Resources and Environment 2012, 2(6): 306-316
DOI: 10.5923/j.re.20120206.09

On the Doubtful Validity of Bio-ethanol as an Environmental Measures: Can CO_2 be reduced by this method?

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Abstract The purpose of this study was to conduct a quantitative assessment of the CO_2-reducing effects of bio-ethanol in its lifecycle, including CO_2 emissions generated in the process of ethanol production, and examine its efficacy as an environmental measure. In the study, the significance of the "Biomass Nippon Strategy", which has been implemented by the Japanese government, as well as the feasibility and economic efficiency of its plan were also discussed. Although the government has set the "revitalization of agriculture, forestry, and fisheries, including farming, mountain, and fishing villages" as a goal for the "Biomass Nippon Strategy", the results of the study, judging from the amount of the subsidy, suggest that the domestic production of ethanol using fallow fields only increases the financial burden on Japanese taxpayers rather than revitalizing the agriculture industry. The results indicate that an emphasis should be placed on the expansion of food production to revitalize the agricultural sector, instead of providing financial support for an ineffective reduction project. If burning by-products from the production of ethanol generates energy, it will increase the rate of CO_2 reduction. However, the domestic production of ethanol and its use proposed in the government's plan are expected to have only limited CO_2-reducing effects.

Keywords Bio-Fuel, Bio-Ethanol, CO_2 Reduction, Revitalization of Agriculture, Subsidies

1. Introduction

The principle of carbon neutrality is based on the idea that “the combustion of biomass, a plant resource, does not increase the amount of CO_2 in the atmosphere”. The reason, according to the principle, is that although CO_2 is emitted by burning bio-ethanol, as in the case of fossil fuels, these greenhouse gas (GHG) emissions are assumed to be recaptured by newly growing plants, the raw material of bio-ethanol. The principle has been evaluated as an effective environmental measure since its adoption in the “Kyoto Protocol Target Achievement Plan”. In response to the current trend, Japan has been producing and using bio-ethanol based on its policy: “The Biomass Nippon Strategy”[1].

However, the principle of carbon neutrality was defined only focusing on parts of the entire system, i.e., the growth stage of plants as materials and the process of fuel consumption. In reality, a large amount of CO_2 is emitted from a massive amount of fossil fuels consumed in the process of ethanol production. To define bio-ethanol as an ecological fuel, it is necessary to assess the CO_2-reducing effect in the entire lifecycle while taking into account these CO_2 emissions.

Previously, we reported the assessment of the effect of reducing oil use[2]. The present study examined the efficacy of bio-ethanol as an environmental measure for CO_2 reduction in the entire lifecycle, including the process of growing plants and bio-ethanol production. The study also discussed the significance of “The Biomass Nippon Strategy”, a strategy that has been promoted by Japan, as well as the feasibility and economic efficiency of the plans.

2. Research Methods

The following methods and formulas were used for the assessment, as adopted from previous study[2].

In the assessment of the CO_2-reducing effects of bio-ethanol as an alternative to gasoline while taking into account its entire lifecycle, the actual CO_2 reduction rate “α” is calculated using the following formula:

$$\alpha = 1 - (1/\gamma)\ (Ep/Eg) \quad (1)$$

“γ” is the energy-profit ratio of bio-ethanol, “Eg” is CO_2 emissions per unit calorific value of gasoline[kg-CO_2/kcal], and “Ep” is CO_2 emissions per unit amount of energy input in ethanol production[kg-CO_2/kcal].

In the calculation of the energy-profit ratio “γ” (amount of

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Published online at http://journal.sapub.org/re

energy produced/amount of fossil fuel input), the energy of byproducts (corn oil, gluten, lignin, bagasse, and feed) should not be included in the amount of energy production because they are created in the process of bio-ethanol production. Since bio-ethanol was assessed as a fuel, the lower caloric value (5,067 kcal/ℓ-ethanol) was used in the present study.

The ratio of CO_2 emissions generated from primary energy sources in ethanol production to gasoline is:

$$Ep/Eg = \sum(Xi\times(Epi/Eg)) \quad (2)$$

"Xi" is the component ratio of primary energy sources: "i", and "Epi" is CO_2 emissions per unit calorific value of primary energy sources (i)[kg-CO_2/kcal]. The larger this value, the larger the amount of fossil fuels used in ethanol production and CO_2 emissions generated.

The CO_2 reduction rate "R"[kg-CO_2/ℓ-ethanol] when bio-ethanol is used as an alternative to gasoline and taking into account the entire lifecycle is calculated by incorporating α into the following formula:

$$R = A\times\alpha \quad (3)$$

A is the amount of CO_2 reduction: "1.541[kg-CO_2/ℓ-ethanol]", when bio-ethanol is used as an alternative to gasoline.

The cost-effectiveness of CO_2 reduction in the entire lifecycle of bio-ethanol was then assessed. The actual cost-effectiveness of CO_2 reduction, "Ceff", is calculated using Formula 4:

$$Ceff = Ce/(A\times\alpha) \quad (4)$$

"Ce" is the cost of bio-ethanol production[yen/ℓ-ethanol]. When α=1 in formula (1) and (4), a carbon-neutral state is adopted. If 1>α>0, the use of bio-ethanol as an alternative to gasoline has less CO_2-reduction effects and its economic efficiency is low. In the case of α<0, the project being nonsense.

3. Status and Assessment of Domestic Bio-ethanol

3.1. The Scale of Plants and Feasibility of Securing Raw Materials

In the U.S., Brazil, and the E.U. (27 countries), bio-ethanol production was steadily increasing as of 2008 (Table 1). The U.S., Brazil, and the E.U. use corn, sugar cane, and wheat as the primary ingredient, respectively, to produce ethanol. They are the world's largest producers of each crop, and have a large amount of stock that exceeds domestic consumption (Tables 2, 3, 4). In fact, the E.U. started to use surplus wheat to produce ethanol as a measure to stabilize its price.

Table 1. Changes in the production of bio-ethanol in major developed countries Unit: 10,000[kℓ]

Country	2004	2005	2006	2007	2008
U.S.	1,289	1,480	1,840	2,696	3,411
Brazil	1,466	1,607	1,675	1,902	2,453
E.U.	54	91	151	216	278
Total world production	4,115	4,487	4,979	5,832	6,570

Source: Calculated from the references[3] and[4].

Table 2. American corn supply and demand

Year	Total world production [kt]	Production in the U.S. [kt]	Proportion[%]	Export [kt]	Year-end-stock [kt]
2005/06	699,127	282,263	40.4	56,084	49,968
2006/07	712,277	267,503	37.6	54,214	23,802
2007/08	791,422	331,177	41.8	60,757	24,056

Source: From the references[5],[6] and[7]

Table 3. Brazilian sugar supply and demand

Year	Total world production [kt]	Production in Brazil [kt]	Proportion[%]	Export [kt]	Year-end-stock [kt]
2004/05	140,726	28,175	20	18,020	585
2005/06	144,709	26,850	18.6	17,090	285
2006/07	155,166	30,850	19.9	19,550	265

Source: Prepared from the references[8] and[9].

Table 4. E.U. wheat supply and demand

Year	Total world production [kt]	Production in the E.U. [kt]	Proportion[%]	Export [kt]	Year-end-stock [kt]
2005/06	620,044	132,356	21.3	15,694	23,391
2006/07	596,101	124,870	20.9	13,873	13,338
2007/08	610,991	119,427	19.5	12,272	11,454

Source: Prepared from the references[5],[6] and[10]

Table 5. A summary of domestic ethanol production plants

Operating body	Year of the start of operation	Raw materials	Expenditure for the project[100 million yen]	Annual production capacity[kℓ/year]
Hokkaido Federation of Agricultural Cooperative Associations	2009	Sub-standard wheat,	60.0	15,000
Oenon Holdings in Hokkaido	2009	Rice	45.0	15,000
JA (ZEN-NOH) in Niigata Prefecture	2009	Rice	13.0	1,000
Bio-ethanol Japan in Osaka Prefecture	2007	Scrap wood from construction work	37.0	1,400
Yamagata Prefecture	2008	Kaoliang	Unpublished	1,800
Okayama Prefecture	2007	Scrap wood from plants	3.5	95
Miyakojima in Okinawa Prefecture	2007	Sugar cane	12.0	1,400
Fukuoka Prefecture	2007	Food waste	Unpublished	120
Total	-	-	170.5	35,815

Source: Prepared from the references[12],[13] and[14].

On the other hand, Japan produced only 30 kℓ of bio-ethanol in 2006[4], and demonstration plants for its production across the country are currently operating supported by government subsidies. Although the government plans to increase the annual production of bio-ethanol to 50,000 kℓ by 2010, it is likely to be difficult to accomplish this goal, according to an estimate of the annual production capacity (approximately 36,000 kℓ) based on the scale of the plants (Table 5)[11]. It is obvious from the current status of the plants that it is impossible to reach the mid- and long-term goal: six million kℓ of domestic ethanol production.

In Japan, molasses, sub-standard wheat and other agricultural crops, cellulosic materials including rice straw and wood, and rice and other crops as raw materials are listed as the main candidates for the primary ingredient of ethanol. Changes in food self-sufficiency rates are shown in Table 6. Self-sufficiency for almost all food items remains low. However, self-sufficiency for rice is high, with a stock at the end of every year.

Table 6. Changes in domestic food self-sufficiency Unit:[%]

Items	2004	2005	2006	2007	2008
Rice	95	95	94	94	95
Wheat	14	14	13	14	14
Vegetables	80	79	79	81	82
Sugar	34	34	32	33	38
Total food self-sufficiency calculated based on calorie supply	40	40	39	40	41

Source: From the reference[15].

The following is an estimate of the ethanol production capacity based on the surplus stock of rice: Changes in rice stocks at the end of terms are shown in Table 7. There were 1.63 million tons of rice in stock at the end of 2008. Oenon Holdings Inc. in Hokkaido is involved in a demonstration project: bio-ethanol production using minimum access rice (a quota of rice to be imported from foreign countries in exchange for import restrictions by placing high tariffs) as a raw material. Table 8 shows minimum access rice in stock in Japan.

There were 970,000 tons of minimum access rice (calculated by deducting the amount used from the import) in stock as of October 2008. The total amount of surplus rice available (2.6 million tons) is calculated by adding this to the above-mentioned stock. Based on the current ethanol yield from rice: 0.447 ℓ/t[16], the ethanol production capacity using the surplus stock in Japan is estimated to be approximately 1.16 million kℓ (≈ 2.6 million tons × 0.447 ℓ/ton).

Table 7. Changes in the year-end stock of domestic rice Unit: 10,000 ton

Items	1999/2000	2001/02	2003/04	2005/06	2007/08
Production	848	877	761	846	820
Demand	857	846	756	839	841
Year-end stock	143	161	207	182	163

Source: From the reference[17].

The following is an estimation of the ethanol production capacity based on the available amount of cellulosic biomass resources. Table 9 shows the total amount of domestic cellulosic biomass resources in 2008. There are 26.60 million tons of cellulosic biomass resources including those that have already been used for other purposes. The total available amount of cellulosic biomass resources was calculated as approximately 14.86 million tons by multiplying the annual yield by the availability rate. As the ethanol yield from wood materials was 0.290 ℓ/ton[16][19], the ethanol production capacity using cellulosic biomass resources available in Japan was calculated to be around 4.31 million kℓ (≈ 14.86 million tons × 0.290 ℓ/ton).

Table 8. Stock of domestic minimum access rice (as of October 2008) Unit: 10,000 ton

Items	Import	For staple food	For processing	For aids	For feed	Stock
Amount*1	902	94	337	232	139	97

*1 There is a rounding error between the amount of import and total amount of rice for specific purposes.
Source: Calculated from the reference[18].

Table 9. Domestic cellulosic raw materials

Raw materials	Annual yields[10,000 ton]	Usage status		Available amount [10,000 ton]
		Purposes: Rate of specific materials that have already been used[%]	Availability rate[%]	
Scrap wood from lumber mills	440	Paper manufacturing, energy source: 95	5	22
Scrap wood from construction work	470	Paper manufacturing, bedding materials for livestock: 70	30	141
Inedible parts of crops (rice straw, chaff, etc.)	1,400	Compost, feed, bedding materials for livestock: 30	70	980
Scrap wood obtained from forests	350	Paper manufacturing: 2	98	343
Total	2,660	44	56	1,486

Source: Calculated from the reference[20].

The total of this and the above-mentioned capacity for ethanol production using domestic surplus rice amount to 5.47 million kℓ - still less than the amount of ethanol required for the E10 plan (six million kℓ). It is difficult to secure sufficient amounts of crops and cellulosic materials in Japan. The sufficient volume of ethanol required for the E10 plan cannot be produced even using the total amount of these materials available in Japan.

In 2007, the National Federation of Agricultural Cooperative Associations (ZEN-NOH/JA) in Niigata Prefecture initiated a demonstration project in which they produce bio-ethanol from high-yielding rice grown on idle agricultural land. A sufficient amount of a raw material may be secured by the large scale production of rice using idle land across Japan. However, it is not known if there is a sufficient area of idle land suited for laborsaving agricultural methods to maintain the cost of the raw material or rice as low as possible. Regarding the production of bio-ethanol from crops grown on idle agricultural land, a serious error has been identified in the estimation of the production cost, as explained in the following paragraphs. Therefore, it is difficult to promote this type of ethanol production on a large scale.

3.2. Production Costs and Economic Efficiency of Imported Ethanol

The government plans to substantially increase the domestic production of bio-ethanol that can compete with other fuel products in Japan and other countries in terms of the price and quality until 2030. Figure 1 shows the price structures of gasoline and bio-ethanol imported from Brazil, and the estimated production cost of domestic bio-ethanol.

As of the end of November 2009, the wholesale price of gasoline was 67.2 yen/ℓ, and the price of ethanol imported from Brazil was 76.4 yen/ℓ. The cost of producing bio-ethanol using American corn was 32 to 38 yen/ℓ, and 60 to 85 yen/ℓ when wheat from the E.U. was used as the raw material. Regarding ethanol from Brazilian sugar cane, its lowest production cost was reported to be 17 yen/ℓ[21], because energy generated by combusting bagasse, a byproduct of ethanol production, was used to substantially reduce energy costs. On the other hand, the production costs (including raw material costs) of domestic bio-ethanol from molasses, sub-standard wheat, and edible wheat were 90.4, 98.0, and 415 yen/ℓ, respectively. In particular, the cost of edible wheat (369 yen/ℓ) was seven times higher than that of sub-standard wheat (52 yen/ℓ). Common agricultural crops have an economic disadvantage as raw materials because their costs are very high. The production cost of domestic bio-ethanol is significantly higher than that of other fuels and foreign bio-ethanol, and it was calculated on the assumption that the project would be partially supported by the government.

Figure 2 shows the estimated production costs of domestic cellulosic bio-ethanol according to the scale of the plant, calculated by NEDO. As the scale of a plant becomes larger, and with subsequent reductions in equipment depreciation and personnel expenses, production costs are expected to decrease. However, even the largest bio-ethanol plant in Japan using cellulosic resources as raw materials produces only 1,400 kℓ of bio-ethanol annually (Table 5).

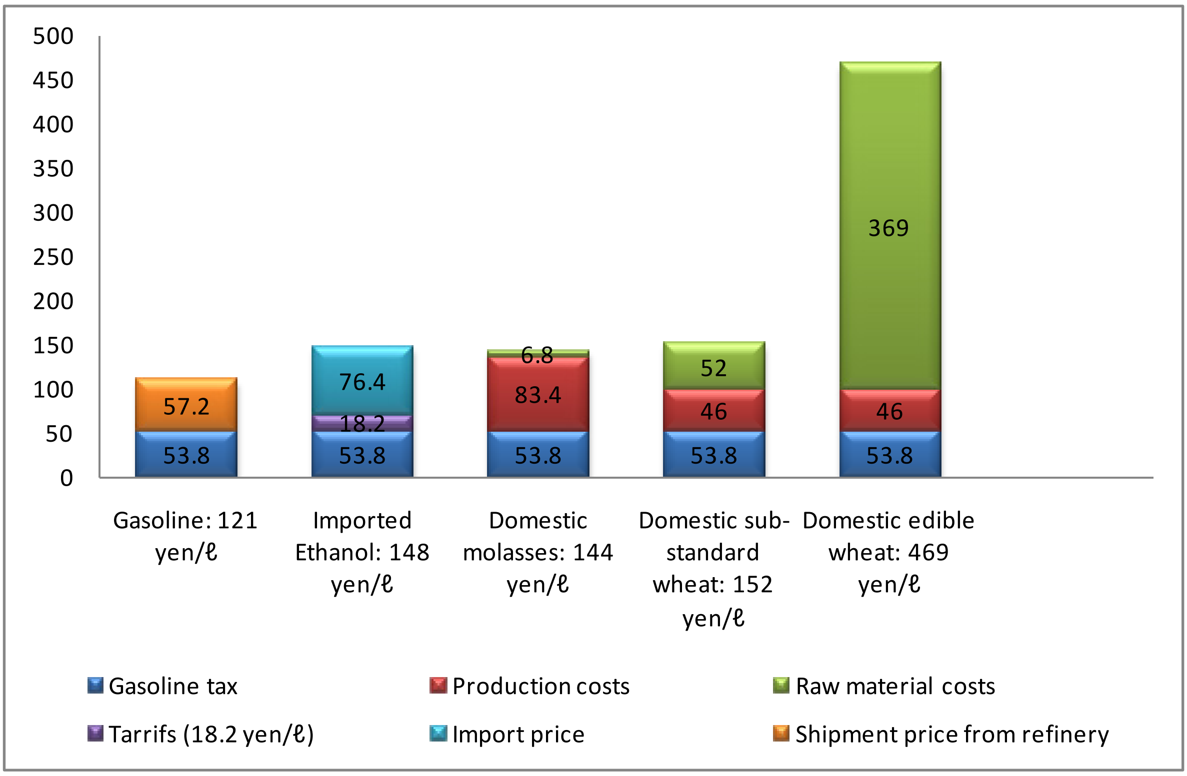
According to the results of an interview survey involving Bio-ethanol Japan in Kansai, the cost of producing bio-ethanol in the company was higher than 100 yen/ℓ. As a reference, the target cost of producing cellulosic bio-ethanol set by related ministries and agencies, including the Ministries of “Agriculture, Forestry and Fisheries”, “the Environment”, and “Economy, Trade, and Industry”, is 100 yen/ℓ[11].

As the production cost of domestic bio-ethanol is 57.3 yen/ℓ, when produced at a plant with a production capacity of 20,000 kℓ/year, it can compete with the current (as of the end of November 2009) prices of gasoline (67.2 yen/ℓ) and imported ethanol (76.4 yen/ℓ) (Figure 1). Therefore, if domestic bio-ethanol can be actually produced at this estimated cost, its large-scale production should not be difficult. However, the amount of raw materials required for its production is calculated at 68.97 million tons/year (≈ 20,000[kℓ/year]/0.290[ℓ/t]), which is more than four times the estimated amount of cellulosic biomass materials currently available (14.86 million tons/year) (Table 9). It is difficult to secure a sufficient amount of cellulosic raw materials, which is expected to be an obstacle in expanding the scale of plants and reducing their production costs in the future.

Japan plans to import bio-ethanol from Brazil until the stable supply of domestic bio-ethanol is secured. As there is a shortage of around 750,000 kℓ of ethanol supply to accomplish the Kyoto Protocol target, if the shortfall is imported from Brazil, 57.3 billion yen (≈ 76.4 yen/ℓ × 750,000 kℓ) will be required, based on the current cost (CIF: cost, insurance, and freight) of importing ethanol from Brazil (Figure 1).

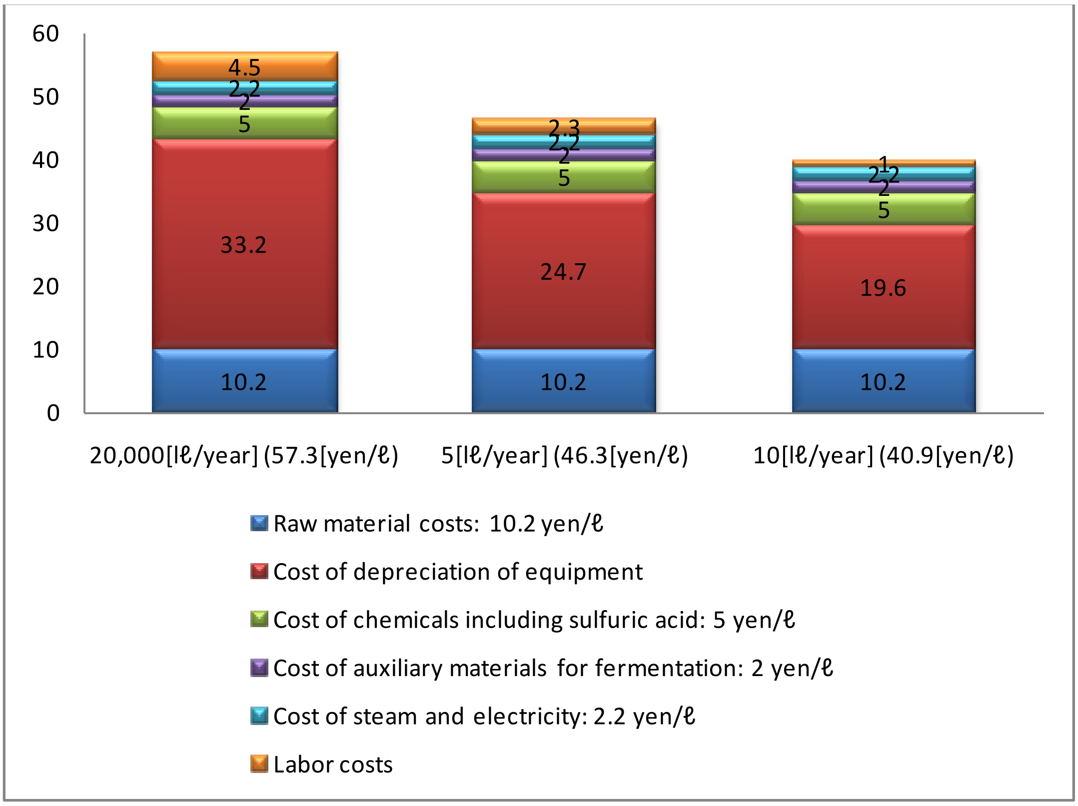
When 450,000 kℓ (≈ 750,000 kℓ × 0.603 (5,067[kcal/ℓ] / 8,399[kcal/ℓ]) of gasoline is replaced by 750,000 kℓ of bio-ethanol[2], 30.2 billion yen (≈ 67.2 yen/ℓ × 450,000 kℓ) is required for importing it, if the distribution cost (cost of shipping from refinery) is 67.2 yen/ℓ (Figure 1). A loss of 27.1 billion yen is estimated to be caused by importing ethanol as an alternative to gasoline.

The current CO_2 reduction rate of bio-ethanol imported from Brazil is approximately 1.39[kg-CO_2/ℓ][2]. Therefore, the CO_2 reduction rate of 750,000 kℓ of imported ethanol, calculated using a quantitative assessment method, is around 1.04 million[t-CO_2] (≈ 1.39[kg-CO_2/ℓ] × 750,000 kℓ). The CO_2 reduction rate of ethanol imported from Brazil is 0.0982%, when it is calculated based on the total amount of domestic CO_2 emissions in 1990, which is stipulated as the base year in the Kyoto Protocol: 1.0591 billion[t-CO_2]. The rate is 0.0854% when the calculation is based on the total amount of domestic CO_2 emissions in 1990: 1.218 billion[t-CO_2][23], and 0.415% if the estimation is based on transportation-related CO_2 emissions in Japan in 2008: 250.90 million[t-CO_2]. At any rate, the CO_2-reducing effects of imported ethanol are very low. It is necessary to reconsider the appropriateness of its promotion because it may cause a substantial trade deficit.



*1 Conditions for the estimations
Gasoline: Wholesale price at the end of November 2009 from the reference[22].
Ethanol imported from Brazil: CIF (cost, insurance, and freight) price
Domestic molasses: 720 kℓ of ethanol produced from 2,200 tons of molasses at a price of 2,000 yen/ton
Domestic sub-standard wheat: (Calculated by the Tokachi Promotion Organization); 11,600 kℓ of ethanol produced from 27,000 tons of wheat at a price of 22 yen/kg
Domestic edible wheat: (Calculated by the Ministry of Agriculture, Forestry and Fisheries); raw material cost=159 yen/kg from the reference[19].

Figure 1. Price structures of gasoline and bio-ethanol[yen/ℓ]*1



*1 Conditions for the estimations
Cost of raw materials: Two yen/kg (mean price of scrap wood), calculated based on an ethanol yield of 0.290 ℓ/ton, 345 days/year in operation. Source: From the reference[12].

Figure 2. Production costs[yen/ℓ] of domestic cellulosic ethanol according to the scale of plants*1

Table 10. Costs of producing ethanol using domestic rice*1 Unit:[yen/ℓ]

Items	Cost of producing rice as a raw material	Cost of producing ethanol	Total
Target costs set in the national policy	50	50	100
Costs estimated by Niigata JA (ZEN-NOH)	45	69	114

*1 Conditions for the estimations
Target costs set in the national policy: Production cost of rice as a raw material: 20 yen/kg, Ethanol yield: 0.4 ℓ/kg.
Estimates by Niigata JA (ZEN-NOH): Production cost of rice as a raw material: 20 yen/kg, Ethanol yield: 0.447 ℓ/kg. Source: From the reference[24].

Table 11. Changes in the production cost of domestic rice

Year	[yen/10a]			Yields [kg/10a]	Production costs (all costs included) [yen/kg]
	Equipment/material costs	Labor cost	Production costs (all costs included)		
2006	76,610	41,995	143,538	511	281
2007	75,183	40,538	140,030	511	274
2008	85,500	38,654	146,754	533	275

Source: From the reference[25].

3.3. Amount of Subsidies in a Demonstration Project in Niigata Prefecture

In 2007, the National Federation of Agricultural Cooperative Associations (ZEN-NOH/JA) in Niigata Prefecture started a demonstration project in which they produce bio-ethanol from high-yielding rice grown on idle agricultural land, and distribute E3 fuel. Table 10 shows the estimated costs of producing bio-ethanol from domestic rice; the target cost set in the government policy is 100 yen/ℓ, whereas the cost was estimated to be 114 yen/ℓ by Niigata JA (ZEN-NOH) - the operating body. According to the breakdown of the production cost, the raw material cost is 20 yen/kg. However, the cost of producing rice as a raw material was calculated while taking into account government subsidies. For reference, Table 11 shows changes in the production costs of domestic rice, published by the Ministry of Agriculture, Forestry, and Fisheries. The mean production cost of domestic rice during the past three years was 277 yen/kg, which means that the above-mentioned raw material cost of 20 yen/kg is less than one thirteenth of the actual rice production cost. Since the mean retail price of edible rice is 350 yen/kg[24], it is obvious that its production will be unprofitable without government subsidies.

Table 12 shows the revenue and expenditure of growing rice as a raw material of bio-ethanol, proposed by Niigata ZEN-NOH (JA) to farmers. There is a difference of approximately 60,000[yen/10a] between the equipment and material costs estimated by Niigata ZEN-NOH (JA), 26,000[yen/10a] including the costs of farm equipment, and the national mean (2008), 85,500[yen/10a] (Table 11). The equipment and material costs calculated by ZEN-NOH (JA) are 50% of the total costs of seeds and seedlings, fertilizers, pesticides, and fuels, and exclude the costs of other materials, land improvement and water use, borrowing and lending, public dues, buildings, farm equipment, and production control, as the expenditure of growing edible rice. There is also a difference of approximately 30,000[yen/10a] between the labor cost calculated by ZEN-NOH (JA) based on working hours per area of six[hours/10a], 9,600[yen/10a], and the national mean (2008) based on working hours per area of 27[hours/10a], 38,654[yen/10a] (Table 11).

The farmers produce the high-yielding rice for the raw material (yield per area: 800[kg/10a]) during the period when edible rice is not produced without purchasing new farm equipment, materials, and devices for its production. In other words, they produce rice for the raw material of ethanol as a sideline business at a low production cost. Despite their cost-saving efforts, they run a deficit of 2,600[yen/10a], according to the above-mentioned estimate. Although they can produce the raw material at a lower cost, compared to edible rice, because it does not require a drying process, its production is far from making profits.

Currently, farmers growing rice as a raw material of ethanol receive subsidies of 30,000[yen/10a] from the government. This translates into 37.5 yen per 1 kg of rice (≈ 30,000[yen/10a]/800[kg/10a]), calculated based on the yield per area of 800[kg/10a]. Since the current ethanol yield from rice is 0.447 ℓ/t, the amount of subsidies to farmers is estimated at 83.9 yen/ℓ (≈ 37.5[yen/kg]/0.447[ℓ/kg]).

The budget for the demonstration plant in Niigata that produces 1,000 kℓ/year of ethanol is 1.3 billion yen (Table 5). The annual cost of depreciation on equipment (excluding the interest) will be 86.7 yen/ℓ (≈ 1.3 billion yen/1,000[kℓ/year]/15 years), if the cost is depreciated over a period of 15 years. An estimate of 43.4 yen/ℓ is supported by the government, as it provides subsidies to cover half of the expenditure of the project. In addition, 3% (1.6 yen/ℓ), which is the percentage of ethanol included in gasoline, of the gasoline tax (53.8 yen/ℓ) is subsidized by the government.

Table 13 summarizes the subsidies provided to support the demonstration project. The government provides subsidies of 128.9 yen/ℓ for the project of Niigata ZEN-NOH (JA), which is imposing a heavy burden on the public. The 4th goal for "The Biomass Nippon Strategy" is the "revitalization of agriculture, forestry, and fisheries, including farming, mountain, and fishing villages". However, the promotion of domestic bio-ethanol production using idle land, as stated in the policy, causes an adverse effect: "an increase in the economic burden on the public", rather than revitalizing agriculture. The subsidies provided for the production and use of bio-ethanol have not generated, and will not generate, the expected CO_2-reducing effects (refer to[3.4]).

Table 12. Revenue and expenditure of growing rice as a raw material of ethanol, proposed by Niigata JA (ZEN-NOH)

Items	Classification	Amount of money[yen/10a]	Calculation methods
Revenue	Revenue from selling rice as a raw material	16,000	Unit selling price: 20 yen/kg, single crop: 800 kg/10a
Expenditure	Equipment/material costs	9,000	50% of the total of seeds and plants, fertilizer, pesticide, and fuel costs
	Farm equipment costs	17,000	-
	Labor costs	9,600	Working hours: 6 hours/10a
	Total	35,600	-
	Total excluding farm equipment costs	18,600	Farm equipment costs are included in the expenses for edible rice
Revenue and expenditure		-2,600	-

Source: Prepared from the reference[26].

Table 13. Estimates of subsidies provided for the demonstration project in Niigata Prefecture Unit:[yen/ℓ]

Items	Stage of rice (raw material) production	Stage of ethanol production	Stage of ethanol use	Total
Subsidies allocated	83.9	43.4	1.6	128.9

3.4. CO_2-reducing Effects in the E10 Plan

In ethanol production using cellulosic materials (scrap wood, timber, rice straw, and chaff), lignin is produced in the process of pretreatment, and rice straw and chaff in raw material production when using rice. If energy generated by combusting these byproducts is used, in the form of electricity, in the process of ethanol production, it will reduce the required energy input from the outside, leading to an improvement in the energy-profit ratio.

Table 14 shows the energy-profit ratio of domestic bio-ethanol when energy is generated by combusting its byproducts and used. In calculation of the energy-profit ratio, the energy of byproducts was not included in the amount of energy production, and the lower caloric value (5,067 kcal/ℓ-ethanol) was used, as described in the preceding paragraphs. The values in the brackets in the table represent the energy-profit ratio when byproducts are converted into electricity and used as energy in the process of ethanol production, while the energy produced does not include surplus electricity. Even if energy is produced from byproducts and used, the energy-profit ratio of bio-ethanol is lower than that of gasoline (6.57) - a fuel to be replaced[2]. Bio-ethanol is not an efficient fuel, with its energy-profit ratio being higher than two.

Table 15 shows the net CO_2 reduction rate α and CO_2 reduction rate R (excluding CO_2 emissions in ethanol production), calculated using Formulas (1) and (3), respectively, based on the ratio of CO_2 emissions generated from primary energy sources to gasoline (Ep/Eg: 0.888) (refer to 3.2) and "γ" (the energy-profit ratio in the brackets in Table 14).

According to the estimation results, the net CO_2 reduction rate α was higher than zero, which suggests that CO_2-reducing effects are expected to some extent. Specifically, the net CO_2 reduction rate for wood (classified into cellulosic materials including scrap wood and timber) and corn (a material rich in starch as with rice) produced in the U.S. was lower than zero[2], and CO_2-reducing effects are not expected. However, these results are not actual measurements, and the validity of the energy-profit ratio should be critically discussed.

The amount of ethanol required for the E10 plan is approximately six million kℓ, although the proportions of raw materials to be used have not been determined. Table 16 shows the CO_2-reducing effects of each raw material that the E10 plan is expected to produce, estimated based on the reduction rate R (excluding CO_2 emissions in ethanol production) for each material (Table 15).

Table 14. Energy-profit ratio of domestic bio-ethanol*1

Raw materials		Cellulosic raw materials		Rice	
		Scrap wood from construction work	Timber from thinning	Rice	Rice, rice straw, chaff
Unit		[kcal/ℓ]		[MJ/10a]	
Energy input	Raw material production	407	770	5,226	5,226
	Ethanol production	5,066(1923)	5,066(1,923)	5,379(32)	13,370(9,238)
	Total	5,473(2330)	5,836(2,693)	10,605(5,258)	18,596(14,464)
Energy production	Thermal energy from ethanol combustion	5,067	5,067	7,916	15,634
	Surplus byproducts	3,143 (0)	3,143 (0)	5,347(0)	4,132 (0)
	Surplus electricity	0	0	10,264(0)	0
	Total	8,210(5,067)	8,210(5,067)	23,527(7,916)	19,766(15,634)
Energy-profit ratio γ		1.50(2.17)	1.41(1.88)	2.22(1.51)	1.06(1.08)
Data resources		*2	*2	*3	*3

*1 The values in brackets in the table represent the energy-profit ratio when byproducts are converted into electricity and used as energy in the process of ethanol production, while the energy produced does not include surplus electricity. The caloric value of ethanol was 5,067 kcal/ℓ.
*2 Calculated from the reference[12].
*3 Calculated from the reference[27].

Table 15. Assessment of CO_2-reducing effects expected based on technological trends

Raw materials	Energy-profit ratio γ	Net CO_2 reduction rate α	CO_2 reduction rate R[kg-CO_2/ℓ]	Remarks
Scrap wood from construction work	2.17	0.591	0.910	NEDO (2005)*1
Timber from thinning	1.88	0.528	0.813	NEDO (2005)*1
Rice	1.51	0.412	0.635	Saga et al. (2007)*2
Rice, rice straw, chaff	1.08	0.178	0.274	Saga et al. (2007)*2

*1 Calculated from the reference[12].
*2 Calculated from the reference[27].

Table 16. CO_2 reduction rates estimated in the E10 plan

Raw materials	CO_2 reduction*1 10,000[t-CO_2]	Total emissions (1990) 105,910 [10,000 t-CO_2]*2	Total emissions (2008) 121,800 [10,000 t-CO_2]*2	Transportation (2008) 25,090 [10,000 t-CO_2]*2
Scrap wood from construction work	546	0.52	0.45	2.2
Timber from thinning	488	0.46	0.40	1.9
Rice	381	0.36	0.31	1.5
Rice, rice straw, chaff	164	0.15	0.13	0.65

*1 Estimated based on the formula: CO2 reduction rate = R[kg-CO2/ℓ] × six million kℓ of ethanol.
*2 Calculated based on documents obtained from the Institute of Energy Economics, Japan. (ref.[23])

Table 17. Assessment of the cost-effectiveness of CO_2 reduction

Production areas: Raw materials	Production costs*1 [yen/ℓ]	Net CO_2 reduction rate α	Nominal cost-effectiveness [yen/t-CO_2]	Actual cost-effectiveness Ceff[yen/t-CO_2]
U.S.: Corn	32.0	0.0710*2	20,800	292,500
U.S.: Wood	60.4	-0.440	39,200	-
Brazil: Sugar cane	17.0	0.922	11,000	12,000
Imported ethanol	76.4	0.899	49,600	55,100
EU: Wheat	60.0	0.149	38,900	261,300
Japan: Scrap wood from construction work	100	0.591	64,900	109,800
Japan: Rice	114	0.412	74,000	179,600

*1) For production costs, refer to[3.2].
*2) Best possible values were estimated based on data used in a study conducted by Shapouri et al. (Ref[2] and[29]).

According to the estimation results, the E10 is expected to reduce CO_2 emissions by only up to 0.52%, on the basis of the total domestic CO_2 emissions in 1990 (the base year stipulated in the Kyoto Protocol). The effects are even smaller (a 0.45% reduction at best) if based on the total domestic CO_2 emissions in 2008. The plan is expected to reduce GHG by less than 3%, even on the basis of the total CO_2 emissions related to transportation in 2008. Although technological innovation may increase the CO_2-reducing effects of bio-ethanol to some extent, they are expected to remain low. This means that Japan continues to invest substantial subsidies in an effort to accomplish the ineffective E10 plan.

4. Assessment of the Cost-effectiveness of CO_2 Reduction

Table 17 shows the actual cost-effectiveness of CO_2 reduction in the lifecycle of ethanol while taking into account CO_2 emissions in the process of its production, calculated using Formula 4 and based on ethanol production costs (refer to[3.2]) and the net CO_2 reduction rate α (refer to Reference 21 and Table 15). The nominal cost-effectiveness was calculated by employing the principle of carbon neutrality (based on the assumption that the net CO_2 reduction rate α=1) adopted by the government. In other words, the value was calculated by excluding CO_2 emissions produced in the process of ethanol production.

The table shows significant differences between the nominal and actual cost-effectiveness of bio-ethanol-based CO_2 reduction, which has been implemented in a number of countries, revealing perception gaps. The reduction rate α was lower than zero for some types of corn and wood (a cellulosic material) produced in the U.S., which does not support the effectiveness of the production and use of bio-ethanol as a CO_2 reduction measure. Regarding American corn in particular, the reduction rate α was very low (α was around 0.0710 or lower), and so was the cost-effectiveness. This also applied to wheat produced in EU countries.

The table also shows the cost-effectiveness of CO_2 reduction using bio-ethanol imported from Brazil - part of "The Biomass Nippon Strategy". In the EU's Emission Trading - an international market for trading GHG emission rights, the closing price in December 2008 was 2,713 yen/t-CO_2 or 20.87 euro/t-CO_2 (conversion rate: 130 yen/euro)[28]. From the viewpoint of the cost-effectiveness of CO_2 reduction, the price of bio-ethanol imported from Brazil is more than 20 times as high as the emission trading market rate; CO_2 reduction using bio-ethanol imported from Brazil is expected to result in significant economic loss. The cost-effectiveness and economic efficiency of bio-ethanol-based CO_2 reduction are markedly lower than those of other GHG reduction measures.

5. Discussion

The efficacy of bio-ethanol as an environmental measure is currently assessed based on the principle of carbon neutrality, which has been adopted by the Japanese government. However, such assessment does not take into account CO_2 emissions in ethanol production. In the present study, quantitative assessment of the net amount of CO_2 reduction was conducted, taking into consideration the amount of CO_2 emitted in the process of ethanol production, and the significance of the "Biomass Nippon Strategy", a national policy, as well as the feasibility and economic efficiency of the plans were discussed.

As a mid- and long-term strategy, Japan plans to substantially increase the domestic production of bio-ethanol that can compete with other fuel products in Japan and other countries in terms of the price and quality until 2030. However, its production cost is relatively high, when compared to gasoline and imported ethanol, and domestic bio-ethanol production is not profitable without government subsidies. According to data of the demonstration project published by ZEN-NOH (JA) in Niigata Prefecture, the government provides 128.9 yen per 1ℓ of bio-ethanol as subsidies, which has been incurred by the public. One of the goals for "The Biomass Nippon Strategy", a national policy, is the "revitalization of agriculture, forestry, and fisheries, including farming, mountain, and fishing villages". However, the promotion of domestic bio-ethanol production using idle land, as stated in the policy, causes an adverse effect: "an increase in the economic burden on the public", rather than revitalizing agriculture. It is not expected to generate substantial CO_2-reducing effects. In fact, the bio-ethanol policy may only serve to increase the economic burden on the public, and waste funds that should be spent to revitalize the Japanese agricultural industry.

Agriculture in Japan had long been supported by rice production. However, now that the Japanese export industry has regained its strength, the country can afford to import food from other countries, which has been weighing on the domestic agricultural industry. In addition to a reduction in tariffs responding to the international trends of free trade, a decrease in the consumption of rice among the Japanese due to changes in their food preferences led to a decline in its price and extensive areas of idle agricultural land. As a measure to address this problem, bio-ethanol production using idle land was proposed, and the "Law concerning Biofuels in Agriculture, Forestry, and Fisheries" was established. However, to revitalize agriculture in Japan, priority should be placed on efforts designed to improve the low food self-sufficiency rate - 41% on a supplied calorie basis. It would be wiser to grow crops on idle agricultural land, and allocate part of the sales of the products, which otherwise would have been used to import foreign agricultural produce, for promotion of the Japanese agricultural industry.

With a bio-ethanol production goal of six million kℓ for the year 2030, Japan has been involved in the effort to promote "E10 Fuel" - a hybrid of gasoline and 10% bio-ethanol. However, as of today, the annual bio-ethanol production capacity is estimated at 36,000 kℓ based on the domestic production scale. It is very difficult to use food crops to produce biofuels in Japan, whose food self-sufficiency rate is very low, compared to other countries with high agricultural production capacities where biofuels are produced using surplus crops. Even if surplus rice and cellulose are used as raw materials, the production capacity is estimated at 5.47 million kℓ - six million kℓ less than required in the E10 plan. Its feasibility is also low in terms of the scale of plants, procurement of raw materials, and production costs.

Energy production by combusting byproducts and its use in the process of ethanol production would improve the energy-profit ratio and CO_2-reducing effects. However, even if these technologies become available, the domestic production and use of bio-ethanol are expected to have only limited CO_2-reducing effects (a reduction of up to 0.52% when compared to CO_2 emissions in 1990).

It should be noted that all of the environmental measures that are currently being implemented are not necessarily eco-friendly. You should not describe the effects of bio-ethanol ambiguously, using a word suggestive of environmental conservation - carbon neutrality. Environmental issues require thorough scientific discussions. The government should understand the nature of an environmental issue, design a feasible plan for effective and economically efficient environmental measures, and invest in it.

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