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ASSESSMENT OF ENERGY POTENTIAL OF AGRICULTURAL WASTES IN NAKHON SI THAMMARAT PROVINCE

Surachet YANWAREE[1], P. Abdul SALAM[1] and *Ekkapong CHEEVITSOPON[2]

[1]*Energy, School of Environment, Resources and Development, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand*

2Department of Food Engineering, King Mongkut's Institute of Technology Landkrabang *Chalongkrung Road, Ladkrabang, Bangkok 10520, Thailand*

Corresponding author: Ekkapong CHEEVITSOPON. E-mail: cheevitsopon@gmail.com

ABSTRACT

Nakhon Si Thammarat is one of province of southern Thailand. The majority of the people in this province work in agriculture; plantation, fishery and livestock. Therefore, lot of agricultural residues and fishery wastes are available and most of them are not used for energy purpose. The main objective of this study is to investigate the energy potential of agriculture wastes in Nakhon Si Thammarat province. The agricultural wastes can be separated into three types: agricultural residues, animal wastes, and wastes from marine shrimp farming. Agriculture residues considered in this study are residues from paddy, Para tree, coconut, and oil palm. Five residues with high theoretical potential for energy are paddy straw, oil palm male bunches, Para wood slab, paddy husk and oil palm empty bunches. Theoretical energy potentials of those five residues are estimated to be 3,700 TJ/year, 830 TJ/year, 780 TJ/year, 560 TJ/year, and 560 TJ/year, respectively. Animal wastes from buffalo, cattle, swine, chicken, duck and goat are studied. Three animal wastes of the most theoretical energy potential are wastes from swine, cattle and chicken. Theoretical energy potentials of those wastes are approximately 160 TJ/year, 130 TJ/year, and 37 TJ/year, respectively. The theoretical energy potential of marine shrimp sediment is estimated to be 780 GJ/year. The results indicated that these agricultural wastes are high potentials as an energy source. The conversion of agricultural wastes to energy can be achieved by two major methods that are thermo-chemical and biochemical methods. Major factors that are considered as suitable method and technology for converting these wastes to energy are the type and quantity of biomass source, the forms of energy products, economic conditions and environmental impact.

Keywords: Biomass; Energy Potential; Agricultural Wastes

INTRODUCTION

Nakhon Si Thammarat province is in south of Thailand. The population of the province is 1,534,887 people. The main job of the people is agriculture, for example, plantation, fishery and livestock. Based on GPP in Nakhon Si Thammarat province [1], the value added of plantation, fishery and livestock is 54,263 million Baht, 3,972 million Baht and 1,285 million Baht, respectively.

Energy used in Nakhon Si Thammarat province is separated into two categories. They are electricity and non-electricity. Based on DEDE data [2], the amount of electricity used in the province is 1,785 GWh. More-over, according to Department of energy business [3], ministry of energy, people in the province consume products of petroleum for non-electricity, such as transportation, about 561,000 kiloliters in 2012. Two petroleum productions that were high demand in the province are diesel and benzene 91 that has 346,822 kilolitres and 81,106 kilolitres, res-pectively.

In Nakhon Si Thammarat province, the most waste in province comes from agricul-ture, for example, residues of Para rubber plantation such as fuel wood, frond leaves and saw dust, agricultural wastes from oil palm plantation such as frond, fiber, shell and empty bunches. However, few literatures are available on using of waste to energy techno-logies in the province.

Therefore, the main objectives of the paper were reviewing of bio-energy conversion, and estimating the different agricultural wastes available in Nakhon Si Thammarat province.

REVIEW OF BIO-ENERGY CONVERSION

The conversion of biomass to energy called bio-energy has many ways which convert biomass to products of energy form. There are power/heat generation and tran-sportation fuels. Many types of technology can convert biomass to energy. Important factors that are considered as suitable tech-nology for converting biomass to energy are the type and quantity of biomass source, the demand form of energy, environmental impact and economic conditions [4, 5]. At present, biomass conversion is two main process technologies. They are thermo-chemical and bioche-mical/biological as shown in Fig. 1. Three main options for thermochemical are combustion, pyrolysis and gasification, while biochemical/-biological has two options which are digestion and fermentation [6].

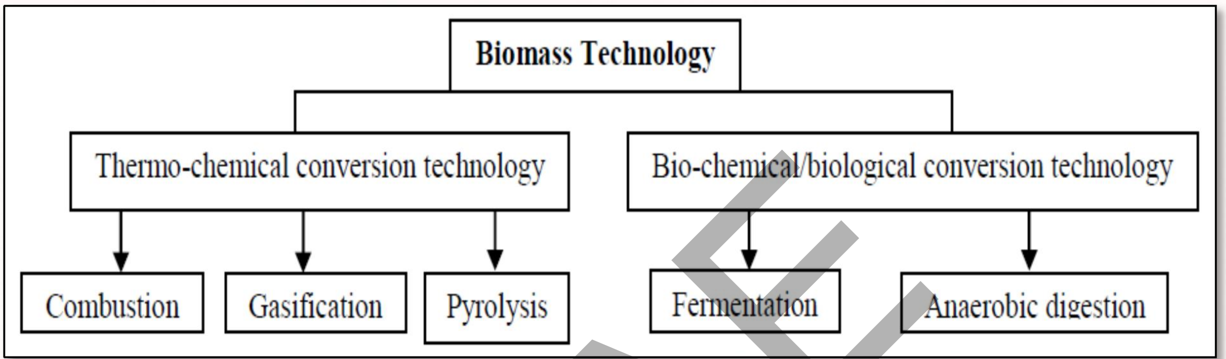

Fig. 1 Biomass conversion technologies [6]

1) Thermo-chemical conversion

Three mains of thermo-chemical process technologies can be produced many energy products that are hot gases, low energy gases, medium energy gas, char and hydrocarbons. The energy products that are occurred depend on the reaction of each thermo-chemical process technology [6].

1.1) Combustion

Combustion is burning of biomass with air. The reaction releases chemical energy storage in the source to heat energy [6]. Biomass combustion can be separated into two different applications that are the household and industries [7]. In the domestic / commercial, biomass sources are burned for cooking, especially in developing countries. The countries use cook stoves for combus-tion. However, impact of cook stove using is air pollution, which leads to health problem in the area. Cook stove improvement increa-ses efficiency and reducing air pollution [7, 8]. In industrial, combustion in the modern industrial system, design of combustion system is important because of the investment cost, the design depends on characteristics of biomass sources. Fluidized bed combustor is a good system because the system has flexibility regarding changes in fuel quality and fast response to load change [7]. Moreo-ver, new developments of biomass combus-tion system that are used in industries are pressurized combustion, whole tree energy system, co-firing, and condensation heat recovery system [7]. Combustion technology is the low cost of construction and operation; combustion boiler can be designed to burn almost any type of biomass fuel [7, 6].

1.2) Gasification

Two main types of gasifier are fixed bed, and fluidized bed. The fixed bed gasifier is traditional processing for gasification. The fixed bed gasifiers are separated into three types which depend on the direction of airflow [6]. Fluidized bed gasification has advantages over fixed bed gasifiers being the uniform temperature distribution achieved in the gasification zone [6]. Two main types of the gasifiers are circulating fluidized bed, and bubbling bed. The selected type of gasifier is dictated by fuel, its final available form, size, moisture content and ash content. Fixed bed gasifiers are suitable for small scale power generation and industrial heating applications [9].

1.3) Pyrolysis

Pyrolysis is the conversion of biomass to liquid, solid and gas by heating the biomass in the absence of air to around 500 OC [6]. The variety of heating rates, temperatures, residence times, and feedstock varieties make many energy products which are charcoal (carbonization, slow pyrolysis), bio-oil (flash pyrolysis, low temper-ature) and fuel gas (flash pyrolysis, low temperature) [10]. Problems with the conversion process and subsequent use of the oil such as its poor thermal stability and corrosively, need to be overcome. The pyrolysis characteristics of three main components are arehemicellulose, cellulose, and lignin. Hemicellulose had a higher CO2 yield, cellulose generated higher CO yield, and lignin owned higher H2 and CH4 yield. Biomass pyrolysis could be achieved based on three main biomass com-ponents [11]. Moreover, the combustion characteristics of the actual biomass depends on the char morphology produced [12].

According to the study of Demirebas et al. [13] oil product from conventional pyrolysis of spruce wood, hazelnut shell, and wheat straw increases by 25.3%, 3.9%, and 21.2%, respec-tively, when the pyrolysis temperature was increa-sed from 575 to 700 K. Moreover, the presence of moisture influenced significantly the thermal degradation degrees of the biomass samples during pyrolysis.

2) Bio-chemical/biological conversion technology

Two main processes are used in biochemi-cal-/biological conversion technology; they are fermentation and anaerobic digestion [6].

2.1) Fermentation

Fermentation is the process of converting biomass resources into bioethanol product [6]. Three generations of biomass sources for bioethanol production are first generation as sugar and starch, second generation as lignocellulosic material, and third generation as micro and macro algae [14]. Ethanol production is typically three steps; they are 1) obtainment of a solution of fermentable sugars, 2) fermentation of sugars into ethanol, and 3) ethanol separation and purification [15].

The first generation uses agricultural feedstock for ethanol production such as sugar, and cassava. Impacts of using the generation are raising food prices and global food storage, and environmental issues such as soil erosion, loss of biodiversity, and high volatile organic compound and NOx pollu-tion [15]. The second generation is produced bio-ethanol from lignocellosic biomass such as agricultural residue, forest harvesting residue, wood

Biomass Technology Thermo-chemical conversion technology Biochemical/-biological conversion technology Combus-tion Gasification Pyrolysis Fermentation Anaerobic digestion processing waste, and non-edible components of corn or sugarcane. Converting of the biomass requires many technologies involving pre-treatment that is high cost. Therefore, the generation cannot be produced economically on a large scale [14]. Microalgae are the third generation for ethanol production. They are a good choice because of using small area for cultivating, having high productivity, and reducing CO2 emission. However, several important scientific and technical barriers remain to be overcome to large-scale production of microalgae [14].

2.2) Anaerobic digestion

Anaerobic digestion is the conversion of organic material directly to a gas or biogas. The biomass is converted by bacteria in an oxygen free environment [6]. Mixtures of biogas are mostly methane and carbon dioxide. The product can be used to generate heat or electricity, or can be converted into bio-fuels such as methanol. Biogas can be produced from almost all kinds of biological feedstock types, from the primary agricultural sectors and from various organic waste streams from the overall society. The largest resource is represented by animal manure and slurries from cattle and pig production [16]. Many factors that affect anaerobic digestion are pH, temperature, toxicity, load rate, and rapidity of the changes [4]. Selected of biogas plant design depends on the technical, climatic, geogra-phical, and economic factors.

Digester operation has two types that are batch digesters, and continuous/semicon-tinuous digesters. Batch digesters are commo-nly used in the present because of low pro-ductivity. Continuous/semicontinuous digesters have three types which are floating drum digester, fixed dome digester, and flexible bag digester. Moreover, digesters were developed for increasing productivity or high rate anaerobic reaction. Examples of new developments are standard rate anaero-bic digester, single-stage and two-stage high rate anaerobic digester [4].

THEORY AND METHODLOGY

1) Estimation of energy potential of agriculture residues

The estimation of residue generated can be calculated from residue to product ratio (RPR). Estimating of energy potential from residue is important to set up the present utilization design of the wastes [17]. Equations for energy potential estimation of agricultural residues are shown in Equations (1) and (2) [17].

$$ARG = \Sigma(RPR \times AH) \quad \ldots(1)$$

$$EPresidue = ARG \times (SAF + EUF) \times LHV\text{-}residue \quad \ldots(2)$$

Where:

ARG	= Amount of a residue generated annually (t/y)
$EP_{residue}$	= Energy potential of residue (J/yr)
RPR	= Residue to production ratio (kg of residue / kg of product)
SAF	= Surplus availability factor
AH	= Amount of harvest of the crop or product (t)
EUF	= Energy use factor
$LHV_{residue}$	= Lower heating value of residue (J/t)

In this study, Amount of agricultural residues (ARG) are estimated by using average annual plantation areas and production data (AH) obtained from Nakhon Si Thammarat Provincial Agricultural Extension office [18] between 2007 and 2011 and residues to production ratios (RPR) values from the study of Garivait [19], who studied biomass resource potential assessment in Thailand and collected residue production ratio values from many public researches, used in this study for evaluating the potential of agricultural residues. Moreover, the sum of SAF and AH value is assumed to be equal to one. LHVresidue for the study are estimated by using Equation (3) [20].

$$LHV = HHV\,(1 - M) - 2.447M \quad (3)$$

Where:

LHV	= Lower heating values (kJ/kg)
HHV	= Higher heating values (kJ/kg)
M	= wet basis moisture content (mass fraction decimal)

Higher heating values (HHV) and wet basis moisture content (M) that are conside-red here are carried out in AIT's Energy Laboratory. HHVs of three samples of each agriculture residue are obtained by using LECO Automatic bomb calorimeter (Model: AC-500). The results from the bomb calori-meter show HHVs in term of Cal /g. Those values can be changed the unit in term of kJ/kg by multiplying the conversion factor as equal as 4.184. M values of three specimens of each residue are found based on proximate analysis by using LECO TGA 701.

2) Estimation of energy potential of animal wastes

Energy potential of animal wastes is estimated by using equation (4) [21].

$$EP_{waste} = 365NA \times FW \times R \times VS \times BY \times LHV_{bg} \quad (4)$$

Where:

EP_{waste}	= Energy potential of animal wastes (MJ/yr)
NA	= Number of animal (heads)
FW	= Fresh waste (kg/head/d)
R	= Recoverable fraction
VS	= Volatile solids (% of fresh waste)
BY	= Biogas yield (m^3/kg VS)
LHV_{bg}	= low heating values of biogas (MJ/m^3.)

A number of animal (NA) base on annual livestock data from Nakhon Si Thammarat livestock office (2011) [22, 23] and values of fresh waste (FW), recoverable fraction (R), volatile solids (VS) and biogas yield (BY) from estimated of DEDE [21]. In addition, amount of goat waste and biogas yield from goat waste obtained from the study of Milbrandt [24]. Moreover, assumption low heating value of biogas (LHV_{bg}) is 21 MJ/m^3.

3) Estimation of energy potential of waste from shrimp Farming

Waste from marine shrimp farming in this study is sediment. Theoretical energy potential of marine shrimp farm waste or sediment is shown as equation (5).

$$EP_{sediment} = SFA \times F \times SY \times BY \times LHV \quad \ldots (5)$$

Where:

$EP_{sediment}$	= energy potential of sediment (MJ/yr)
SFA	= Marine shrimp farming area (Rai/yr)
F	= Culture Factor
SY	= Sediment yield (m^3/Rai)
BY	= Biogas yield (m^3/m^3 of sediment)
LHV	= Lower heating value of biogas from sediment (MJ/m^3)

The amount of sediment from marine shrimp farming are estimated by using average annual marine shrimp farming (SFA) data in Nakhon Si Thammarat province, between 2007 and 2011, from Nakhon Si Thammarat Provincial Fisheries Office [25]. According to marine shrimp farmer enquiry, minimum farmer culture marine shrimp farm about two times per Rai per year (F). Srinakorn et al. [26] estimated that sediment in shrimp grow out ponds about 3-6 m3 per Rai depending to time period to raise shrimp. There-fore, estimating the sediment yield (SY) in shrimp farming is assumed to be 4.5 m3 per Rai. More-over, biogas yield of sediment bases on experi-ment of Srinakorn et al. [26]. The biogas yield (BY) that is used in this study is 0.164 liter per liter of sediment. The lower heating value of biogas (LHV) from sediment is about 19 MJ/m3 [26].

ASSESSMENT OF THEORETICAL ENRGY POTENTISAL OF AGRICULTURAL WASTES

1) Agricultural residues

In Nakhon Si Thammarat province, Agriculture is divided into two main types. There are perennial plants and farm plants. According to information from Nakhon Si Thammarat Provincial Agricultural Extension office (2011), major plants in the province are paddy, rubber tree, coconut and oil palm.

Based on Nakhon Si Thammarat Industrial office (2013), main agriculture industries in the province were Para wood lumbering factories, rice mills and palm oil mills Number of Para wood lumbering factories, rice mills and palm oil mills was 55 plants, 40 plants and 3 plants, respectively. In the study, residues from the plantation were separated into two groups that are field waste group and processing waste group. The agricultural residues available were shown in Table 1.

Table 1 Agricultural residue in Nakhon Si Thammarat province

Type of plant	Field waste group	Processing waste group
Paddy	Straw	Husk
Rubber tree	-	Saw dust Slab
Coconut	Frond	-
Oil palm	Frond Male bunches	Empty fruit bunches Fiber Shell

The theoretical yield potential of agricul-tural wastes in Nakhon Si Thammarat province can be estimated based on average annual production data obtained from Nakhon Si Thammarat Provincial Agricul-tural Extension office between 2007 and 2011 and Nakhon Si Thammarat Industrial office. These yield potentials were separated into two groups that were yield potential of field waste group and processing waste group. These yield potentials were given in Table 2 and Table 3, respectively

Table 2 Average theoretical yield potential in field wastes group

Plant	Production yield (kton/year)	Residue	RPR	Yield potential (kton/year)
Paddy	345	Straw	0.75	259.0
Oil palm	254	Frond	2.604	662.1
Coconut	116	Frond	0.182	30.1

Table 3 Average theoretical yield potential in processing wastes group

Plant	Production yield (kton/year)	Residue	RPR	Yield potential (kton/year)
Paddy	205.4	Husk	0.22	45.2
Oil palm	200.0	Empty bunches	0.20	40.0
		Fiber	0.14	28.0
		Shell	0.06	12.0
Coconut	952.2	Saw dust	0.03	28.6
		Wood slab	0.12	114.3

Based on results at AIT's Energy Laboratory, moisture content, higher heating values and lower heating values were shown in Table 4.

Table 4 Moisture content (% wet basis), HHV and LHV of agricultural residues

Plants	Residues	Moisture (%)	HHV (kJ/kg)	LHV (kJ/kg)
Paddy	Husk	8.86	13,921	12,472
	Straw	8.44	15,871	14,324
Oil palm	Shell	13.59	18,281	15,464
	Male bunches	10.85	16,328	14,291
	Empty bunch	20.98	18,337	13,977
	Frond	66.38	5,349	174
	Fiber	18.36	16,476	13,002
Coconut	Frond	12.63	15,327	13,081
Para tree	Saw dust	20.60	15,104	11,489
	Wood slab	37.50	12,399	6,831

Therefore, the theoretical energy potential of agriculture residues was estimated by using an amount of theoretical yield potential of agricultural residues (Table 2 and Table 3) and using heating values (LHV) in Table 4. The energy potentials of these residues were shown in Table 5.

According to Table 5, five residues with high theoretical potential for energy in Nakhon Si Thammarat province were paddy straw, oil palm male bunches, Para wood slab, paddy husk and oil palm empty bunches. However, current usages of those agricultural residues by inquiring farmers and factory officers had concluded that:

Oil palm male bunches and coconut fronds were left in or heap on plantation areas. Those residues were not used now because they were difficult for collection. However, some coconut fronds were used to propose coconut stick broom.

Table 5 Average theoretical energy potential of agricultural residue

Plants	Residue	Energy potential (TJ/year)
	field wastes group	
Paddy	Straw	3,710
	Frond	115
	Male bunches	836
Coconut	Frond	394
	processing wastes group	
Paddy	Husk	564
	Empty bunches	559
Oil palm	Fiber	364
	Shell	186
Para tree	Saw dust	328
	Slab	781

Paddy straws in this province are burned in the paddy fields and used as cattle food. Moreover, some straw was used for mushroom cultivation.

Oil palm fronds were high yield but have high in moisture content (66.4 % wet basis). Hence, they were dried before using for combustion. However, those oil palm fronds were ground and used as animal food.

Paddy husks were wastes from paddy mill processing. They were easier to collect than residues from agricultural fields. Some paddy husks were used as fuel for drying, mushroom cultivation and charcoal making.

Para wood saw dust and slabs were residues from Para wood processing factories. They were burned in the boiler inside each factory. Some of those wastes were sold. Moreover, In Nakhon Si Thammarat province, there existed 9.2 MWe of power plant, owned by Changraek bio-power Co., Ltd, where para wood residues were used as raw material for electricity generation. The power plant used about 122.64 to 131.40 kton of Para wood residues annually.

Oil palm empty bunch, shells and fibers were wastes from oil palm mills. They were used in boiler for steam generation inside the factory. Some of those wastes were sold for other utilization. As per the interviewing staff from S.P.O agro-industry Co., Ltd., the company was palm oil mill and produce electricity from palm oil processing wastes. The capacity of the power plant was 6.9 MWe. More oil palm fibers and oil palm empty bunches were used for raw material in power plant. Few of those wastes were sold to outside.

2) Animal wastes

Animal wastes in this study come from major animals in Nakhon Si Thammarat province. These animals were cattle, buffalo, swine, chicken and duck.

The amount of animal waste yields was estimated by using annual livestock data from Nakhon Si Thammarat livestock office and values of fresh waste (kg /head/d) and recoverable fraction from estimated of DEDE [21]. The theoretical yield potential of animal wastes in Nakhon Si Thammarat province was shown in Table 6.

Table 6 Average theoretical yield potential of animal wastes

Plants	Residue	Energy potential (TJ/year)
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	Male bunches	836
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Table 7 Average theoretical yield potential of animal wastes

Animal	Number (103 heads)	Average waste (kton/year
Buffalo	4.40	6.42
Cattle	165.30	150.84
Swine	242.50	141.62
Chicken	3,704.10	32.45
Duck	406.30	1.78
Goat	13.00	0.95

Animal wastes can be estimated theoretical energy potential by the amount of average yield potential of animal waste (Table 6) and amount of volatile solid and biogas yield from testing results from DEDE [21]. In addition, amount of goat waste and biogas yield from goat waste obtained based on [24]. Moreover, assumption low heating values of biogas were 21 MJ/m3. The theoretical energy potential of animal wastes was shown in Table 7.

Table 8 Average theoretical energy potential of animal wastes

Animal	Number (103 heads)	Average waste (kton/year
Buffalo	250,603	5.26
Cattle	6,191,210	130.02
Swine	7,633,715	160.31
Chicken	1,754,225	36.84
Duck	141,449	2.97
Goat	47,450	1.00

Based on Table 7, three animal wastes of the most theoretical energy potential were wastes from swine, cattle and chicken. Nevertheless, current usages of those animal wastes by inquiring Nakhon Si Thammarat Livestock officers concluded that:

The majority of cattle, buffalo, and duck culture were household cultures which were one family or one house has 1-4 heads of buffalo and cattle. In addition, duck culture in the country was separated pattern; they were not farming pattern. However, Main pattern livestock of swine, chicken, and goat was small to big farming.

Based on Table 7, cattle had the most waste and energy potential. However, collecting of cattle waste was difficult because the cattle culture pattern was household 1-4 heads per house and is free range farming; duck and buffalo were also free range farming. On the other hand, Chicken, swine and goat culture pattern was farming. Collecting of those wastes was easier than free range farming. However, the potential of goat was low when compared with the potentials of chicken and swine.

4) Sediment from shrimp farming

The theoretical energy potential of marine shrimp farm waste considered only sediment. The potential of wastes from marine shrimp farming, that were estimated by using annual marine shrimp farming data in Nakhon Si Thammarat province, between 2007 and 2011, from Department of Fishery. Thus, average annual shrimp farm area in the province was 28,004 Rai. The theoretical energy potential of the sediment was shown in Table 8.

Amount of Sediment (m3/year)	Amount of biogas (103 m3/year)	Energy Potential (GJ/year)
252,040	41.34	786

According to Table 8, the theoretical energy potential of marine shrimp sediment was estimated to be 780 GJ/year. However, biogas generation from shrimp pond sediment was less than biogas production of swine farm because the digestion was batch that influences amount of bacteria and limits bacteria growing [26]. Therefore, biogas form shrimp sediment system will develop to be continuing system and will study to find process in order to increase amount of biogas generation. Biogas from the sediment is one waste that will be interesting in the future.

CONCLUSION

Agriculture wastes in Nakhon Si Thammarat province can be separated into three types. They were agricultural residues, animal wastes and wastes from marine shrimp farming.

Agricultural residues considered in this study were residues from paddy, Par tree, coconut and oil palm. These plants were mainly economic plants in the province. Paddy straw, oil palm male bunches, Para wood slab, paddy husk and oil palm empty bunches were five residues with high theoretical potential for energy. However, some of these residues were used for many applications such as animal food, mushroom cultivation as fuel in existing biomass power plant in the province.

Animal wastes considered in the study were wastes from buffalo, cattle, swine, chicken, duck and goat. Three of most theoretical animal waste potentials were wastes from cattle, swine and chicken. Animal cultivation pattern was one factor for using the animal wastes converting to energy. Wastes of cattle, duck and buffalo were difficult to be collected because these animals were disrupted in regulative area, but swine, chicken and goat were grown on farms, hence, wastes of those animals was convenient for collection.

Marine shrimp farm waste considered in the study was marine shrimp sediment. The theoretical energy potential of the sediment in this province was fewer that the potentials of agricultural residues and animal wastes. However, biogas form shrimp sediment system should develop to be continuing system and should study to find ways for increasing of amount of biogas generation.

Two main methods that use in order to change agricultural waste to energy are thermochemical and biochemical methods. Choosing suitable method depends on properties of wastes, applications of energy products, cost of conversion technologies and environmental impact.

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