Validity of Bio-Ethanol as a Countermeasure against Global Warming

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Abstract: Recently the fuel ethanol production from crops has attracted much attention not only in the US, EU and Brazil, but also in Japan because the bio-ethanol is perceived as being "carbon neutral" and useful as a countermeasure against global warming. In fact, the Japanese government has declared that the production of 780 thousand kiloliters of bio-ethanol, which is equivalent to 500 thousand kiloliters of oil and could reduce CO_2 production by 1.2 million tons, should be a goal for 2010.

However, there are many problems in bio-ethanol production, pointed out from various points of view. First of all, the utility of bio-ethanol production as a countermeasure against global warming should be examined carefully and objectively. In this study, an assessment on the validity of bio-ethanol production and use was tried as to quantitatively estimate the effectiveness of bio-ethanol. For this purpose, a new index of CO_2 emission reduction "ν" was proposed and formulated as a function of the ratio of energy output to input "μ", and used as criteria for estimating the utility of bio-ethanol.

As a result, it was concluded that the ethanol from crops is never "carbon neutral" because additional energy input is required to produce the fuel and has only a minimal contribution to the issue of global warming. It also even has the possibility of increasing CO_2 emissions. The amount of bio-ethanol is also rather small when compared with the fuel demand for transportation. The economic analysis of bio-ethanol production has also indicated that the financial benefits of bio-ethanol were not positive figures.

Key Words: bio-ethanol, carbon neutral, index of CO_2 emission reduction, energy balance

INTRODUCTION

In the 1980s, after the second oil crisis in 1979, several plans and programs were tried to realize the production and utilization of ethanol from agricultural crops made in mainly Southeast Asian countries by governmental organizations and companies in Japan. The main purpose of these projects was to utilize biomass, which has a characteristic of being a renewable resource, as an alternative energy to petroleum energy. However, all of the projects were abandoned due to several reasons: 1) the amount of potential ethanol production was estimated to be too small compared with the energy demand in Japan, 2) the conversion of crops to ethanol would lead to a decline in the economical value of the crops (i.e. the value of crops is much higher as food than as fuel), 3) the high oil prices did not continue for a long time, and there were other reasons pointed out about 25 years before (Matsuda and Kubota, 1984).

Recently, however, the fuel ethanol production from crops has again attracted again much attention not only in the US, EU and Brazil, but also in Japan because the bio-ethanol is perceived to as being "carbon neutral" and useful as a countermeasure against global warming. In fact, the Japanese government has declared that the bio-ethanol production of 780 thousand kiloliters of bio-ethanol, which is equivalent to 500 thousand kiloliters of oil and could reduce 1.2 million tons of CO_2 emissions, should be a goal for 2010. Here, the main aim of ethanol production was changed to the reduction of CO_2 emissions.

However it should be pointed out that the principle of "carbon neutral" can not be applied simply to the bio-fuel production: When vegetation grows, and then becomes extinct and decomposed

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under natural condition such as forest and grassland, the principle of "carbon neutral", which means that atmospheric CO_2 levels will be constant even if biomass resources are combusted or decomposed, is surely valid under steady state conditions. In the case of artificial bio-fuel production, however, additional CO_2 emissions are unavoidable due to the energy inputs in all processes of bio-fuel production , i.e. cultivation, transportation, processing and so on. So far there are many reports on the energy balance of bio-ethanol production in the U.S. and E.U. (examples of such kinds of reports are listed in the " References"), whereas very few discussions on this issue have been found in Japan. In addition, there were considerable amounts of variations in the findings of these reports, mainly due to the difference in assumptions or data used, and discussion tended to focus on the energy balance (i.e. comparison between energy input and output) and the effect of the reduction of CO_2 emissions had not been substantially discussed quantitatively. Thus, it is important to establish a scientific and quantitative method to evaluate the validity of bio-fuel production correctly and precisely from the standpoint of the reduction of CO_2 emissions.

In this study a new index of CO_2 emission reduction " ν " was proposed and formulated as a function of the ratio of energy output to input "μ", and used as criteria for estimating the utility of bio-ethanol production.

1.METHOD FOR QUANTITATIVE EXPRESSION OF THE CO_2 REDUCTION EFFECT OF BIO-ETHANOL FOR GASOLINE

The production of bio-fuel is valid only when a positive effect in the reduction of CO_2 emissions can be obtained using bio-fuel as an alternative to petroleum. As such, this study was dedicated solely to this effect and to the method for its quantitative expression, although there are many other points to be taken into consideration about the production and use of bio-fuel on the global environment including the effect on ecosystems, resources, human health and so on.

1.1 Basic Unit of the reduction of CO_2 emission with bio-ethanol

If the principle of "carbon neutral" could be applied directly to the production and use of bio-ethanol as an alternative to gasoline, 1.54 kg of CO_2 emissions could be saved per 1L of ethanol. This value is termed "the basic unit of the reduction of CO_2 emissions with bio-ethanol as an alternative to gasoline ", for short the term " the basic unit of the reduction of CO_2 emissions " can be used. This value was obtained as a product of 0.602 (= gasoline equivalent of ethanol in calorie basis) and 2.544 kg (= CO_2 emissions with 1L of gasoline consumption). The gasoline equivalent of ethanol on a calorie basis is a ratio of lower calorific value of ethanol, 21.14 MJ/L (thermodynamic data), and that of gasoline (average value), 35.11 MJ/L (thus, 0.602 = 21.14 ÷ 35.11). The value of CO_2 emissions with 1L of gasoline consumption (2.544) is a LCI data, which contains all CO_2 emissions during the whole process of petroleum utilization, i.e. oil well drilling and importation from the Middle East region to Japan. Actually, the real amount of CO_2 emission reduction can be calculated as the product of this basic unit of the reduction of CO_2 emission (1.54) and a new index of CO_2 emission reduction " ν " as described later.

1.2 Evaluation using the ratio of energy output to input "μ"

The ratio of energy output to input "μ" has long been used as an index of the utility of energy production systems (Matsuda and Kubota,1984). In the case of bio-ethanol production, this index was defined as follows:

$$\mu = (\text{Lower calorific value of ethanol, 21.14 MJ/L}) \div (\text{Total energy input for ethanol production}) \quad (1)$$

The energy input consists of two main parts: the agricultural energy input to obtain raw crops, and the processing energy input to convert the raw materials to ethanol. The former contains machinery and fuels, chemical fertilizers for N, P, and K, herbicides as well as insecticides, transport, electricity and so on. The conversion of raw crops into ethanol by fermentation is a well-known and established process, so the energy required for the process could be estimated technologically. When by-products such as bagasse, corn stalks and cobs are used as heat sources to decrease energy input in the cooking or distilling processes, the heat of the combustion of the by-products should not be added to the energy output but should be subtracted from the energy input.

When this index "μ" was used to evaluate the utility of bio-ethanol for the reduction of CO_2 emissions, $\mu > 1$ should usually be required since major parts of energy input are fossil fuels per energy consumption under present circumstances, and the CO_2 emissions per energy consumption of these fuels can be regarded as nearly equal to that of gasoline. In fact, energy input for the construction of facilities, waste water treatment, labor and other costs are often neglected when the value of μ is calculated. Therefore a minimum of more than 1.2 should be required for the value of μ for effective CO_2 emission reduction to be guaranteed. In addition,

$$\text{Net energy gain } \mathbf{D} = (\text{Energy output } \mathbf{E}) - (\text{Energy input } \mathbf{F}) \quad (2)$$

From equation (1) and (2), the following relation can be derived since $\mu = \mathbf{E}/\mathbf{F}$.

$$\mathbf{D} = (1 - 1/\mu)\,\mathbf{E} \quad (3)$$

1.3 Proposal for a new index of CO_2 emission reduction "ν"

Since the ratio of energy output to input "μ" is an index of pure energy balance, the effectiveness of the bio-ethanol use as an alternative to gasoline from the standpoint of CO_2 emission reduction cannot be expressed directly as a function of μ. Here, a new index of CO_2 emission reduction "ν" is derived and proposed as follows:

ν = (Net reduction of CO_2 emissions by bio-ethanol use) ÷ (Gross reduction of CO_2 emissions by bio-ethanol use)

$$= (\mathbf{A} - \mathbf{B}) / \mathbf{A} = 1 - \mathbf{B} / \mathbf{A} \quad (4)$$

Where, **A**; The amount of CO_2 emissions by bio-ethanol used as an alternative to gasoline when the principle of "carbon neutral" is applied simply, kg-CO_2/L-ethanol, **B**; The net amount of CO_2 emissions by bio-ethanol used as an alternative to gasoline when energy input for production of fuel was taken into account, kg-CO_2/L-ethanol.

Then, the term **A** and **B** can be represented by the following equations, respectively:

$$\mathbf{A} = \mathbf{Q}a \times \mathbf{E}f \quad (5)$$

Where **Q**a; Lower calorific value of ethanol, MJ/ L-ethanol, **E**f; CO_2 emission with gasoline consumption per unit energy, kg- CO_2/ MJ.

$$\mathbf{B} = \mathbf{Q}t \times \mathbf{E}s \quad (6)$$

Where **Q**t; Total energy input for ethanol production, MJ/ L-ethanol, **E**s; CO_2 emission per unit energy input, kg- CO_2/ MJ.

Since energy input for ethanol production contains various energy sources that have different basic units of CO_2 emissions, **E**s should be expressed as follows:

$$\mathbf{E}s = \Sigma\,(\mathbf{x}i \times \mathbf{E}si) \quad (7)$$

Where **E**s*i*; CO_2 emission of energy source *i* per unit energy input, kg- CO_2/ MJ, **x***i*; distribution ratio of energy source *i* in total energy input. –

In addition, the CO_2 emissions per unit energy are different from each energy source *i*, a coefficient ε should be defined to express a characteristic of CO_2 emissions of energy sources on the basis of gasoline:

$$\varepsilon = \mathbf{E}s / \mathbf{E}f = \Sigma\,(\mathbf{x}i \times \mathbf{E}si) / \mathbf{E}f = \Sigma\,(\varepsilon i \times \mathbf{x}i) \quad (8)$$

$$\varepsilon i = \mathbf{E}si / \mathbf{E}f \quad (9)$$

Where εi; an index of CO_2 emission characteristic of each energy input source *i*.

Table 1 shows some examples of the values of εi (= **E**s*i* / **E**f). As shown in this table, the value of ε

Table 1 The basic unit of CO_2 emission, Es*i*, and a characteristic coefficient of CO_2 emissions of energy sources, εi, of energy sources *i*

Energy Source	**E**s*i*, 10^{-3} kg-C/kJ	εi (=**E**s*i* / **E**f)
gasoline	1.892(**E**f)	1.00
light oil	2.024	1.07
kerosene	1.964	1.04
heavy oil	2.112	1.12
coal	2.584	1.37
natural gas	1.533	0.810

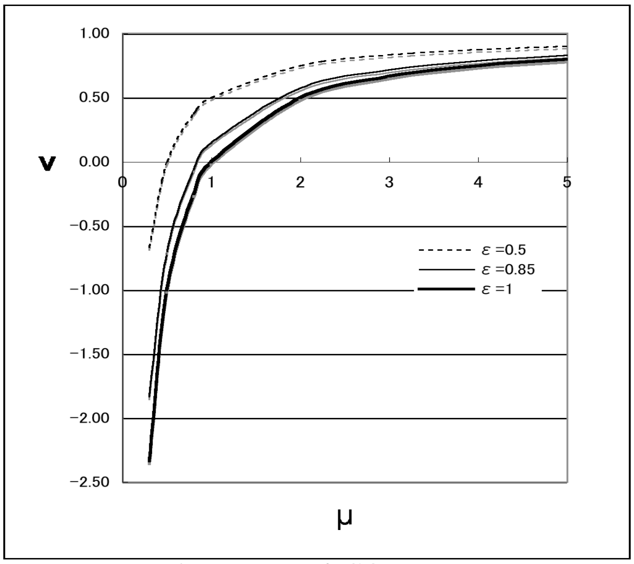

Fig. 1 An index of CO_2 emission reduction "ν" as a function of the ratio of energy output to input "μ"

can be approximated to be unity since fossil fuels are presently a main part of the energy input .

From equations (4) to (8), the following expression can be derived:

$$\nu = 1 - B / A = 1 - (Qt * Es)/(Qa*Ef) = 1 - \varepsilon (Qt / Qa) \quad (10)$$

In the case of bio-ethanol production, the ratio of energy output to input μ defined by Eq.(1) is:

$$\mu = Qa / Qt \quad (11)$$

Thus, from equations (10) and (11), ν can be expressed as a function of μ and ε as follows:

$$\nu = 1 - \varepsilon (1/\mu) \quad (12)$$

Figure 1 shows the value of ν as a function of μ with ε as a parameter, indicating that the value of ν is controlled mainly by μ and not affected strongly by the value of ε if ε is near unity.

1.4 Cost-benefit performance of bio-ethanol expressed by the index "ν"

Since the main purpose of ethanol production in Japan is the reduction of CO_2 emissions, the cost-benefit performance of bio-ethanol in terms of CO_2 emission reduction should be examined. Here, a new economic index fe using the index of CO_2 emission reduction ν is derived and proposed as follows:

fe = (The cost of bio-ethanol, ¥/L-ethanol)
÷ [(the basic unit of the reduction of CO_2 emissions with bio-ethanol, 1.54 kg-CO_2/L-ethanol)
×(the index of CO_2 emission reduction ν)] (13)

The value of fe (¥/kg-CO_2) defined by Eq.(13) can be compared with the cost in CO_2 emissions trading afterward.

Table 2 Some examples of the index of CO_2 emission reduction "ν" as well as the ratio of energy output to input "μ" in U.S. and Brazil

No.	1[*1]	2[*2]	3[*3]	4[*4]
Crop	sugar	corn	corn	corn
Country	Brazil	U.S.	U.S.	U.S.
Energy Input (kJ/t-ethanol)				
Agriculture	2291	11127	7039	7507
Processing	560	15466	14325	14927
Total	2851	26593	21364	22434
"μ"	7.41	0.77	0.99	0.94
"ν"	0.87	-0.30	-0.01	-0.06
Note	(2003)	(2003)	(2002)	(1995)

*1: data from a report of Sao Paulo provincial government in Brazil, 2004
*2: Pimentel et. al, 2005
*3: USDA, 2002
*4: Lorenz et. al, 1995

2. RESULTS AND DISCUSSION

2.1 The validity of bio-ethanol in terms of the reduction of CO_2 emission

Table 2 shows some examples of the values of the index of CO_2 emission reduction "ν" as well as the ratio of energy output to input "μ" for ethanol production from agricultural products in the U.S. and Brazil, which were obtained from literature data.

Some of the data in Table 2 were modified: for example, the output was regarded as fuel ethanol only, and lower calorific value of ethanol was used in every case. As shown in the Table, there is a large difference in the value of μ between Brazil and the U.S. because the requirement of nitrogen with sugar cane is much smaller than that of corn, which results in a smaller energy input for agriculture. Concretely, the amount of nitrogen fertilizer application for sugar cane is 58.3 kg-N/ha, whereas that for corn is about 150 kg-N/ha. Since energy input for nitrogen fertilizer is the largest item in agricultural section, the difference in nitrogen requirement between crops strongly affected the total energy input in agriculture. In addition, bagasse was used as fuel for the processing section (cooking and distillation) in Brazil, which was the reason for the very small energy input for this part. Bagasse, used as an organic resource for the reproduction of crops, should be originally returned to field soil, it should be pointed out that the incineration of the entire bagasse may cause some influence on renewability of agricultural production.

In all of the cases for corn as a raw material in the U.S., the value of μ was close to or less than unity, meaning that the value of ν was nearly zero or minus. This fact shows that bio-ethanol is never " carbon neutral " and has only a minimal contribution to the issue of global warming. It also even has the possibility of increasing in CO_2 emissions as the energy input for ethanol production comes from various sources and is rather large.

The values of μ in Japan were calculated as follows although the data is rather old (Matsuda and Kubota,1981) : rice;0.394, wheat;0.576, sweet potatoes; 1.564. This means that the energy input for the agricultural production in Japan was much larger than that in the U.S.. Thus it would be impossible to obtain a value of μ larger than unity (i.e. $\nu>0$) even if a very high development in ethanol production process could be achieved as long as agricultural products are used as raw materials for fuel ethanol.

2.2 Cost-benefit performance of bio-ethanol

The cost-benefit performance of bio-ethanol in terms of CO_2 emission reduction can be examined using the index of fe (¥/kg-CO_2) defined by Eq. (13).

Table 3 shows some examples of cost-benefit performance of bio-ethanol with various raw crops as well as their producing region. Provided, that the value of fe in Table 3 is obtained under the condition of ν=1.0 (i.e. "carbon neutral"). Since the real value of ν is less than 0.2 in the case of agricultural crops as raw materials from the discussion above, note that the real values of fe

Table 3 Some examples of cost-benefit performance of bio-ethanol in terms of CO_2 emission reduction

Country	Raw crop	Cost-benefit performance fe EURO*1/ ton- CO_2	¥/ ton-CO_2
Brazil	Sugar cane	72 ～ 100	11520 ～ 16000
U.S.	Corn	220 ～ 480	35200 ～ 76800
E.U.	Wheat	340 ～ 730	54400～116800
Japan	Grain crops		65000*2

Note: *1; 1 EURO = ¥160
*2; The production cost of bio-ethanol is assumed to be ¥160 per litter.

will be more than five times higher than those in Table 3.

If the fe values in Table 3 are compared with the cost in CO_2 emissions trading, 9 EURO(13 US dollar)/ ton- CO_2, it is very clear that bio-ethanol is an overly expensive fuel. The reason for this very low cost performance is the high production cost of bio-ethanol. Even in the cases when woody or cellulosic materials used as raw materials for ethanol production, the cost was not cheap, because the production process became complicated and a low yield of ethanol is the main current cause of difficulty.

2.3 The contribution of bio-ethanol in terms of energy supply in Japan

The Japanese government is now planning the production of 100 thousand kL of bio-ethanol per year using domestic biomass resources (this amount is equivalent to 60 thousand kL of gasoline). However, the amount of CO_2 emission reduction is 154 thousand tons of-CO_2 per year, even if "carbon neutral" is assumed. This amount is, however, only 0.012% of the total Japanese CO_2 emissions in the year of 2005. The possible amount of ethanol production as well as the real amount of CO_2 emission reduction would be much smaller than above because the value of ν would be much smaller than unity and the economically available biomass resources would be a very small amount. If a large amount of bio-ethanol could be imported from another country, for example Brazil, to compensate for the shortage of fuel, the following evaluation could be supposed: If the cost of imported bio-ethanol was ¥70 per litter and the value of ν in Brazil was 0.8(refer to Table 2), the cost-benefit performance of bio-ethanol in terms of CO_2 emission reduction fe (¥/ton-CO_2) defined by Eq. (13) would be as follows:

$$fe = 70 * 103 / (1.54 * 0.8) = 56818 \text{ (¥/ton-}CO_2\text{)}$$

On the other hand, the cost in CO_2 emissions trading in November 2007 was 22.65 EURO / ton-CO_2(=3692¥/ton-CO_2). The cost of imported bio-ethanol is 15 times more expensive from the standpoint for the cost in CO_2 emissions trading.

Although only the ethanol production from crops was discussed in this article because most of the current bio-ethanol production was operated using crops such as sugar cane and corn, the main source of bio-ethanol, however, should not be crops as food of mankind and livestock but be woody or cellulosic materials. As such bio-ethanol using woody or cellulosic materials should be examined carefully in the next step of the study. The quantitative estimation of the amount of woody or cellulosic biomass really available as a source of bio-ethanol would be also important. A preliminary study by the author indicated that the amount of such biomass in Japan would not be so abundant as had been expected from an optimistic stand point. In addition, since the fundamental reason why bio-ethanol is desired is acquirement of liquid fuel for automobiles, it will be very important to study what could be a source of power for automobiles as well as the future vision of environmentally-friendly transportation systems.

CONCLUSIONS

The fact should be emphasized that the ethanol from crops is never "carbon neutral" and has only a minimal contribution to the issue of global warming. It also even has the possibility of increasing in CO_2 emissions. Also, the amount of bio-ethanol was rather small when compared with the fuel demand for transportation. The economic analysis of bio-ethanol production has also indicated that the financial benefits of bio-ethanol were not positive figures. Although the concern about environmental impacts was not discussed in this study, there are many factors that should be investigated more extensively.

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