Technical Paper

Special articles：Biomass
特集：バイオマス

Integrated Bio-cycles Farming System for Production of Bio-gas through GAMA DIGESTER, GAMA PURIFICATION and GAMA COMPRESSING

Cahyono AGUS*1*2, Bambang Hendro SUNARMINTO*2*3, Bambang SUHARTANTO*2*4, Ambar PERTIWININGRUM*4, WURATNI*5, Iwan SETIAWAN*5, and Dibyo PUDJOWADI*6

(Received January 31, 2011)

Sustainable Integrated Bio-cycle Farming System (IBFS) is a good approach to integrate a multi-sector (Agriculture, Horticulture, Plantation, Forestry, Animal Husbandry, Fishery etc) to produce food, feed, fuel, fertilizer, pharmacy, edu-tainment, eco-tourism etc. Through technological strategy of 7R (Reuse, Reduce, Recycle, Refill, Replace, Repair and Replant) with added value in economic, environment and socio-cultur aspect, this method can be approached as a characteristic of Education for Sustainable Development (EfSD). Tunnel digester for anaerobic digestion of organic materials produced organic fertilizer and bio-gas energy. The design of GAMA DIGESTER has been optimized to improve the methane (CH_4) content in the biogas. The purity of methane in biogas increased to be 80% by the first generation of GAMA PURIFICATION unit. GAMA COMPRESSING unit, which is still under study for design improvement, is targeted to produce Compressed Methane Gas (CMG) in the near future. The GAMA DIGESTER, GAMA PURIFICATION and GAMA COMPRESSING could product sustainable bio-energy in the total system of IBFS.

Key Words
Bio-energy, Integrated farming system, Organic cycles, Sustainable development

1. The Role of Integrated Farming

Nowadays, people still have an old paradigm about agriculture as only a soil plant cultivation which merely produce commodity for self-consumption. It is necessary to develop a new paradigm that agriculture has multi-functions which have not been and need to be appreciated appropriately by people. Agriculture must be able to give a function as a primary supplier for food, clothing, and shelter for the life of all human beings in the world, so must be developed by eliminating sectoral egoism (Agus, 2006; 2010).

The biomass productivity in tropical areas is considered as the highest in the world due to the high number and distribution of rainfall, air temperature, soil temperature, humidity, soil moisture rezime and solar radiation (Agus, 2004). Tropical soil is considered as old soil and lack of nutrient, however, due to the supporting of the high activities of soil microorganism and the high rate of closed organic cycles, the growth of plants on the tropical land is relatively fast. However, the economic productivity in tropical areas is lower than that in temperate areas due to the biological management is less efficient and effective. By employing appropriate strategies, technologies and management, tropical areas should be managed to have very high economic activities as well as very high biomass production. The development of multifunction and sustainable Integrated Farming System is expected to become one of the alternative agricultural system for the elaboration of RPPK (Revitalisation of Agriculture, Fishery, and Forestry) which was launched by Indonesian President on June 2005.

The intensity of agriculture in much of Indonesia has increased dramatically with higher yields per hectare and, in some cases, an improvement in the quality of food produced. However, this has been achieved against an increasing public concern about the environment, especially in

*1 Faculty of Forestry UGM
Bulaksumur, Yogyakarta, 55281 Indonesia
*2 KP4 UGM University Farm
Jl Kalitirto, Berbah, Yogyakarta, Indonesia
*3 Faculty of Agriculture UGM
Bulaksumur, Yogyakarta, 55281 Indonesia
*4 Faculty of Animal Husbandary UGM
Bulaksumur, Yogyakarta 55281 Indonesia
*5 Faculty of Engineering, UGM
Jl. Grafika, Yogyakarta 55281, Indonesia
*6 KPWN Ministry of Forestry
Gd Manggala Wanabhakti 14fl, Jakarta, Indonesia

terms of agriculture's effects on the soil, water, air and habitat resources. Awareness of the environmental impacts of agricultural production, coupled with over-supply of some products such as wheat for animal feed, has highlighted the need to find more sustainable farming practices (Bailey *et al.*, 2003).

All forms of energy spend very high cost, however, renewable energy generally gets cheaper, while fossil fuels generally get more expensive. Biomass (plant material) is a renewable energy source due to its energy contains from the sun. Through the process of photosynthesis, plants capture the sun's energy. When the plants are burned, they release their sun's energy. By this mechanism, biomass do functions as a sort of natural battery for storing solar energy. As long as biomass is produced sustainably, with only as much used as is grown, the battery will last indefinitely.

According to a report published by the United Nations Food and Agriculture Organization, the livestock sector generates more greenhouse gas emissions as measured in CO_2 equivalent – 18 percent – than transport (FAO, 2006). Methane is 23 times more potent as a greenhouse gas than carbon dioxide (over a 100-year period) and now accounts for 16% of global greenhouse gas emissions from human activities (EPA, 2010). Producing energy from recovered methane can also avoid the use of higher-emitting energy resources such as wood, coal or oil. This can reduce end user and power plant emissions of CO_2 and air pollutants. Reducing methane emissions have many important energy, safety, economic, and environmental benefits.

With respect to the importance of cheap energy sources to be an integrated part of the bio-cycle, biogas production unit to convert the agricultural wastes (especially the livestock wastes in the form of manure) into a useful form of sustainable fuel. The biogas production unit developed in the IBFS consists of an optimized design of digester to maximize the methane content of the biogas, a purification unit to further increase the methane content, and the long term target to complete the system is a compressing unit for methane storage, The development of biogas purification unit is a big step towards more economical values of biogas because once purification succeed then the biogas will be easy to be converted into electricity and also more economical to be stored in a compressed tank (Agus *et. al.*, 2010) The purpose of this paper is to propose an integrated biocycles farming system for Indonesia and other tropical countries, and to experimentally obtain the fundamental data of the GAMA biomethanation process in the proposed system.

2. Development of Integrated Biocycles Farming System

Integrated farming model was developed by KP4 UGM with more in-depth studies conducted through ICM (Integrated Crop Management), INM (Integrated Nutrient Management), IPM (Integrated Pest Management) and IMM (Integrated Moisture Management). The ICM was conducted using the agroforestry pattern which combines various types of agricultural crops, plantation, forestry, fisheries and animal husbandry system, than able to provide daily, monthly and yearly earnings, even earnings for decades for farmers. The INM was conducted by integrating and enabling the nutrient cycle, bio-fertilizer, green fertilizer, compost, organic fertilizer and chemical fertilizer. The use of nutrient effectively requires a balance between nutrient added through chemical fertilizers into soil and available during the degradation of organic ingredients in the soil. The habitat stability, supply of sludge organic and adequate soil organic matter are the primary basis to improve the soil biological fertility. Fermentations of 1 unit livestock dung (including 12 cows) using digester was expected to produce liquid fertilizer about 180 kg/dt and bio-gas energy which is enough to warm up stove for 12 h (Agus, 2010).

The IPM was practiced using bio-pesticide to manage the pest and disease combined with chemical pesticide as well as the use of animal and plant to control weeds. The IMM was carried out by technical irrigation, non-technical irrigation, rainfall water retention, ditch, alternate flooded, tunnel-well, strip system or pump well, so as to be able to provide water outside conventional planting seasons so that harvest can be made and the price of commodity is higher.

Integrated Bio-cycle Farming System (IBFS) has multifunction and multi-product (Food, Feed, Fuel, Fiber, Fertilizer, Pharmacy, Edutainment, Eco-tourism etc) with technological strategy of 7R (Reduce, Reuse, Recycle, Refill, Replace, Repair and Replant). The system should collaborate and develop networking system between ABCG (Academic, Business, Community and Government) with economical-, environmental- and socio-cultural-approach as a characteristic of Education for Sustainable Development (Fig. 1). This model facilitates the learning needed to maintain and improve our quality of life and the quality of life for generations to live and act sustainably; as well as giving them an understanding of the environmental, social and economic issues involved (Agus *et. al.*, 2010).

The key characteristics of IBFS developed in UGM University Farm are (i) an integration of agriculture and non-agriculture sector, (ii) value of environment, esthetics and economics, (iii) rotation and diversity of plants, (iv) artificial and functional bio-technology, nanotechnology, pro-

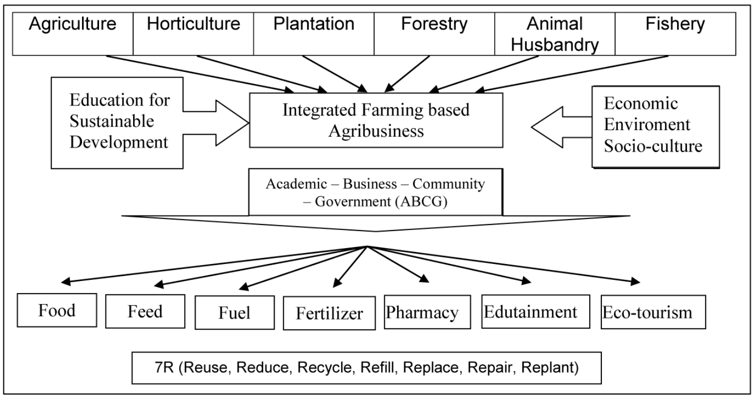

Fig. 1 The concept of development of multifunction and sustainable integrated-farming in UGM University Farm

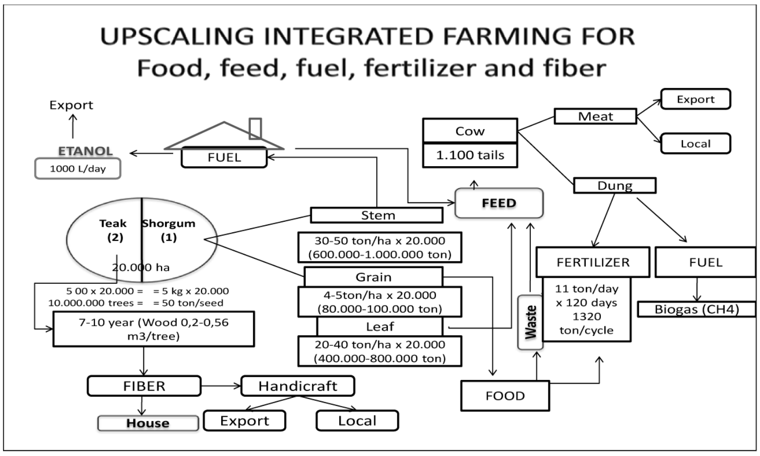

Fig. 2 Upscaling project iIntegrated Farming based Agribussines for Food, Feed, Fuel, Fertilzer and Fiber

biotik, (v) management of closed organic cycle and integration in an integrated system among ICM, IPM, IMM, INM, IVM, (vi) management of integrated bio-protection and ecosystem health management, (vii) landscape ecological management, agro-politant concept, (viii) specific management of plants and (ix) holistic and integrated system (Agus, 2010).

Organic material cycles was adapted in Integrated Biocycles Farming System as described in Fig. 2. Plant producing grain, shoot and leaf for food, feed, organic-fertilizer and fuel. Livestock need feed from plant and produce organic fertilizer for plant and biogas for fuel. Integrated Farming based Agribusiness that consist of Teak (500 tress/ha) and Sorghum (5 kg seed/ha), producing grain for food at 4 - 5 t/ha, producing shoot for fuel at 30 - 50 ton/ha and leaf for feed at 20 - 40 t/ha. At commercial units of 20,000 ha, this agribussiness can produce grain for food about 80,000 - 100,000 t, produce shoot for about 600,000 - 1,000,000 t that equivalent for ethanol fuel production at 1,000 L/d, and produce leaf for feed at about 400,000 - 800,000 t. Teak plantation after 7-10 year-old, will producing wood 0.2 - 0.56 m^3/tree that can be used for housing and handicraft for export and local consumption. Livestock of 1,100 catles producing meat for export and local consumption, besides producing dung for organic fertilizer and biogas (Agus *et. al.*, 2010).

3. Development of GAMA DIGESTER, GAMA PURIFICATION and GAMA COMPRESSING

Gadjah Mada (GAMA) University developed GAMA DIGESTER for anaerobic digestion of livestock manure using tunnel closed-anaerobic-digester to produce organic fertilizer and bio-gas energy (Fig. 3). The digester worked on simple "plug-flow" pattern with inlet on one end and over-flow at the other end to collect the digested sludge. Several techniques have been tested to improve the meth-

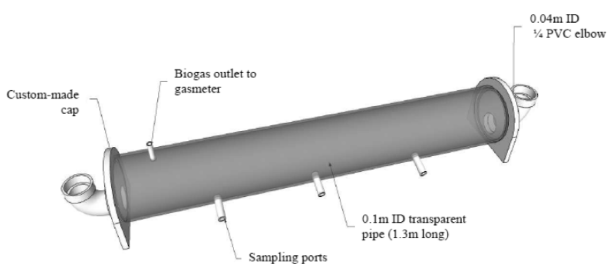

Fig. 3 Laboratory scale of the tunnel digester (Wiratni and Angenent, 2010)

ane content in the biogas, such as co-digestion with landfill leachate (Wiratni and Subandiyono, 2009). Furthermore, it had also been confirmed that sludge recycle and simple mixing mechanism could significantly improve both the biogas production rate and the methane content in the biogas (Wiratni and Angenent, 2010). The mixing was conducted by a mixing rod placed inside the digester and connected with ropes on both side so that it could be pulled back and forth through both ends (Figs. 3 and 4). The simple plug flow system represented in Fig. 3 was scaled up to the volume of 1.6 m^3 and it took the cow manure slurry (1:2 ratio of the manure and water mixture). To reach the relatively good process, which was mainly indicated by slow precipitation and high methane production rate, the optimum hydraulic residence time (HRT) was 14 d and for the aforementioned dimensions of the digester, it can handle as much as 0.11 m^3 of fresh slurry per day. Longer HRT resulted in more solid precipitation while shorter HRT led to much less biogas production and the increasing tendency of microbe washed out. The biogas with the composition listed in Table 1 represented the biogas composition at this optimum HRT and feeding rate on the simple plug flow system represented in Fig. 3.

The biogas was further purified by GAMA PURIFICATION system consisted of CO_2 selective adsorbent, silica gel, and active carbon packed in a 1 m length of galvanic iron pipe (Fig. 5). The experiment to test the purification capacity of the CO_2 selective adsorbent obtained from the Indonesian Institute of Science was tested by flowing the artificial biogas made by mixing the commercial CH_4 and CO_2 at the typical composition as that of real biogas (60% CH_4). The detail design and data will be published in another paper. The purification system has been tested on real biogas, too, by flowing the biogas produced from the digester in the University Farm. For the field test, the pressurized tank was replaced by the tank of compressed biogas of the 0.7 MPa pressure. The comparison between inlet and outlet gas compositions is descriped in Table 1. The purification set up was also equipped with a simple heater (an iron pipe with electric heater) to heat the air used for adsorbent regeneration. The purification system was intentionally designed with two columns so that while one column was undergoing regeneration by flowing heated air (the air temperature was varied between 100-200℃), the other column could be normally operated for CO_2 removal process. The optimization of the regeneration condition is still on-going and the results will be published in separate publication.

The possibility of compressed storage of the purified biogas into Compressed Methane Gas (CMG) using the technique of high pressure adsorption was studied using GAMA COMPRESSING illustrated in Fig. 6. Basically the compression was conducted by compressing the purified biogas into a container stuffed with the porous carbon material as methane adsorbent. The adsorbent was derived from poly-

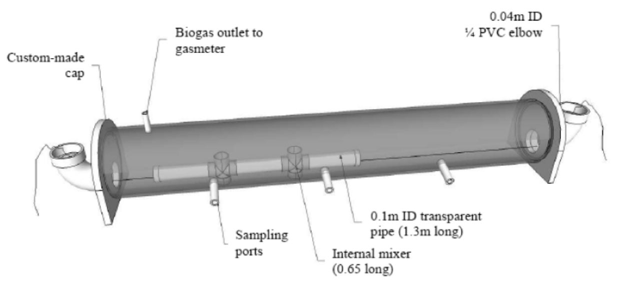

Fig. 4 Laboratory scale of the tunnel digester with simple mixer (Wiratni and Angenent, 2010)

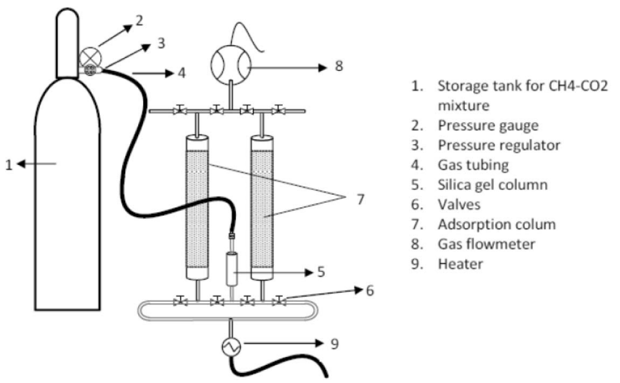

Fig. 5 Laboratory set-up for optimizing GAMA PURIFICATION

Table 1 The content of gaseous material in biogas by GAMA PURIFICATION

Element	Initial (% mol)	Purified (% mol) (± sd)	Increase/decrease (%)
H_2	0.00	0 ± 0	0.00
N_2	11.35	4.53 ± 0.67	− 60.06
CO	0.00	0 ± 0	0.00
CH_4	50.24	82.37 ± 2.50	63.95
CO_2	32.68	9.43 ± 1.16	− 71.13
H_2S	0.00	0.067 ± 0.12	0.00
NH_3	1.56	0.17 ± 0.13	− 88.89

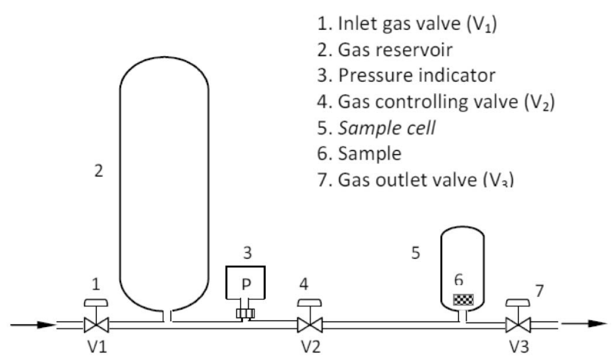

Fig. 6 Experimental set-up for GAMA COMPRESSING using the high pressure adsorption technique (Prasetyo et al., 2010)

meric resins with pyrolysis at 700oC for 2 h. The reactants for preparation of microporous carbon precursor i.e.: phenol (with purity of 99%), resorcinol (with purity of 99%), para-tert-butyl phenol (with purity of 99.5%), and formaldehyde aqueous solution (as 36% formalin) were commercially obtained and used without further purification. The experimental material production and testing procedures with the laboratory set up presented in Fig. 6 and the resulting porous carbon provided the optimum pore size distribution for methane storage purpose was reported by Prasetyo *et al.* (2010).

Typical chemical composition of biogas produced from anaerobic digester was consisted of methane (CH_4) 40-50% mol, carbonic gas (CO_2) 30-60% mol, hydrogen (H_2) 1% mol, nitrogen (N_2) 0.5% mol, carbon monoxide (CO) 0.1% mol, oxygen (O_2) 0.1% mol and hydrogen sulphur (H_2S) 0.1% mol. By developing GAMA PURIFICATION unit, the purity of methane in biogas could increase 63% more than before to be 80% mol, meanwhile the content of NH_3 decreased 88%, and CO_2 decreased 71% (Table 1). The purified biogas improved the feasibility of using biogas for generating electricity as the purification significantly reduced the corrosivity of the biogas due to the trace gases such as H_2S and CO_2.

The development of the porous carbon for methane storage has been concluded to find that the optimum surface area could be obtained by controlled pyrolysis on resorcinol p-tert-butyl phenol formaldehyde polymer. According to Prasetyo et al. (2010), the resulting porous carbon possessed relatively high surface area (up to 2,248 m^2/g) and sufficiently good methane uptake (up to 8.98 mmol / g-carbon at 3.5 Mpa and 298 K). Further study to improve the porous carbon network is still going on and will be reported in another publication.

Organic material could be cycled well and optimized through GAMA DIGESTER, GAMA PURIFICATION and GAMA COMPRESSING. It could contribute well on the management of total system of IBFS to support sustainable development with added value of environment, economic and sosio-culture.

4. Conlusion

Integrated Bio-cycle Farming System (IBFS) is a methodical approach to integrate a multi-sector (Agriculture, Horticulture, Plantation, Forestry, Animal Husbandry, Fishery etc) to product food, feed, fuel, fertilizer, pharmacy, edutainment, eco-tourism etc. Through technological strategy of 7R (Reuse, Reduce, Recycle, Refill, Replace, Repair and Replant) with added value in economic, environment and socio-cultur aspect, this method can be approach as a characteristic of Education for Sustainable Development (EfSD). GAMA DIGESTER developed by tunnel digester for anaerobic digestion of organic materials produced organic fertilizer and bio-gas energy and significantly optimized by sludge recycle and simple mixing mechanism. The purity of methane (CH_4) in biogas increased to be 80% by GAMA PURIFICATION unit. A custom made adsorbent had been developed by controlled pyrolysis on resorcinol p-tert-butyl phenol formaldehyde polymer and the resulting porous carbon showed a good potential to be implemented in the GAMA COMPRESSING unit to produce Compressed Methane Gas (CMG). The GAMA DIGESTER, GAMA PURIFICATION and GAMA COMPRESSING could product sustainable bio-energy in the total system of IBFS.

Acknowledgment

This work is the revision and extension of the paper in RE 2010 International Conference in Yokohama with the paper number 00468 Development of Multi-function and Sustainable Integrated Farming System for Food, Feed, Fuel, Fiber and Fertilizer. The opportunity is gratefully acknowledged.

References

1) Agus, C., Karyanto, O., Kita, S., Haibara, K., Toda, H., Hardiwinoto, S., Supriyo, H., Na'iem, M., Wardana, W., Sipayung, M., Khomsatun, Wijoyo, S., *New Forest J.*, **28**, 277-285 (2004)
2) Agus, C., Proceeding of seminar on Research Cluster UGM, August 26, 2006, Yogyakarta, Indonesia
3) Agus, C., Presenting paper on The 16th Annual International Sustainable Development Research Conference, 30 May - 1 June 2010, Hong Kong
4) Agus, C. Sunarminto, B. H., Suhartanto, B, Pertiwiningrum, A., Setiawan. I, Wiratni, Pudjowadi D., Presenting paper on The RE 2010 International Conference on 27 June - 2 July, 2010, Yokohama, Japan
5) Bailey, A. P., Basford, W. D., Penlington, N., Park, J. R., Keating, J. D. H., Rehman, T., Tranter, R. B., Yates, C. M., *Agriculture, Ecosystems and Environment*, **97**, 241-253 (2003)
6) EPA, (2010), Methane, United States Environmental Protection Agency, http://www.epa.gov/methane/qanda.html, (Access 10 June 2011)
7) FAO, 2006, Livestock a major threat to environment, http://www.fao.org/, (Access 10 June 2011)
8) Prasetyo, I., Rochmadi, Yunanto, R., Ariyanto, T., Wiratni, Regional Conference on Chemical Engineering 4-6 Desember 2010, Bangkok, Thailand
9) Wiratni, Angenent, L. T., CHEMECA Chemical Engineering Conference 3-4 September 2010, Adelaide, Australia
10) Wiratni, Subandiyono, Regional Conference on Chemical Engineering 22-23 January 2009, Manila, The Phillippines