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The 2nd Korea-Indonesia Workshop and International Symposium on Bioenergy from Biomass

"ACCELERATING RESEARCH ON BIOMASS BASED BIO-FUEL PRODUCTION ON LARGE SCALE"

National Research Council (DRN) Building, Puspiptek, Serpong, Banten, Indonesia, June 13 - 15th, 2012

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Conceptual Model of an Integrated Agricultural Residues Management

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Abstract. The demand of energy for transportation, industrial activity, and household usage is mostly supplied by fossil fuel. This type of fuel is non-renewable so its availability tends to decrease besides its negative impact on environment. Realizing this situation the Government of Indonesia has put emphasis on its national development strategy to search for alternative energy sources, especially those coming from sustainable resources. This paper presents a conceptual approach of integrated wastes management, which enables the utilization of agricultural residues as a source of bioethanol production more environmentally favorable within the economical and technological capabilities of developing countries. The development and the need for further research to realize the concept will be described, covering: (1) Development of bioreactor systems for bioethanol fermentation (design, start up, optimization and control), (2) Development of anaerobic wastewater treatment systems from bioethanol production, (3) Development of anaerobic digestion system of solid wastes from bioethanol production, (4) Nutrients recycling of anaerobically treated solid wastes from bioethanol production through composting, (5) Development of algal cultivation system grown on effluent of bioethanol production and its downstream processing, (6) Development of biodiesel production technology from algal biomass, (7) Systematic map of abundance and characterization of unused biomass for assessment and management of agricultural wastes, and (8) Design, piloting and assessment of an integrated system of bioenergy production and agricultural wastes management.

Keywords: agricultural residues, anaerobic treatment, bioenergy, bioethanol, integrated environmental management

1. Introduction

Only a very small portion of the agricultural plants is harvested as a product, the largest portion becomes by-products or wastes. The agricultural residues have the potential to pollute the environment. On the other side, the agricultural residues consist of organic material and a variety of nutrients or minerals that are essential for plants. Recycling of the organic matter, nutrients or minerals enables the recovery of these valuable materials in the forms of bioenergy and organic fertilizer. This will eventually lead to reduced use of inorganic fertilizers, increased agriculture productivity due to improved soil characteristics (physical, chemical and microbiological) as well as overcome environmental pollution associated with the biomass disposal. Such a practice will in the long run contribute to sustainable agricultural development, which is a demand for modern agricultural practices.

In the perspective of energy crisis situation, the Government of Indonesia has put emphasis on its national development strategy to search for alternative sources of energy, especially those coming from sustainable sources. Several pilot projects have been initiated recently for the development of biodiesel using crude palm oil (CPO) and development of bioethanol using cassava and molasses. The use of these types of resources has been felt competing with food production and potentially threatening the food security.

The abundance of agricultural residues in Indonesia exhibits a potential source of feedstock for production of renewable bio-based energy. The agricultural residues can be converted to ethanol by biological process. The potential yield of bioethanol from lignocellulosic materials varies significantly among feedstocks. Mabee and Saddler (2010) reported that hydrolysis resulted in yields of between 0.5 and 0.75 g sugars/g cellulose on feedstocks that include also agricultural residues (corn stover). Fermentation of these sugar fractions can result in ethanol yields of 95% of the theoretical maximum, which is 0.51 g ethanol/g sugar. It has been demonstrated that variations in sub-process design has a large impact on total yields. The bioconversion of C6 sugars through separate hydrolysis and fermentation (SHF) and simultaneous saccharification and fermentation (SSF) yielded sugars between 0.61 and 0.86 g/g cellulose, respectively. It can be expected that bioethanol yields from agricultural residues have a potential in the range of between 0.11 and 0.27 m^3/t, while wood residues could deliver bioethanol yields between 0.12 and 0.30 m^3/t (dry basis, given that the density of 100% ethanol is 790 kg/m^3).

Detailed reviews have been published on the theme of lignocellulosic biomass utilization and bioethanol production. These cover different key related issues, such as state of the art in bioethanol production from lignocellulosic biomass from a process engineering point of view (Cardona and Sanchez, 2007), bioethanol production technologies from different feedstocks (Sims *et al.* 2010; Mabee and Saddler, 2010; Gnansounou, 2010; Binod *et al.* 2010; Hashem and Darwish, 2010), prospects, challenges and feedstock availability (Sukumaran *et al.* 2010), and techno-economic analysis of lignocellulosic ethanol (Gnansounou and Dauriat, 2010).

The aim of this paper is to introduce a conceptual approach of wastes management in order to make the utilization of agricultural residues as source of bioethanol more economically and environmentally favorable and creates a win-win situation for environmental management within the economical and technological capabilities of developing countries. This paper also points out the research and development areas needed to support the realization and the implementation of the proposed integrated system of agricultural waste management.

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2. Proposed Conceptual Model of Integrated Agricultural Residues Management

Fig. 1 shows the schematic diagram of the proposed model of integrated agricultural residues management. In this concept, unused agricultural biomass is converted into bioenergy (bioethanol). Solid and liquid wastes generated from the bioethanol production process are treated anaerobically to produce biogas. Solid residue (digestate) from the anaerobic digestion of the solid wastes and the excess sludge from the anaerobic treatment of the wastewater is composted to recycle their organic matters and nutrients, whereas the leachate out of this composting process is used as liquid fertilizer. Nutrients (N, P) in the anaerobically treated wastewater are recovered by using the effluent as media for microalgal cultivation. The harvested microalgal biomass is then processed to produce biodiesel and bioethanol.

To earn the benefits from the proposed approach, however, further comprehensive and systematic research works are still needed, not only focusing on the optimization of the bioethanol conversion itself but also on the potential utilization of all corresponding biomass-ethanol by-products in an integrated resource management system. The selection of the best design for lignocellulose to bioethanol conversion technology should be decided on the basis of technical feasibility (high energy efficiency), overall economic viability (lowest cost), and environmental consideration (lowest pollutant load).

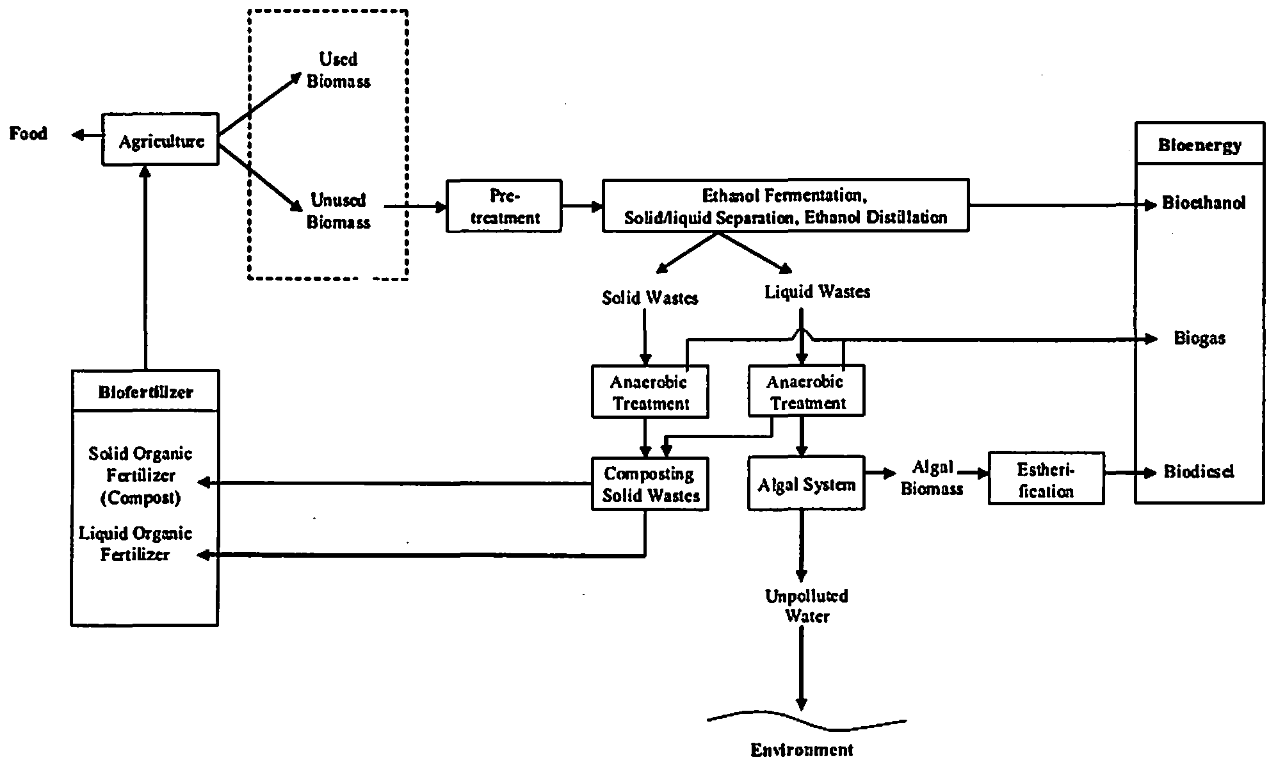

Fig. 1. A schematic diagram of the conceptual model of an integrated agricultural residues management

The following paragraphs describe the progression of the continuing research works related to each area of the proposed model and the identified strategic research and development programs that are considered to be essential to support the successful implementation of the proposed system.

3. Research Advancement and the Identified Works Needed

3.1. Development of Bioreactor Systems for Bioethanol Fermentation

Bioethanol has been identified and portrayed as an alternative for ensuring energy security in future fuel interests and global requirements. The important aspect of choosing the bioethanol option is its benefit to the environment. Bioethanol is one of the best tools to fight vehicular pollution; its clean burning reduces the harmful gasses and particulate emissions that pose health hazard. The implementation of bioethanol policy can be helpful in improving environment and rural economic development with sustainable agricultural practices (Chandel *et al.* 2007).

To be competitive and find economic acceptance, the cost for bioconversion of biomass to the liquid fuel must be lower than the current gasoline prices. This is becoming more attainable because of increasing efforts of researchers working towards better efficiency to bring down the cost of biomass-to-ethanol conversion. The cost of feedstock and cellulolytic enzymes are two important parameters for low cost ethanol production. The choice of feedstock determines the economic viability of ethanol production because of its availability and the ongoing uses.

It is also necessary to find out the lowest cost route for biological conversion of cellulosic biomass to ethanol with high ratel and desired yields. In this respect the technology development and process optimization play a determining role, covering optimization of the four major unit operations: pretreatment, hydrolysis, fermentation and product separation/distillation. Pretreatment and fermentation of cellulosic biomass in cost effective manner are major challenges of cellulose to ethanol technology research and development. The choice of most suitable pretreatment and process will depend upon type of biomass, the kinetic properties of microorganisms and type of lignocellulosic hydrolysate in addition to process economics aspects (Hsu *et al.* 2011; Talebnia *et al.*, 2010).

Current research and development are mostly addressed to process optimization of ethanol production from agricultural products or by-products such as sugar (molasses), corn, and cassava. It is still lack of information about criteria for designing and optimization of bioreactor systems for bioethanol production from agricultural residues. For a flourishing bioethanol industry, support in the forms of R&D work and pilot projects on lignocellulosic bioethanol is of particular important. Advances in pretreatment coupled with the recent development of genetically engineered microorganism that ferment all possible sugars in biomass to ethanol at high yield and productivity are the major key factors to make bioethanol program successful at commercial scale.

In order to fulfill the requirements, suitable bioreactor systems should be developed, covering batch, fed batch and continuous fermentation. It is necessary to select the most suitable bioreactor system and its optimum operating conditions for bioethanol fermentation, covering substrate concentration, dilution rate, agitating rate and duration of fermentation. The expected outputs from the works should cover established design criteria of bioreactor systems, quantified effect of key operating conditions on reactor performance, and formulated recommendation on bioreactor system and its optimum operating conditions. In addition, experiments are worthy conducted using improved pentose metabolic ability of yeast by mutation and gene recombination with different types of substrates, substrate pretreatment, and microorganisms or enzymes.

3.2. Anaerobic Treatment of Wastes from Biomass-Ethanol Production

3.2.1. Treatment of Wastewater from Bioethanol Production

Wastewater remaining after distillation of bioethanol (stillage) exhibits a considerable pollution potential. Most of the components in the stillage of ethanol production from lignocellulosic materials originate basically from the soils on which these materials are grown, and therefore should be returned to soil. However, application of untreated stillage to standing pasture can result in phytotoxicity. The residual water is unstable; it contains significant amounts of organic compounds such as acetic acid, furfural, and hydroxymethyl furfural, residual sugars, and other components, which need to be treated before its disposal into the environment. The presence of inhibitors, such as hardwood extractives associated with phenolic compounds present in the feedstock, results in low biodegradability of the wastewater.

Biodegradation of organic material is basically an enzymatic process. The low biodegradability can be understood as a result of unavailability of enzyme or specialist microorganisms that are capable to live actively in such a condition. In addition, adaptation of the specific microorganisms requires considerably longer time. For this reason, to decompose the organic substances following requirements are necessary: i) to maintain specific microorganisms in a suitable bioreactor system, ii) to improve the concentration of microorganisms, and iii) to increase contact time between pollutants and microorganisms. Aerobic or anaerobic bioreactor system can be principally designed to fulfill the requirements.

Considering its practicality and operational costs, anaerobic systems seem more favorable to be developed for effluent treatment with high concentration of phenolic compounds, for example the systems operated according to the Principe of Up flow Anaerobic Sludge Blanket (UASB) and Anaerobic Fluidized Bed Reactor (AFBR). The biofilm technology has been widely investigated and developed for treatment of various types of wastewater because of its advances compared with other anaerobic systems. The biofilm formation makes it possible to increase biomass concentration of up to 50 g/L, so that bioreactor capability can be improved dramatically. Organic load can be increased up to 5-15 kg COD/m^3.d for UASB and 15-30 kg/m^3.d for AFBR, much higher than organic load of conventional system that is only about 1-5 kg COD/m^3.d (Moletta, 2005; Qureshi *et al.* 2005).

Nevertheless, research work specifically addressed to treat effluent of bioethanol production from lignocellulosic materials is still limited. Research activity is needed to provide an economically viable solution for the treatment of wastewater from bioethanol production of lignocellulosic biomass, with specific objectives: i) To determine the wastewater characteristics with respect to organic content and by-product inhibitors on methane fermentation (such as COD, BOD, total suspended solids/TSS, total dissolved solids/TDS, total nitrogen, phosphate, lignin, and phenolic compounds), ii) to evaluate influence and control of by-product inhibitors on methane fermentation, iii) to evaluate performance of anaerobic treatment systems through biokinetic parameter determination and biogas production rate, iv) to design, start-up and optimize a suitable anaerobic treatment system based on experimental data and simulation, and v) to evaluate the system stability towards hydraulic as well as concentration shock load situations.

The developed bioreactor system should be evaluated in terms of organic load, effluent quality, organics removal, and specific biogas production rate. These performance parameters are influenced by some factors, such as wastewater characteristics, reactor system configuration, and operating conditions (biomass concentration, cell retention time, hydraulic retention time, and organic loading rate). The relationship between reactor performance and these factors should be investigated in order to obtain optimum design parameters and operating conditions of the bioreactor system.

3.2.2. *Treatment of Solid Waste from Bioethanol Production*

Similar to the anaerobic bioreactor systems developed for the wastewater treatment, it is beneficial to develop anaerobic digestion systems for stabilization of solid wastes from bioethanol production. The stabilization process may eliminate organic material that causes odor problems. The stabilization process is also to make the further handling easier and it utilization possible. Anaerobic digestion process is developed mainly with the reason of energy conservation, energy recovery, and utilization of sludge. The anaerobic digestion system may be designed based on mean cell retention time concept, volumetric load, and volume reduction. Stability level of treated sludge may be determined by placing sludge into a vessel for some days. Organic acids (acetic acid, formic acid, etc) formed under anaerobic condition is then measured. Lower stability of sludge, higher organic concentration is contained in sludge and more organic acids are formed. The stability testing is stopped after 10 days. Sludge with acetic acids concentration of ≤ 35 mg/g can be considered as stable (Roedinger and Kapp, 1990).

In the case of anaerobic wastewater treatment, organic materials are converted to biogas with main content of methane (50-70%vol.) and carbon dioxide (30-40%vol.). An approximate of 0.39 m^3 of methane can be produced from one kilogram of COD eliminated. The caloric value of biogas is 16,000-20,000 kJ/m^3, about 60-80% of caloric value of natural gas (Hutzler, 2004). Similarly, utilization of organic solid wastes of bioethanol production can be considered as an alternative for reducing the energy consumption and environmental problems. Fig. 2 shows a schematic diagram of negative impacts of biomass-ethanol production and alternative solution through anaerobic treatment of the liquid or solid wastes. Current trend indicates an increasing attention on the utilization of organic materials as source of biogas production (Geissen, 2008).

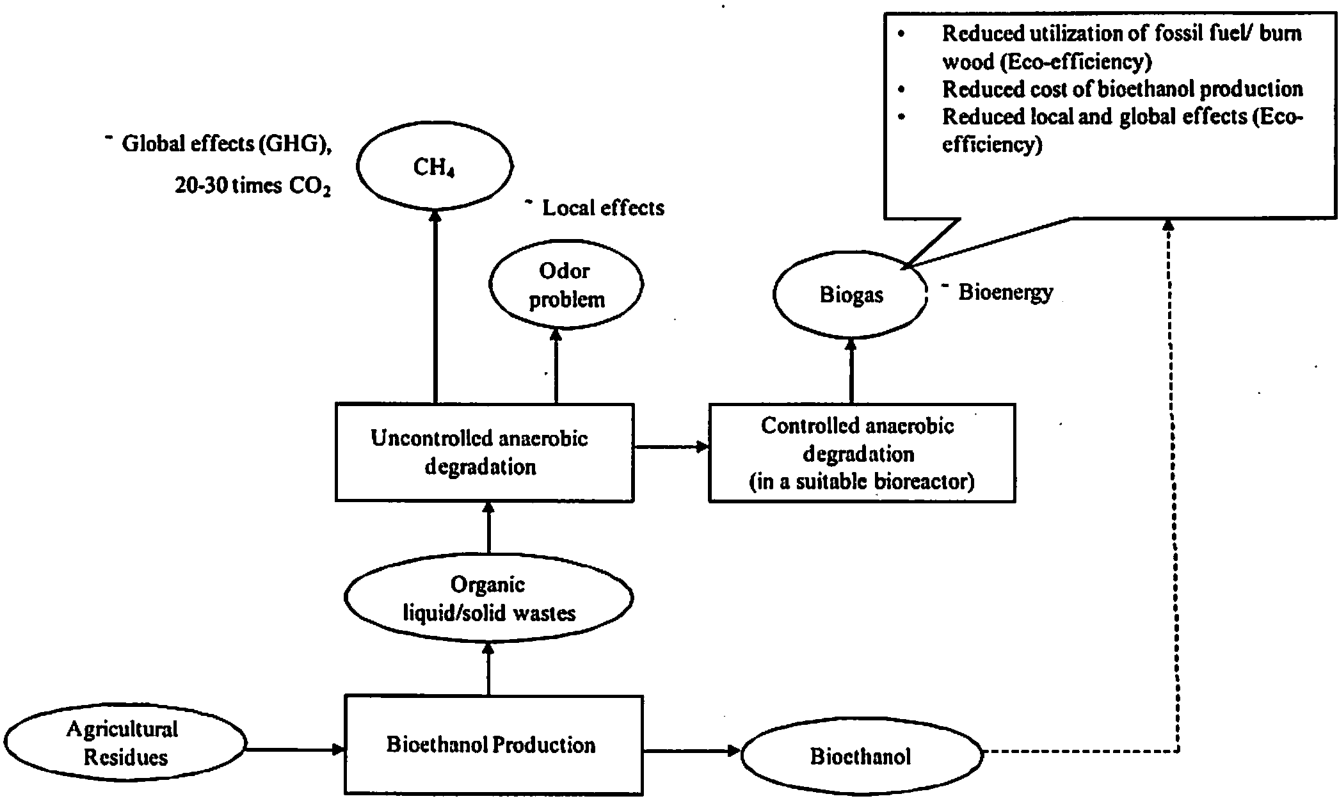

Fig. 2. A schematic diagram of negative impacts of biomass-ethanol production and alternative solution through anaerobic treatment of the liquid and solid wastes

In order to develop an economically viable solid wastes generated from lignocellulosic-bioethanol production, following information is considered valuable: i) Characteristics of solid wastes from bioethanol production, including their biodegradability and associated potential by-product inhibition on methane fermentation, ii) Influence and control of by-product inhibitors on methane fermentation, iii) Kinetics parameters and overall digester performance, including biogas production rate, iv) optimized design parameter and operating conditions derived from simulation and experiments, as well as v) Analysis of cost/benefit of the recycling system in terms of including economical and environmental aspects.

3.3. *Development of Method for Recycling Organic Matters and Nutrients*

Treatment of both solid waste and wastewater of lignocellulosic-ethanol production by anaerobic process generates digestate and bacterial sludge, respectively. These materials are not stable; therefore need to be stabilized by composting before applying for agricultural

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purposes. Products of composting are stable solid organic fertilizer (compost) and liquid organic fertilizer that contain valuable organics and nutrients which are mostly essential for plants. In this way, organics and nutrients contained in the materials are recycled back properly to soil.

In the long term the nutrient recycling method may protect environment and, at the same time, improve soil structure, reduce soil degradation, as well as improve growth and productivity of agricultural crops. This will certainly contribute to the development of sustainable agriculture. The idea behind nutrient recycling and the corresponding research activities needed are illustrated in Figs. 3 and 4.

By using nutrients contained in the organic fertilizer, synthetic fertilizer demand can be reduced. The N and P in the fertilizers are in organic form and are not all readily available to plants. When it is applied to land, part of the organic nitrogen will be mineralized or biologically converted into ammonium (NH_4^+), nitrate (NO_3^-), or both to become available to plants over time.

Composting of sludge does not remove organic matter completely. Organic matter is still remained in the compost and the liquid fertilizer in certain concentration. Depending on the degree of composting, the compost may contain up to 30 percent of organic carbon. Organic matter in low concentration improves soil structure and the workability of most soils. In sandy soil, organic matter increases the soil's ability to hold water. In clayey soil, organic matter opens up the soil to allow better air and water movement into and through the soil. Organic matter also improves water retention, permits easier root penetration, and reduces water runoff and soil erosion (Suprihatin, 2004).

Land application programs usually involve application to agricultural cropland, although applications to forests and turf have been used. Sludge applications increase the organic matter and fertility of poor soils and are especially beneficial to reclaimed land damaged from mining, other excavation activities, or soils damaged by erosion. Much of the nitrogen in wastewater solids is bound up with organic molecules which undergo chemical changes before becoming available to plants. Because these chemical changes take place over time, the nitrogen in these organic solid becomes available for the plants for several years, similar to a slow-release encapsulated fertilizer (Muse, Mitchell, and Mullins, 1991).

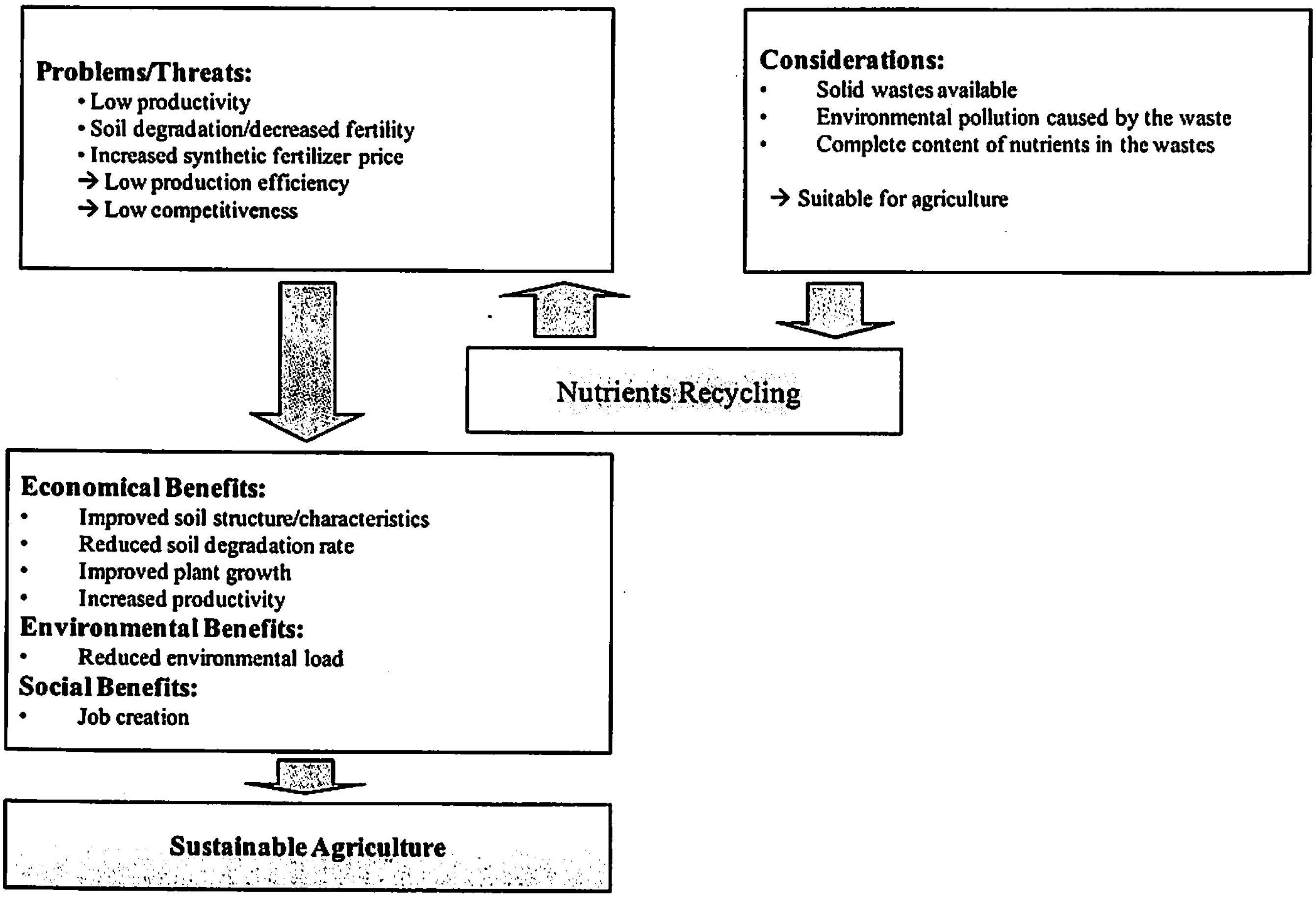

Fig. 3. The idea behind nutrient recycling

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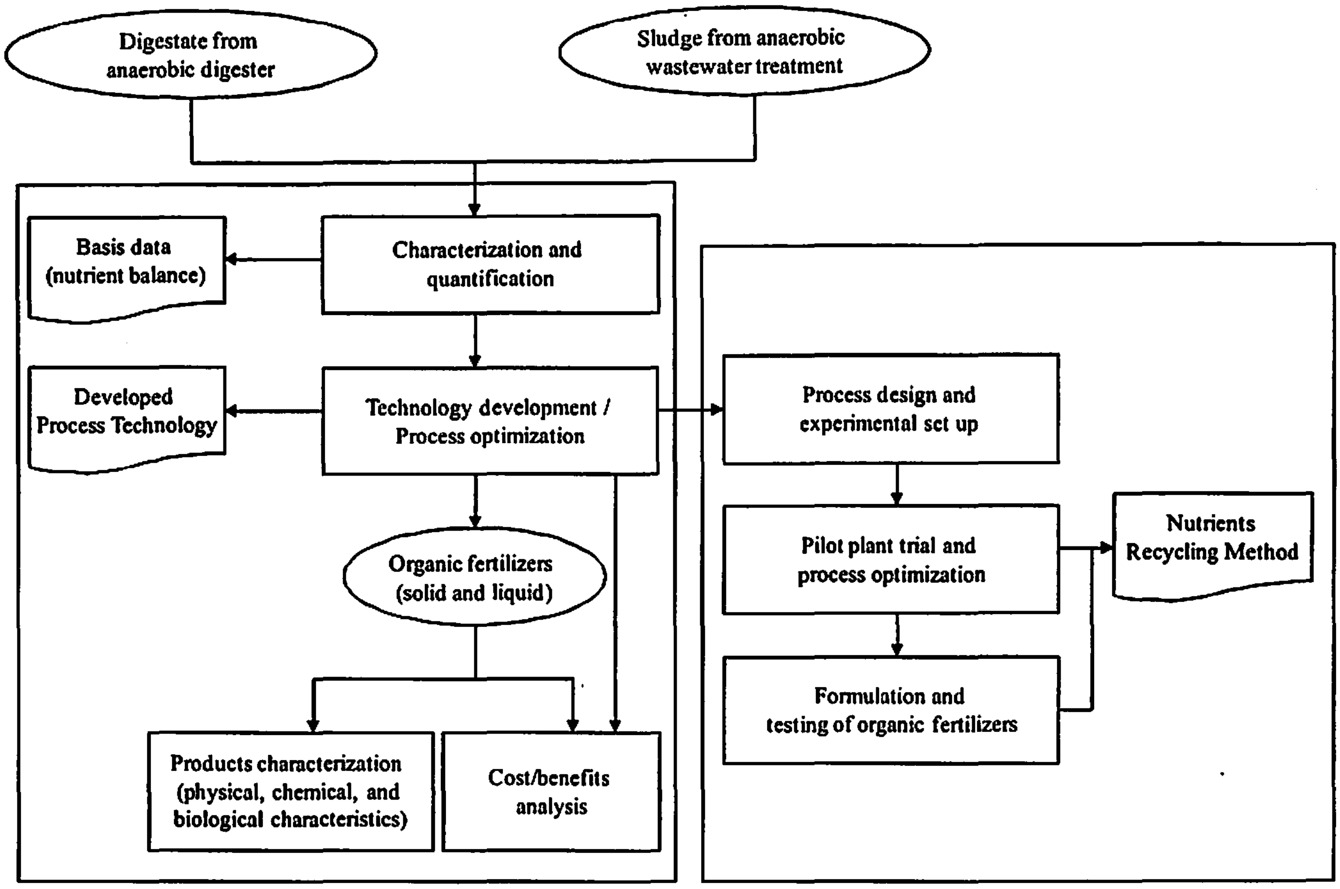

Fig. 4. Research activities in nutrients recycling and the possible outputs

3.4. Advanced Treatment of Wastewater by Using Microalgal System

The anaerobically treated wastewater from the bioethanol production still contains a considerable amount of organic material and nutrients, which contribute to significant environmental problems if directly discharged. On the other hand, standard advanced treatment of the wastewater is costly and technically challenging. Alternatively, simple stabilization ponds may provide solution to the advanced wastewater treatment with low investment, operation, maintenance and energy costs (Suprihatin, 1989; Garcea *et al.* 2000). The climatic and geographical conditions, i.e. intensity of sunlight, warm temperature and availability of land also support the application of the systems in Indonesia. Algal cultivation can utilize unused marginal dryland/farm lands, so that it will not compete with food crop production.

In pond systems, organic matters are oxidized by bacteria. Algae then utilizes the products of aerobic oxidation (CO_2, NO_3^-, PO_4^{3-}) for the synthesis of algal cells using solar energy in a photosynthesis process. About 115 g of algal cells is produced from 1 g of phosphorous. The removal of nutrients (nitrogen and phosphorous) by algae in the pond system can therefore prevent eutrophication in the receiving water body. On the other side, the aerobic bacteria utilize oxygen produced during the algal photosynthesis for oxidation of organic pollutants. The use of algae in the wastewater treatment system has therefore some benefits, such as high quality of effluent and high economical value of algae. The algal biomass contains some valuable materials, i.e. protein, fat, glycerol, pigments, enzyme, amino acids, antibiotics, and biological fertilizer. Algae is also one of the promising biomass feedstock for renewable energy production owing to their widespread availability, fast growth rate, and high oil and other biomass yields. An experiment showed that 70% of nitrate and phosphate ions can be effectively removed after six days of algae culture. Dry biomass production reached at 0.25-0.5 g/L.d. Microalgal cell formation is a very efficient way to utilize solar energy. Table 1 shows algal productivity, presented as biodiesel yield, compared with various types of crops. The biomass yield, oil yield, and nutrient removal ability of micro-algae depends on wastewater characteristics and lighting conditions.

Algal biomass contains up 50% (d.b) of carbon from carbon dioxide. To produce 100 ton dry matter of algal biomass requires about 183 ton carbon dioxide (Chisti, 2007). Therefore, algal production contributes to reduce green house gas (GHG) emission. It should be noted that reduction of GHG emission take place only if the produced algal biomass is converted to biodiesel or bioetahnol that is used for substitution of fossil fuel.

The challenges of the high costs of culturing the algae in large scale have limited the practical use of microalgae for bioenergy production. These limitations, however, will be overcome by coupling algae production with wastewater treatment of biomass-ethanol production.

Another important step of the algal production is the separation of the algae. Algae biomass is difficult to separate by conventional sedimentation process because of the low density difference between algae and water. An alternative process to separate the algae from its medium is the use membrane filtration. This process does not depend on the algal density. Furthermore, the technology produces high quality permeates and makes it possible to reuse the nutrients contents (N, P). This technology creates a win-win solution for environmental management in terms of providing sustainable technology of effluent treatment within the economical and technological capabilities of developing countries.

Table 1. Biodiesel yield of microalgae compared with various types of crops

No.	Type of crop	Productivity (L/ha)	Relative land area demand
1	Corn	172	342
2	Soybean	446	132
3	Cannola	1,190	50
4	Jatropha	1,892	31
5	Coconut	2,689	22
6	Oil palm	5,950	10
7	Microalgae:		
	- Oil content of 70% (d.b) (lab. scale)	136,900	0.4
	- Oil content of 30% (d.b) (technical scale)	58,700	1

Source: Chisti (2007)

Although these benefits have been reported in literature, research works specifically applied to algal production from effluent of the biomass-ethanol production for biodiesel production is still limited. These works should cover the following specific objectives: i) to select and cultivate high growth rate algae species that can flourish on wastewater of bioethanol production, in order to determine the growth characteristics, biomass and oil yield in batch and continuous cultures and the extent of nitrogen and phosphorous removal as well as theoretical consumption of CO_2, ii) to evaluate the feasibility of using sedimentation, centrifugation, and membrane filtration for algae harvesting with special respects of operation performance and product quality, iii) to develop process for oil extraction from algal biomass and its conversion to biodiesel fuel, with special interests on optimum process conditions and oil and biodiesel yields and characteristics, and iv) to evaluate technical and economic implications of the developed combined system of wastewater treatment and algal cultivation for biodiesel production.

John *et al.* (2011) stated that in the perspective of bioenergy issues, algae are gaining wide attention as an alternative renewable source of biomass for production of bioethanol. Microalgae generates high starch/cellulose biomass waste after oil extraction, which can be hydrolyzed to generate sugary syrup to be used as substrate for ethanol production. Macroalgae are also harnessed as renewable source of biomass intended for ethanol production. There are very few studies on this issue, and intense research is required in the future for efficient utilization of algal biomass to produce environmentally friendly bioethanol. The review concludes that the utilization of algal biomass for bioethanol production is undoubtedly a sustainable and eco-friendly approach for renewable biofuel production. As the importance of microalgae in biodiesel production is growing, an equal or more attention is needed for the efficient use of these easily cultivable microorganisms to generate the green fuel bioethanol. There are possibilities to culture the algal strains even in marine or other wastewaters for bioethanol production. Genetic engineering of selected strains to survive in adverse conditions and development of new bioreactor for effective production and recovery of ethanol are necessary for generating fuel from algal biomass.

3.5. Systematic Mapping of Abundance and Characterization of Unused Biomass

To design an optimum management of agricultural wastes as source of bioethanol production, availability of reliable database is of particular importance. A comprehensive survey is necessary for quantifying the lignocellulosic biomass production in Indonesia and its distribution in order to establish a systematic map of abundance of unused biomass, to determine the characteristics of various types of lignocellulosic biomass (cellulose, hemicellulose and lignin, glucose, D-xylose, D-glucose, D-galactose, D-mannose and L-arabinose), and to assess the existing management of agricultural wastes. Some agricultural residues may be not preferable for bioethanol production due to their existing use, but some others can be used directly.

3.6. Design, Piloting and Assessment of the Integrated System

Having collected the relevant data, it is necessary to give a more real picture through design, piloting and assessment of the integrated system of bioenergy production and agricultural wastes management. This is necessary for effective implementation and promotion of the innovative sustainable management system. In this context, the development of a reliable model will be helpful as a simulation tool to exercise various possible scenarios and to decide the most practical, economical and environmentally sound design of the integrated bioenergy production and the agriculture waste management.

With the established and developed facilities, it is possible: i) to simulate the performance of various possible scenarios of the integrated management system, ii) to determine the best design, and iii) to assess the technical, socio-economical and environmental feasibility of the system. A streamlined Life-Cycle Assessment (LCA) can be used to determine the best system in terms of overall environmental performance. And finally, a pilot project facility will be required to demonstrate the performance and effectiveness of the integrated system.

4. Conclusion

The abundance of agricultural residues in Indonesia represents a potential source of feedstock for production of renewable bio-based energy. In order to achieve the