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Article

Regulatory Promotion of Waste Wood Reused as an Energy Source and the Environmental Concerns about Ash Residue in the Industrial Sector of Taiwan

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Abstract: The objective of this paper was to provide a preliminary analysis of the utilization of energy derived from waste wood in Taiwan, a highly industrialized country with a high dependence (over 99%) on imported energy. The discussion focuses on the status of waste wood generation and its management over the past decade. Findings show that the quantities of biomass waste collected for reuse purposes in the industrial sectors of Taiwan has exhibited an increasing trend, from about 4000 tons in 2001 to over 52,000 tons in 2010. Although waste wood can be reused as a fuel and raw material for a variety of applications based on regulatory promotion, the most commonly used end use is to directly utilize it as an auxiliary fuel in industrial utilities (e.g., boilers, heaters and furnaces) for the purpose of co-firing with coal/fuel oil. The most progressive measure for promoting biomass-to-power is to introduce the feed-in tariff (FIT) mechanism according to the Renewable Energy Development Act passed in June 2009. The financial support for biomass power generation has been increasing over the years from 0.070 US$/kWh in 2010 to 0.094 US$/kWh in 2012. On the other hand, the environmental regulations in Taiwan regarding the hazard identification of wood-combusted ash (especially in filter fly-ash) and its options for disposal and utilization are further discussed in the paper, suggesting that waste wood impregnated with chromated copper arsenate (CCA) and other copper-based preservatives should be excluded from the wood-to-energy system. Finally, some recommendations for promoting wood-to-energy in the near future of Taiwan are addressed.

Keywords: waste wood; reuse; waste-to-energy; regulatory promotion; wood ash; heavy metal

1. Introduction

The utilization of energy from biomass waste for the production of heat and power in large utilities (e.g., boilers and incinerators) and co-firing with fossil fuels (especially coal) in large power plants has received much attention in the past two decades mainly due to the advances in waste-to-energy (WTE) technologies, increasing energy prices and the global warming issue [1,2]. More importantly, the decentralized energy from domestic waste resources not only enhances fuel diversification, but also possesses environmental benefits in terms of greenhouse gas (GHG) emissions and associated global warming [3]. In this regard, biomass materials such as woody residues are increasingly being recognized as valuable bioresources because they are both renewable and rich in carbon sources. The organic carbon can be further reused as a green energy source. Moreover, electricity and heat generated from biomass through combined heat and power (CHP) systems are offsetting those generated from fossil fuels with GHG emission reduction credits. As a result, there is an increasing interest in co-firing non-hazardous biomass with coal in the coal-fired power plants and/or large-scale mass-burn municipal solid waste (MSW) incineration plants, which have been designed with the best available control technology for any toxic air pollutants emitted from their flue stacks [4].

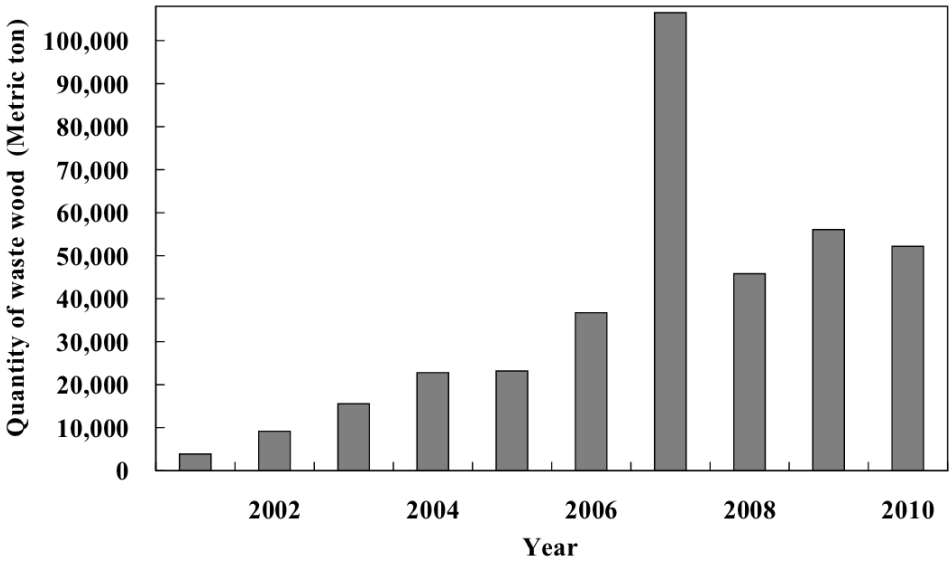
Due to the fact that waste wood is a low-cost biomass fuel, woody waste has been considered very attractive for large-scale biomass combustion plants. According to the European standards concerning the classification of waste wood [5], it may be categorized into seven different quality classes, including chemically untreated wood, bark, binder-containing and halogen-free coated wood, surface-treated wood, creosoted timber, salt-impregnated wood, and halogen plastics containing wood composite materials. Considering the fact that the biomass may be contaminated with a variety of substances such as wood preservatives, binders, paints, glues, plastic laminating materials or other non-wood materials, waste wood is often not a virgin fuel. As a result, its impurities may have negative impacts on environmental loadings. It should be noted that some chemically-treated woods impregnated with either chromated copper arsenate (CCA) or copper-based preservatives are of special concern because of their toxic heavy metals. More significantly, copper has been considered as a catalyst for the formation of dioxins [6].

A previous paper [7], only presented a comprehensive description of governmental regulations and policies for promoting industrial wastes (*i.e.*, pulp sludges, waste wood, sugarcane bagasse, textile sludges, and scrap plastics) as energy sources. The environmental regulations on the emissions of hazardous air pollutants as well as benefit analysis from industrial waste-to-energy (IWTE) were also discussed. By contrast, the objectives of this paper were to give the current status of waste wood generation and its management in the industrial sector of Taiwan, and to describe the updated information about regulatory policies for promoting waste wood as energy source based on the current waste management, energy management (via cogeneration) and renewable (biomass) energy development regulations. Furthermore, there are concerns about the contents of heavy metals and toxic organic compounds present in the ash residues produced from the combustion of waste wood. The environmental regulations in Taiwan regarding the disposal and utilization of wood-combusted ash were further discussed in the paper.

2. Generation and Management of Waste Wood in the Industrial Sector of Taiwan

According to the Waste Management Act (WMA) in Taiwan [7], waste is classified into general waste (municipal waste) and industrial waste. Furthermore, industrial waste includes general industrial waste and hazardous industrial waste. It should be noted that the term industrial waste refers to the waste generated by the industrial sector, including agricultural farms and industrial & mining plants. In 2000, the central government in Taiwan formally established an on-line reporting system that tracks the complete life cycle (cradle-to-grave) of industrial wastes from major generation sources to their disposal sites. The on-line reported volume of waste wood generated by the industrial sector in Taiwan during the years of 2001–2010 is shown in Figure 1 [8]. From the data in this Figure, it can be seen that the quantities of biomass waste for reuse purposes exhibited an increasing trend, from about 4000 tons in 2001 to over 52,000 tons in 2010. Exceptionally, the volume reported in 2007 reached a maximum at 106,000 tons, which should be attributed to the high economic growth and fast oil price rise at this period. Obviously, this treatment method can not only reduce the quantity of industrial waste for incineration treatment and landfill disposal, but can also cost down expenditures on waste management and energy usage in the industrial sector.

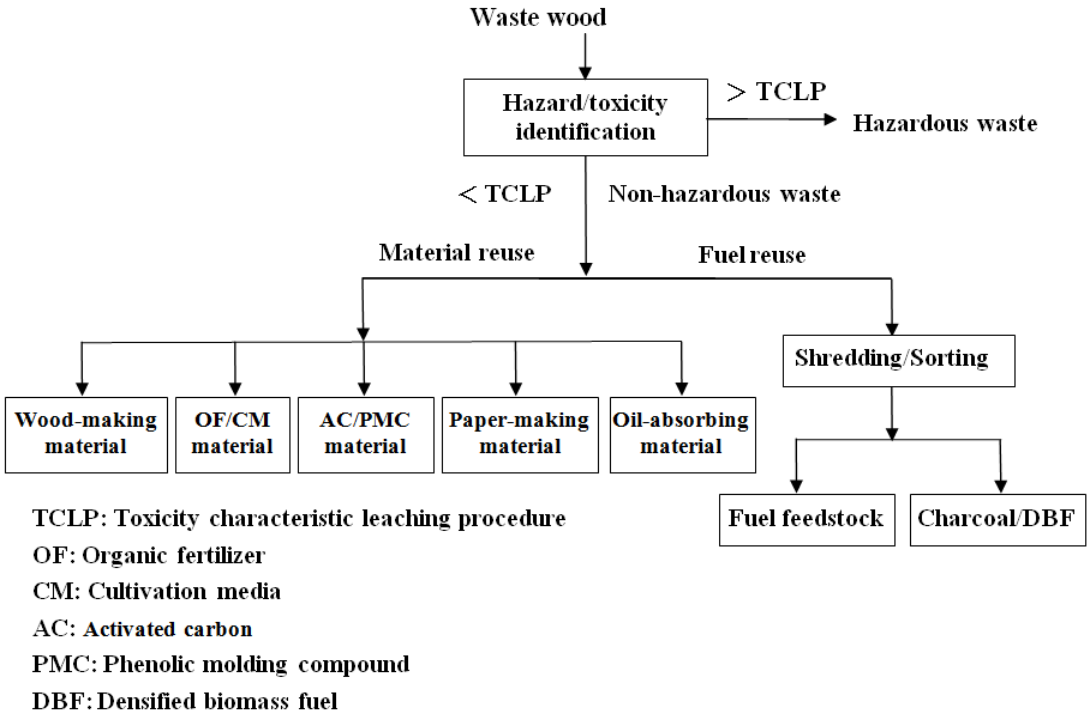
Figure 1. On-line reported quantities of reused waste wood generated from the industrial sector of Taiwan.



According to the definition in the WMA regulations, reuse refers to the industrial waste reuse by the generators themselves, or through the sale, or transfer or entrusting to others for reuse as a raw material, fuel, land reclamation fill, or for other approved purposes. In this respect, the Responsible Agency at the central government level has promulgated the "*Regulations Governing the Permitting of Industrial Waste Reuse*" under the authorization of the Article 39 of the Act since 2002. With respect to the types of waste wood reuse, it can be reused as fuels and raw materials for a variety of applications, as shown in Figure 2. However, the most commonly used method is to directly utilize it as auxiliary fuels in industrial utilities (e.g., boilers, heaters and furnaces) for the purpose of co-firing with coal/fuel oil. The results are reasonable due to the fact that waste woods, including wood pallets,

construction/demolition wood waste, package material, particleboard and chipboard, had higher heating values of around 20 MJ/kg on a dry basis [5]. On the other hand, sulfur oxides (SO_x) are among the most important gaseous pollutants from coal combustion processes from the viewpoints of acid rain and corrosion processes. In this regard, the contents of sulfur in the waste wood are relatively low, ranging from 0.03 to 0.2 wt% on a dry basis in comparison with most coals that have sulfur contents of about 1 wt% [5]. Therefore it should be expected that sulfur oxides (SO_x) would not be emitted in a large extent during the combustion of waste wood.

Figure 2. Outline flowchart of waste wood reuse for material and fuel utilization according to the Waste Management Act in Taiwan.



3. Governmental Policies and Regulatory Promotion for Reusing Waste Wood as Energy Source

As described above, the reuse of waste wood in Taiwan is regulated under the Waste Management Act. Herein, the recyclable biomass must be a general industrial waste, which is almost always generated by industrial plants. To resolve the problem of industrial waste treatment caused by lack of appropriate incineration facilities in Taiwan, some types of general industrial waste with a high combustible portion, including waste wood, have been announced to be encouragingly reused as auxiliary fuels in the industrial utilities such as boilers, heaters and cement kilns [7]. Furthermore, these types of general industrial waste have been co-combusted together with municipal solid waste (MSW) in waste-to-power incinerators with permits from local governments in recent years. As a result, the amount of general industrial waste treated in the MSW incineration plants increased from 0.73 million tons in 2001 to 1.45 million tons in 2006, and to 2.27 million tons in 2011.

Besides, combined heat and power (CHP) systems which were applied to the generation of electricity from the industrial boilers and MSW incinerators in Taiwan have been successfully used in the past two decades. For example, total installed capacity of cogeneration systems in Taiwan was on

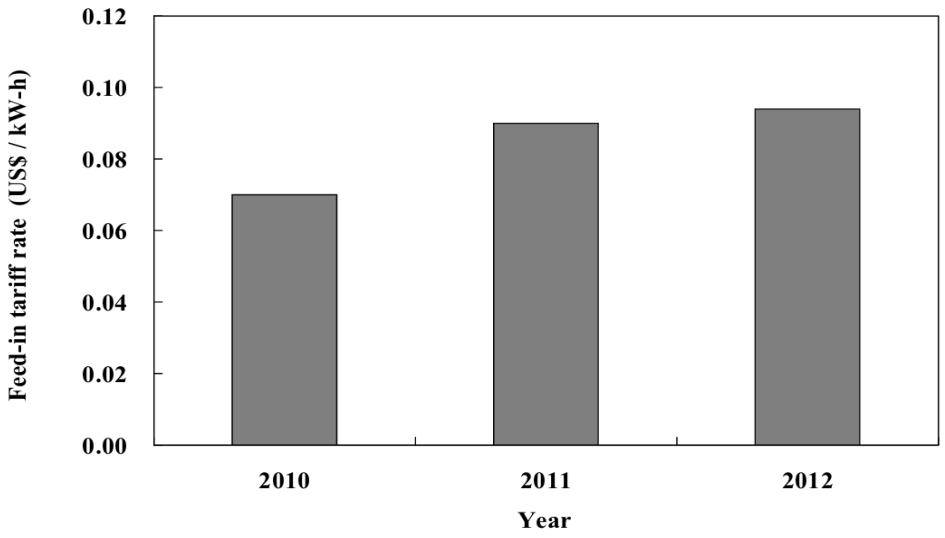
an increasing trend from about 1.8 millions kW in 1991 to around 7.6 million kW in 2011. From the data on waste-to-power and/or cogeneration systems in Taiwan, this can be attributed to the regulatory promotion resulting from the promulgation of the Energy Management Law (EML), which aims at rational and efficient utilization of energy, including fossil fuels and electrical energy. According to the act, the energy user, who meets the levels of effective thermal ratios and total thermal efficiencies set up by the central competent authority in its cogeneration system, may ask the local vertical integrated utilities (*i.e.*, Taipower; one of state-owned companies) to purchase its excess electricity and supply backup electricity needed for its system maintenance or at the time of system breakdown. Under the authorization of the Law, the competent authority first promulgated the regulation (*i.e.*, "*Measures for Implementing the Cogeneration system*") in 2002. However, it should be noted that the regulation shall be temporarily effective prior to the pass of the Electricity Act Amendment aimed at the liberalization of electric sector in Taiwan. Using the reported data from the Taipower, about 9.5×10^9 kWh of excess electricity in 2010 were purchased from private cogeneration systems by the state-owned company in contrast to around 2.16×10^9 kWh in 1995, 8.14×10^9 kWh in 2000, and 1.28×10^{10} kWh in 2005.

Determined to transform Taiwan into a sustainable low-carbon society, the Legislative Yuan passed the Renewable Energy Development Act (REDA) in June 2009. The purpose of the Act is to promote the use of renewable energy, to boost the energy diversification, to improve the environmental quality, to foster the related industries, and to upgrade Taiwan's sustainable development. With respect to the regulatory promotion for wood-to-energy, important provisions and measures in the REDA bill can be summarized as follows:

- Biomass energy shall mean the domestic energy produced by directly utilizing or processing the agricultural & forest plants, biogas, general wastes, and general industrial wastes;
- The goal of the Act is to increase Taiwan's renewable energy generation capacity by 6.5 million kilowatts to 10 million kilowatts under subsidy assistance within 20 years. The central competent authority should set the promotion goals for various renewable energy sources and their respective rates biennially;
- Electricity generated from renewable energy sources should be connected to and purchased by the local operator of the electricity grid (*i.e.*, Taipower Co., Taipei, Taiwan). The feed-in tariff (FIT) paid for electricity generated from renewable energy sources shall be not lower than the average cost of electricity generated by the sector using fossil fuels.

Based on all kinds of determining factors, including installation costs, operating years, maintenance costs, annual power generation capacity, capital cost rate and other relevant factors, the FIT rate of each category of renewable energy for the next year shall be set by a "special" examination commission and officially announced by the central government level at the end of the current year. Figure 3 showed the variations on the FIT rates for waste-to-energy (renewable power) in Taiwan, indicating that the financial incentive for biomass power generation has been increasing over the years. For example, the current FIT rate for waste-to-energy is 0.094 US$/kWh, higher than the rate (*i.e.*, 0.090 US$/kWh) from the previous year 2011.

Figure 3. Variations of feed-in tariff rate for waste-to-energy (renewable power) in Taiwan.



4. Environmental Concerns about Ash Residue from the Combustion of Waste Wood

From the standpoint of the energy use of waste wood as a replacement for coal, its heating value is the most important fuel property. However, this biomass resource may be not the same as fresh wood cut from a forest because it can come contaminated with toxic/hazardous chemicals. In the lumber mills, wood residues such as sawdust and wood scraps could be recycled or composted, instead of being burned for the production of heat and electricity in a CHP (cogeneration) system. Although it is preferable to use virgin woods as fuels or auxiliary fuels due to their low toxics contents, the combustion or co-firing of treated woods is promising due to local availability of the biomass fuel, lower transportation costs and waste management policy. In a previous study [9], it was referred that several air toxics could be emitted from the combustion of waste wood because this biomass may be impregnated and/or laden with lead-containing paints, salts, chromated copper arsenate (CCA) or copper-based preservatives. In construction/demolition waste wood, it is likely that PVC wire-attached and PVC-coated wood materials can be generated from many sources in construction and building materials. As a consequence, these heavy metals will remain in the bottom ash, and also attach to the surfaces of fine particles, or be contained inside fly-ash particles. In general, the heavy-metal concentrations in ashes of waste wood incinerators are considerably higher than those of virgin wood and herbaceous biomass ashes, especially in Cu, Zn, Ni, Cr, and Pb [10,11].

According to the Waste Management Act in Taiwan, the resulting ash from wood combustion may be classified as a hazardous industrial waste because it contains toxic or dangerous substances in a sufficient concentration or quantity to endanger human beings or pollute the environment, mainly based on its toxicity characteristic leaching procedure (TCLP). This standard was designed to identify wastes likely to leach dangerous concentrations of certain toxic chemicals into groundwater (drinking supplies) from landfills. Currently, the central government has designated the regulatory levels for 10 metals as listed in Table 1. In this regard, the ash from the co-firing of biomass materials (e.g., waste wood) with coal could be of concern because the production of mixed ashes, including fly ash and bottom ash, could include toxic heavy metals. The environmental aspects of the utilization, reuse and

disposal of these mixed ashes, particularly of the fly ashes, will require careful consideration, meaning that compliance with the standard specifications and classifications could be a requirement [12,13].

On the other hand, there are also some concerns about the potential for wood-derived ashes to contain significant levels of organic pollutants such as polychlorinated dibenzodioxins/furans (PCDD/Fs) [14,15]. It should be noted that most of these toxic organic pollutants are listed as persistent organic pollutants (POPs) by the Stockholm Convention effective on 17 May 2004. The concerns are particularly with the fly ashes because the combustion conditions may be relatively poor in the industrial boilers, resulting in higher levels of these toxic pollutants as a result of the incomplete combustion. According the designation of WMA in Taiwan, ash residue can be listed as a hazardous waste if its total PCDD/Fs contents exceed 1.0 ng I-TEQ/g.

Table 1. Toxicity characteristic constituents (toxic metal) and their regulatory levels in Taiwan.

Toxic metal [a]	Regulatory level (mg/L)
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

[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.

5. Conclusions and Recommendations

In response to the problem of sustainable waste management in Taiwan, the waste-to-energy system has been established through a regulatory promotion under the "joint-venture" of the ministry-level departments in the past decade. Taking into account the alternative energy utilized and GHG emissions mitigated, the reuse of waste wood generated by the industrial sector as auxiliary fuels in the utilities equipped with cogeneration systems was encouraged. According to the online reported quantities for reuse purposes, it has thus exhibited an increasing trend, from about 4000 tons in 2001 to over 52,000 tons in 2010. Furthermore, Taiwan's cabinet (Executive Yuan) approved the Renewable Energy Development Act in June 2009, suggesting that the Act could further promote the combustible biomass with fossil fuels in the industrial and private power plants with some economic incentives. This is due to the fact that the surplus electricity shall be sold to the state-owned company (Taipower Co., Taipei, Taiwan) at an officially designated feed-in tariff (FIT) rate. However, there are concerns about the contents of heavy metals and toxic organic compounds present in the wood ash, which is the residue generated from the combustion of waste wood and wood products. In this respect, the ash from the combustion of wood impregnated with chromated copper arsenate (CCA) and copper-based

preservatives could be treated as hazardous waste according to its properties on the toxicity characteristic leaching procedure (TCLP).

To better promote the waste wood co-utilization for energy production in the near future of Taiwan, the following actions are recommended:

- Put high priority on fresh wood types such as driftwood, fruit trimmings, tree trimmings (from parks and streets), and sawdust;
- Encourage the utilization of waste wood in municipal solid waste (MSW) incinerators to enhance the production of electricity from the combined heat and power (CHP) systems;
- Boost the application of biomass-to-electricity by a certified system for validating amount of waste wood co-fired in the power plant, and a profitable feed-in tariff (FIT) system for a period of several years (e.g., 20 years);
- Establish a definite legislation for the resource utilization (e.g., fertilizer) of wood ash from the thermal recovery of chemically untreated woody biomass, exclusive of filter fly-ash.

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