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Waste to Energy Production from Agricultural Waste of Paddy (Oryza Sativa) Industry in Malaysia: Life Cycle Cost Exploration

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***Abstract:** Due to rapid expansion in road transportation, a more environmentally benign fuel is required in order to control the air pollution. More competent and feasible development of the transportation sector has attracted many interests from various countries including Malaysia. Ethanol fuel is cleaner and sustainable compared to gasoline fuel. Although first generation bioethanol has been utilized globally, it raised the concern about food versus fuel issues. The solution for this is by utilizing agricultural waste as feedstock for bioethanol production. Therefore, this paper investigated the rice straw bioethanol production and its effect on economy and environment when rice straw bioethanol is utilized as a gasoline substitute in Malaysia. Approximately 6% of total gasoline consumption could be saved if rice straw is utilized for bioethanol production, while reducing 92% of air pollution. Based on the life cycle cost model, it was found that the total production cost for 50 ML rice straw bioethanol production plant with a lifetime of 20 years amounts to nearly 200 million USD, which the unit production cost is 0.16 USD per liter of bioethanol, which is Lower than the gasoline price. Therefore, Malaysia should consider bioethanol as a potential alternative fuel to address the problem of depleting fossil sources and global warming.*

***Keywords:** Agricultural Waste, Air pollution, Bioethanol production*

I. INTRODUCTION

There has been significant raise of greenhouse gases emissions due to the burning of fossil fuels being used in the growing transportation sector.

Global fuels consumption by the transportation sector accounted for 64.5%, which greatly contributes to the global warming [1]. In addition, transportation sector is responsible to 19% and 70% of the global carbon dioxide (CO_2) and carbon monoxide (CO) emissions, respectively [2, 3].

Malaysia, as one of the fastest progressing countries in the South East Asia, seems to produce an identical emission pattern in its transportation sector. As recorded in the Compendium of Environment Statistics 2013 by Department of Statistics (DOS) Malaysia [4], Malaysia's transportation produces the highest yearly emission of 68.5% in the year 2012. Transportation sector also polluted the air quality by producing 1.8 million-tonnes of carbon oxide, 230 ktonnes of nitrogen dioxide, 15 ktonnes of sulphur dioxide and 5 ktonnes of particulate matters. Furthermore, an increment of 6.5% CO and 5.1.

SO_2 production occurred from 2011 to 2012, while 5% rise on both nitrogen dioxide and particulate matter emissions. For the current problems on fossil fuel dependency and environmental degradation, bioethanol is considered as an alternative to gasoline fuel due to higher octane number and friendlier to the environment [5]. Study on the first generation bioethanol production and performance have widely been conducted and used in large-scale production [6- 8]. However, bioethanol production in large-scale by using first generation feedstock has led to a great change in the agricultural product prices. As an example, global corn price had increase by almost 100% in just a few years. As the demand for biofuel grows, more agricultural space is needed to meet the demand; therefore raising the needs for deforestation. Hence, the utilization of ample and cheaper second generation feedstock such as lignocellulosic material is viewed as one of the solutions in reducing the dependency on first generation feedstock in the mass production of bioethanol. For bioethanol to be produced as a commercial transportation fuel, the selling price needs to be lower than or similar to the price of gasoline. Currently, lignocellulose bioethanol production requires a relatively high cost, which is unfavorable to be produced at large-scale. Compared to the production of bioethanol from sugarcane and corn (in which the feedstock used accounts for 40 – 70% of the total cost), utilization of waste from forestry, agriculture and industry would significantly reduce the cost related to the feedstock used [9].

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However, study of second-generation bioethanol production is still limited. Located in a tropical climate, Malaysia possesses vast biomass sources, which could be exploited to reduce gasoline dependency in road transport. In 2011, the production of rice straw in Malaysia was 2 million tonnes [10]. Sadly, open burning is a widely practiced method to dispose rice straw [11].

This leads to the emission of an estimated 1.5kg CO_{2eq} per 1 kg of rice straw burnt [12]. Meanwhile, gasoline fuel production and application released about 4.1 kg CO_{2eq}/kg_{gas} of emission. Rice straw bioethanol production and application only released emission about 0.31 kg CO_{2eq}/kg_{et} [13].Therefore, a total of 3.79 kg (92.4%) CO_{2eq} of emission is avoided when substituting 1kg of gasoline with bioethanol produced from rice straw. If rice straw is used to produce bioethanol, compared to open-field burning for disposal of rice straw, about 79% of emission can be avoided. Hence, significant reduction of environmental pollution can be achieved when rice straw is utilized for bioethanol production [14]. The main objective of the paper is to carry out techno-economic analysis of rice straw bioethanol as a fossil fuel replacement in Malaysia. The analysis includes the determination of bioethanol life cycle cost, while considering taxation and subsidy policy imposed by the government.

II. MATERIALS AND METHODS

Materials

Paddy (*Oryza sativa*), which is usually grown twice or once a year in Malaysia is used for this evaluation. Considered as a major food crop, rice is abundantly available in almost all continents, especially in countries such as India, China and South East Asian countries. The composition of rice straw is illustrated in Table 1 [15]. Spatial units covered in Rice Atlas and the number of rice-growing seasons are presented in Fig. 1 [16].

Table. 1 Composition of rice straw

Components (%)	Weight (dry)
Total digestible nutrients (TDN)	44.0
Digestible energy, mcal/kg	1.9
Crude fiber	29.8
Cellulose	43
Hemicellulose	25
Lignin	12
Dry matter	90
Ash	16
Silica	15.8
Crude protein	4.5
Potassium	1.2
Fat	1.0
Total nitrogen	0.67
Calcium	0.4
Magnesium	0.11
Phosphorous	0.08
Sulphur	0.04

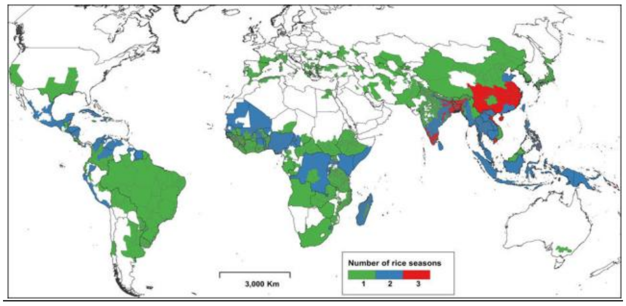

Fig. 1 Spatial units covered in Rice Atlas and the number of rice-growing seasons

Methods

The rice straw bioethanol production process in Malaysia was adapted from the economic feasibility and environmental sustainability of bioethanol production from cellulosic material technologies, which was established in Japan, shown in Fig. 2 [17-20]. First, rice straw was cut to uniform size of less than 2 mm to increase the surface area for pretreatment process. Then, it is subjected to hydrothermal pretreatment to separate the lignin from cellulose and hemicellulose. Next, cellulose and hemicellulose were converted into C5 and C6 sugars via enzymatic hydrolysis. Then, the simple sugars were converted into ethanol in the fermentation process via recombinant yeast, *Saccharomyces cerevisiae*. Lastly, the fermentation broth would go through a distillation process to produce bioethanol purity up to 98 mass%. Solid residues, mainly lignin structure was then filtered and used for power generation. Generated power would be used for plant operation and the excess energy could be sold back to the power grid [21].

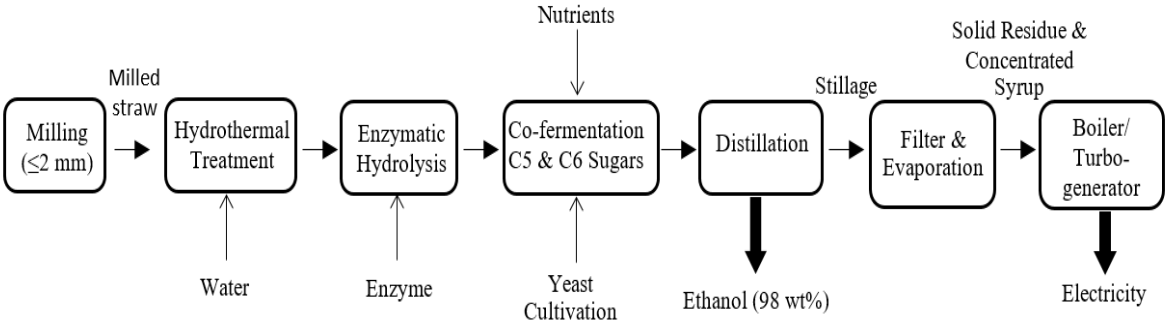

Fig. 2 Process flow diagram of rice straw bioethanol production

Estimation of bioethanol production potential

The mass of rice straw produced is usually proportional to the sum of rice produced. Therefore, the possible quantity of bioethanol produced from rice straw annually, *ABP*, is

$$ABP = RSP \times DWR \times CR \qquad (1)$$

With *RSP* is the annual rice straw production (ton/year); *DWR* is the dry mass ratio of rice straw; and *CR* is the conversion rate. In this study, water content of rice straw collected in Malaysia is exactly 14%, therefore, Eq. (1) was used with a dry weight ratio of 0.86 to estimate the potential bioethanol production. The bioethanol conversion rate was estimated at 740 L/ton [22]. A total of 679,239 ha of paddy were planted in 14 states in Malaysia as of 2014, reported by Department of Agriculture Malaysia; with an average paddy yield of 4,194 kg/ha. Malaysia produced about 2,848,559 tons of paddy in 2014. Rice production in Malaysia is estimated based on percentage of paddy recovery rates, which are 65% for Peninsular, 63% for Sabah and 60% for Sarawak. In 2014, Malaysia produced about 1,013,729 tonnes of rice straw, which can be utilized for biofuels production. [23].

Cost Analysis

Life cycle cost

The life cycle cost, *LCC* model of bioethanol production is formulated and divided into five categories as in Eq. **Error! Reference source not found.**, where *CC*, *OC*, *MC*, *FC* and *BP* stands for Capital Cost, Operating cost, Maintenance Cost, Feedstock Cost, and Bi-Products, respectively.

$$LCC = CC + OC + MC + FC - BP \qquad (2)$$

Consequently, the net present worth of bioethanol production cost is calculated as:

$$LCC = \mathrm{CC} + \sum_{i=1}^{n} \frac{OC + MC_i + FC_i}{(1+r)^i} - \sum_{i=1}^{n} \frac{BP_i}{(1+r)^i} \qquad (3)$$

Where *n*, *r* and *i* refers to Project Life Time, Discount Rate, and Project Year, respectively.

Present value factor, *PVF* is used to derive the present value of bioethanol financing for a distinct reduction rate. The present value factor for the period *i*, is calculated using the equation as follow,

$$\mathrm{PVR} = \frac{1}{(1+r)^i}, \qquad (4)$$

Computing this for the project lifetime of *n* years, the present value compound factor, *CPW* is presented as follows,

$$\mathrm{CPW} = \sum_{i=1}^{n} \frac{1}{(1+r)^i} \qquad (5)$$

$$\mathrm{CPW} = \frac{(1+r)^n - 1}{r(1+r)^i} \qquad (6)$$

The capital cost is estimated using the following equation, using the assumption that the introductory investment cost or capital cost for lignocellulosic ethanol depends on the plant production capacity [21]:

$$CC = 20.695X^{0.49} \qquad (7)$$

Where *CC* is the capital cost in million USD and *X* is the plant capacity in million liters per year. The estimation of capital cost includes the equipment, installation, site development and other initial costs. Due to additional equipment cost, the capital cost increases by 34.2% when residues are used for energy generation [24]. Usually, cellulosic bioethanol plant is estimated to cost 6 to 10 times of the capital cost required for a first generation feedstock plant with the same capacity [25]. As the technology matures in the future, the capital cost is expected to reduce [26]. Operating costs are highly dependent on plant capacity. For calculations, the cost per ton of the produced bioethanol is fixed. For lignocellulosic bioethanol, the operating rate is estimated at 128 USD/ dry tonnes of lignocellulosic material [26]. The Operating Costs, *OC* for the project lifetime are:

$$OC = \sum_{i=1}^{n} \frac{OR\ X\ PC}{(1+r)^i} \qquad (8)$$

Where *OR* and *PC* refers to Operating Rate and Annual Bioethanol Production Capacity, respectively.

Maintenance is expected to occur annually and the cost is estimated as the ratio of the maintenance rate for the initial investment and presumed unchanged over the total project life time. The maintenance cost per year for lignocellulosic is accounted for 3% of total capital investment [21]. With *MR* and *CC* representing Maintenance Rate and Capital Cost, respectively, the total Maintenance Costs, *MC* over the project lifetime *n* is given as,

$$\mathrm{MC} = \sum_{i=1}^{n} \frac{MRXCC}{(1+r)^i} \qquad (9)$$

The total raw material cost is the total annual Feedstock Utilization *FN* multiplies with the raw material price *FP*. Centered on the feedstock price, the total feedstock cost, *FC* for the project period is given by,

$$\mathrm{FC} = \sum_{i=1}^{n} \frac{FB\ X\ FN}{(1+r)^i} \qquad (10)$$

For bioethanol produced from second generation feedstock, the cultivation cost is not included. This is because the feedstock used is agricultural waste. Only collection and transportation cost are considered in this study. In Malaysia, delivered rice straw cost at production plant is estimated at 15.7 USD/dry ton (RM 65.4/dry ton) [27].

Lignin and other residue after pretreatment and distillation were filtered and utilized for power generation. The energy generated was used for the plant operation, and the surplus was sold to the grid in the form of electricity [28]. The energy credit *ECD* is calculated by multiplying the energy price *EP* with the surplus electricity generated *PG*. For lignocellulosic bioethanol plant, about 6.2 MJ of surplus energy is produced per liter of bioethanol produced. Hence, the energy credit cost, *ECD* over the project period is given as follows:

$$\mathrm{ECD} = \sum_{i=1}^{n} \frac{EP\ X\ PG}{(1+r)^i} \qquad (11)$$

Payback Period

The payback period is the length of time required for an investment to regain its initial outlay in terms of profits or savings. This method used the ratio of initial investment to annual gross profit, to monitor the project. Taxes are presented as percentage of total bioethanol sales. With *TBS*, *TPC*, *TAX* refers to Annual Total Bioethanol Sales, Annual Total Production Cost, Total Annual Tax, respectively, the Payback Period *PP* is given as

$$PP= \frac{CC}{TBS-TPC-TAX} \qquad (12)$$

Here, *TBS*, *TPC*, and *TAX* are given as,

$$TBS=\frac{BFP\ X\ PC}{\rho} \qquad (13)$$

$$TPC= 1.1X\ \frac{LCC}{n} \qquad (14)$$

$$TAX = (TBS - TPC) \times TR \qquad (15)$$

With *BFP*, ρ, and *TR* stands for Bioethanol Fuel Price, bioethanol density, and Tax Ratio, respectively.

Total bioethanol costs include of the sum of the life cycle cost, delivery cost and profit margin. Usually, the distribution cost and profit margin are about 10% of bioethanol production cost. The final bioethanol production cost is expressed as follows,

$$TPC=1.1X\frac{LCC}{n} \qquad (16)$$

Final bioethanol unit cost is presented as the cost required for the production of one litre bioethanol. The final bioethanol unit cost *FBC* is calculated by multiplying the sum of bioethanol production cost and density of bioethanol and divided by the annual production capacity. It is expressed as follows:

$$FBC = \frac{TPC\ X\ \rho}{PC} \qquad (17)$$

Sensitivity analysis is then utilized to anticipate the outcome of a selection that is different from the primary estimation. It is an investigation to reveal the dissimilarity of the anticipate results with differences in primary assumption on which the forecast is centered on. It also provides estimation on how uncertainties such as changes in world raw material cost influences the project feasibility. Investigated elements are raw material cost, discount percentage, introductory capital cost and operation cost. In this study, the rice straw price is taken as the collection and transportation cost only.

III. RESULTS AND DISCUSSION

Potential Bioethanol production

Based on Eq. (1), the potential of bioethanol production from rice straw in Malaysia can be estimated. The potential bioethanol production in Malaysia is given in Table 2.

Table. 2 Potential bioethanol production in Malaysia

	Planted	Production	Production	Available	bioethanol
State		(tonnes)	(tonnes)	(tonnes)	(ML/year)
Johor	2,976	12,859	8,358	4,501	2.86
Kedah	212,401	1,036,180	673,517	362,663	230.80
Kelantan	69,412	280,076	182,049	98,027	62.38
Melaka	2,608	8,530	5,545	2,985	1.90
N. Sembilan	2,070	9,335	6,068	3,267	2.08
Pahang	11,872	35,296	22,942	12,354	7.86
Perak	81,503	352,930	229,405	123,525	78.61
Perlis	52,088	266,506	173,229	93,277	59.36
P. Pinang	25,564	150,112	97,573	52,539	33.44
Selangor	37,842	242,320	157,508	84,812	53.97
Terengganu	16,045	78,535	51,048	27,487	17.49
Sabah	41,387	140,226	88,342	51,884	33.02
Sarawak	123,471	235,655	139,247	96,408	61.35
Malaysia	**679,239**	**2,848,560**	**1,834,831**	**1,013,729**	**645.14**

Based on Table 2, a total of 645 ML potential bioethanol can be produced from rice straw in Malaysia. With the domestic gasoline consumption of about 15,800 ML/year [29], about 4.1% of gasoline consumption can be replaced with bioethanol produced from rice straw.

Life Cycle Cost

The potential of rice straw as feedstock is evaluated by fixing the project lifetime as 20 years with the assumption that the plant operates at 100% capacity over that period. The initial capital cost is to be funded by private investment and no loan is involved. In addition, it is assumed that bioethanol and surplus electricity selling prices remain constant throughout the 20 years period. The economic data and assumption of the analysis is given in Table 3.

Table. 3 Economic indicator and assumption for rice Straw bioethanol cost analysis

Item	Data
Project period	20 years
Plant production capacity	50 ML
Feedstock price	$15.7/ton
Operation cost rate $128/ton Maintenance rate	2% of capital cost annually
Tax rate	15% of bioethanol profit
Surplus Electricity Price	$0.034/kWh
Discount rate	8%

Using 8% rate of discount, the life cycle cost of rice straw bioethanol production Malaysia is calculated. The payback period, together with the life cycle cost of rice straw bioethanol are tabulated in Table 4.

Table. 4 Payback period and life cycle cost for rice straw bioethanol production plant in Malaysia

Item	Value ($ USD)	Distribution (%)
Capital cost	140,721,590	70.4 %
Operation cost	49,577,717	24.8 %
Maintenance cost	27,632,506	13.82 %
Feedstock cost	10,415,109	5.21 %
Energy credit	28,399,219	14.2 %
LCC without byproduct	228,346,922.85	
Total LCC	199,947,703.70	
Unit production cost ($/L)	0.16	
Payback period (year)	15.76	

Life cycle production cost is evaluated for a bioethanol plant with 50 ML capacity annually. Figure 3 shows the life cycle cost, *LCC* of rice straw bioethanol production in Malaysia, and the distribution of cost is shown in Fig. 4

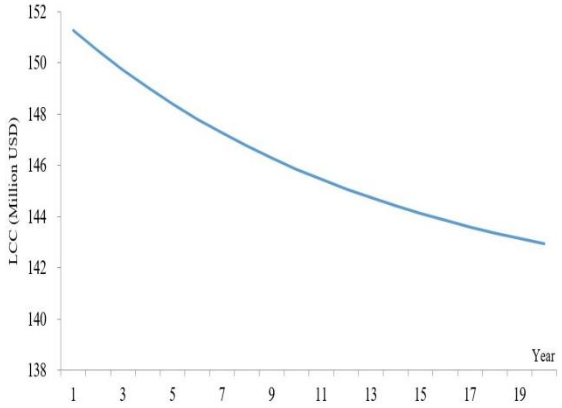

Fig. 3 Rice straw bioethanol life cycle production cost for 20 years project period

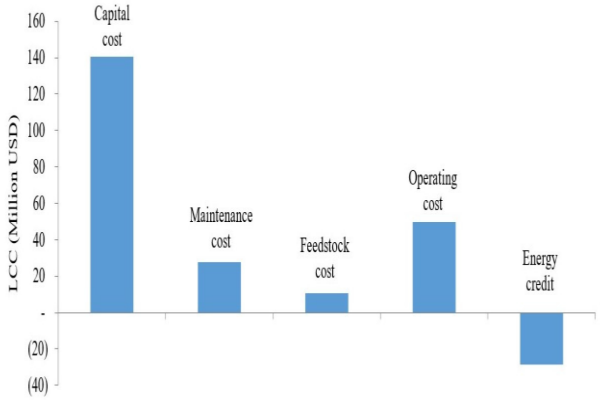

Fig. 4 Fraction of rice straw bioethanol life cycle production cost

The total life cycle cost of the bioethanol production from rice straw is near $200 million USD, considering the energy credit. Capital cost is highest cost (70.4% of the total cost), due to the additional equipment required to separate the lignin from cellulose in order to ease the hydrolysis process. Another significant chunk is the operating cost, which is 24.8% of the total cost. Energy credit is a basis of earnings, which covers 14.2% of the total life cycle cost. The cost to produce 1 L bioethanol from rice straw is calculated to be $0.16 USD. However, this project is not economically feasible mainly due to the high capital requirement, since the plant payback is evaluated to be 15.76 years; which is nearly reaching the project life time. Nevertheless, the unit price of rice straw bioethanol of 0.16 USD/L is considered appropriate, since it is lower than gasoline fuel taken at 0.44 USD/L.

Sensitivity analysis

Figure 5 presents the several elements of sensitivity analysis done for bioethanol from rice straw. As predicted, the changes in the capital cost significantly influences the total production cost. For instance, capital cost of 80 million USD decreases the total life cycle production cost of 127 million USD and inflates to 270 million USD with the capital cost of 200 million USD.

Other parameters do not have significant effect on the total production cost due to their low percentages of the total life cycle cost. Hence, for lignocellulosic ethanol to be economically feasible, the capital cost need to be reduced, either by exploring new pretreatment methods or reducing the equipment cost.

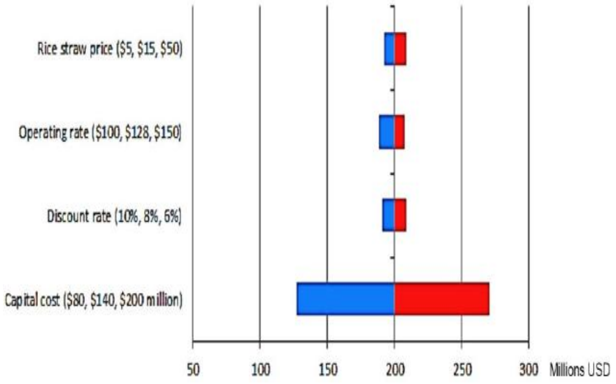

Fig. 5 Sensitivity analysis of life cycle costs for rice straw bioethanol production

Taxation and subsidy landscape on bioethanol unit price

The final unit production cost for rice straw bioethanol includes of the total production and distribution cost, and profit margin. Normally, 10% of the final bioethanol production cost is taken as the distribution cost and profit margin. The investigated landscapes are total tax exemption, 20% taxation, 39% and 66% subsidy. The value for subsidy investigated is chosen centered on the highest and lowest value [30]. The presented gasoline price is centered on the market value of 0.44 USD/liter (March 2019). The final bioethanol production cost compared to gasoline replacement is measured using a 0.89 substitution ratio, which is the ratio of fuel consumption between these two fuels [31]. Table 5 presents the scenarios investigated for rice straw bioethanol production cost compared with gasoline fuel at present production cost. The results shown that final rice straw bioethanol production cost is cheaper compared to conventional gasoline at all conditions, even if 20% taxation is applied to the final bioethanol price.

Table. 5 Bioethanol taxation and subsidy landscape at current production cost

	Amount of tax	Tax	Subsid y	Subsidy	gasoline
	exemption	20 %	39 %	66 %	
Bioethanol cost ($/liter)	0.16	0.16	0.16	0.16	-
Taxes/Subsidy ($/liter)	-	0.03	0.06	0.11	-
Total ($/liter)	0.16	0.19	0.10	0.05	0.44
Total ($/liter gasoline)	0.18	0.21	0.11	0.06	0.44

Rice straw bioethanol Fossil

Apart from that, final bioethanol cost is also investigated as a function of raw material cost for the similar tax scenarios. Figure 6 shows the results of investigated landscapes. Bioethanol produced from rice straw is shown to be competitive with gasoline fuel for all ranges of rice straw price and landscapes, even if the 20 % tax is applied to final bioethanol price at highest feedstock cost.

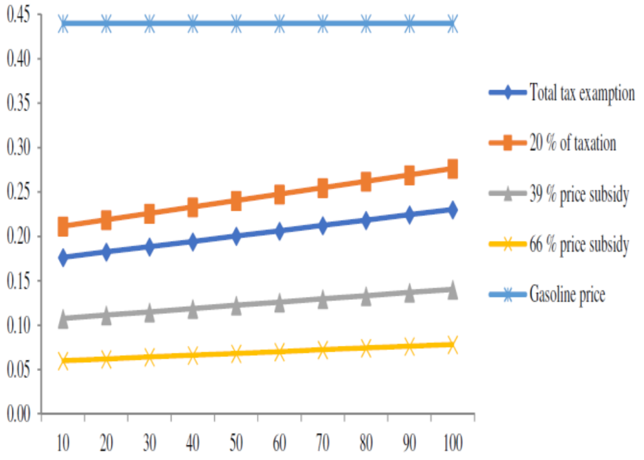

Fig. 6 Taxation and subsidy scenarios of rice straw bioethanol unit cost at different feedstock cost

IV. CONCLUSIONS

Bioethanol has become an important alternative liquid fuel, utilized for road transport as a substituting for gasoline. This could cure the dependency on fossil fuel while reducing environmental pollution. However, the main issue with first generation bioethanol is the usage of food sources as feedstock. The possible solution is by using agricultural waste as feedstock for bioethanol production. In this study, economic analysis of bioethanol production from rice straw is conducted. By using all rice straw, Malaysia could reduce the annual gasoline consumption by 6%. This percentage can be further increased by utilizing all agricultural waste for bioethanol production. From the costing point of view, bioethanol produced from rice straw in Malaysia is 0.16 USD/L; lower than gasoline price at 0.44 USD/L. This is due to low feedstock cost, where the delivered cost for dry rice straw is only 15.7 USD/ton. In addition, bioethanol produced from rice straw has the potential to reduce the pollution by 92%; and 84 % of pollution from the open-field burning can be avoided. However, the high capital cost of 140million USD is required for a 50ML bioethanol plant. For all tax scenarios investigated, rice straw bioethanol in Malaysia is lower than gasoline fuel, even at the highest feedstock cost. Therefore, concluded that rice straw bioethanol is a feasible alternative fuel. More research on pretreatment and conversion technology are required to reduce the high capital cost.

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