Green waste includes foliage, plant residues, fallen flowers, garden refuse, leaf litter, cut grass, residues of pruning, weeds and other organic matter discarded from gardens and greeneries but exclude organic waste of the type obtained from municipal collections. These green wastes would land in dumping sites, or will be burned, if not collected and processed contributing to the large scale contamination of land, water and air. Leaves accumulating in the urban and suburban locations such as sidewalks, lawns, and playgrounds are not only an unseemly sight but adds to the overall problem of municipal solid waste (MSW) disposal. In India and several other countries, foliage is often piled-up and set on fire. The resulting ash returns some of the NPK content of the foliage to the soil but much of nitrogen, phosphorous, and organic carbon gets lost. The burning of leaves also adds to air pollution and global warming. Green waste when decomposes in soil may release methane and foul odors, before getting converted into humus. However green waste can be a potential resource for energy and other value added products, if properly processed. The present review aims at summarizing different processing options for green waste towards energy production and value added product generation. Green waste is mostly dealt with aerobic treatment (composting), anaerobic treatments, incineration, biomass briquetting, cellulosic ethanol from biomass, biohydrogen production, bioplastics etc.

Keywords: Green waste, Aerobic processing, Anaerobic Treatment, Briquetting, Cellulosic ethanol, Bioplastics, Biohydrogen production

1. Introduction

Maintenance of green spaces such as home gardens, parks, lawns and other green interiors produces a significant amount of green waste, includes foliage, plant residues, decayed and fallen flowers, garden refuse, leaf litter, cut grass, pruned things of trees, weeds and other organic matter discarded from gardens but exclude organic waste of the type obtained from municipal collections.

India is blessed with huge land cover, relatively high population density, and green consciousness, much land is left undeveloped. The number of parks and other recreational centers, home gardens etc. contribute to the increasable quantum of garden biomass generation. Consequently, maintenance of green areas produces a significant amount of waste [1].The total annual production of leafy biomass in India is of the order of 1130 million tons[2] . This green waste would land in dumping sites, or will be burned if not collected and processed contributing to the large scale contamination of land, water and air. Although not in focus as much as domestic green waste such as foliage, grass, and plant residues, is a major constituent of solid waste [3[.Leaves accumulating in the urban and suburban locations such as sidewalks, lawns, and playgrounds are not only an unseemly sight but adds to the overall problem of municipal solid waste disposal [4]. Road sweepings and road side plantations are some areas which generate significant biomass waste [5]. Leaving a thick layer of leaves on your lawn or garden can create conditions that lead to rotting of the grass or perennials beneath. In India and several other countries foliage is often piled-up and set on fire. The resulting ash returns some of the NPK content of the foliage to the soil but much of nitrogen, phosphorous, and organic carbon gets lost. The burning of leaves also adds to air pollution and global warming [4]. Green waste when decomposes in soil may release methane and foul odors, before getting converted to humus. Leaves and yard trimmings can be harmful to lakes and streams after washing into storm sewers [3].The use of green waste as a raw material can broaden the options giving it more flexibility and a broader application range because it would (1) rely on more-biodegradable products and processes that create less pollution and generally have fewer harmful environmental impacts; (2) develop less expensive products;(3) use less expensive raw materials [6],[7].

Green waste contains recalcitrant or complex compounds such as cellulose and lignin, and relatively small amounts of saccharides, amino acids, proteins, aliphatic compounds and carbohydrates [1],[8].The main components of plant biomass are carbohydrates (approximately 75%, dry weight) and lignin (approximately 25%), which can vary with plant type. The carbohydrates are mainly cellulose or hemicellulose fibers, which impart strength to the plant structure, and lignin, which holds the fibers together. Some plants also store starch (another carbohydrate polymer) and fats as sources of energy, mainly in seeds and roots [7]. The characterization of green waste is given in Table 1. The green waste is amenable to biodegradation by composting as they have major concentrations of heterogeneous organic substrates, including sugars, fats, proteins, hemicelluloses, celluloses, and lignin[11] .The other options for economical means of green waste processing are: anaerobic treatments, incineration, biomass briquetting, cellulosic ethanol from biomass, biohydrogen production, bioplastics etc.

Table 1: Characterization of green waste [9,10]

Paramater Waste	Leaves	Grass	Branches	Yard
Total organic carbon(% dw)	30.1	40.6	40.4	36.2
C/N Ratio	21.6	17.5	13.1	18.7
Fats/lipids(% dw)	2.59	2.41	1.04	2.49
Cellulose(% dw)	9.48	39.67	14.71	27.20
Hemicellulose(% dw)	3.24	16.89	12.87	11.25
Lignin/humus(% dw)	33.88	17.63	42.89	24.34
Volatile Solids(% dw)	63.3	81.7	81.7	73.8
Cellulose/lignin ratio	0.28	2.25	0.34	1.12

2. Technologies available for green waste processing

2.1Aerobic processing (composting)

Composting is the biological oxidative decomposition of organic constituents in wastes under controlled conditions. It requires special conditions, temperature, moisture, aeration, pH and C/N ratio, to enable optimum biological activity during the different stages of composting [12],[13]. The main products of aerobic composting are CO_2, H_2O, mineral ions and stabilized organic matter, often called humus. CO_2 and water losses can amount to half the weight of the initial materials. The major groups of microorganisms that participate in composting are bacteria, fungi, and actinomycetes. The process is accomplished through different phases i.e. initial phase during which readily degradable components are decomposed [14]. During a thermophilic phase cellulosic materials are oxidatively degraded rapidly by microbes. This is followed by maturation and stabilization phases [15].

Rihani et al. (2010) used sugar beet leaves and produced compost with low amounts of heavy metals, relatively high contents of nutrients and significant reduction of pathogens, suggesting the significance of processing agricultural green waste for compost production [16]. Kumar et al. (2010) studied the co-composting of food waste and green waste at low initial carbon to nitrogen (C/N) ratios in-vessel lab-scale composting reactor they found optimal moisture content for co-composting is 60%, and the substrate at a C/N ratio of 19.6 can be decomposed effectively to reduce 33% of total volatile solids (TVS) in 12 days [17].

Similarly, Kalamdhad et al. (2009) investigated rotary drum composting of vegetable waste and tree leaves and produced quality compost with a total nitrogen content of 2.6% and total phosphorus as 6 g/kg. They suggested that institutional organic waste, i.e. vegetable wastes and tree leaves, etc., can be composted successfully within 7 days period in a rotary drum composter by maintaining aerobic conditions through passive air supply by exhaust fan [18].Tai and He (2007) reported a novel composting process for plant wastes from gardening, such as leaves, grass and flowers in Taiwan military barracks. The time required to complete composting is shortened to 2–3 months [1].

Gajalakshmi and Abbasi (2004) evaluated neem leaves as a source of fertilizer-cum-pesticide vermicompost. Vermicomposting of neem (*Azadirachta indica A.Juss*) was accomplished in high-rate reactors operated at the earthworm (Eudrilus eugeniae) densities of 62.5 and 75 animals per litre of reactor volume [19]. They (Gajalakshmi et al. 2005) also studied vermicomposting of leaf litter ensuing from the trees of mango (Mangifera indica). After over nine months of continuous operation the vermireactors with 62.5 animals l^{-1} generated 13.6g vermicast per litre of reactor volume (l) per day (d) whereas the reactors with 75 animals l^{-1} produced 14.9g vermicast $l^{-1}d^{-1}$ [4].

Wong et al (2001) evaluated the feasibility of co-composting of soybean residues and leaves and the effects of turning frequency on compost quality. Soybean residues were mixed with leaves and sawdust in 1:1:3 (w/w wet weight) for achieving a C/N ratio of about 30. All treatments with different turning frequencies reached maturation at 63 days as indicated by the soluble organic carbon, soluble NH_4-N, C/N ratio and cress seed germination index [20].

Almost any organic material is suitable for composting process. The materials need a proper ratio of carbon-rich materials 'browns' and nitrogen-rich materials 'greens'. Among the brown materials are dried leaves, straw and wood chips. Nitrogen materials are fresh or green such as grass clippings and kitchen scraps. The carbon provides energy for the microbes, and the nitrogen provides proteins. Achieving the best mix is more an art gained through experience than an exact science. The change in the C/N ratios reflects the organic matter decomposition and stabilization achieved during composting[21].

The decomposition of organic matter is brought about by living organisms, which utilize carbon as a source of energy and the nitrogen for building cell structures. If the C/N ratio of compost is more, the excess carbon tends to utilize nitrogen in the soil to build cell protoplasm. This results in loss of nitrogen of the soil and is known as robbing of nitrogen in the soil. If on the other hand the C/N ratio is too low the resultant product does not help improve the structure of the soil. It is hence desirable to control the process so that the final C/N ratio is less than or equal to 20 [18],[22].

2.1.1 Advantages of green waste composting

- Green waste composting is an environment friendly method as it produces fairly hygienic products.
- During incubation process the high temperatures were successfully went through as problems of foul odour and presence of pathogenic organism were not observed//minimized/reduced.
- It is easy to carry out and produces products that deliver fertilizer efficiency between humic soil and organic fertilizer.
- Composting is an appropriate method to deal with the green waste for military barracks, schools, institutions and commercial areas which consist of large green areas, undeveloped land and plenty of labor.
- Large quantities of green waste can be managed in sustainable matter.
- Organic matter and nutrients return to the natural cycle through the application of compost to the soil.
- Activity of earthworms and other natural soil organisms beneficial for plant growth increases with the use of compost [23], [24].

2.1.2 Disadvantages

- Long time duration, space requirement and need for manpower are the major shortcomings for this eco-friendly technology.
- As it contains only limited levels of plant nutrients compost is a soil emendation, not a fertilizer.
- Loss of nitrogen, VOCs, protracted processing and curing time, cost of equipment, and the challenge of augmenting a successful marketing plan for compost.
- As an outcome of modernization, the constituents of waste is changing that comprises of pesticides, polychlorinated bi-phenyls, heavy metals in high concentrations resulting in the compost that is undesirable for land application.[82],[86].

2.2 Anaerobic Treatment

Anaerobic digestion is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen. In the first step polymers like starch, cellulose, lipids, proteins are hydrolyzed to amino acids, sugars, fatty acids etc. In the process of acidogenesis these are converted into a mixture of hydrogen gas, low molecular weight acids like acetic acid and carbon dioxide. In the process of methanogenesis these are reacted together to generate methane. Anaerobic digestion is broadly used as a renewable energy source because the process produces biogas which is rich in methane and carbon dioxide suitable for the production of energy that can replace fossil fuels. The digestate left after biogas production is rich in nutrient value and can be used as fertilizer.

Jagadabhi et al. (2011) demonstrated about the two stage anaerobic digestion of tomato, tree leaves and grass silage in leach bed reactor (LBR) and up flow anaerobic sludge blanket reactor (UASB). LBR studies showed that COD solubilization for tree leaves and grass silage was higher (50%) than tomato (35%) and leaves (15%). Biomethanation of the leachates in UASB reactors resulted in methane yields of 0.03–0.14 $m^3\,CH_4\,kg^{-1}$ VS fed for the studied crop materials [25]. Kaparaju et al. (2010) investigated the biogas production of wheat silage in UASB reactor by thermophilic anaerobic digestion batch and continuous mode. In batch experiments at two different substrate concentrations results showed higher methane yields over continuous method [26].

Prochnow et al. (2009) summarized knowledge on suitability and sustainability of grassland biomass for anaerobic digestion. Methane yields from grass are influenced by many factors. While the effects of some parameters such as grass species, cutting period and management intensity can be regarded as well known, other parameters such as preservation and processing still need investigation. Profitability can be achieved depending on grass silage supply costs and the concept of anaerobic digestion and energy use. Grassland biomass for biogas production competes with other feedstock and other forms of grassland use [27].

Lehtomaki.et al.(2008) conducted anaerobic digestion of grass silage in batch leach bed processes for methane productions, with and without a second stage upflow anaerobic sludge blanket (UASB) reactor. 66% of the methane potential in grass was obtained within the 55 days solids retention time in the leach bed–UASB process without pH adjustment, whereas in the one-stage leach bed process 20% of the methane potential in grass was extracted. The methane potential of the digestates varied from 0.141 to 0.204 m^3 CH_4 kg^{-1} added volatile solids [28].

Parawira et al. (2004) characterized anaerobic batch biodegradation of potato waste alone and co-digested with sugar beet leaves. The effects of increasing concentration of potato waste expressed as percentage of total solids (TS) and the initial inoculum-to-substrate ratio (ISR) on methane yield and productivity were investigated. Co-digestion improved the accumulated methane production and improved the methane yield by 31–62% compared with digestion of potato waste alone [29].

Yu et al. (2002) proposed a two phase anaerobic digestion using grass. The biphasic system consists of a solid phase and a methane phase. Leachate is recirculated through the solid phase until a desired level of volatile fatty acid is accumulated in the leachate. The leachate is then transferred to the methane reactor where volatile fatty acid is converted to methane. The system produced an average of 0.15m^3 of methane per kg of grass. The average methane concentration in the produced gas was 71%.[30] .

Sharma et al.(1999) operated the system is a batch digestion with a regular input of a calculated amount of plant biomasses based on first order decay kinetics in order to maintain a regular biogas production rate. For nearly three years the system was tested in a laboratory-scale fed-batch digester using dried water hyacinth as feed providing the desired biogas production rate. A field-scale domestic digester of masonry construction with a working volume of 10 m^3 was designed and tested for about 9 months by feeding a mixture of dried water hyacinth or banana stem along with sugarcane press mud, yielding an average biogas production of 90–100% of the expected rate calculated on the basis of the feed rate [31].

Jagadish et al. (1998) developed plug flow digestors for biogas generation from leaf biomass. The long term operation of such biogas plants using a mixed green leaf biomass feedstock is reported along with its design features. Results show that during long term operation, such biogas plants have the ability to produce up to 0.5 m^3 gas/m^3 reactor/day (ambient conditions) at specific conversion rates ranging between 180 and 360 l biogas/kg TS (total solids) at a 35 day retention time [32] .

Gunaseelan (1988) studied anaerobic digestion of *gliricidia* leaves for biogas and organic manure .*Gliricidia maculata* is a tree grown in India for green leaf manuring. The digestibility of *Gliricidia* leaves for biogas production was determined in 3 liter batch digesters at room temperature (32±3°C). Results indicate a gas yield of 165–180 ml CH_4 g^{-1} VS added and a VS reduction of 37–39%. Determination of the N, P, and K content of the digester influent and effluent slurries indicates that the anaerobically digested slurry of the *Gliricidia* leaves is better in quality than the fresh *Gliricidia* leaves as organic manure [33].

Ghosh et al. (1985) reported that Bermuda grass is deficient in nitrogen and phosphorus. Accordingly, several mesophilic digestion runs were conducted with Bermuda grass at HRT = 12 days and Organic Loading Rate = 1.6 kg VS m^{-3} d^{-1}, with and without external nitrogen and phosphorus additions. It was found that supplementing the feed with NH_4Cl increased the CH_4 yield by 96% and cellulose conversion by 33%. Nitrogen addition appeared to decrease hemicellulose conversion and phosphorus addition had no effect on hemicellulose conversion or CH_4 production. It was speculated that the metabolism of the breakdown product (glucose) of cellulose requires the least investment of enzymes and energy. The CH_4 yield from grass mixture was higher than that of Bermuda grass without external nutrient addition [5],[34], [35].

Anaerobic process in comparison to aerobic process can be ecologically advantageous when the factors like exhaust emissions and energy balances are considered. Anaerobic digestion has benefit over all other methods as there is net production of energy in the form of biogas which when used prevents negative effects on environment. The preferred treatment method depends on the composition and structure of the material. In general, structured materials with high lignocellulose content are less readily degradable under anaerobic conditions and are therefore more suitable for aerobic treatment. Anaerobic treatment is preferred for unstructured materials with a high content of readily-degradable organic compounds [36].

2.2.1 Advantages of anaerobic digestion of green waste

- Biomass sludge is produced in less quantity as compared to aerobic treatment technologies.
- The method proved successful in treating wet wastes having less than 40% dry matter.
- Produces minimal odour as 99% of volatile compounds are oxidatively decomposed upon combustion, e.g. H_2S forms SO_2.
- Slurry produced is an enhanced fertilizer for plants due to its availability and rheological properties
- Biogas is produced which is a source of carbon neutral energy.
- Increased reaction rates as compared to the destruction of organic matter.
- It is a highly stable method with high depuration rate and energy recovery with a good process economy.
- Solar energy that is stored in the biomass is converted to an energy carrier (biogas) by anaerobic treatment.

2.2.2 Disadvantages

- The pH in the reactor may decrease due to rapid acidification.
- Larger volatile fatty acids production (VFA) inhibits the activity of methanogenic bacteria.
- Increase in the feed concentration leads to the depletion of overall performance by the reactor.
- Anaerobic digestion is more expensive than composting [37].

3. Other Technologies

3.1 Green waste Briquetting

The process of compaction of residues into a product of higher density than the original raw material is known as briquetting [38]. Biomass briquettes are generally made from agricultural waste and are a replacement for fossil fuels such as oil or coal, and can be used to heat boilers in manufacturing plants, and also have applications in developing countries. Biomass briquettes are a renewable source of energy and avoid adding fossil carbon to the atmosphere. Use of biomass briquettes can earn Carbon Credits for reducing emissions in the atmosphere. Biomass briquettes also provide more calorific value/kg and save around 30-40 percent of boiler fuel costs.

Briquetting has aroused a great deal of interest in developing countries all over the world lately as a technique for upgrading of residues as energy sources. The process also helps to reduce deforestation by providing a substitute for fuel wood [38]. Two different types of briquetting technologies are currently in use. The first, called pyrolizing technology relies on partial pyrolysis of biomass, which is mixed with binder and then made into briquettes by casting and pressing. The second technology is direct extrusion type, where the biomass is dried and directly compacted with high heat and pressure. Setting up the briquette production unit raw material should be locally available [85].

Felfli et al. (2011) studied the status of biomass briquetting and its perspectives in Brazil including determination of the availability and characteristics of the agro-residues for briquetting. Wood residues, rice husk and coffee husk were characterized and identified as the more promising agro-residues for briquetting in the short-term in Brazil [39]. Yumak et al. (2010) used soda weed (*Salsola tragus*) as a rural fuel source for briquetting and found that moisture rates of 7–10%, pressure of 31.4 MPa, and temperatures of 85–105 °C were suitable for briquetting soda weed [40]. Ma et al. (2002) established a new briquetting technology to simplify the briquetting process and reduce energy consumption, by utilizing the linkage function of biomass fiber. Results show that briquetting pressure to fix the linkage of biomass fiber is no more than 120 MPa, and a higher pressure causes a negative effect. The reasonable lower limit of biomass content is about 15%. Biomass drying in the air for a certain period (water content is generally less than 12%) is suitable for briquetting using the new mechanism [41].

Finell et al. (2002) made RCG (reed canary-grass, *Phalaris arundinacea* L.) an interesting new source of raw material for the pulp and paper industry in northern Europe. Pulp produced from briquetted RCG had more fines as compared to the non-briquetted reference material. Hand sheets produced using pulp from briquetted RCG were thinner, denser, and had lower air permeability compared to the non-briquetted reference material. The strength properties of pulp made from briquetted RCG indicated little or no difference compared to the reference material [42].

A study on briquettes from biomass was performed by Yaman et al. (2001) in which a western Turkish lignite (Kütahya-Seyitömer) was blended with some biomass samples such as molasses, pine cone, olive refuse, sawdust, paper mill waste, and cotton refuse, and this blend was used in the production of fuel briquettes [43]. Paulrud and Nilsson (2001) investigated how spring-harvested reed canary-grass briquettes with various chemical compositions with respect to ash content influence the formation of emissions during combustion in a 180 kW burner. The combustion experiments imply that spring-harvested reed canary-grass can be burned with success in combustion equipment that is designed for the differences in ash content [44].

Ali Moral (2000) evaluated biomass briquetting of biomass residues like rice husk, rice straw, wheat straw, maize stalk, sawdust, bagasse, coconut coir and groundnut shell. These residues found in a variety of forms have high moisture content, low bulk residue, low heat release rate per unit volume and high transportation and storage costs when used as received [45].

3.1.1 Advantages Green waste Briquetting

Biomass briquettes offer many benefits over traditional fuels like coal, fuel oil, natural gas and propane as well as over the pre-compacted raw materials like wood chips, paper, green wood etc.

- The purchase price of biomass briquettes is less than natural gas, propane and fuel oil.
- Compacting biomass waste into briquettes reduces the volume by 10 times, making it much easier to store and transport.
- They have a long shelf-life.
- Briquettes are immeasurably cleaner than the other fuel alternatives.
- Briquettes burn in a controlled manner, slow and efficiently [46] .
- Product has consistent quality, burning efficiency also ideally sized for complete combustion.
- It helps to solve the problem of residue disposal.
- It is one of the alternatives to save the consumption and dependency on fuel wood.
- The technology used is pollution free and eco-friendly [83].

3.1.2 Disadvantages

- High investment cost.
- High maintenance cost [47].

3.2 Cellulosic ethanol from green waste

Green waste is a popular cellulosic material for ethanol production. As world reserves of petroleum are depleting fast, in recent years ethanol has emerged as most important alternative resource for liquid fuel and has generated a great deal of research interest. The research on improving ethanol production has been accelerated for both ecological and economical reasons, mainly for its use as an alternative to petroleum based fuels. The most abundant organic raw material in the world is lignocellulosic biomass; production of ethanol from renewable lignocellulosic resources may improve energy availability. Utilization of these wastes will reduce dependency on foreign oil and secondly, this will remove disposal problem of wastes and make environment safe from pollution [48]. Pretreatment is prerequisite to make lignocellulosic biomass accessible to enzymatic attack (either by microorganisms or enzymes), by breaking the lignin seal, removing hemicellulose, or disrupting the crystalline structure of cellulose. Pretreatment alters the structural features of biomass which are classified as physical or chemical. The chemical structural features involve the compositions of cellulose, hemicellulose, lignin, and acetyl groups bound to hemicellulose whereas physical structural features include the accessible surface area, the crystallinity, and the physical distribution of lignin in the biomass matrix, the degree of polymerization, the pore volume, and the biomass particle size [49].

Production of ethanol from green waste has the abundant and diverse raw material compared to sources like corn and cane sugars, but requires a greater amount of processing such as physical and chemical fiber pre-treatments including: grinding, pyrolysis, steam explosion, ammonia fiber explosion, CO_2 explosion, ozonolysis, acid hydrolysis, alkaline hydrolysis, oxidative delignification, organic solvent and biological pretreatment of the lignocellulosic materials to remove lignin and hemicellulose and reduce fiber crystallinity [50].

Jutakanoke et al. (2012) investigated the susceptibility of sugarcane leaves to cellulase hydrolysis by GC220 cellulase in the presence of either dilute sulfuric acid or lime. The acid pretreated samples released more glucose than the lime treated ones (5.7% and 3.9% weight by weight (w/w, DS), respectively). Fermentation of the obtained glucose sources by *Saccharomyces cerevisiae* for 12 and 24 h, respectively, yielded ethanol at 4.8% and 8.0% (w/w, DS), respectively[51]. Xu et al. (2011) demonstrated

Bermuda grass as a promising feedstock for the production of fuel ethanol. A variety of chemical, physico-chemical, and biological pretreatment methods have been investigated to improve the digestibility of Bermuda grass with encouraging results [52]. Romero-Anaya et al. (2011) investigated phosphoric acid activation at 450 °C of recalcitrant biomass originated in ethanol production from banana plants. The results are quite reproducible, showing good porosity developments and a strong dependence on the precursor, the H_3PO_4 concentration and the H_3PO_4/sample weight ratio used [53].

Gabhane et al. (2011) tested the influence of heating source (Hot plate (HP), Autoclave (AC) & Microwave (MW) for their efficiency to pretreat garden biomass (GB).The results indicated that all three heating devices are useful for pretreatment, however, the efficiency of MW on GB was found be better than AC and HP. A maximum of 53.95% of cellulose recovery was obtained in case of MW heating along with 46.97% of reducing sugar yield. This when compared to AC and HP is significantly higher (more than 10% increase) and time saving (only 15 min reaction time) as well [54].

Behera et al. (2010) carried out the batch fermentation of mahula (*Madhuca latifolia* L. a tree commonly found in tropical rain forest) flowers using immobilized cells (in agar-agar and calcium alginate) and free cells of *Saccharomyces cerevisiae*. The ethanol yields were 151.2, 154.5 and 149.1 g kg^{-1} flowers using immobilized and free cells, respectively [55]. Kaparaju et al. (2009) investigated the production of bioethanol, biohydrogen and biogas from wheat straw within a biorefinery framework. Initially, wheat straw was hydrothermally liberated to a cellulose rich fiber fraction and a hemicellulose rich liquid fraction (hydrolysate). Enzymatic hydrolysis and subsequent fermentation of cellulose yielded 0.41 g-ethanol/g-glucose, while dark fermentation of hydrolysate produced 178.0 ml-H_2/g-sugars [56].

Felix and Tilley (2009) studied on integrated energy, environmental and financial analysis of ethanol production from cellulosic switchgrass [57]. Hamelinck et al. (2005) evaluated the state of the art of hydrolysis-fermentation technologies to produce ethanol from lignocellulosic biomass, which is based on dilute acid hydrolysis, has about 35% efficiency from biomass to ethanol. The overall efficiency, with electricity co-produced from the not fermentable lignin, is about 60%. Improvements in pre-treatment and advances in biotechnology, especially through process combinations can bring the ethanol efficiency to 48% and the overall process efficiency to 68% [58].

3.2.1 Advantages of green waste cellulosic ethanol production

- Renewable transportation fuel.
- The raw material for cellulose ethanol production is plentiful as cellulose is present in every plant [59].
- Cellulosic ethanol exhibits net energy content three times higher than corn ethanol.

3.2.2 Disadvantages

- Requires a greater amount of processing.
- High cost of cellulose enzymes is the key barrier to economic production of cellulosic ethanol.

3.3 Bioplastics

Bioplastics is the designation for innovative plastics manufactured from regenerative raw materials. They can replace the previously used fossil plastics and plastic materials in many applications. Apart from wood, cellulose is the most significant renewable resources in terms of quantities; around 1.3 billion tones are annually harvested for technical applications world-wide. However, chemical processes are necessary to separate the cellulose fibers from undesired by-products such as lignin and pentoses. Cellulose has potentials in the production of plastics. For example, cellulose esters are amorphous thermoplastics which contain special plasticizers or are modified with other polymers. They are characterized by high toughness and are often used as polymer components in compounds with other bioplastics [60].

Striving to achieve cost-competitive biomass-derived materials for the plastics industry, the incorporation of starch (corn and potato) to a base formulation of albumen and glycerol was considered. Gonzalez-Gutierrez et.al. (2010) studied the effects of formulation and processing, albumen/starch-based bioplastics containing 0–30 wt. % starch were prepared by thermo-plastic and thermo-mechanical processing. Consequently, albumen biopolymers may become a biodegradable alternative to oil-derived plastics for manufacturing transparent packaging and other plastic stuffs [61].

Yu and Stahl (2008) utilized sugarcane bagasse for production of biopolyster. Sugarcane bagasse was pretreated in dilute acid solution, releasing sugars and other hydrolysates. Poly (3-hydroxybutyrate) was the predominant biopolyester formed on the hydrolysates, but the cells could also synthesize co-polyesters that exhibit high ductility [3].

3.3.1 Advantages of bioplastics from green waste

- Independence – Bioplastic is made from renewable resources: corn, sugarcane, switchgrass, soy and other plant sources as opposed to common plastics, which are made from petroleum.
- Energy efficiency – Production uses less energy than conventional plastics.
- Safety – bioplastic also generates 68% fewer greenhouse gasses and contains no toxins [62].
- Bioplastics reduces global warming, pollution and dependence on fossil fuels.
- It represents 42% reduction in carbon footprint as per studies.
- Bioplastics can be made from agricultural by products, from used plastics bottles and other containers using microorganisms.

3.3.2Disadvantages

- Bioplastics are not currently proved to be more sustainable than petrol-based plastics.
- Technically, bioplastics could be recycled but would then require being part of a separate collection and having enough quantity of good quality recyclable waste, recycling infrastructure and sustainable outlet.
- Biological degradation without the required conditions (micro-organism, temperature and humidity) is very slow and can last several years [63].

3.4 Biohydrogen production

In accordance with sustainable development and waste minimization issues, bio-hydrogen gas production from renewable sources, also known as "green technology" has received considerable attention in recent years. Recent reviews on hydrogen indicated that the worldwide need on hydrogen is increasing with a growth rate of nearly 10% per year for the time being [64] and contribution of hydrogen to total energy market will be 8-10% by 2025[65].Due to increasing trend of hydrogen demand, development of cost effective and efficient hydrogen production technologies has gained significant attention. Although being an abundant and almost zero cost feedstock green waste do not contain easily fermentable free sugars, but complex carbohydrate polymers, i.e. cellulose and hemicellulose, which are tightly bonded to lignin. Thus, their biotransformation to hydrogen is not an easy task in most cases. Even in the case that cellulolytic microorganisms are used for fermentative hydrogen production, residues have to be subjected to some kind of pretreatment, so that their delignification and the subsequent loosening of the structure of cellulose and hemicellulose can be achieved, facilitating thus the subsequent liberation and uptake of sugars [84].

Keskin and Hallenbeck (2012) did a comparative study on photofermentative biohydrogen production from beet molasses, black strap, and sucrose. With yields of 10.5 mol H_2/mol sucrose for beet molasses (1 g/l sugar); 8 mol H_2/mol sucrose for black strap (1 g/l sugar) and 14 mol H_2/mol sucrose for pure sucrose. One stage photofermentation system appears promising over two-stage systems [66]. Cui and Shen (2012) studied the effects of acid (HCl) and alkaline (NaOH) pretreatments on saccharification of grass and subsequent microbial hydrogen production at 35 °C and initial pH 7.0. Results showed that the saccharification efficiency and hydrogen production from grass pretreated by acid and alkali were higher than those from unpretreated grass and that acid pretreatment was better than alkaline pretreatment for enhancing the hydrogen yield from grass [67].

Lignocellulosic biomass contains approximately 70–80% carbohydrates. If properly hydrolyzed, these carbohydrates can serve as an ideal feedstock for fermentative hydrogen production. Nasirian et al. (2011) investigated the effects of various sulfuric acid pretreatments on the conversion of wheat straw to biohydrogen. Simultaneous saccharification and fermentation method proved to be the most effective and economical way to convert wheat straw to biohydrogen, whereas Foglia et al. (2010) did the integrated study on a two-stage fermentation process of biomass residues for the production of biohydrogen [68],[69].

Cui et al. (2010) carried out batch experiments to convert poplar leaves pretreated by different methods into hydrogen using anaerobic mixed bacteria at 35 °C. The results showed that enzymatic pretreatment is an effective method for enhancing the hydrogen yield from poplar leaves [70]. The bio-hydrogen generation potential of sugar industry wastes was investigated by Ozkan et al. (2010).In the first part, acidogenic anaerobic culture was enriched from the mixed anaerobic culture (MAC) through acidification of glucose and in the second part glucose acclimated acidogenic seed was used, along with the indigenous microorganisms, MAC, 2-bromoethanesulfonate treated MAC and heat treated

MAC. Reactors with initial COD concentration of 4.5 g/L had higher H_2 yields (20.3–87.7 mL H_2/g COD) with minimum methanogenic activity, than the reactors with initial COD concentration of 30 g/L (0.9–16.6 mL H_2/g COD) [71].

Sarkar and Kumar (2010) considered forest residues (limbs, tops, and branches) and straw (from wheat and barley) for producing biohydrogen in Western Canada for upgrading of bitumen from oil sands. Two types of gasifiers, namely, the Battelle Columbus Laboratory (BCL) gasifier and the Gas Technology Institute (GTI) gasifier are considered for biohydrogen production. Carbon credits of $119 and $124/tonne of CO_2 equivalent are required for biohydrogen from forest and agricultural residues, respectively [72].

Ivanova et al. (2009) utilized air-dried samples of sweet sorghum, sugarcane bagasse, wheat straw, maize leaves and silphium without chemical pretreatment as sole energy and carbon sources for H_2 production by the bacterium *Caldicellulosiruptor saccharolyticus*. The best substrate was wheat straw, with H_2 production capacity of 44.7 L H_2 (kg dry biomass)$^{-1}$ and H_2 yield of 3.8 mol H_2 (mol glucose)$^{-1}$. Acidogenic fermentation of vegetable based market waste to harness biohydrogen was demonstrated by Mohan et al. (2008). The waste was evaluated as a fermentable substrate for hydrogen (H_2) production with simultaneous stabilization by dark-fermentation process using selectively enriched acidogenic mixed consortia under acidophilic microenvironment. Experiments were performed at different substrate/organic loading conditions in concurrence with two types of feed compositions (with and without pulp). Higher H_2 production and substrate degradation were observed in experiments performed without pulp (23.96 mmol/day(30.0 kg COD/m^3); 13.96 mol/kg COD_R (4.8 kg COD/m^3)) than with pulp (22.46 mmol/day (32.0 kg COD/m^3); 12.24 mol/kg COD_R (4.4 kg COD/m^3) [73],[74].

Similarly Zhang et al. (2007) reported biohydrogen production from the cornstalk wastes with acidification pretreatment. The test results showed that the acidification pretreatment of the substrate plays a crucial role in conversion of the cornstalk wastes into biohydrogen gas by the cow dung composts generating hydrogen [75]. Antonopoulou et al. (2007) produced hydrogen from sorghum extract using mixed acidogenic microbial cultures, coming from the indigenous sorghum microflora and *Ruminococcus albus*, The highest hydrogen yield obtained from sorghum extract fermented with mixed microbial cultures in continuous system was 0.86 mol hydrogen per mol of glucose consumed, at a hydraulic retention time of 12 hours. On the other hand, the hydrogen yield obtained from sorghum extract treated with *R. albus* was as high as 2.1-2.6 mol hydrogen per mol of glucose consumed [76]. Hanaoka et al. (2005) obtained hydrogen from woody biomass at a much lower pressure compared to other carbonaceous materials such as coal and heavy oil in steam gasification using a CO_2 sorbent. H_2 yield increased with increasing reaction temperature. Cellulose is the major constitute of plant biomass and highly available in agricultural wastes [77]. Hydrogen gas production potential from microcrystalline cellulose was determined as 2.18 mol H_2/mol cellulose with 12.5 g/L cellulose concentration at mesophilic conditions [78].

Liu et al. (2003) reported the maximum hydrogen yield of 102 ml/g cellulose which is only 18% of the theoretical yield. Low yield was explained as partial hydrolysis of cellulose [79]. Utilization of cellulose hydrolysate provided 4.10 mmol/h H_2 production rate [80]. Similarly, production of hydrogen gas was higher from hydrolysate of Avicel cellulose or xylan than that of pure xylose or glucose [81].

3.4.1 Advantages of hydrogen production using green waste

- Hydrogen is a clean energy with zero emissions when burned and an efficient energy carrier.
- Lignocellulosic residual remains from large sources of biomass on which production of 2nd generation hydrogen can be based.

3.4.2 Disadvantages

- Cost of production and cost of storage are high, not an economical process.
- Flammability hazard
- Storage problem.
- Major limitation of hydrogen production from biomass and wastes, however, remains the relatively low rates and yields of hydrogen generation.

4. Conclusion

In serious consideration of the environmental issues associated with the dumping of the green wastes, search for suitable alternatives to deal with the wastes is in progress worldwide. Researchers have been showing their interest in biomass based fuels as it provides energy and reduces the effects on environment. Bio resources are available in the form of foliage, plant residues, fallen flowers, garden refuse, leaf litter, cut grass, residues of pruning, weeds and other organic matter discarded from gardens and greeneries which can be processed and converted into various forms of energies that can be used as fuels. Processing and valorization of green waste would reduce the quantity of green waste reaching dumping sites or burned open. The environmental consequences of improper green waste disposal can also be minimized through processing green waste for value added product generation. Although these options seem to be useful, cost effectiveness and compatibility of these processes in large scale is the major concern. Further research is necessary to make these processes efficient and economically viable for converting green wastes into valuable products.

References:

[1] Tai, Hua-Shan., & He, Wei-Hsiung, A novel composting process for plant wastes in Taiwan military barracks, Resources, Conservation and Recycling, 51, 408–417, 2007.

[2] Singh, Y., Waste biomass to energy, Environment and waste management; 2010. www.wealthywaste.com/waste-biomass-to-energy

[3] Yu, Jian., & Stahl, Heiko.,Microbial utilization and biopolyester synthesis of bagasse hydrolysates, Bioresource Technology, 99 (17), 8042-8048, 2008.

[4] Gajalakshmi, S., Ramasamy, E.V.,& Abbasi, S. A., Composting–vermicomposting of leaf litter ensuing from the trees of mango (Mangifera indica),Bioresource Technology, 96, 1057–1061, 2005.

[5] Singh Jasvinder, & Gu Sai, Biomass conversion to energy in India—A critique, Renewable and Sustainable Energy Reviews, 14, 1367–1378, 2010.

[6] Wyman, C.E., & Goodman, B.J., Biotechnology for production of fuels, chemicals,and materials from biomass, Applied Biochemistry and Biotechnology, 39, 39–59, 1993.

[7] Jacobus P. H., & Van Wyk,.Biotechnology and the utilization of biowaste as a resource for bioproduct development, Trends in Biotechnology,19, 5; 2001.

[8] Cofie Olufunke., & A. Adams, Bradford Organic Waste Reuse for Urban Agriculture. Case study of Ouagadougou city in Burkina Faso, 2006.

[9] Haung, G.F., Fang, M., Wu, Q.T., Zhou, L.X., Liao, X.D., & Wong, J.W.C., Co-composting of pig manure with leaves, Environmental technology, 22, 1203-1212, 2001.

[10] Komilis, Dimitris P., & Ham, Robert K., The effect of lignin and sugars to the aerobic decomposition of solid wastes, Waste Management, 23, 419–423, 2003.

[11] Cheung, H.N.B., Huang, G.H., & Yu, H.,Microbial-growth inhibition during composting of food waste: Effects of organic acids, Bioresource Technology,101, 5925-5934, 2010.

[12] Barrington, S., Choiniere, D., Trigui, M., & Knight, W., Effect of carbon source on compost nitrogen and carbon losses, Bioresource Technology, 83, 189–194, 2002.

[13] Barrington, S., Choiniere, D., Trigui, M., & Knight, W.,Compost convective airflow under passive aeration. Bioresource Technology, 86, 259–266, 2003.

[14] Bari, Q. H., & Koenig, A, Effect of air recirculation and reuse on composting of organic solid waste. Resources, Conservation and Recycling, 33, 93–111, 2001.

[15] Chanakya, H. N., Ramachandra, T. V., Guruprasad, M., & Devi Vinuta,Micro-treatment options for components of organic fraction of MSW in residential areas. Environ Monit Assess, DOI:10.1007/s10661-007-9711-5, 2007.

[16] Rihani, Mohammed., Malamis, Dimitri., Bihaoui, Bouchra., Etahiri, Samira., Loizidou, Maria.,& Assobhei, Omar., In-vessel treatment of urban primary sludge by aerobic composting, Bioresource Technology, 101(15), 5988-5995, 2010.

[17] Kumar, Mathava., Ou, Yan-Liang., & Lin, Jih-Gaw, Co-composting of greenwaste and food at low C/N ratio, Waste management, 30 (4), 602-609, 2010.

[18] Kalamdhad, Ajay S., Singh, Yatish K., Ali, Muntjeer., Khwairakpam,& Meena.,Kazmi, A.A.,.Rotary drum composting of vegetable waste and tree leaves, Bioresource Technology,100, 6442–6450, 2009.

[19] Gajalakshmi, S., & Abbasi, S. A., Neem leaves as a source of fertilizer-cum-pesticide vermicompost. Bioresource Technology, 92, 291–296, 2004.

[20] Wong, J. W. C., Mak, K. F., Chan, N. W., Lam, A., Fang, M., Zhou, L. X., Wu, Q. T., & Liao, X. D., Co-composting of soybean residues and leaves in Hong Kong, Bioresource Technology,76, 99–106, 2001.

[21] Compost Guide. Tips for home composting http://compostguide.com/compost-materials/

[22] CPHEEO Manual on municipal solid waste management. Central Public Health and Environmental Engineering Organization, New Delhi, 2000.

[23] Alfayez Eng.khalid., Biological Treatment of Municipal Solid Waste. Training – Biogas Project.March-December, 2003.

[24] Shiralipour, Aziz., Dennis, B. Mcconnel.,& Wayne, H. Smith, Uses and benefits of MSW compost: a review and an assessment, Biomass and Bioenergy, 3, 267-279, 1992.

[25] Jagadabhi Padma, Shanthi., Kaparaju, Prasad.,& Rintala, Jukka.,Two-stage anaerobic digestion of tomato, cucumber, common reed and grass silage in leach-bed reactors and upflow anaerobic sludge blanket reactors, Bioresource Technology,102 (7) , 4726-4733, 2011.

[26] Kaparaju, Prasad., Serrano, María., & Angelidaki, Irini., Optimization of biogas production from wheat straw stillage in UASB reactor, Applied Energy, 87(12), 3779-3783, 2010.

[27] Prochnow, A., Heiermann, M., Plöchl, M., Linke, B., Idler, C., Amon, T.,& Hobbs, P.J., Bioenergy from permanent grassland–A review: 1.Biogas, Bioresource Technology,100 (21), 4931-4944, 2009.

[28] Lehtomaki, A., Huttunen, S., Lehtinen, T.M., & Rintala, J.A., Anaerobic digestion of grass silage in batch leach bed processes for methane production, Bioresource Technology, 99 (8), 3267-3278, 2008.

[29] Parawira, W., Murto, M., Zvauya, R.,& Mattiasson, B., Anaerobic batch digestion of solid potato waste alone and in combination with sugar beet leaves, Renewable Energy, 29 (11), 1811-1823, 2004.

[30] Yu, H. W., Samani, Z., Hanson, A., & Smith, G.,Energy recovery from grass using two-phase anaerobic digestion, Waste Management, 22, 1-5, 2002.

[31] Sharma, Archana., Unni Bala G.,& Singh, H. Devendra., A novel fed-batch digestion system for biomethanation of plant biomasses, Journal of Bioscience and Bioengineering, 87 (5), 678-682, 1999.

[32] Jagadish, K.S., Chanakya, H.N., Rajabapaiah, P., & Anand, V.,Plug flow digestors for biogas generation from leaf biomass, Biomass and Bioenergy,14 (5-6), 415-423, 1998.

[33] Gunaseelan, Nallathambi V., Anaerobic digestion of gliricidia leaves for biogas and organic manure, Biomass, 17(1), 1-11, 1988.

[34] Ghosh, S., Henry, M. P., & Christopher, R. W.,Hemicellulose conversion by anaerobic digestion, Biomass, 6, 257-269, 1985.

[35] Gunaseelan, Nallathambi V., Anaerobic digestion of biomass for methane production: a review, Biomass and Bioenergy, 13, 83-114, 1997.

[36] Veeken, Adrie., & Hamelers, Bert, Effect of temperature on hydrolysis rates of selected biowaste components, Bioresource Technology,69, 249-254, 1999.

[37] Klaus Fricke., Heike Santen., & Rainer Wallmann., Comparison of selected aerobic and anaerobic procedures for MSW treatment, Waste Management,25,799–810, 2005.

[38] Bhattacharya, S. C., Leon Augustus M., & Rahman Md. Mizanur., A Study on Improved Biomass Briquetting. Energy for Sustainable Development, 6(2), 67-71, 2002.

[39] Felfli Felix Fonseca., Mesa P Juan M.., Rocha, Jose´ Dilcio., Filippetto Daniele., Luengo, Carlos A.,& Pippo, Walfrido Alonso.,Biomass briquetting and its perspectives in Brazil. Biomass and Bioenergy, 35 (1), 236-242, 2011.

[40] Yumak, Hasan., Ucar, Tamer.,& Seyidbekiroglu, Nesim, Briquetting soda weed (Salsola tragus) to be used as a rural fuel source, Biomass and Bioenergy, 34 (5), 630-636, 2010.

[41] Ma, Yongliang., Xu, Kangfu., & Hao, Jiming.,An Experimental Study on Biomass Coal Briquetting Process. Proceedings of the 6th International Conference on Greenhouse Gas Control Technologies. Kyoto, Japan, pp.1829-1832,1 – 4 October, 2002.

[42] Finell, Michael., Nilsson, Calle., Olsson, Rolf., Agnemo, Roland.,& Svensson, Stefan.,Briquetting of fractionated reed canary-grass for pulp production. Industrial Crops and Products,16 (3), 185-192, 2002.

[43] Yaman, S., SahanSahan, M., Haykiri-Acma H., Sesen, K.,& Kucukbayrak, S.,Fuel briquettes from biomass–lignite blends,Fuel Processing Technology, 72 (1),1-8, 2001.

[44] Paulrud, Susanne., & Nilsson Calle, Briquetting and combustion of spring-harvested reed canary-grass: effect of fuel composition, Biomass and Bioenergy, 20 (1), 25-35, 2001.

[45] Moral, Nawsher Ali,. Briquetting of Biomass in Bangladesh.In: Renewable energy: the energy for the 21st century. World Renewable Energy Congress VI, Brighton, pp2402-2405,1-7 July, 2000.

[46] Sunomi, IIc. High Productivity Solutions for the North American Renewable Energy Market, Benefits of Biomass Briquettes; http://www.sunomi-llc.com/benefits.html

[47] Toan, Pham Khanh., Cuong, Nguyen Duc., & Leon Augustus M., Activities and Achievements of a Biomass Briquetting Project in Vietnam, 2005.

[48] Prasad, S., Singh, Anoop.,& Joshi, H. C., Ethanol as an alternative fuel from agricultural, industrial and urban residues, Resources, Conservation and Recycling, 50 (1), 1-39, 2007.

[49] Ntaikou, I., Antonopoulou, G., & Lyberatos, G., Biohydrogen Production from Biomass and Wastes via Dark Fermentation: A Review, Waste Biomass Valor, 1, 21–39, 2010.

[50] Sun, Y., & Cheng J.,Hydrolysis of lignocellulosic materials for ethanol production: a review, Bioresource Technology, 83, 1–11, 2002.

[51] Jutakanoke, Rumpa., Leepipatpiboon, Natchanun., Tolieng, Vasana., Kitpreechavanich, Vichien., Srinorakutara, Teerapatr.,& Akaracharanya, Ancharida.,Sugarcane leaves: pretreatment and ethanol fermentation by Saccharomyces cerevisiae, Biomass and Bioenergy, 39,283-289, 2012.

[52] Xu, Jiele., Wang Ziyu.,& Cheng Jay J.,Bermuda grass as feedstock for biofuel production: A review. Bioresource Technology, 102 (17), 7613-7620, 2011.

[53] Romero-Anaya, A.J., Molina, A., Garcia, P., Ruiz-Colorado, A.A., Linares-Solano, A., & Salinas-Martínez de Lecea C., Phosphoric acid activation of recalcitrant biomass originated in ethanol production from banana plants, Biomass and Bioenergy, 35 (3), 1196-1204, 2011.

[54] Gabhane, Jagdish., William, S.P.M. Prince., Vaidya, Atul Narayan., Mahapatra, Kalyani.,& Chakrabarti, Tapan., Influence of heating source on the efficacy of lignocellulosic pretreatment – A cellulosic ethanol perspective, Biomass and Bioenergy, 35 (1), 96-102, 2011.

[55] Behera, Shuvashish., Kar, Shaktimay Mohanty., Rama, Chandra., & Ray, Ramesh Chandra.,Comparative study of bio-ethanol production from mahula (Madhuca latifolia L.) flowers by Saccharomyces cerevisiae cells immobilized in agar agar and Ca- alginate matrices. Applied Energy, 87 (1), 96-100, 2010.

[56] Kaparaju Prasad., Serrano María., Thomsen Anne Belinda., Kongjan Prawit., & Angelidaki Irini.,Bioethanol, biohydrogen and biogas production from wheat straw in a biorefinery concept, Bioresource Technology, 100 (9), 2562-2568, 2009.

[57] Felix, Erika., & Tilley, David R., Integrated energy, environmental and financial analysis of ethanol production from cellulosic switchgrass, Energy, 34 (4), 410-436, 2009.

[58] Hamelinck, Carlo N., Hooijdonk, Geertje van., & Faaij, Andre PC., Ethanol from lignocellulosic biomass: techno-economicperformance in short-, middle- and long-term, Biomass and Bioenergy,28 (4),384–410, 2005.

[59] Cellulosic Ethanol, Research Report, July 2007. http://www.moraassociates.com/publications/0707%20Cellulosic%20Ethanol.pdf

[60] Jurgen,Lorcks..From Fachagentur Nachwachsende Rohstoffe e.V. (FNR),publicationsHofplatz 1 • 18276 Gülzow • Germany info@fnr.de • www.fnr.de,Bioplastics,1-24, 2006.

[61] Gonzalez-Gutierrez, J., Partal, P., García-Morales, M., & Gallegos, C., Development of highly-transparent protein/starch-based bioplastics, Bioresource Technology,101 (6), 2007-2013; 2010.

[62] Grinning Planet. http://www.grinningplanet.com/articles/trash-recycling/advantages-and-disadvantages-of-bioplastics.htm

[63] PRO EUROPE, Fact sheet on bioplastics, Packing recovery organization Europe, 2009.

[64] Winter, C.J., Into the hydrogen energy economy—milestones, Inter. J. of Hydrog Energy, 30, 681-685, 2005.

[65] Armor, J.N.,The multiple roles for catalysis in the production of H_2,Applied Catalysis A: General,176, 159-176, 1999.

[66] Keskin Tugba., Hallenbeck Patrick C.,Hydrogen production from sugar industry wastes using single-stage photofermentation,Bioresource Technology, 112,131-136, 2012.

[67] Cui, Maojin., & Shen, Jiaquan, Effects of acid and alkaline pretreatments on the biohydrogen production from grass by anaerobic dark fermentation ,International Journal of Hydrogen Energy, 37(1), 1120-1124, 2012.

[68] Nasirian, Nima., Almassi, Morteza, Minaei, Saeid.,& Widmann Renatus.,Development of a method for biohydrogen production from wheat straw by dark fermentation, International Journal of Hydrogen Energy, 36 (1), 411-420, 2011.

[69] Foglia Domenico,., Ljunggren, Mattias., Wukovits, Walter., Friedl, Anton., Zacchi, Guido., Urbaniec, Krzysztof., & Markowski, Mariusz., Integration studies on a two-stage fermentation process for the production of biohydrogen, Journal of Cleaner Production, 18,72-80, 2010.

[70] Cui, Maojin., Yuan, Zhuliang., Zhi, Xiaohua., Wei, Liling., & Shen Jianquan., Biohydrogen production from poplar leaves pretreated by different methods using anaerobic mixed bacteria. International Journal of Hydrogen Energy,35(9), 4041-4047, 2010.

[71] Ozkan, Leyla., Erguder, Tuba H., & Demirer, Goksel N., Investigation of the effect of culture type on biological hydrogen production from sugar industry wastes, Waste Management, 30 (5),792-798, 2010.

[72] Sarkar, Susanjib.,& Kumar, Amit., Biohydrogen production from forest and agricultural residues for upgrading of bitumen from oil sands, Energy,35 (2), 582-591, 2010.

[73] Ivanova Galina., Rákhely Gábor., Kovács Kornél L.,Thermophilic biohydrogen production from energy plants by Caldicellulosiruptor saccharolyticus and comparison with related studies, International Journal of Hydrogen Energy, 34 (9), 3659-3670, 2009.

[74] Mohan, S. Venkata., Mohanakrishna, G., Goud, R. Kannaiah.,& Sarma, P. N., Acidogenic fermentation of vegetable based market waste to harness biohydrogen with simultaneous stabilization, Bioresource Technology, 100 (12), 3061-3068, 2008.

[75] Zhang, Mao-Lin., Fan, Yao-Ting., Xing, Yan., Pan, Chun-Mei., Zhang, Gao-Sheng.,& Lay, Jiunn-Jyi, Enhanced Biohydrogen production from cornstalk wastes with acidification pretreatment by mixed anaerobic cultures, Biomass and Bioenergy,.31 (4), 250-254, 2007.

[76] Antonopoulou, G.,Ntaikou, I.,Gavala, H.N.,Skiadas, I.V.,Angelopoulos, K.,& Lyberatos,G,Biohydrogen production from sweet sorghum biomass using mixed acidogenic cultures and pure cultures of Ruminococcus albus. Global nest journal, 9 (2), 144-151, 2007.

[77] Hanaoka, Toshiaki., Yoshida, Takahiro., Fujimoto, Shinji., Kamei, Kenji., Harada, Michiaki., Suzuki, Yoshizo., Hatano, Hiroyuki., Yokoyama, Shin-ya.,& Minowa, Tomoaki, Hydrogen production from woody biomass by steam gasification using a CO_2 sorbent, Biomass and Bioenergy, 28 (1), 63–68, 2005.

[78] Lay, J.J.,Biohydrogen generation by mesophilic anaerobic fermentation of microcrystalline cellulose, Biotechnology and Bioengineering,74, 281-287, 2001.

[79] Liu, H., Zhang, T., & Fang, H.P.P., Thermophilic H_2 production from cellulose containing wastewater, Biotechnol. Letters, 25, 365-369, 2003.

[80] Taguchi, F., Yamada, K., Hasegawa, K., Saito-Taki, T., & Hara, K., Continuous hydrogen production by Clostridium sp. strain no. 2 from cellulose hydrolysate in an aqueous two-phase system, Journal of Fermentation and Bioengineering, 82, 180-183, 1996.

[81] Taguchi, F., Mizukami, N., Yamada, K., Hasegawa, K., & Saito-Taki, T., Direct conversion of cellulosic materials to hydrogen by Clostridium sp. strain no. 2, Enzyme Microbial Technology,17, 147-150, 1995.

[82] Composting – A Manure Treatment Technology http://www.arb.ca.gov/ag/caf/dairypnl/compovrvw.pdf

[83] Aerobic and Anaerobic Biodegradation. www.ensobottles.com/.../Aerobic%20Anaerobic%20Biodegradation_20090430.pdf

[84] AlternateFuels.Com. http://www.alternatefuels.com/hydrogen.htm

[85] Briquette,Wikipedia. en.wikipedia.org/wiki/ Briquette

[86] Economic and Environmental Manure Solutions, Cornell University, Department of Biological and Environmental Engineering, Ithaca, NY. Web Page http://www.bee.cornell.edu/extension/manure/composting.htm