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Article

An Analysis of Waste Management Policies on Utilizing Biosludge as Material Resources in Taiwan

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Abstract: Biosludge is a by-product of secondary wastewater treatment processes. Due to its high contents of organic carbon and plant nutrients, this bioresource can be practically reused as raw feedstock for making organic fertilizers and building materials. The objective of this paper was to provide a preliminary analysis of biosludge utilization in Taiwan, including food processing sludge, wine brewery sludge, textile sludge, pulp sludge and agricultural sludge. The discussion focused on the status of biosludge generation in recent years (2004–2010), and its sustainable management principle. This paper also presents updated information about the governmental regulations and policies for promoting these biosolids as material resources, as well as validating the regulatory levels of toxic constituents in the biosludge and its derived product (e.g., organic fertilizer). Based on the preliminary benefit analysis of utilizing biosludge as raw material for organic fertilizer, reusing biosludge, being a beneficial resource, should be superior to those by traditional treatments (*i.e.*, incineration and sanitary landfill).

Keywords: biological wastewater treatment; sludge; organic fertilizer; regulatory promotion; benefit analysis

1. Introduction

It is well known that elimination of biodegradable pollutants from industrial and agricultural effluents, using an activated sludge process, has been considered to be the most suitable method for lowering their negative discharges into sewers or the receiving water body. Meanwhile, an increasing issue associated with waste activated sludge concerned its impact on the environment and human health because the byproduct may unavoidably contain toxic pollutants (e.g., heavy metals) along with a large fraction of pathogens [1,2]. On the other hand, the biosludge may be the most difficult waste to dewater because it contains so much water initially. Also, this type of water is tightly attached by chemical and physical means to surface area by minute micro-organisms. As a result, biosludge management for its reuse and disposal has been regulated by many developed countries. These regulations relevant to agricultural applications in soil, are risk-based rules, and include requirements for the water content, organic carbons, nutrients, toxic metals, pathogen organisms, among others.

Due to advances in waste-to-energy (WTE) technologies, predicted future energy shortages and global warming issues, recovery of energy from various types of agricultural and industrial biosludge has received much attention in recent years [2]. However, these approaches could cause public concern due to the possible adverse effects of the toxic and odorous pollutant emissions in the biosludge-to-energy facility. With the high cost of the biosludge treatment process (e.g., anaerobic digestion and incineration) and strict regulations regarding the emissions of hazardous air pollutants (*i.e.*, chlorinated pollutants, heavy metals, acidic gases and odorants) from WTE facilities, the utilization of biosludge as an energy source for the production of heat, biofuels and electricity has gradually waned across all industries in recent years [2]. In view of its richness in organic biomass and soil nutrient contents, the best management option may be to utilize the dried and digested biosludge for agricultural purpose. As a result, the use of biosludge thus changed from 20% for land application (agricultural use) in the USA in 1972 to 55% in 1997 [3].

The removal of biochemical oxygen demand is the objective of secondary treatment in the allied plants such as food processing, wine brewing and swine raising, while wastewater sludge was further treated to make stabilization and dewatering (<75 wt%) before its utilization as a raw material for the agricultural uses, and for the production of usable materials. However, the unavoidable byproduct may contain toxic pollutants (e.g., heavy metals) and pathogens, thus limiting its agricultural and industrial applications. In our previous paper [4], we presented a comprehensive description about the governmental regulations and policies for promoting industrial waste (*i.e.*, pulp sludge, scrap wood, sugarcane bagasse, textile sludge and scrap plastics) as energy source in Taiwan. In this study, the open-access documents officially published by the Taiwan central government were used to provide a systemic and analytical description about the utilization of biosludge as raw material for material resources. These biosludge resources include food processing sludge (FPS), wine brewing sludge (WBS), pulp sludge (PS), textile sludge (TS) and agricultural sludge (AS). In the present study, the agricultural sludge referred only to biosludge, which is generated by secondary biological wastewater treatment facilities in the agricultural sector or manufacturing processes. The environmental regulations and related policies on promoting biosludge as material resources in Taiwan as well as its preliminary benefit analysis were further discussed.

2. Analysis of Biosludge Generation and Its Management in Taiwan

According to the Waste Management Act in Taiwan [4], waste is generally classified into general waste (municipal waste) and industrial waste. Furthermore, industrial waste includes general (non-hazardous) industrial waste and hazardous industrial waste, which are generated from industrial processes, agricultural facilities and allied enterprises. The latter refers to the industrial waste, which contains toxic or dangerous substances in a sufficient concentration or quantity to endanger human beings or pollute the environment. In brief, hazardous industrial waste is mainly based on its toxicity characteristic leaching procedure (TCLP), which was designed to identify waste likely to leach dangerous concentrations of certain toxic chemicals into groundwater (drinking supplies) from landfills [5]. In Taiwan, the Environmental Protection Administration (EPA) designated the regulatory levels for 36 different toxic chemicals, including 10 metals, 3 pesticides and 23 organics. Pertaining to the toxicity characteristics of biosludge, the constituents (*i.e.*, toxic metals and pesticides) and their regulatory levels in Taiwan are listed in Table 1.

Table 1. Toxicity characteristic constituents and their regulatory levels in Taiwan.

Contaminant	**Regulatory level (mg/L)**
Heavy metal [a]	
Mercury	0.2
Selenium	1.0
Cadmium	1.0
Chromium (VI)	2.5
Lead	5.0
Chromium [b]	5.0
Arsenic	5.0
Silver	5.0
Copper [c]	15.0
Barium	100.0
Pesticides	
Organic chloride pesticides	0.5
Organic phosphorus pesticides	2.5
Carbamates pesticides	2.5
Organic pollutants	
Hexachlorobenzene	0.13
2,4-Dinitrotoluene	0.13
Vinyl chloride	0.2
Benzene	0.5
Carbon tetrachloride	0.5
1,2-Dichloroethane	0.5
Hexachlorobutadiene	0.5
Trichloroethylene	0.5
1,1-Dichloroethylene	0.7
Tetrachloroethylene	0.7
2-(2,4,5-TP) (Silvex)	1.0
2,4,6-Trichlorophenol	2.0
Nitrobenzene	2.0
Hexachloroethane	3.0
Pyridine	5.0

Table 1. *Cont.*

Contaminant	Regulatory level (mg/L)
Organic pollutants	
Chloroform	6.0
1,4-Dichlorobenzene	7.5
2,4-Dichlorphenoxyacetic Acid	10.0
Chlorobenzene	100.0
Pentachlorophenol	100.0
Cresol	200.0

[a] Including its compounds (*i.e.*, total content); [b] Exclusive of residues (*i.e.*, waste leather powder, leather debris and leather piece) generated from the tannery processes of using or manufacturing anima skin; [c] Only for those designated wastes, including spent catalyst, collected dust, spent liquor, sludge, filter material, fly ash or bottom ash as a result of incineration.

In recent years, the Taiwan's EPA established an on-line reporting system that tracks the complete life cycle (cradle-to-grave) of industrial waste from generation source to disposal site. Meanwhile, industrial generators have adopted waste reuse (or recycling) and pollution prevention as top strategies for their industrial waste management. In this regard, the management of biosludge in Taiwan has been regulated under the Waste Management Act. Table 2 lists the annual statistics during the years of 2004–2010 based on the on-line reported amounts of the biosludge targets, including FPS, WBS, PS, TS and AS. Herein, these dewatered biosolids are officially defined by generating from wastewater treatment facilities or manufacturing (formulating) processes in the food processing, wine brewing, pulp making, textile dyeing and livestock raising industries, respectively. From the data in Table 2, it can be seen that most of these waste activated biosolids in recent years have remained relatively steady at about 43,000, 11,000, 40,000 and 13,000 tons per year on an average for FPS, WBS, TS and AS, respectively. It implied that the food/drink, wine, textile and livestock markets (or industries) in Taiwan may be considered mature with flat plateau to declining overall volumes. By contrast, the reported volumes of PS have been on the decrease since 2007, which could be attributed to both enhanced waste paper recycling and the financial (economic) crisis which commenced during this time.

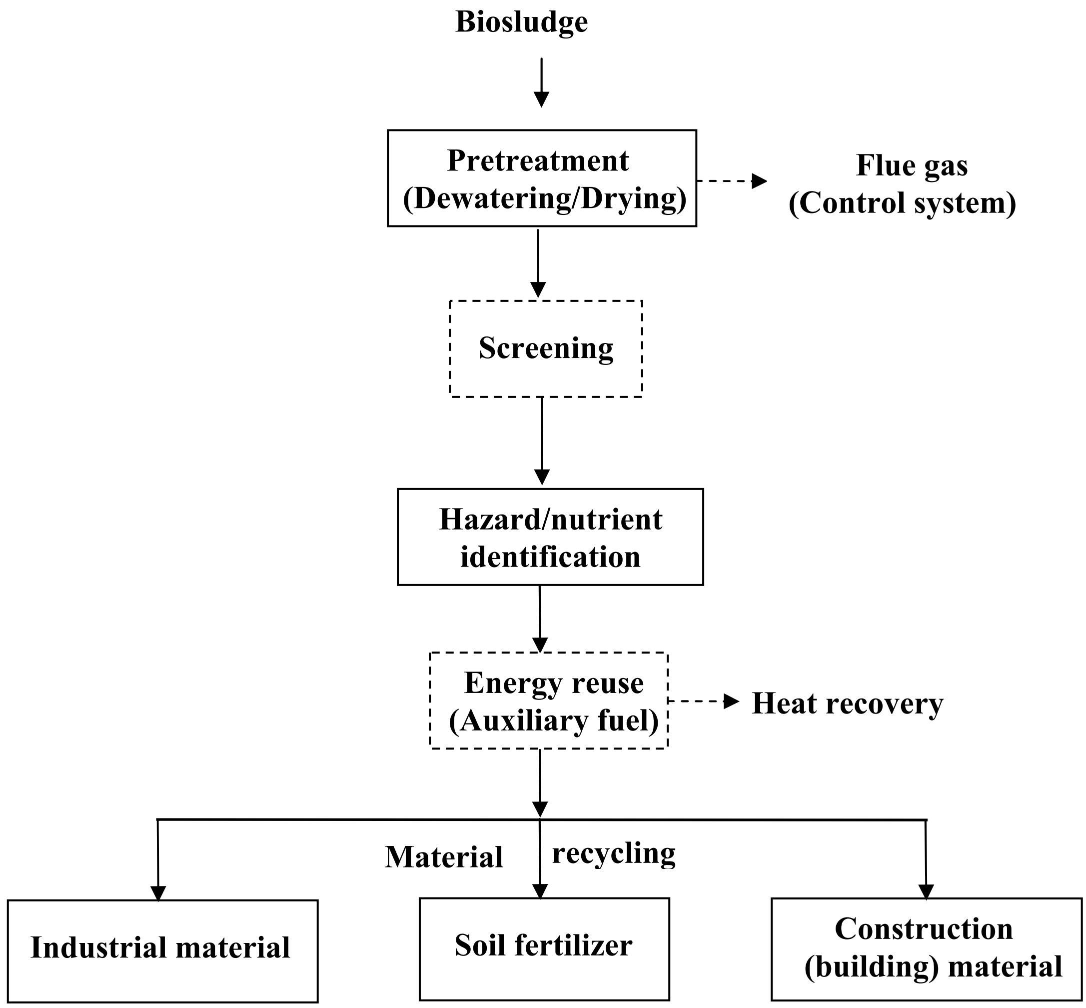
Table 2. Statistics on the on-line reported amounts of industrial biosludge for reuse in Taiwan. [a]

Year	Food processing sludge	Wine brewery sludge	Pulp sludge	Textile sludge	Agricultural sludge
2004	43,497	8,210	293,694	38,581	7,656
2005	42,829	9,682	352,075	46,141	10,179
2006	37,804	11,519	417,529	41,189	13,696
2007	54,318	10,304	432,432	35,957	13,988
2008	39,096	11,461	311,529	34,970	14,352
2009	42,813	11,387	181,061	40,533	11,640
2010	42,801	10,934	181,873	41,588	13,659

[a] Unit: metric ton.

It is well known that biosludge is mainly derived from activated sludge processes for the removal of biochemical oxygen demand. As a result, the preference order of biosludge management is to minimize (volume reduction), to utilize (reuse, recycling, or land reclamation), and to dispose (sanitary landfill). First, lowering biosludge volume by dewatering and/or drying pretreatment is needed and aims to cut transport and treatment costs. The potential applications of biosludge used as an agricultural fertilizer or other material resources are relevant because this bioresource contains dead microbe biomass, inorganic material, plant nutrients, trace elements, organic compounds, and pathogens. Therefore, there have been a number of studies on biosludge as a raw material for agricultural use [6], and for the production of usable materials [7]. Figure 1 shows the conceptual flow diagram of utilizing biosludge as material resources, including pretreatment, screening, hazard/nutrient identification, energy recovery (if necessary) and material recycling units.

Figure 1. Conceptual flowchart of biosludge recycling for material utilization.



3. Governmental Regulations and Policies for Promoting Biosludge as Material Resources

In response to the impact of industrial waste management generated by common treatments (*i.e.*, sanitary landfills and incinerators) on the environmental policy for pursuing sustainable development, the competent authorities at all levels in Taiwan are aggressively promoting the "Complete Recycling for Zero Waste" project for the purpose of ensuring that recyclable resources from waste can be efficiently recycled and reused, and eventually achieving the goals of complete sorting and zero waste. As described above, the law governing the reuse/recycling of industrial waste in Taiwan is the Waste Management Act. Under the authorization of Article 39 of this Act, the responsible agencies at the central government level (*i.e.*, the Ministry of Economic Affairs and the Council of Agriculture) after consultation with the EPA has promulgated the "*Regulations Governing the Permitting of Industrial Waste Reuse*" and "*Regulations Governing the Permitting of Agricultural Waste Reuse*" related to the reuse of industrial waste and agricultural waste since 2002. As listed in Table 3, the target biosolids discussed in the present study were legally designated to be reused as raw material for organic fertilizer, plant cultivation medium, or other material resources. However, it is necessary to control the heavy metals and other toxic chemicals present in biosludge in order to protect soil quality and hence crop quality.

Table 3. Reuse of biosludge, approved by Taiwan's responsible agencies.

Category	Source(s)	Reuse type(s)
Food processing sludge	Generated by secondary biological treatment facilities or manufacturing processes in the food/drink industry	Raw material for organic fertilizer
Wine brewery sludge	Generated by secondary biological treatment facilities or manufacturing processes in the wine brewing/formulating and beer industry	Raw material for organic fertilizer, raw material for plant cultivation medium
Pulp sludge [a]	Generated by wastewater treatment facilities in the paper & pulp and paper product industries	Raw material for heat-insulation material, raw material for fire-proof building material, fuel for boiler, auxiliary fuel for cement kiln
Textile sludge [a]	Generated by wastewater treatment facilities or manufacturing processes in the textile industry	Raw material for heat-insulation material, raw material for fire-proof building material, auxiliary fuel for brick/tile kiln or cement kiln or boiler
Agricultural sludge	Generated by secondary biological wastewater treatment facilities in the agricultural sector or manufacturing processes (sludge only contains animal/ plant residues)	Raw material for organic fertilizer, raw material for plant cultivation medium

[a] Not appropriate for biosludge pertaining to hazardous waste, which is based on the Identification Characteristics of Hazardous Wastes under the authorization of the Waste Management Act.

Since the admission of Taiwan to the World Trade Organization (WTO) on January 1, 2002, the central competent authority, the Council of Agriculture (COA), has planned agricultural policies to promote the ecological operation by minimizing the use of chemicals and synthetic fertilizers for the sustainable development of Taiwan's agriculture. In this context, Taiwan's COA implemented the "Adjustment Plan for Fertilizer Policy" to encourage the use of organic fertilizers as well as biological fertilizers under the enacting of Fertilizer Management Act (FMA). The core purpose of the Act is to perform fertilizer management in good condition, maintain fertilizer quality and soil capacity, enhance agricultural productivity, and protect the environment. Under the authorization of the Act, the regulation known as "The Category, Item, and Specification of Fertilizer" was established and formally announced in August, 2000. In the types of organic fertilizer, dried microbe-based biomass fertilizer has been coded as Item No. 5-06, in which its applicable range is to utilize the biosludge generated from the secondary wastewater treatment in the food/drink manufacturing, wine/beer brewing or livestock raising industries. Because of the high water content and organic biodegradable nature of the biosludge, it must be treated by heating, anaerobic digestion, drying, and/or formulating processes to produce the organic fertilizer. A list of properties and toxic metal limits that define the quality of the organic fertilizer are presented in Table 4. As shown in the table, the acceptable levels of heavy metal contaminants (including As, Hg, Cd, Pb, Cu, Ni, Cr, and Zn) in the fertilizer were set by the intended use for the material. Also, this type of organic fertilizer should neither mix chemical fertilizer and minerals nor contain chemical agents (*i.e.*, precipitant, coagulant, or flocculant).

Table 4. Regulations for the specifications of organic fertilizer (*i.e.*, dried microbe-based biomass fertilizer) derived from biosludge in Taiwan [a].

Item	**Mandatory value**
Organic matter (% dry wt)	>50.0
Heavy metal limit (mg/kg, dry wt)	
Arsenic (As)	<25.0
Mercury (Hg)	<1.0
Cadmium (Cd)	<2.0
Lead (Pb)	<150
Copper (Cu)	<100
Nickel (Ni)	<25.0
Chromium (Cr)	<150
Zinc (Zn)	<250
Moisture content (%wt)	<20.0
pH	5.0–9.0

[a] The microbe-based fertilizer must be evaluated via crop toxicity test, showing that it is nontoxic. Also, the organic fertilizer shall be not mixed with chemical fertilizer, minerals, or dewatered sludge containing chemical agents (*i.e.*, precipitant, coagulant, or flocculant).

4. Preliminary Benefit Analysis of Utilizing Biosludge as Raw Material for Organic Fertilizer

As described above, the organic nature of biosludge, along with plant nutrients and several trace elements made it a valuable resource as a good fertilizer for agricultural use, and as inorganic material for industrial use [8]. However, high concentrations of toxic heavy metals, hazardous organic compounds, and pathogens may preclude the beneficial use of biosludge, or lead to the control of fertilizer use. On the other hand, excessive contents of nitrogen and phosphorus in biosludge may be a pollution source in both groundwater and surface water when it is applied to soils as organic fertilizer, resulting in eutrophication. In comparison with common treatment options (*i.e.*, direct incineration and sanitary landfill), the benefits of utilizing biosludge as raw material for organic fertilizer were analyzed and addressed as follows [9,10].

- Increased number of beneficial microbes in soils.
- Possible moderating of soil acidity.
- Lowering of biosludge treatment cost.
- Mitigating of greenhouse gases (*i.e.*, methane and nitrous oxide) emissions.
- Reduced hazardous air pollutants (*i.e.*, heavy metals, acidic gases and chlorinated organics) emissions as a result of incineration treatment.
- Reduced hazardous odorants (*i.e.*, organic acids, ammonia, and hydrogen sulfide) emissions as a result of landfill treatment.
- Increased cation-exchange capacity resulting in improved soil fertility.
- Increased water retention in soils.
- Reduced application rate of synthetic fertilizer.

5. Conclusions

In response to the demand for a sustainable waste management in Taiwan, the waste-to-material system has been established through a regulatory framework under the "joint-venture" of the ministry-level departments in the past decade. In this regard, biosludge from secondary wastewater treatment processes contains plant nutrients and is also high in organic matter, making it highly beneficial as soil conditioners. According to the on-line reported quantities of food processing sludge, wine brewing sludge, textile sludge, pulp sludge and agricultural sludge collected by the Taiwan EPA, a systemic and analytical description about the generation of biosludge and its sustainable management was addressed in the present study. However, high concentrations of heavy metals (e.g., cadmium, mercury, lead), organic compounds (PCBs, dioxins), and human pathogens (polio virus, typhoid bacillus) in biosludge may preclude the beneficial use of biosludge, or lead to the control of fertilizer use.

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Conflict of Interest

The author declares no conflict of interest.

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