Development of energy self-sufficiency of agroindustry

T Bantacut\textsuperscript{1} and M Romli\textsuperscript{2}

\textsuperscript{1} Professor, Department of Agroindustrial Technology, Faculty of Agricultural Technology, IPB University, IPB Dramaga Campus, Bogor Indonesia
\textsuperscript{2} Professor, Department of Agroindustrial Technology, Faculty of Agricultural Technology, IPB University, IPB Dramaga Campus, Bogor Indonesia.

E-mail: bantacutajuddin@gmail.com

Abstract. Agroindustrial production processes consume considerable amount of energy and generate a lot of organic wastes. These wastes pollute the environment because of their rich organic compounds that will undergo decomposition. The main compounds contained in the waste are energy-carrying materials such as fibre, carbohydrates, protein, and oil/fat. The use of these materials as energy sources can save natural resources while cutting the load of environmental pollution. This paper discusses the assessment of adequacy of energy contained in the waste and proposes an integrated flow model to support the agroindustrial production process. The amount of waste obtained from the mass balance model is then multiplied by the energy content of each waste to obtain energy potential. Energy conversion is used to calculate steam (heat) and electricity needed to support the production process. Some examples are given to show that agroindustry has the potential to become an energy independent industry by applying the principle of less input and multiple outputs through the reuse, recovery, and recycling of the waste. Some future research recommendations are proposed to enable the implementation of energy self-sufficient agroindustry.

Keywords: agroindustry, self-sufficiency energy, waste energy recovery

1. Introduction

Agroindustry generates large amounts of multi-phase and multi-component wastes in liquid, solid and gas forms. Waste composition varies according to the source of raw materials, product properties, operations, and processing steps. In general, agroindustrial wastes contain large amounts of organic matter (fibre, carbohydrates, protein, fat, oil, etc.); and for wastewater is indicated by the high B\textsubscript{OD} (biochemical oxygen demand), COD (chemical oxygen demand), and suspended solids values [1]. This characteristic of the waste indicates its large potential to be used as an energy source, as well as its large pollution impact on the environment if not managed properly [2-5].

Many research works have been done to minimise the load of environmental pollution either through treating waste before disposal or utilising components that still have economic value [6]. In this context, waste utilisation can be done collectively within the value chain [7] to meet economies of scale and technical feasibility or through on-site recycling, recovery, and utilisation as energy sources [8-10]. Thinking about wasted resources, pollution and environmental damage has led to the concept of industrial ecology which is based on the relationship of one industry with other industries through the exchange of waste [11]. These emerging concepts are then incorporated into industrial and regional...
planning disciplines that create industrial estates, ecologically sustainable industrial parks, industrial symbiosis, and by-product synergies [12,13]. The planning phase must consider all variables comprehensively to improve business competitiveness, cut waste and pollution, create jobs and improve working conditions [14].

In the area of energy, many aspects and methods have been analysed such as biochemical conversion [15], anaerobic treatment [16], biohydrogen and biomethane [17], biogas electricity [17], pyrolysis and gasification [18], bioethanol production [19], methane generation [20], energy from food wastes [21], and biogas harvesting [4,5]. In line with utilisation as an energy source, processing of agroindustrial waste to produce product is believed to be very cost-effective in the long run [1,22]. From now onwards, the development of agroindustrial estates will be increasingly difficult because raw material production is increasingly spreading [23], production scales are getting smaller [24], demand for products is increasingly diverse [26,27] and environmental carrying capacity is decreasing [26,27]. In such situations, the focus on reducing waste and preventing pollution must be at the individual industry level. Optimising on-site waste management through reuse, recovery and recycling can help control the exploitation of natural resources (raw materials) and environmental pollution. This paper discusses the use of waste to develop energy-independent agroindustries to reduce waste transportation and treatment costs while increasing efficiency, cutting production costs, and creating value-added products. Some examples are given to show that energy independence can be achieved and also some recommendations are given to implement the concept.

2. Method
The generic model of material balance applied to an agroindustrial activity according to its actual process flowsheet is used to analyse the level of agroindustrial energy self-sufficiency. Bantacut and Pasaribu have developed a material balance model for palm oil production (CPO) [8] which is then further developed for several other agroindustries such as sugar mills [9], rice mills [10], corn flour [28], and tapioca production [29]. The development of these models is used to analyse and determine the level of self-energy sufficiency in agroindustry in general. The steps for developing the material balance model are discussed below.

2.1. Data used
Primary and secondary data are used in developing models. Secondary data, including mass flow, energy requirements, by-products, and the rate of conversion of inputs into outputs for each stage of the process are obtained from various research results. This is based on the fact that many research works have been carried out for each specific stage in the whole process of agroindustrial production. Synthesis of separate research results enables improvements in the production process to obtain optimal process efficiency. Primary data, in the form of actual mass balance, are collected from direct observations and measurements in agroindustry and are used to evaluate the accuracy of the model output by comparing the calculated value with the measured value. The general steps for developing a material balance model and the calculation of the sufficiency level are explained below.

2.2. System boundary
The Material Balance Model is a useful tool for analysing and estimating the energy sufficiency of agroindustry [9] which involves many factors that are interconnected with each other and various constraints. Factors and constraints on the balance model can be material, energy requirements and by-products. A comprehensive approach may cover all possible process steps from raw material preparation to the final product. However, modification to limit the scope by setting system boundaries is also possible depending on the research needs. For example, the boundary of a rice milling system consists of five compartments, namely drying, de-husking, whitening, polishing and grading. The main output is head rice and by-products (broken rice, rice husk and rice bran). Broken rice is produced from the grading process, rice husk is produced from de-husking, and rice bran is produced from whitening and polishing [10]. For sugar factories, the compartments cover milling stations, purification stations,
evaporation stations, cooking stations (vacuum pan), and centrifugation stations. The main output is white crystal sugar and by-products including bagasse, filter cake, water, and molasses [9]. This system boundary approach applies to all agroindustries.

2.3. Model description
The model is developed based on the mass flow of processes (compartments) which represent the actual mass flow and mass balance of an agroindustry. Inputs are treated as independent variables and outputs as dependent variables. Modelling uses coefficient values in the form of ratios (efficiency) of the dependent and independent variables based on the principle of linear equations.

2.4. Mass balance model
A mass balance model represents a mathematical relationship of mass input and output flows in a system. It can model the production, transportation, and fate of pollutants in an environment and show every flow in the system and every accounted component in the closed system [30]. The first step in creating a mass balance is to separate the compartments of identifiable segments (steps) of processes within which individual boundary can be defined. Then, a mass balance is set to link inputs (material in) and output (material out) for all compartments. By-product is assumed to be recyclable. Secondary data on the mass flows of the process are used to define values of the efficiency equation (the ratio of variables). The mass balance model represents the whole production processes.

Matrix operation is used to calculate the value of variables. Input values for the matrix operation are variables of mass balance and efficiency value of each compartment. Some levels of mass balance may be made depending on the complexity of production process and consistency of the models, namely simple, medium and complex models.

2.5. Calculation of by-product energy content
The potential energy can be calculated by the equation:

\[
\text{Potential energy (MJ)} = \text{Mass (ton)} \times \text{calorific value (MJ/ton)}.
\]  

(1)

The biomass total is calculated from the mass balance model, whereas the calorific values are obtained from the literature.

2.6. Process flow of an agroindustry
The stages of processing in an agroindustry vary from the simplest to very complex one. Figure 1 illustrates stages of the process. The figure shows that each stage can be made into a compartment as the basis of making the mass balance equation. The total mass that enters must be equal to the total mass that comes out. The figure assumes that there are two inputs (I₁ and I₃), only one product (Pₙ), and four solid/liquid wastes (W₁, W₂, W₄, W₅), two gaseous wastes (V₄, V₅), and five intra-flows of mass (X₁, X₂, X₃, X₄, X₅). The two inputs are treated as independent variables, while others 12 variables (X, W, V and P) are dependent variables. Therefore, 12 equations are needed to determine the values of all dependent variables.

There are six material balance equations that can be generated, one for each process stage, as follows:

\[
\begin{align*}
I₁ - X₁ - W₁ &= 0 \\
X₁ - X₂ - W₂ &= 0 \\
I₃ + X₃ - X₅ &= 0 \\
X₅ - X₄ - W₄ &= 0 \\
X₄ - X₅ - S₄ &= 0 \\
X₅ - W₅ - Pₙ &= 0
\end{align*}
\]  

(2)  

(3)  

(4)  

(5)  

(6)  

(7)
Figure 1. A hypothetical process stage of an agroindustry.

The remaining six equations can be formulated based on ratios of outputs to inputs of each process which is called efficiency equation. The number of equations of each stage is determined by the number of mass outflows minus one (n-1). According to the figure 1, stage 4 can have two efficiency equations because it has three outflows (X4, W4, and V4), while the others have only one respectively. The efficiency equation of Process-1 can be either ratio of X1 to I1, X1 to W1 or W1 to I1 depending on data (research results) availability. Following this principle, possible six efficiency equations are:

\[
\begin{align*}
    a_1 &= \frac{X_1}{I_1} \\
    a_2 &= \frac{X_2}{X_1} \\
    a_3 &= \frac{X_3}{I_2} \\
    a_4 &= \frac{W_4}{X_3} \\
    a_5 &= \frac{X_5}{X_4} \\
    a_6 &= \frac{P_n}{X_5}
\end{align*}
\]

Values of \(a_1\) to \(a_6\) are taken from literatures or they can also be taken from direct field observation in an agroindustry. The excel application can be used to solve the equations by applying matrix operations.

2.7. Development of energy independent agroindustry

The solution from the equations is quantity of all mass flows within the industry (intra-flows) and outflows. These quantities are multiplied by the energy potential to determine the total potential energy of the wastes. Then, the energy potential is converted into steam and electricity. Some efficiency factors are used to calculate the actual energy. There are some variations in using the efficiency factors, below are examples:

- Boiler efficiency for hot air: 30% [31]
- Boiler efficiency for steam: 68% [32]
- Electricity efficiency from steam: 77% [33]
Analysis of the potential for energy self-sufficiency requires data on actual energy consumption to be compared with the model results. The level of sufficiency varies depending on the commodity, the technology used and the capacity of the agroindustry. Supporting data to calculate the energy produced from each by-product is collected from literature and field surveys. The calculated potential energy is then distributed through a process chain energy network to develop an energy independent production process. The comparison between total energy recovery and consumption determines the level of energy sufficiency of each agroindustry. Figure 2 illustrates a way to develop energy independent agroindustry.

![Diagram](image)

**Figure 2. Steps to develop energy independent agroindustry.**

The conclusion can be drawn by calculating the value of $E_e$ (Excess Energy), where $E_e = E_t - (E_1 + E_2 + E_3)$.

If $E_e = 0$, then the agroindustry has the potential to be self-sufficient; if $E_e > 0$ the industry has excess energy that can be sold through public grits; and if $E_e < 0$ then the industry requires external energy input either partially or completely.

### 3. Results and discussions

#### 3.1. Waste generation and calorific value

The main output of the material balance model is the flow of materials into and out of the industry. This flow refers to the amount of input that enters the production system. To analyse the level of energy independence, the model determines the amount of waste containing energy that can be used to calculate potential energy. Table 1 shows some examples of the results of the material balance model. In these examples, although the types of waste are limited, they are sufficient to show the potential magnitude of waste or by-products as energy sources. The table presents the amount of waste produced from the agroindustrial production process and the calorific values show the potential of the material to be used in generating energy.
Table 1. Wastes generation and their calorific value.

| Agroindustry | Type          | Volume (ton) | Calorific Value (kcal/kg) | Reference Capacity | Reference |
|--------------|---------------|--------------|---------------------------|-------------------|----------|
| Sugar mills  | Bagasse       | 1,042.98     | 2,019                     |                   | [9]      |
|              | Filter cake   | 81.75        | 3,319                     |                   |          |
|              | Molasses      | 62.10        | 2,700                     |                   |          |
| Rice Mills   | Rice husk     | 4,020        | 3,489                     | 20 ton paddy/day  | [10]     |
| CPO Mills    | Empty Fruit Bunches | 14,265    | 2,294                     | 60 ton Fresh Fruit | [8]      |
|              | Nut shells    | 1,959        | 5,114                     |                   |          |
|              | Fibre         | 4,613        | 4,589                     |                   |          |
|              | Effluent      | 21,058       | 52                       |                   |          |
| Tapioca      | Stockpile     | 533.4        | 2,484                     | 1,000 ton fresh cassava/day | [29]     |
|              | Cassava peel  | 117          | 707                       |                   |          |
| Corn Flour   | Corn husk     | 1.632        | 3,500                     | 12 ton fresh corn/day | [28]     |
|              | Corn cob      | 1.298        | 4,500                     |                   |          |

*Biogas equivalent

Energy content varies according to type and source of wastes. The variation also exists in a single agroindustry such as stockpile and cassava peel of tapioca processing. Palm kernel shells have a very high caloric content, but cassava peel value is very low. One disadvantage of raw biomass is the unstable electrochemical performance [34]. The difficulty arises when liquid and solid wastes are to be managed simultaneously. Solid wastes can be burned directly while wastewater and material with high moisture content must be treated before used either by anaerobic digestion or drying. Likewise, low density materials need to be compacted before burning to increase the calorific value and facilitate handling in storage and transportation.

3.2. Energy need for production processes

Energy needs in the production process vary from one agroindustry to another, depending on the units of operation and the process involved. The overall energy consumption is determined by the capacity, efficiency of the engines/machineries, and the process steps which can be summarised into two types namely heat energy (steam) and electrical energy. Steam is used for heating and electricity for lighting and to drive the engines and equipment. Total heat energy steam is calculated from amount of material to be heated and dried, while total electrical energy is determined from the machinery and equipment specification. Table 2 shows an example of detailed calculation to obtain the energy need of an agroindustrial process. This method is also used to calculate energy consumption of other agroindustries.

3.3. Energy self-sufficiency of agroindustry

The use of various types of biomass for energy generation is faced with various technology choices. Direct combustion to heat the boiler can be applied to solid materials with low water content such as bagasse, husk and wood wastes. Drying (preliminary heating) is required for solids with high water content such as oil palm empty fruit bunches, fermentation is needed for carbohydrate-containing materials such as molasses, and anaerobic digestion is used to produce biogas from liquid waste [15,18]. Figure 3 shows choices of technology for biomass conversion to energy.
Table 2. Energy needs for corn flour processing (12 ton corn).\(^a\)

| Process                  | Total Material Processed (ton) | Energy needs (kWh/ton) | Total energy needs (kWh) |
|--------------------------|-------------------------------|------------------------|--------------------------|
| Corn husk removing       | 12                            | 22                     | 264                      |
| Corn in cob drying       | 10.4                          | 10                     | 104                      |
| Corn shelling            | 9.1                           | 22                     | 200                      |
| Corn kernel drying       | 7.73                          | 15                     | 116                      |
| Corn hulling             | 7.03                          | 40                     | 281                      |
| Corn milling 1           | 5                             | 22                     | 110                      |
| Corn milling 2           | 4.3                           | 20                     | 86                       |
| Corn oil extraction      | 2.1                           | 7.5                    | 16                       |
| **Total**                |                               |                        | **1,177**                |

\(^a\)Source: [28]

Figure 3. Method of using biomass for energy (slightly modified from [35]).

Biomass used to produce heat or steam (heat engine/boiler) is then used for mechanical power to move and transport objects, for heating material (evaporator, dryer), and to generate electricity. This demonstrates that biomass is being capable of fulfilling all types of energy needs in agroindustry. Table 3 compiles some research results to show the waste capability of meeting energy requirement of agroindustry. The examples in Table 3 show that the waste produced by agroindustry can provide enough energy for the production process and, in part, produce excess energy. This shows that integration of the main line with the utilisation of waste to produce energy requires a new approach in plant design. Power generators, either direct combustion or conversion processes (pyrolysis, gasification, anaerobic digestion, fermentation, etc.) must be an inherent part of agroindustrial development from the early stages of design and planning. This will change perspectives in making the process flow, and stringing tools, equipment and machinery. Together with the addition of electricity generation stations that utilize by-products, there will be a reduction in the need for means of channelling electrical energy from public networks. The features of agroindustry in the future will be very much different in many aspects, for example the change from energy users to energy suppliers. The philosophy of further development is that agroindustry is an independent energy processing activity with a single input and multiple outputs.
Table 3. Energy generation, need and surplus of selected agroindustry.

| Agroindustry                     | Energy of wastes (kcal) | Energy need | Surplus (KWH) | Conclusion | Reference |
|----------------------------------|-------------------------|-------------|---------------|------------|-----------|
| Sugar Mills (3000 TCD)           | 2,237,500,774\(^1\)    | 482,349,600 | 60,000        | Surplus    | [9]       |
| Rice Mill (20 ton/day)           | 8,496,654\(^2\)        | 2,409,178   | 1,278         | Surplus    | [10]      |
| CPO mills (60 ton FFB/hour)      | 65,006,768\(^3\)       | 20,097,900  | 1,020         | Surplus    | [8]       |
| Tapioca (1,000 ton fresh cassava/day) | 1,407,714,408\(^4\)    | 99,261      | 11,735        | Surplus    | [29]      |
| Corn Flour (12 ton fresh corn/day) | 3,329,828                | 1,177       | 2,692         | Surplus    | [28]      |

Notes: \(^1\)Including bagasse, filter cake, and bioethanol from molasses; \(^2\)Husk only, \(^3\)Empty fruit bunches, fibre, kernel shell and biogas from wastewater by anaerobic digestion; \(^4\)Stock pile and cassava peel, \(^5\)Corn husks and cob.

These industry examples show the potential energy sources of fibre (bagasse, filter cake, kernel shells, empty fruit bunches, corn husks, corn cobs, rice husks, cassava peels, and stockpiles), short chain carbohydrates (molasses), and wastewater containing organic material (indicated by the amount of biochemical/chemical oxygen demand). Therefore, agroindustries that process raw materials containing fibre (carbon), simple carbohydrates or oils (fats) can be built on the principle of independent energy. Therefore, most agroindustries can be defined as industries that produce products and energy. Figure 4 represents an example of a new look of an agroindustrial basic process design.

4. Conclusions and recommendations
The analysis has shown that material balance model can be used to assess level of energy independence of an agroindustry. The model outputs that have been discussed lead to the following conclusions:

a. Agroindustrial wastes contain enough energy to supply the energy needed in the production process.
b. Agroindustries that generate a large proportion of waste compared to their main products can be developed into industries that produce excess energy, and thus become energy suppliers.
c. With the principle of single-input multi-product, agroindustry can be developed with a new rule, namely the minimum input - optimum output.

There are some works need to be done prior to application of energy independent agroindustry:

a. Energy sufficiency depends on the amount of waste produced. The feasibility of electricity production is determined by the technical scale (minimum power) and economies of scale. This technical and economic feasibility analysis needs to be done to be able to classify an agroindustry as meeting the requirements to be developed with the principle of energy surplus.
b. Research on developing small scale power plant needs to be done so that small scale industries can also apply the principle of independent energy.
c. Completing (a) and (b) is necessary to make a list of agroindustries that must apply energy independently so they must be limited to using fossil fuels.
Figure 4. Self-sufficient energy rice mill closed production system [10].

5. References
[1] Prasertsan P, Prasertsan S and H–Kittikun A 2009 Recycling of agro-industrial wastes through cleaner technology (Fundamentals in Biotechnology ) ed Doelle HW et al (Oxford Eolss Publ., Co Ltd.) Biotechnology –Vol. X
[2] Ali S M, Sabae S Z, Faye Z M, Monib M and Hegazi N A 2011 J. Adv. Res. 2 85–95
[3] Bantacut T and Ardhiansyah E L 2018 J. Nat. Adv. Res. 8 10-22
[4] Bantacut T and Aulia A N 2019 Nature Environment and Pollution Technology 18 413-423
[5] Bantacut T and Fitriani A Y 2019 Jurnal Teknologi Lingkungan 20 83-92
[6] Sadh P K, Duhan S and Duhan J S 2018 Bioresour. Bioprocess. 5
[7] Winkler H 2011 CIRP Journal of Manufacturing Science and Technology 4 243–246.
[8] Bantacut T and Pasaribu H 2015 Jurnal Teknologi Industri Pertanian 25 215-226
[9] Bantacut T and Novitasari D 2016 J. Clean. Prod. 126 478-492
[10] Bantacut T and Nurdiansyah M 2017 Journal of Energy Technologies and Policy 7 34-48
[11] Hond F 2000 Reg. Environ. Change. 1 60-69
[12] Bantacut T 2016 Developing Country Studies 6 10-20
[13] Deutz P and Gibbs D 2008 Reg. Stud. 42 1313–1328
[14] Gibbs D and Deutz P 2005 Geoforum 36 452–464
[15] Balat M 2006 Energy Sources, Part A 28 517–525.
[16] Demirer G N, Duran M, Ergüder T H, Güven E, Ugurlu Ö and Tezel U. 2000 Biodegradation 11 401–405
[17] Poggi-Varaldo H M, Munoz-Paez K M, Escamilla-Alvarado C, Robledo-Narváez P N, Ponce-Noyola M T, Calva-Calva G, Ríos-Leal E, Galindez-Mayer J, Estrada-Vázquez C, Ortega-Clemente A and Rinderknecht-Seijas NF 2014 Waste Manag. Res. 32 353–365.
[18] Kivaisi A K and Rubindamayugi MST 1996 Renew. Energ. 9 971-921
[19] Malkow T 2004 Waste Manag. 24 53–79
[20] Domínguez-Bocanegra A R, Torres-Muñoz J A and López R A 2015 Fuel 149 85–89
[21] Rani D S and Nand K 2004 *Waste Manag.* **24** 523–528  
[22] Déniel M, Haarlemmer G, Roubaud A, Weiss-Hortala E and Fages J 2016 *Renew. Sust. Energ. Rev.* **54** 1632–1652  
[23] Madurwar MV, Ralegaonkar R V and Mandavgane SA 2013 *Constr. Build. Mater.* **38** 872–878  
[24] Gandhi V, Kumar G and Marsh R 2001 *IFAMR* **2** 331-344  
[25] Bantacut T 2013 *Pangan* **19** 245-256  
[26] Boehlje M and Bröring S 2011 *IFAMR* **14** 1-16  
[27] Bommarco R, Kleijn D and Potts SG 2013 *Trends Ecol. Evol.* **28** 230-238  
[28] Bantacut T and Zuriel A 2018 *Int. J. Adv. Res.* **6** 173-186  
[29] Bantacut T and Ramadhani A 2018 *Int. J. Adv. Res.* **6** 521-532  
[30] Davis M L and Cornwell D A 2013 *Introduction to Environmental Engineering* 5th edition (New York: McGraw Hill Companies)  
[31] Basappaji K M and Nagesha N 2013 *IJAER* **8** 1783–1790  
[32] Yadav J P and Singh B R 2011 *JPSET* **2** 1-15  
[33] Narvaez RA, Blanchard R, and Mena A 2013 *Journal of Energy and Power* **3** 27–36  
[34] Xu K, Dong J, Li X, Wang J, Hu Z, Li A and Yao H 2019 *Biomass Bioenerg.* **130** 1-9  
[35] Capareda S C 2011 Biomass Energy Conversion ed Nayeripour M and Kheshti M (Texas A&M University USA)