A Decision Support Tool for Regional Biomass Waste Management and its Application in Regional Australia

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EXCECUTIVE SUMMARY

Biomass waste from organic municipal solid waste and food manufacturing can be used as a source of renewable energy via incineration, gasification or anaerobic digestion. Alternatively, after composting type processing it can be returned to improve the nutrient and drainage structure of agricultural soils, thereby reducing the demand for phosphate rock based fertilizers and their associated highly toxic contaminants particularly Cd.

This project is developing a new analytical tool for planning and assessing alternative systems for the management of biomass waste on a regional scale, focusing on both energy and nutrient recovery from biomass waste, and Cd contamination control in the system by-products. This tool integrates material flow analysis of nutrient and heavy metals (Phosphorus and Cadmium) together with energy and greenhouse gas balance accounting. The wide range of data required as input for this tool has been obtained through extensive literature reviews and field trips to interview food industries and local governments in the region of interest.

The project has focused on one of the most intensive food production areas in regional Australia, the Murrumbidgee Irrigation Area (MIA). The tool has been used to explore various scenarios of implementing new conversion plants to recover both energy and nutrients from existing biomass waste flows that currently have no competitive use and whose management could be greatly improved. The results highlight that large amounts of energy from biomass are potentially available compared with the current situation. Large GHG emissions reductions can be achieved by reducing direct methane emissions from landfills and from replacing the present fossil fuel energy supply with bioenergy. Extra Phosphorus is also recovered in the form of anaerobic compost through anaerobic digestion with the associated Cadmium flow being almost the same amount as compost product in the current situation. However this Cadmium contamination can be reduced by changing to lower Cd contamination phosphate fertilizer or the greater use of organic compost.

INTRODUCTION

Material and energy recovery from waste has an important role in sustainable waste management as it can reduce all of the following: waste to landfill, the extraction of raw materials and fossil fuels and greenhouse gas emissions (Lens, Hamelers et al. 2004). Biomass waste from organic municipal solid waste and food manufacturing can be used as a source of renewable energy source, via incineration, gasification or anaerobic digestion (Sims 2002). Or after composting type processing, it can be returned to improve the nutrient and drainage structure of agricultural soils, thereby reducing the demand for phosphate rock based fertilizers, and their high toxic contaminants particularly Cd (Kwonpongsagoon, Moore et al. 2006; Seyhan 2006).

In Australia, a number of new biomass waste energy and nutrient recovery plants have been developed over the past decade years. An anaerobic digestion plant (EarthPower Ltd), has been operating in western Sydney since 2003 to process food processing waste and source separated commercial organic wastes and produce green electricity (3.5 MWe) and organic fertilizer. Moreover, a Mechanical-Biological waste treatment plant (Global Renewable Ltd) has been operating in Western Sydney since 2004 to process residue waste and can divert 80 % of this waste from landfill and produce bioenergy (2 MWe) from anaerobic digestion of it's organic fraction as well as producing compost. A new Mechanical-Biological waste treatment plant will be constructed soon in the Macarthur region of NSW. Furthermore, almost all existing landfills are capturing landfill gas to produce electricity in the Sydney metropolitan area with total capacity of 26.8 MWe (Rutovitz and Passey 2004; The Australian Business Council for Sustainable Energy 2005)

In regional Australia, some cities in intensive agricultural areas play a key role in food production for the large metropolitan cities like Sydney and Melbourne. These cities have small populations but have a number of food manufacturers that produce large amounts of various food products for Australia and export (Carbon Partners Pty Ltd 2006; Murrumbidgee Irrigation Ltd 2006). These cities have some advantages over large metropolitan cities with regards to waste management in that they have large amounts of source separated organic waste from these food processing plants. Such waste can be used to provide renewable energy and nutrient sources with less heavy metal contamination except, notably, the Cadmium associated with the use of Phosphate fertilizer (Kwonpongsagoon, Moore et al. 2006). Furthermore, these regional cities have logistical advantages in producing composted products close to end users; farmers in the region and electricity and steam for the nearby food production facilities (Rutovitz and Passey 2004). However, to date bioenergy plant development in these regions has been limited for reasons including the absence of regulation to control biomass waste disposal as large amount of wastes are disposed of on land without pretreatment, the high capital cost of conversion technologies, competitive use of some biomass waste streams, regulatory and institutional barriers and a lack of information and understanding of the options available (Carbon Partners Pty Ltd 2006; Matteson and Jenkins 2007).

Assessment of energy, nutrient and associated contaminant resource flows can facilitate decision makers in both government and industry in better understanding the externalities and opportunity costs of current waste management and the potential benefits of greater resource recovery. (Korhonen 2002).

A new analytical tool that integrates energy/greenhouse gas accounting and material flow analysis accounting that can be applied at a regional scale is described in this paper. This will provide a comprehensive analysis of alternative systems for management of biomass waste. The goal is to design a system that will optimize the use of biomass waste in both reducing greenhouse gas emissions and recycling P, while controlling Cd contamination of soils.

METHODOLOGY

The methodology to develop the analytical tool is presented in Figure 1. The methodology consists of five main steps, with each step containing a number of sub-steps. The Material Flow Analysis (MFA) models developed in step 3 and 5 are the model components themselves and are evaluated together to plan sustainable biomass waste management system.

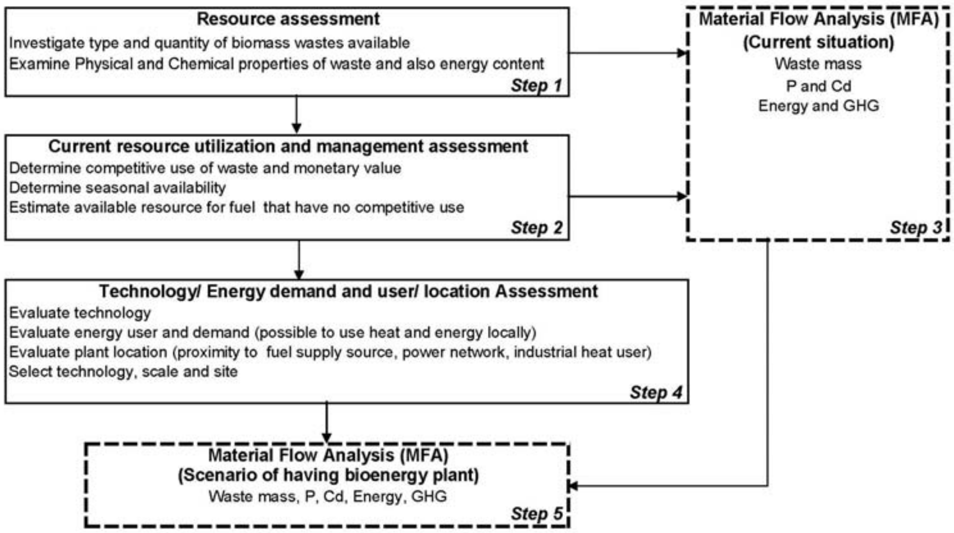

Figure 1 Diagram of methodology to develop the integrated planning model. (The single-lined boxes represent the main steps. The dotted boxes are main steps and also the model components. The arrows show flow of data to the steps and model components.)

Material Flow Analysis (MFA) is an environmental accounting tool that traces and provides account of valuable resources or toxic substances flowing through a process or region (Daniels and Moore 2002; Brunner and Rechberger 2004). Our particular focus in this paper is on P and Cd, nutrients, energy and greenhouse gas emissions. The system boundary of this MFA model is Murrumbidgee Irrigation Area in 2006. The MFA models of P and Cd are conducted by several steps beginning with determination of the relevant processes and goods in the MIA. Mass flows of related goods and substance concentrations in each of these goods are then assessed. The type, quantity, and properties of biomass waste in the MIA were obtained from an extensive literature search and field trips to interview industries and local government in the region. Following this, the substance flows and stocks are calculated and balanced as shown in the MFA diagram.

P and Cd balances associated with all goods and wastes flowing through the region have been developed. However, this paper presents only the results for the substance flows related to biomass waste with potential for biomass waste recovery and reuse. This then means some of the flows of substances, such as the P associated with fodder output from the Feed Mill are not presented in the MFA diagram in this paper.

Energy and greenhouse gas (GHG) flow models are undertaken in a different way. Flow diagrams of the biomass waste are first developed and then their associated energy content is incorporated to generate the energy flow model. Greenhouse emissions are obtained from estimates in the literature for different possible biomass treatments; for example, methane emissions from anaerobic lagoons.

In step 5, selected biomass conversion and energy production technology, scale and site obtained from step 4 are used to modify the MFA model in the current situation from step 3. Here, the “process boxes” of bioenergy plant are inserted in the model, and the flows of biomass waste that is available for bioenergy production are diverted to the biomass energy plant. Then the output from the bioenergy plant, in terms of digestate, ash, compost, P, Cd, energy and GHG are determined by multiply substance and energy flow in the waste input with appropriate “Transfer Coefficient”. These transfer coefficients are obtained from a literature review and from the reports on the real operating plant in other regions (Brunner and Rechberger 2004).

Finally, trade offs among energy, GHG, P and Cd are evaluated using the data from the Material Flow Analysis model in step 3 and 5. Moreover, new scenarios using new bioenergy technologies and new and changed inputs of biomass waste flow to the bioenergy plant can be assessed, by rearranging the flow and changing transfer coefficients in “bioenergy plants process box” in the MFA model. The new output from the plants can then be used to evaluate the trade offs among energy, GHG, P and Cd, for this newly developed scenario.

RESULTS AND DISSCUSSION

Current biomass waste, substance and energy flow.

The study are in this project is the Murrumbidgee Irrigation Area (MIA), one of the largest agricultural areas in Australia. A number of food factories are in this area including wineries, rice mills, juice making, and fruit and vegetable processing. Two intensive cattle feedlots and a beef abattoirs and one of Australia’s largest poultry producer and processor are also located in this region ((Murrumbidgee Irrigation Ltd 2006).

Total biomass waste produced in the region in 2006 was 508,843 tonnes consisting of 300,875 tonnes/y of food processing waste (including grape marc, fruit peel and pulp, rice husk, rice bran and meat processing byproduct), 192,000 tonnes/y of animal waste (including cattle and chicken manure with bedding material), 15,130 tonnes/y of organic fraction in municipal solid waste and 838 tonnes/y of sludge from wastewater treatment plants.

The majority of food processing wastes in this region are being utilized. However, some of them are still dumped on land without pretreatment and less than 1 percent is sent to landfill. The detail of food processing waste utilization and management in MIA in 2006 is presented in Table 1.

Table 1 Food processing waste utilization and management in MIA in 2006

Food processing waste utilization and management	Percent
Used as feedstock in local feedmills	34
Exported as feedstock	26
Used as bedding material	5
Composted	11
Dumped on land (no pretreatment)	23
Disposed of in Landfill	1

All animal waste is cycled back to soil; cattle manure is composted in the compost plant in the feedlots along with bedding material and used as a soil conditioner while chicken litter is sold to farmers and applied on land directly with no pretreatment. Most of the organic fraction in municipal solid waste is not separated and, instead, disposed of in landfill with sludge from the wastewater treatment plant. An exception is garden waste which is composted in a compost plant.

The details of biomass waste flows are presented in Figure 2. The MFA diagram here shows only the flow of solid organic wastes in the MIA in 2006. The flow of Phosphorus, Cadmium, energy and greenhouse gas emissions in the current situation are presented in Figure 3, 4 and 5 respectively.

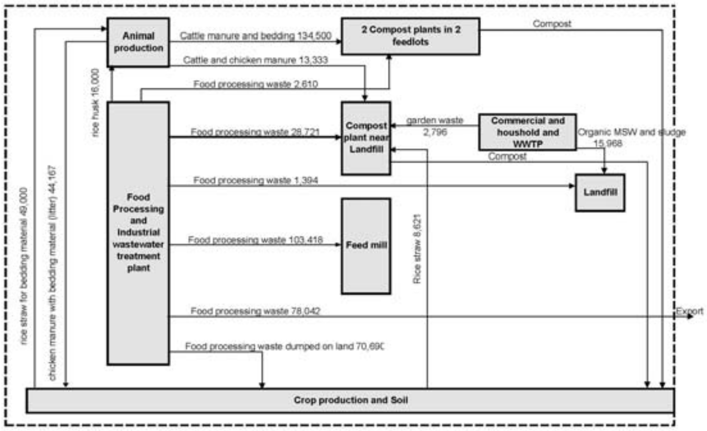

Figure 2 Current biomass waste flow diagram in MIA in 2006 (tonnes/year)

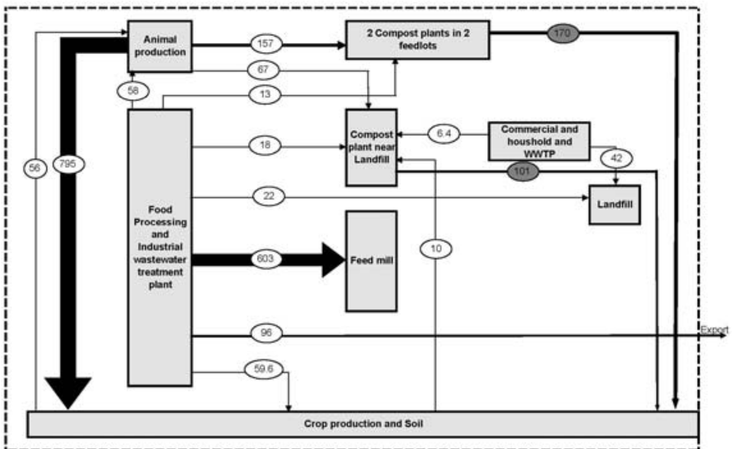

Figure 3 Current Phosphorus flow diagram in MIA in 2006 (tonnes/year), as associated only with biomass waste flows from Figure 2.

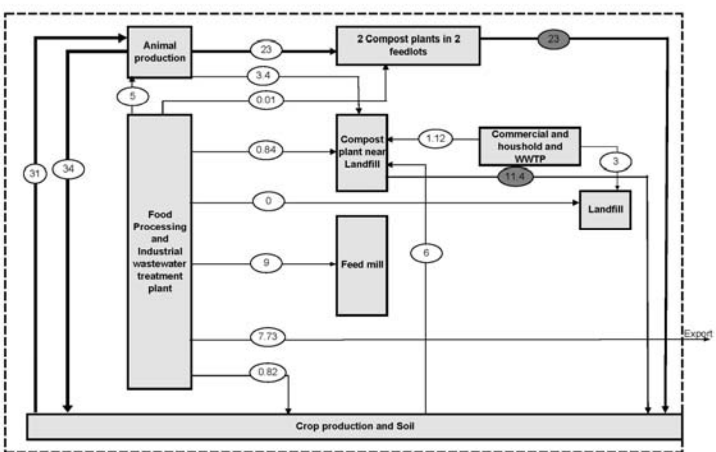

Figure 4 Current Cadmium flow diagram in MIA in 2006 (kg/year), as associated only with biomass waste flows from Figure 2.

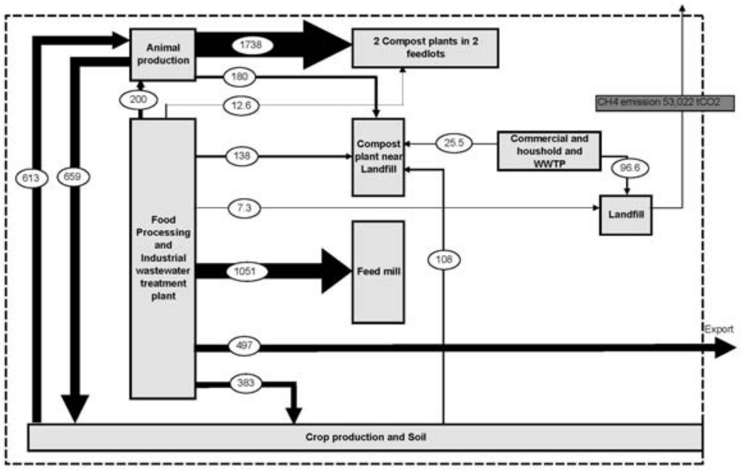

Figure 5 Current energy/GHG flow diagram in MIA in 2006 (TJ/year and tCO_2/y), as associated only with biomass waste flows from Figure 2.

As presented in Figure 3, Most of Phosphorus associated with biomass waste in the region are cycled back to soil. The major flow of Phosphorus in the biomass waste flow in the region is the flow of chicken manure applied on land as fertilizer, which account for 795 t/y or 40%. The second largest flow of P is in the flow of food processing waste sent to the feed mill, which account for 603 t/y or about 30% of total P flow. The flow of P associated with cattle manure and bedding sent to compost plant represent the third largest flow of P, and accounts for only 157 t/y or 8% of total P flow. About 5% or 96 t/y of P in total biomass waste in the region is exported as feedstock, and 3% or 59.6 t/y of P in food waste are disposed of on land which yield no benefit to crops.

In term of Cadmium as presented in Figure 4, the majority of cadmium flow associated with biomass waste flows of 613 kg/y is in the flow of rice straw to be used as bedding material, as rice straw has a high contamination of cadmium. As a result, chicken litter applied to land as fertilizer, and cattle manure and bedding material collected together and sent to compost plants in the feedlots are the second and third highest flows of Cadmium in the region. This in turn makes a compost product flow from the compost plant in feedlot, and the compost plant near landfill, having Cadmium of 37 kg/y and 11.3 kg/y respectively.

Studies have indicated that Cadmium contamination in crops results from the input of Phosphate fertilizer, accounting for around 200 kg/y as some of phosphate fertilizer applied in the region is single superphosphate which has a high Cadmium contamination. Therefore, changing to low Cadmium contamination phosphate fertilizer type or using more organic compost can reduce the Cadmium contamination in rice straw and hence the cadmium contamination in the compost product.

In terms of energy and GHG flow in Figure 5, CH_4 emission from the landfill account for 53,000 tCO_2 equivalent. The highest energy flow of 1,738 TJ/y is the flow of manure and bedding material to compost. The second highest energy flow is in the flow of biomass waste to the feed mill, representing an energy flow of 1,051 TJ/y. The diagram also shows that 497 TJ/y of energy flow is in exported food waste, and 254 TJ/y of energy flow is in food waste disposed of on land. These wastes have very high potential to produce energy, but at present none of these wastes are used to produce bioenergy.

Biomass wastes, substance and energy flow for a scenario of having a bioenergy plant in the region.

This scenario involves building new biomass conversion plants in the region to recover both energy and nutrient from biomass waste which currently has no competitive use and therefore no monetary value. Firstly, food processing wastes that are dumped on the land are diverted to co-digest with manure in the anaerobic digestion plant in the feedlots. We assumed that the compost plants in each of the 2 cattle feedlots are replaced with in-vessel anaerobic digesters as the feedlot in the region plan to do. Therefore, all cattle manure is processed in anaerobic digestion plants to produce electricity and steam to use in their feed mill, and also anaerobic compost for sale. Sludge resulting from Dissolve Air Flotation (DAF) process in the chicken processing plant is diverted from land injection to an onsite anaerobic digestion plant to produce biogas, to displace the use of natural gas in their boiler. Sewage sludge is disposed of in the landfill as it has a high Cd content. The organic fraction of MSW is still disposed of in the landfill as it will cost too much for the council to separate if from the overall waste stream. However, landfill gas will be captured and used to produce electricity.

The MFA diagram for biomass waste, P, and Cd, and the energy and GHG flow diagram of the newly constructed scenario are presented in the Figure 6, 7, 8, 9 respectively.

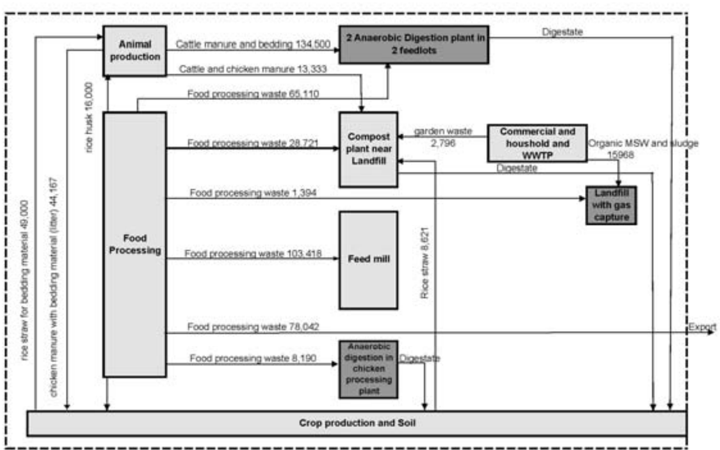

Figure 6 Scenario biomass waste flow diagram in (tonnes/year)

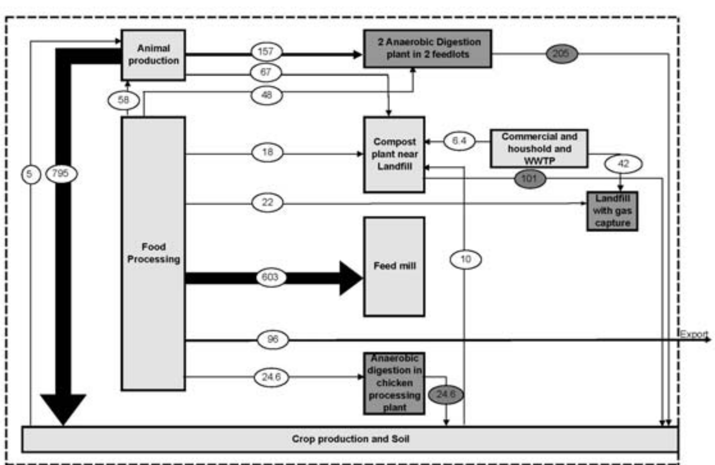

Figure 7 Scenario Phosphorus flow diagram in MIA (tonnes/year), as associated only with biomass waste flows from Figure 6.

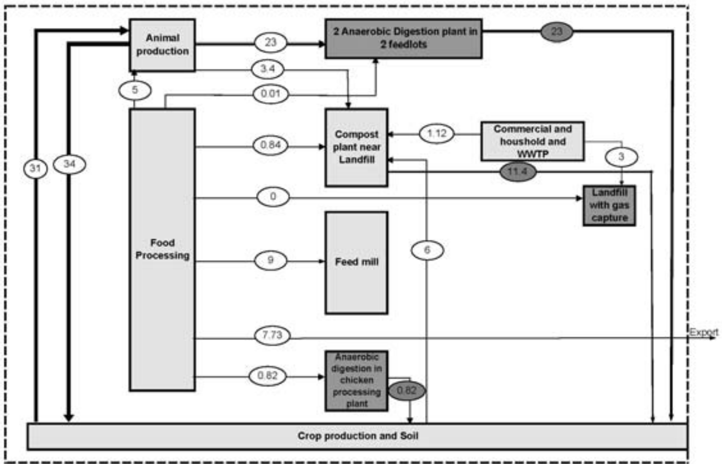

Figure 8 Scenario Cadmium flow diagram in MIA (kg/year), as associated only with biomass waste flows from Figure 6.

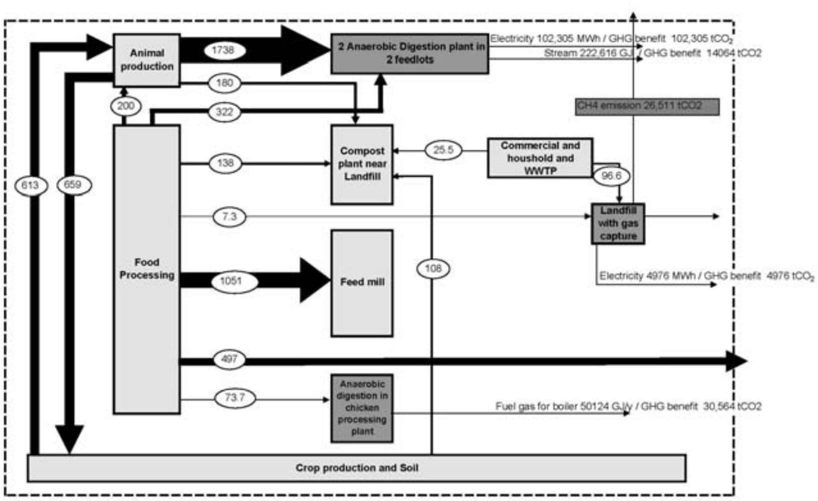

Figure 9 Scenario Energy/GHG flow diagram in MIA in 2006 (TJ/year and tCO_2/y), as associated only with biomass waste flows from Figure 6.

In the scenario in Figure 7, Phosphorus in waste is used more efficiently, as P in waste dumped on land (no use) is transformed to digestate or anaerobic compost via anaerobic digestion and can be sold to farmers to use in the region. The amount of P in the total product of anaerobic compost from 3 anaerobic digestion plants is 330 t/y, compare to 271 t/y of P in compost product in the current situation.

In terms of the Cadmium flows in Figure 8, Cd is low in waste dumped on land in the current scenario, therefore when these wastes are converted by anaerobic digestion plants in the scenario, Cd flow associated with digested or anaerobic compost output is almost the same as Cd flow associated with compost product from composting plant in current situation.

In terms of energy and GHG flow in Figure 9, in the scenario, most of the biomass wastes in the region are recovered to produce energy; manure and bedding material and also food processing waste are processed in anaerobic digestion to produce electricity of 102,305 MWh/y and steam of 222,616 GJ/y, the GHG benefit is a total 116,370 tCO_2/y, which results from avoiding burning of fossil fuel for electricity generation and combustion of natural gas for steam production. DAF sludge from chicken processing waste is processed in an onsite in-vessel anaerobic digestion plant, and produces biogas to use in the boiler, replacing some of the natural gas. This energy account for 50,124 GJ/y with a GHG benefit of 30,564 tCO_2/y. About 50% of Landfill gas is captured giving a benefit of 26,511 tCO_2 equivalent and production of electricity of 4976 MWh.

In this scenario, large amounts of energy from biomass are recovered compared with no energy recovered at all in current situation. Large amounts of GHG emissions are reduced by reducing direct methane emission from landfills and indirect GHG emission reduction from replacing fossil fuel energy with bioenergy. Extra Phosphorus is also recovered in the form of anaerobic compost through anaerobic digestion, with Cadmium flow associated with anaerobic compost being almost the same amount as compost product in current situation. However, this Cadmium contamination can be reduced by changing to low Cd contamination phosphate fertilizer type or using more organic compost.

CONCLUSION

This project is developing a new analytical tool for planning and assessing alternative systems for the management of biomass waste on a regional scale, focusing on both energy and nutrient recovery from biomass waste, and Cd contamination control in the system by-products. This tool integrates material flow analysis of nutrient and heavy metals (Phosphorus and Cadmium) together with energy and greenhouse gas balance accounting. Data input into the tool has been sourced from various kinds of resources and databases including: government reports, the Australian Bioenergy Atlas and published research reports. Most important has been the data sourced from interviewing food industries, waste management practitioners and local governments in the region.

This tool has been applied within one of the major food production areas in Australia, the Murrumbidgee Irrigation Area (MIA). This area produces large amounts of biomass waste, which can be use as an energy and nutrient source after appropriate conversion processes. Currently, these wastes are used to produce feedstuffs and compost but one fourth is still disposed of on land without pretreatment. Furthermore, more wastes are likely to be disposed of on land if the demand for food waste to produced feedstuff decreases when the current drought ends. We have therefore explored a scenario involving a new conversion plant to recover both energy and nutrients from biomass waste that has no competitive use and is currently being improperly managed. The results from the scenario showed the benefits of such a plant including energy recovery, greenhouse emission reductions and more Phosphorus cycling with no increasing Cadmium contamination to crops and soil.

The MFA model developed here will be used with STAN, the MFA software developed by TU Vienna, Institute for Water Quality, Resources and Waste Management, to facilitate the evaluation of different bioenergy technologies, and scenarios of changing the flow input into the bioenergy plant. For example, the anaerobic digestion plant can be replaced with pyrolysis plant. The changed conversion factors of the new plant will be inserted into the MFA model, with resulting changes in energy and substance flow outputs from the plant. Similarly, some biomass waste flows that are exported as feedstock may be changed to input to any bioenergy plant in the region.

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REFERENCES

Brunner, P. H. and Rechberger, H. (2004). *Practical Handbook of Material Flow analysis*. Lewis Publishers, Vienna.

Carbon Partners Pty Ltd (2006). *Waste Generation and Resource Efficiency Inquiry Submission.*Australian Government Productivity Commision Canberra.

Daniels, P. L. and Moore, S. J. (2002). "*Approaches for quantifying the metabolism of physical economies: part 1 methodological overview;*." Journal of Industrial Ecology **5**(4): 69-93.

Korhonen, J. (2002). "*A material and energy flow model for co-production of heat and power*." Journal of Cleaner Production **10**(6): 537-544.

Kwonpongsagoon, S., Moore, S. J., Waite, D. T. and Brunner, P. H. (2006). "*A substance flow analysis in the southern hemisphere: cadmium in the Australian economy*." Clean Technologies and Environmental Policy **Article In press (online first)**.

Lens, P., Hamelers, B., Hoitink, H. and Bidlingmaier, W. (2004). *Resource recovery and reuse in organic solid waste management* IWA Publishing, London.

Matteson, G. C. and Jenkins, B. M. (2007). "*Food and processing residues in California: Resource assessment and potential for power generation*." Bioresource Technology **98**(16): 3098-3105

Murrumbidgee Irrigation Ltd. (2006). "*Regional Production in Murrumbidgee Irrigation Area*." from http://www.mirrigation.com.au/AboutUs/Water_for_Life.htm#Production.

Rutovitz, J. and Passey, R. (2004). *NSW Bioenergy Handbook*. NSW Department of energy, Utilities and Sustainability (DEUS), Sydney.

Seyhan, D. (2006). *Development of a method for the regional management and long-term use of non-renewable resources: The case for the essential resource phosphorus. Institue for water quality, resource and waste management* Vienna, Vienna University of Technology. **PhD**.

Sims, R. E. H. (2002). *The Brilliance of Bioenergy in Business and in Practice*. James & James (Science Publishers) LtD, London.

The Australian Business Council for Sustainable Energy (2005). *Waste to Energy: A Guide for Local Authorities.*The Australian Business Council for Sustainable Energy,Melbourne.