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Continuous production of high-value products, biodiesel and biogas from microalgae cultivated with livestock waste compost: A feasible study

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Abstract*— Under the background of energy crisis, global warming and climate changes, much attention has been paid to bioenergy which will hopefully become one of the major energy sources for both developed and developing countries in future. Microalgae as the renewable and alternative energy feedstock have come under increased research interest in an attempt to seek for sustainable development. Microalgae growth needs large amounts of chemical or organic fertilizers, causing substantial costs and releases of nutrients into the environment via rainwater or runoff. In practice, using nutrient-rich wastewaters to cultivate microalgae appears a promising choice for the removal of nutrients and production biofuels. On the other hand, livestock production is rapidly increasing especially in developing countries because of increased consumption demands for meat. As a result, large quantities of animal wastes are left over, threatening environmental hygiene and becoming a barrier for development if not disposed of appropriately. Hence, seeking for an effective ways to manage livestock wastes is also extremely important. In this paper the feasibility of microalgae cultivation with livestock waste compost will be evaluated. The authors propose a feasibility framework where livestock waste compost will be chosen to cultivate microalgae and the biomass will be harvested to continuously produce bioproducts such as high values, biodiesel and biogas. Applying livestock waste compost to cultivate microalgae for the production of high-value products, biodiesel and biogas appears as a sustainable solution to realize both livestock waste management and biofuel recovery, thus driving the industry towards sustainable growth.

***Keywords*—microalgae; biofuels; livestock waste; compost; microalgal biorefinery**

I. INTRODUCTION

The continuous dependence on fossil fuels will have catastrophic results, leading to a lack of energy security and excessive emissions to the environment [1]. Depletion of fossil fuels in near future, fluctuations in oil prices, global warming and climate changes have stimulated the search for renewable energy sources that can satisfy the ever-growing energy requirements. Renewable energy opens up prospects for appropriate conservation of resources as well as an environmentally-friendly solution to fix energy security problems [2].

Microalgae are seen as one of the most promising biofuel feedstock to solve global energy crisis and climate change. Microalgal biofuels are thought as the third generation biofuels and the advantages of microalgae as a biofuel feedstock include potentially high photosynthesis efficiency and biomass yields, no competition with food crops for arable land and freshwater resource, and carbon mitigation [3,4].

Microalgal production needs a lot of fertilizers, resulting in high costs during operation and adverse environmental effects by leaking nutrients into environment. Therefore, fertilizer driven microalgal cultivation is not sustainable. Application of wastewater rich in nutrients such as nitrogen and phosphorus to cultivate microalgae is a prevailing way to improve the economic and environmental sustainability in practice [5–8]. Microalgae can evidently improve water quality, since wastewater nutrients (mainly nitrogen and phosphorus) can be absorbed and incorporated into microalgal cells, achieving contaminant removal and biomass accumulation.

According to current literature, there is a lack of information published on the livestock waste compost application in microalgal cultivation for continuous production of high-value products, biodiesel and biogas. In this study, the viability will be testified. This is an exploratory study and the objective of this research is to propose a feasibility concept for microalgal cultivation with livestock waste compost for biofuel production and waste management.

II. LIVESTOCK WASTE

Livestock production is rapidly increasing especially in developing countries because of increased consumption demands for meat. About 56 billion livestock are cultivated and slaughtered worldwide annually for human consumption. By 2050 this number is expected to be double, faster growth than any other agricultural sub-sectors [9]. Especially the developing world will witness most of those increases due to the growing demand. Intensive animal agricultural methods by raising animals at high stocking density, using economies of scale, modern machinery, and biotechnology are prevailing in Europe and North America and are increasingly common in Asia and Latin America. It is suggested that the livestock sector is now one of most significant contributors to environmental issues, resulting in land degradation, greenhouse gas emissions, water and waste pollution, and increased health problems. The global trend with the increase in meat demands and the appearing environmental problems have not been given sufficient attention.

During livestock production, large quantities of animal wastes are left over, threatening environmental hygiene and becoming a barrier for development if not disposed of appropriately [10]. In the United States approximately 35 million dry tons of livestock waste is produced every year, while in the EU-27 more than 1500 million fresh tons of livestock waste is generated annually [11]. Taking Finland as an example, the total amount of annual livestock manure produced is around 16 million tones wet weight, 80% and 14% of which are accordingly from cattle and pig farm [12]. Hence, effective management of livestock wastes is also extremely significant.

III. INTEGRATION OF MICROALGAE CULTIVATION WITH WASTE MANAGEMENT

A. *Waste composting*

The concentrated animal feeding operations have been generating a large quantity of animal manure yearly as a by-product. The manures produced are subsequently applied on agricultural farmland as fertilizers, becoming one of the main sources of terrestrial pollution. Livestock wastes are rich in nutrients such as nitrogen and phosphorus (Table 1). In practice, they can be composted for agricultural, horticultural or silvicultural usage.

TABLE I. CHARACTERISTICS OF RAW LIVESTOCK WASTE MATERIALS FOR COMPOSTING.

Parameter	Pig manure [a]	Chicken manure [b]	Dairy manure [c]
Moisture (%)	78.89	55.00	84.30
pH	8.37	6.95	7.5
OM (%)	73.01	–	–
TC (%)	–	35.00	44.15
TP (g kg^{-1})	15.13	18.40	4.71
TN (g kg^{-1})	29.82	43.70	–
TN (%)	–	–	1.61
C/N	–	8.01	27.4
TK (g kg^{-1})	8.16	35.20	22.41
Cu (g kg^{-1})	1.18	–	–
Zn (g kg^{-1})	2.17	–	–

[a] Source from [13];
[b] Source from [14];
[c] Source from [15]

Composting is a microbial decomposition process of organic materials in a predominantly aerobic environment, where bacteria, fungi and other microbes break down organic substances into stable, usable organic matters called compost [16]. Livestock waste composting can be employed due to its eco-compatibility and relatively easy operational procedures [17]. During the composting, the volume of wastes is reduced and the destruction of pathogenic microorganisms occurs as well. The stable and mature compost, which is preferably applied for agricultural purposes due to an improved fertility (richness in nitrogen and phosphorus), can also provide the nutrient source for microalgal growth.

B. *Integration of microalgae cultivation with waste management*

Microalgal photosynthesis and biomass growth require sufficient supplies of CO_2, light, and nutrients. The nutrient requirements for most of the microalgae species contain N, P and potassium (K) (silicon is also needed for marine species) and other trace metals such as zinc (Zn) and magnesium (Mg). The P and N requirement of microalgae growth are at concentration less than 0.2 µmol P L^{-1} and more than 0.2 µmol N L^{-1}, respectively [18]. These requirements can be met by livestock manure and wastewater. However, using wastewater to cultivate microalgae needs the up-grading of the existing water treatment plants [19]. Therefore, livestock waste compost would be suitable substitutes for inorganic fertilizer for commercial microalgae cultivation for the production of bioproducts.

Livestock waste is rich in nitrogen and phosphorus (Table I). After composting improved fertility occurs, and thus the compost is seen as organic fertilizer. In the concept, livestock waste compost will be chosen to cultivate microalgae and the biomass will be harvested to continuously produce high-value products and biodiesel, while the residues will be subsequently applied to produce biogas through digestion. The technology roadmap for microalgae cultivation with livestock waste compost for the continuous production of biofuels is exhibited in Fig. 1.

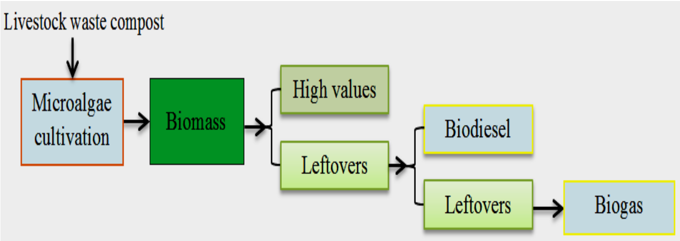

Fig. 1. Technology roadmap for microalgae cultivation with livestock waste compost for the production of high-value products, biodiesel and biogas

C. *System integration and engineering*

System integration and engineering technologies can be employed to optimize the microalgal growth system, where microalgae can grow robustly under the optimal conditions. In addition, the microalgal biorefinery concept involves many approaches and system integration and engineering technologies are the methods to optimize each approach. Not only low-value products like biofuels (biodiesel, bioethanol and biogas) but also high-value products like cosmetics and pharmaceuticals can be co-produced, which is the objective of microalgal biorefinery.

Fig. 2 exhibitss microalgal biorefinery option: microalgae cultivation – biomass harvest – high value extraction – biodiesel production – biogas generation. Special attention is paid to the integration of microalgal cultivation with waste compost and the production of high-value products, which are expected to improve the cost-effectiveness of microalgal biorefinery [20]. Another significant interest during microalgal biorefinery resides in the use of leftovers after anaerobic digestion, which leads to a flux of ammonia (NH^{4+}–N) and phosphate (PO_4^{3-}) that can be subsequently recirculated as nutrient sources for microalgal cultivation or can be further processed for the production of fertilizers [21,22]. In addition, it is advantageous to recycle the CO_2 released from waste composting and anaerobic digestion together with harvest water to regrow microalgae, which in turn, provide the substrate for the production of biofuels and fertilizers.

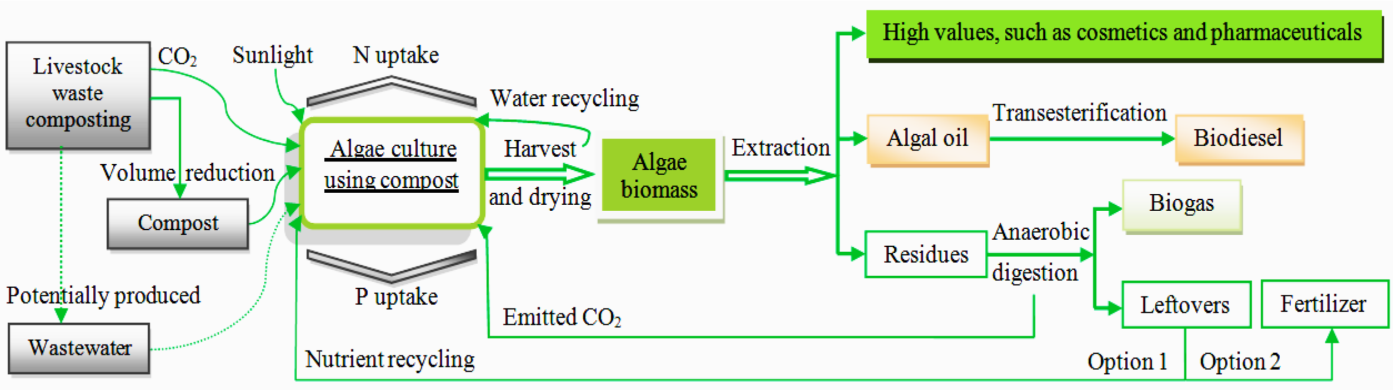

Fig. 2. System integration and engineering for microalgae cultivation with livestock waste compost for the production of high-value products, biodiesel and biogas

IV. CONCLUSIONS

Livestock waste is rich in nitrogen and phosphorus. After composting improved fertility occurs, and thus the compost is seen as organic fertilizer. The biomass produced from livestock waste compost can be applied to continuously produce high-value products, biodiesel and biogas. Harvest water can be recycled into microalgal production system. The digestate can be recirculated as nutrient sources for microalgal cultivation or can be further processed for the production of. In addition, it is advantageous to recycle the CO_2 released from waste composting and anaerobic digestion to regrow microalgae, which in turn, provide the substrate for the production of biofuels and fertilizers. Livestock waste represents as one example of valuable and sustainable nutrient resources to cultivate microalgae for bioproduct production, since it will always be generated as long as human beings exist.

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