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The Feasibility of National Fuel-alcohol Programs in Southeast Asia

S. Matsuda and H. Kubota

Research Laboratory of Resources Utilization, Tokyo Institute of Technology, 4259 Nagatsuta, Midori-ku, Yokohama, 227 Japan

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ABSTRACT

The feasibility of producing fuel alcohol from crops containing sugars or starch in Southeast Asian countries has been investigated from various points of view. A review of energy balance analysis showed that in fuel-ethanol production from crops the ratio of energy output to energy input is close to or less than unity unless bagasse is used as a heat source. The cost of ethanol production depends mainly on the price of raw material (crops), which may be supported by low labor cost in farming. The total ethanol energy planned to be supplied in the Philippines and Thailand is only 2–4% of the current fossil energy consumption in those countries. Fuel-ethanol production from crops will thus make little contribution to the improvement of trade balance. On the other hand, the exportation of excess crops by the non-oil producing countries is the main source of revenue to be used in the importation of crude oil, petroleum products, machines and so on. Increased land use to cultivate crops for ethanol production would cause large scale destruction of the ecosystem of tropical regions.

Key words: fuel alcohol, Southeast Asia, energy balance, ethanol fermentation, food and energy, environmental impact, energy-production agriculture.

INTRODUCTION

As a liquid fuel, ethanol made from agricultural crops containing sugars or starch has a great advantage in that it can be readily utilized in

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internal combustion engines. If the price of ethanol made from crops is comparable with that of gasoline, a new type of agriculture – energy-production agriculture – whose main purpose is not to harvest foods but to gain energy, will become feasible. In fact a mixture of unleaded gasoline and ethanol is already on the market as fuel for automobiles in the United States, Brazil and other countries. At present, extensive research on the feasibility of energy-production agriculture is being undertaken seriously in many countries. Some national fuel-alcohol projects are now being promoted in Southeast Asian countries also.

On the other hand, many problems in biomass energy have been pointed out.[1] The fuel-alcohol programs should be examined carefully from various points of view, such as energy balance, economical, social and environmental impacts, before the plan of biomass use is implemented.

In this paper, a quantitative analysis was attempted in order to discuss whether agriculture for fuel ethanol can be implemented in Southeast Asian countries, where conditions at first seem formidable for this type of agriculture.

ENERGY BALANCE OF FUEL-ALCOHOL PRODUCTION

For energy-production agriculture to be feasible, the ratio of energy output to input, μ, must be more than unity. Table 1 shows some calculated examples of μ for ethanol production from agricultural products.

The low heating value of ethanol must be used as energy output so long as the ethanol produced is consumed as fuel. For these calculations the low heat value of 95 wt.% ethanol of 20·33 MJ litre^{-1} was used. When by-products such as bagasse, corn stalks and cobs are used as heat sources to decrease energy input in the cooking and distilling process, the heat of combustion of the by-products should not be added to the energy output but should be subtracted from the energy input.

The energy input consists of two main parts: the agricultural energy input to obtain raw crops, and the process energy input to convert the raw materials to ethanol. Since the ethanol fermentation process from sugars or starch is well known, the minimum amount of energy required for a process can be estimated from a thermodynamic analysis of the process.

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TABLE 1
Energy Output[a] and Energy Input[b] for Ethanol Production (energy unit: MJ litre^{-1} alcohol)

Raw material	*Country*	*Energy input*		$\mu = \frac{\text{Energy output}}{\text{Energy input}}$
		Agriculture[c]	*Industry*[d]	
Sugar cane	Brazil	4·86	13·74[e]	1·09
Sugar cane	Brazil	4·86	1·05[f]	3·44
Cassava	Brazil	4·27	15·78[e]	1·01
Corn	USA	13·00	14·44[g]	0·74
Corn	USA	13·00	42·05[h]	0·37
Sweet potato	Japan	24·78	16·53[i]	0·49
Sweet potato	Japan	24·78	29·75[j]	0·37

[a] The low heat value of 95 wt.% ethanol, 20·33 MJ litre^{-1}, is used as an energy output.
[b] Total primary energy consumption to obtain unit volume of 95% ethanol.
[c] Refer to Table 2.
[d] Energy consumption in the industry includes operation energy and construction energy of the plant which is estimated as 1·05 MJ litre^{-1} by the authors. Energy for treatment of wastes and wastewater is not included.
[e] Operation energy estimated by Da Silva and Serra[2] plus construction energy.
[f] All operation energy in the plant is assumed to be supplied from combustion of by-products (bagasse).
[g] Minimum energy introduced by Chambers *et al.*,[3] 13·39 MJ litre^{-1}, plus construction energy. By-products are not assumed to be consumed here.
[h] Operation energy in the conventional process introduced by Chambers *et al.*,[3] 41·00 MJ litre^{-1}, plus construction energy.
[i] Estimated by the authors.
[j] Average operation energy in the practical process using raw sweet potato.

Taking a typical ethanol fermentation process using sweet potato, the minimum necessary energy requirement for this process is estimated by the authors to be about 15·48 MJ litre^{-1} of primary energy. About 90% of the total energy input is consumed in the production of steam, more than 75% is used as a heat source in the distilling process and the rest is used in generating electricity. Hence, the total energy consumption is calculated to be about 20·59–34·73 MJ litre^{-1} based on the data of

practical plants of ethanol fermentation from sweet potatoes. It should be noted that all these values indicate only the energy cost for operation of ethanol production and that the energy consumption for treatment of wastewater and solid wastes has not been included.

The agricultural energy input depends heavily on the type of farming and shows large variation from country to country. It is rather difficult to estimate this energy input precisely.[4] Figure 1 shows the estimated examples of items of energy input for a few crops. As seen here, although the absolute values of energy input vary with the kind of crops and with country, the components of the various systems are similar. So far, however, there is no report giving an estimation of energy input in Southeast Asian countries. Judging from their low yield of crops per unit area of farmland, the present energy input level in these countries will perhaps be very low. In order to obtain a high yield of crops, much more energy, especially chemical fertilizers, will be required. Table 2

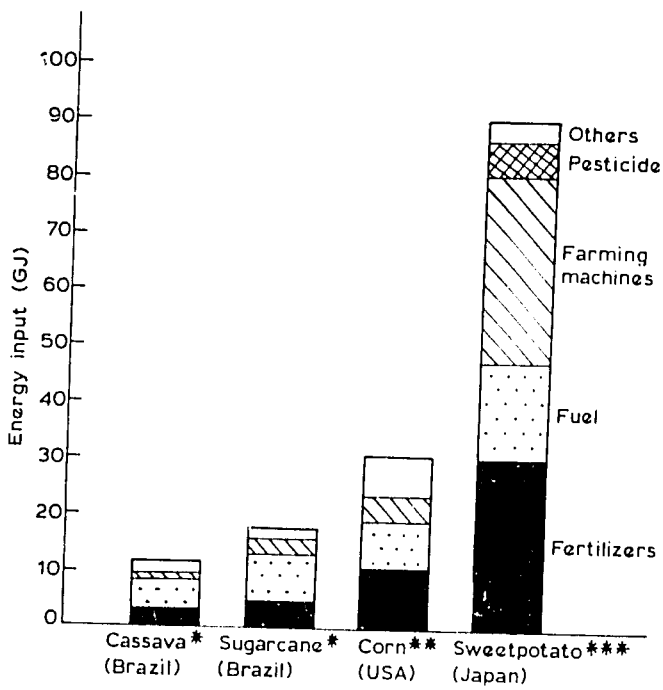

Fig. 1. Agricultural energy input per unit land area per year of several crops. * Da Silva and Serra,[2] ** Pimentel *et al.*,[5] *** Udagawa.[6]

TABLE 2
Agricultural Energy Input to Ethanol Production

Crop (country)	*Energy input*[a] *(GJ ha^{-1} year^{-1})*	*Agricultural yield (t ha^{-1} year^{-1})*	*Alcohol production*		*Energy input per unit amount of ethanol produced (MJ litre^{-1})*
			Per crop (litre t^{-1})	*Per farmland area (litre ha^{-1} year^{-1})*	
Sugar cane (Brazil)	17·31[b]	54[b]	66[b]	3 564	4·86
Cassava (Brazil)	10·77[b]	14·5[b]	174[b]	2 523	4·27
Corn (USA)	29·84[c]	5·1[c]	450[f]	2 295	13·00
Sweet potato (Japan)	89·86[d]	20·6[f]	176[f]	3 626	24·78

[a] Details are shown in Fig. 2.
[b] By Da Silva and Serra.[2]
[c] By Pimentel *et al.*[5] The unit of agricultural yield, originally bushel acre^{-1}, is converted into t ha^{-1}.
[d] By Udagawa.[6] The amounts of energy of labor, livestock power, seeds and compost are subtracted from the total energy input.
[e] From the Agricultural Statistics in Japan.
[f] Estimated by the authors.

shows the basis of the calculation of the agricultural energy input for ethanol produced from each crop listed in Table 1. Table 1 shows that the value of μ is close to or less than unity in most cases (though not where the sugar cane is fermented into ethanol with bagasse used as fuel). This indicates, as pointed out previously by several investigators, that energy-production agriculture in the form of ethanol production will not contribute significantly to the net production of energy; in fact, it may increase the total energy consumption.

RAW MATERIAL COSTS

Ethanol has a great advantage as liquid fuel in that it can be used directly in internal combustion engines. Thus, ethanol production as a means of supplying alternative liquid fuel may be valuable, even if the value of μ

TABLE 3
Cost Estimation for Ethanol Production

Raw material	*Country*	*Year*	*Raw material cost (US$ litre^{-1})*	*Process cost (US$ litre^{-1})*		*Ethanol cost*[a]	
				Operation cost excluding raw material cost	*Fixed cost and others*	*Per volume (US$ litre^{-1})*	*Per energy content*[b] *(US$ MJ^{-1})*
Sugar cane	Philippines[d]	1980	0·397	0·043	0·100	0·540[c]	0·026 6
	Brazil[e]	1980	0·163	0·017	0·102	0·282	0·013 9
Cassava	Brazil[f]	1981	0·270	0·141	0·136	0·547	0·026 9

[a] Production cost without profits. The cost of wastewater treatment is not included.
[b] Calculated value on the assumption that 1 litre of 95 wt.% ethanol contains 20·33 MJ (low heat value). For comparison, the price of gasoline (35·98 MJ litre^{-1}) from an oil refining plant in Japan is about S0·59 litre^{-1}, equivalent to S0·0108 MJ^{-1}.
[c] High price of ethanol is attributed to the cost of new farm development.
[d] From the national alcohol project in the Philippines.
[e] By Noda and Shiratsuki.[7] Practical value at plant producing 120 000 litres of ethanol per day.
[f] By Noda and Shiratsuki.[7] Estimated value on the assumption of plant of 100 000 litres per day in scale.

is smaller than unity, provided that the input energy source used is not petroleum but other solid fuels such as coal and wood. In other words, despite the negative energy balance, fuel–ethanol production could be feasible if the ethanol cost per unit calorie content is cheaper than that of gasoline.

A few examples of cost estimation for ethanol production are presented in Table 3. These examples show that the price of raw materials accounts for the large portion of the ethanol cost. Therefore, while there may be no possibility of ethanol production in a country where prices of crops are very high, ethanol production may be feasible in Southeast Asian countries or other countries where raw materials can be obtained at a relatively low price. As far as the economy is concerned, the feasibility of ethanol production depends on the change of prices of both crude oil and agricultural materials. The prices of sugar cane given in Table 3 are found to be equivalent to the sugar price of $100 per ton in Brazil and of $250 per ton in the Philippines. The chronological change of the international market price of sugar shown in Fig. 2 indicates that these prices correspond to the lowest value from 1977 to 1979, when there was an oversupply of sugar. Figure 2 also shows the comparison

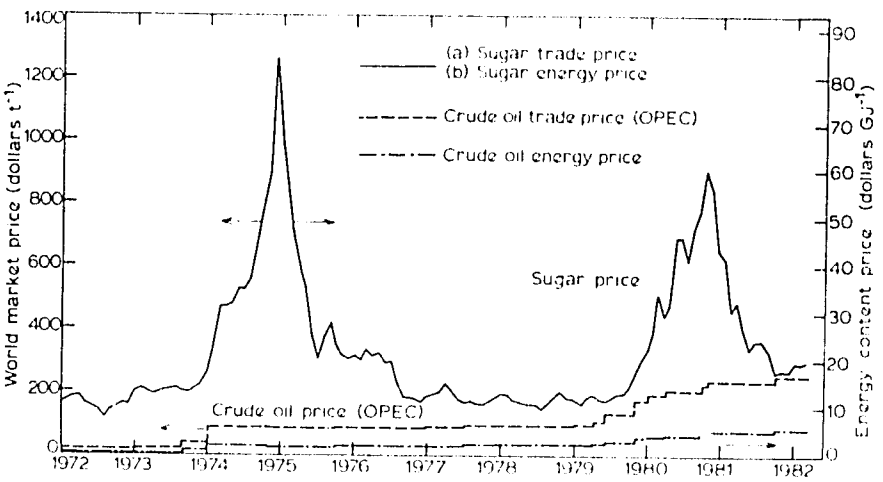

Fig. 2. Chronological change of sugar and crude oil prices. The following values of heat combustion were used for calculation of the energy content price: 39·33 MJ litre^{-1} for crude oil and 15·06 GJ t^{-1} for sugar. The specific gravity of crude oil was assumed to be 0·85.

between crude oil and sugar in terms of the price per unit energy content. From this comparison it is clear that the sugar price per unit energy content is still much greater than that of crude oil, in spite of the rapid increase in the price of oil in recent years. It can also be observed in Fig. 2 that the sugar price has a tendency to increase in parallel with the oil price. Similar situations exist concerning the prices of other agricultural products. That is, the rise of crude oil price has an important effect on the prices of crops, in that it causes an increase of the costs of chemical fertilizers, machines and so on, and inevitably an increase of the prices of agricultural products.

The ethanol costs in Table 3 do not include the treatment cost of solid waste and wastewater. Recycling of these wastes is essential if agriculture is to be carried out with the minimum consumption of chemical fertilizers. However, the facility cost and energy consumption for this recycling procedure will be high. Since all these factors will increase the actual cost of ethanol production, it is dangerous to judge the feasibility from such estimated costs as in Table 3.

Cheap agricultural products can make for cheap ethanol as mentioned above. The feasibility of energy-production agriculture in Southeast Asian countries relies upon an assumption that cheap crop feedstocks are available. In fact, agricultural products in these countries are inexpensive not because of high productivity in agriculture but because of low labor costs in farming.

For example, according to the national alcohol program of the Philippines, the total gain for farmers from sugar cane fields will be 1300 million pesos. This industry employs 340000 farmworkers supporting 2 million family members, implying that the income of a householder will be only about US$500 per year. This income figure is lower than the Philippines' national average per capita income of US$560 in 1979. Obviously the national alcohol projects rely upon the small income of farmers and also assume that the current income situation will not improve in the future.

As seen in Table 4, the income per unit of farmland area for crops used as raw materials for ethanol fermentation is low in comparison with other agricultural products.

If the purpose of the project is aimed at increasing the income of farmers, there are likely to be alternatives such as the production of rubber trees and palm oil trees which may result in a greater benefit.

TABLE 4
Income per Unit Farmland Area of Several Crops

Crop	*Country*	*Yield* ($t\ ha^{-1}\ year^{-1}$)	*Proceeds*[a] ($US\$\ ha^{-1}\ year^{-1}$)
Sugar cane	Thailand	41·7	657
	Philippines	42·4	396
Cassava	Thailand	13·9	670
	Philippines	9·8	665
Sweet potato	Philippines	9·6	417
	Japan	21·3	2 335
Rubber tree	Thailand	7·9	4 461
Durian	Thailand	94	5 257
Rice (polished)	Philippines	1·3	304
	Thailand	1·2	226
	Indonesia	1·9	687
	Japan	4·4	5 413

[a] Average yearly income gained during the life span of each crop: proceeds = yield × market price per unit weight. Materials of producing cost of these crops were not available.

POTENTIAL ETHANOL ENERGY OUTPUT

Table 5 shows the national alcohol production programs of Thailand, the Philippines and Indonesia. The Philippine government has adopted a positive policy on ethanol production. According to the program, about 20% of the total gasoline demand will be replaced by ethanol and the excess alcohol will eventually be used as an alternative to light oil or be converted into ethylene for use in chemical industries. In Thailand, the government does not take any positive measure to promote the program. The plan in Indonesia is much larger in scale than in the other two countries, but it does not appear to be a practical program with regard to time and budget constraints.

In Table 6 the energy supply according to the national alcohol program is compared with the present primary energy consumption in each country. The Table also shows two kinds of potential alcohol

TABLE 5
National Alcohol Projects in Some Southeast Asian Countries

Country	*Main raw materials*	*Cultivation area in plan (10^4 ha)*	*Alcohol production*		*Gross equivalent energy*[c] *(PJ)*	*Explanation*
			Total (10^7 litre year^{-1})	*Per area (10^3 litre ha^{-1} year^{-1})*		
Thailand	Sugar cane Cassava	–[a]	48	–[a]	9·76	Production goal of 1985
Philippines	Sugar cane Sweet potato	26·3	92·5	(3·52)[b]	18·81	Production goal of 1988
Indonesia	Cassava Sweet potato	–[a]	2 000	–[a]	406·7	Given as goal for long-range plan

[a] No information available.
[b] Calculated value (production/cultivation area = 92·5 ÷ 26·3); current actual ethanol yield per land area of each crop is 2670 litre ha^{-1} year^{-1} for sugar cane, 1670 litre ha^{-1} year^{-1} for cassava and 870 litre ha^{-1} year^{-1} for sweet potato.
[c] The low heat value of 95 wt.% ethanol (= 20·33 MJ litre^{-1}) was employed for the calculation.

TABLE 6
Comparison of Planned Ethanol Energy Production and Current Fossil Energy Consumption

Country	*1978 Fossil energy consumption*[a] A (*PJ year*$^{-1}$)	*Gross ethanol energy (PJ year*$^{-1}$*)*			B/A (%)	C/A (%)	D/A (%)	B/D (%)
		Amount in the national plan[b] B	*Potential amount I*[c] C	*Potential amount II*[d] D				
Philippines	460·7	18·8	86·2	71·5	4·1	18·7	15·5	26·3
Thailand	431·8	9·8	133·5	123·0	2·3	30·9	28·5	8·0
Indonesia	1 196·2	406·7	436·4	119·7	34·0	36·5	10·0	339·8

[a] Domestic consumption of primary energy from petroleum, hard coal, brown coal, natural gas, hydroelectric, nuclear and geothermal electricity, but excluding fuelwood energy (United Nations[8]).
[b] From Table 5.
[c] Total potential amount of ethanol energy when sugar cane is assumed to be cultivated on a fifth part of the 'other land' in the land utilization statistics (e.g. unused arable land, wasteland, city area, road, lake, river and so on). Ethanol yield of 2670 litre ha^{-1} year^{-1} was assumed.
[d] Total potential amount of ethanol energy when whole production amount of field crops[9] (corn, sweet potato, cassava and sugar) is assumed to be converted into alcohol. Alcohol production per unit weight of raw materials was assumed as follows: 450 litre t^{-1} for corn, 176 litre t^{-1} for sweet potato, 255 litre t^{-1} for cassava and 630 litre t^{-1} for sugar.

energy. The procedure for the calculation of these potentials is described in the footnotes. These values of the potential energy productions give an indication of the likely contribution of alcohol energy in the future. For example, since the energy quantity planned by the national program of Indonesia is close to potential amount I, which exceeds considerably potential amount II, it is evident that the program is likely to be impractical. Table 6 clearly shows that the gross ethanol energy output of the various schemes is much smaller than the current primary energy consumption of each country. If the available amount of ethanol energy is limited to this content, the production of ethanol is unattractive as an alternative for petroleum, for the following reason. Present petroleum refining technology can considerably vary the gasoline yield from crude oil. For example, while one is maintaining the amount of gasoline produced, one can reduce the amount of crude oil consumed by offsetting the shortage of energy with the direct combustion of biomass. This is much more efficient as a means of energy conversion of biomass than is ethanol production from crops.

The primary energy consumption in Southeast Asian countries and some others is presented in Table 7. This shows that the total primary energy consumption in Southeast Asian countries and their surrounding countries such as India and Pakistan is only a fraction of the world energy consumption. The *per capita* energy consumption in this region is much lower than the average world value. A noteworthy fact is that biomass energy in the form of fuelwood is presently consumed at a quite high rate of 17–70% of total energy consumption. The small magnitude of ethanol energy expected to be produced in the national alcohol programs is emphasized in Table 8. This shows that the equivalent amount of fuelwood corresponding to ethanol energy in the national alcohol program is only 5–12% of the fuelwood production in the Philippines and Thailand.

We should take note of the fact that the solar energy conversion efficiency of forest is much higher than that of farmland, and also that the ecosystem of forest is far more stable than that of farmland, particularly in the tropics. However, the high rate of consumption of fuelwood — much higher than the rate of timberwood production, as seen in Table 8 — is reportedly causing a shortage of forest resources in these developing countries. Therefore, increasing wood energy production should be implemented by using wood wastes obtained from forest stand improvements and supported by sound environmental management of the forest.

TABLE 7
Energy Consumption in Southeast Asia and Some Other Countries (1978)

Country	*Total energy consumption* A *(PJ year^{-1})*	*Fossil energy*[a] *(PJ year^{-1})*	*Fuelwood energy*[b] *Amount* B *(PJ year^{-1})*	B/A *(%)*	*Population* C *(10^6 persons)*	*Per capita energy consumption* A/C *(GJ person^{-1} year^{-1})*	*Ratio of fossil energy consumption to world fossil energy consumption (%)*
Philippines	616·8	460·7	156·1	25·3	46·4	13·3	0·18
Thailand	614·2	431·8	182·4	29·7	45·1	13·6	0·17
Indonesia	2 007·5	1 196·2	811·3	40·4	145·1	13·8	0·47
Vietnam	560·2	179·9	380·3	67·9	49·9	11·2	0·07
Burma	205·0	59·8	145·2	70·8	32·2	6·4	0·02
Malaysia	331·8	277·0	54·8	16·5	13·0	25·5	0·11
Singapore	168·2	168·2	–	–	2·3	73·1	0·07
Total[c]	4 503·7	2 773·6	1 730·1	38·4 (av.)	334·0	13·5 (av.)	1·08
(*Reference*)							
India	4 535·0	3 326·7	1 208·3	26·6	638·4	7·1	1·30
Pakistan	498·3	387·0	111·3	22·3	76·8	6·5	0·15
Japan	12 881·3	12 870·8	10·5	0·08	114·9	112·1	5·02
USA	73 373·9	73 282·3	91·6	0·12	218·1	336·4	28·58
World total	265 908	256 411	9 497	3·6 (av.)	4 258	62·3 (av.)	100·0

[a] See footnote *a* of Table 6.
[b] Whole amount of fuelwood production[10] is assumed to be consumed domestically. A value of 6·44 GJ m^{-3} was employed as heat of combustion of fuelwood.
[c] Since statistics for Laos and Cambodia were not available, this value does not represent the exact sum total of Southeast Asian countries.

TABLE 8
Comparison of Equivalent Amount of Fuelwood Corresponding to the Ethanol Energy and Current Amount of Fuelwood Production

Country	*Ethanol energy (E) in national alcohol production plan*[a] *(PJ)*	*Equivalent amount of fuelwood corresponding to E*[b] A *(10^6 m^3)*	*Current fuelwood production*[c] *(10^6 m^3)*			A/B (%)	A/C (%)
			Fuelwood B	*Timberwood*	*Total (1978)* C		
Philippines	18·8	2·92	24·5	9·8	34·3	11·9	8·5
Thailand	9·8	1·52	28·3	4·7	33·0	5·4	4·6
Indonesia	406·7	63·15	125·9	27·8	153·7	50·2	41·1

[a] From Table 6.
[b] The heat of combustion of fuelwood is assumed to be 6·44 GJ m^{-3}.
[c] Figures estimated by United Nations FAO.[10]

BALANCE OF TRADE, FOOD AND ENERGY

Figure 3 shows the balance and value of trade in agricultural products, crude oil and petroleum products in some Southeast Asian countries. There is an obvious contrast between the excess of exports over imports in the oil producing countries, Indonesia and Malaysia, and the excess of imports over exports in the non-oil producing countries, the Philippines and Thailand.

In the latter countries, nearly 50% of exports are occupied by agricultural products, which are different in each country. On the other hand, the value of trade in crude oil and petroleum products imported is only

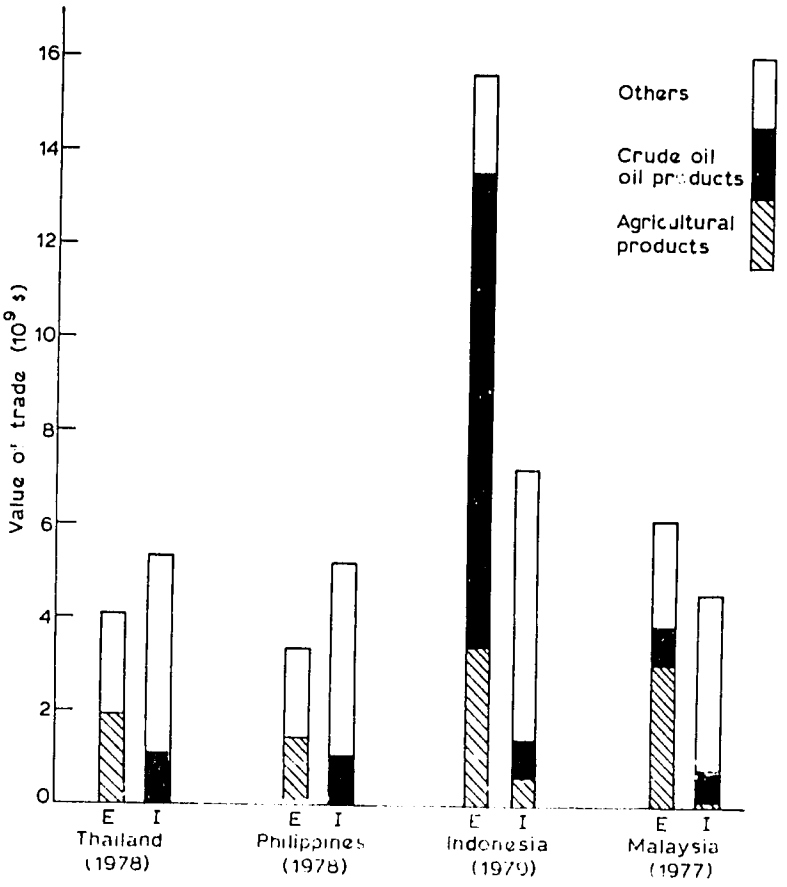

Fig. 3. Trade in four Southeast Asian countries.[11] E, exports; I, imports.

about 20% of the total value of imports and is much smaller than that of agricultural products. The largest part of imports is machinery followed by automobiles, steel, metal products and organic chemicals.

The statistics shown here are for the year 1978, before the second oil-crisis in 1979, after which the price of oil more than doubled. There is no doubt that oil prices are depressing the economies of these countries.

Nevertheless, the economic importance of the exports of excess agricultural products is quite evident from the following calculations. Let it be assumed that the excess agricultural products are not exported but converted to ethanol for use as an energy source. The calculated results are shown in Table 9. The Table indicates that in Thailand and the Philippines the conversion to fuel ethanol of the total quantity of rice, corn, wheat and sugar now exported could save only 3–10% of the import cost of crude oil. Even if one takes a higher price of 2·4 times that of 1978 as the oil price in 1980, the saving remains only 7–23% at most.

It should be noted from Table 9 that the crude oil requirements will not be greatly reduced even if the production of crops for ethanol can be increased to a level equivalent to the current exports of agricultural products. At present, the crops exported as food will bring much more profit because the price of food per unit energy content is still much higher than that of petroleum.

The feasibility of energy conversion of biomass, as related to the self-sufficiency rate of food and energy, is often discussed on the basis originally presented by Rask,[12] shown in Fig. 4. In countries belonging to the second division in the Figure, which export excess food and import fuel, production of ethanol as a fuel is thought to be feasible. Since both the Philippines and Thailand (along with the United States and Brazil, where the 'gasohol' is now on the market) are in the second division, biomass energy conversion seems to have value at first glance. However, it should be noted that each axis represents a simple ratio of production to consumption of food and primary energy. Provided the feasibility of biomass energy conversion is discussed, both axes should be replaced by the absolute quantity of energy. Figure 5 is derived in such a way. This shows that the absolute quantity of energy contained in excess food is too small compared with that of petroleum imported or exported. For the calculation of energy conversion, high heat values of individual foods are used here. If one takes the net energy output of ethanol production, naturally the absolute value of food energy will

TABLE 9

Hypothetical Trade Balance – Alcohol Production from Excess Fermentable Crops (1978)

Country	*Exports of agricultural products*			*Potential ethanol product*		*Possible reduction of oil imports due to ethanol production*	*Imports of crude oil and oil products*	**B/A** (%)	**B/C** (%)
	Crop	*Value* **A** *(US$ 10^6)*	*Quantity (10^6 t)*	*Quantity*[a] *(10^9 litre)*	*Oil equivalent*[b] *(10^9 litre)*	**B**[c] *(¢ 10^6)*	**C** *(¢ 10^6)*		
Thailand	Rice	513	1·60	0·74					
	Corn	208	1·96	0·88					
	Sugar	195	1·04	0·66					
	Total	916		2·28	1·18	102·4 (244·6)	1 118	11·2 (26·7)	9·2 (21·9)
Philippines	Sugar	197	1·05	0·66	0·34	29·5 (70·5)	1 061	15·0 (35·8)	2·8 (6·6)
USA	Corn	5 302	50·14	22·56					
	Wheat	4 335	34·10	15·04					
	Rice	731	2·28	1·06					
	Total	10 368		38·66	19·99	1 733·9 (4 144·3)	44 086	16·7 (40·0)	3·9 (9·4)

[a] Each alcohol production per unit weight of raw material used is same as that in footnote *d* of Table 6.

[b] One litre of 95 wt.% ethanol (20·33 MJ litre^{-1}) is assumed to be equivalent to 0·517 litre of crude oil (39·33 MJ litre^{-1}).

[c] Crude oil price in 1978 ($13.79 BAR^{-1} = $86.74 × 10^{-3} litre^{-1}) was used for conversion. Figure in parentheses is calculated from crude oil price in 1980 ($32.96 BAR^{-1} = $207.32 × 10^{-3} litre^{-1}).

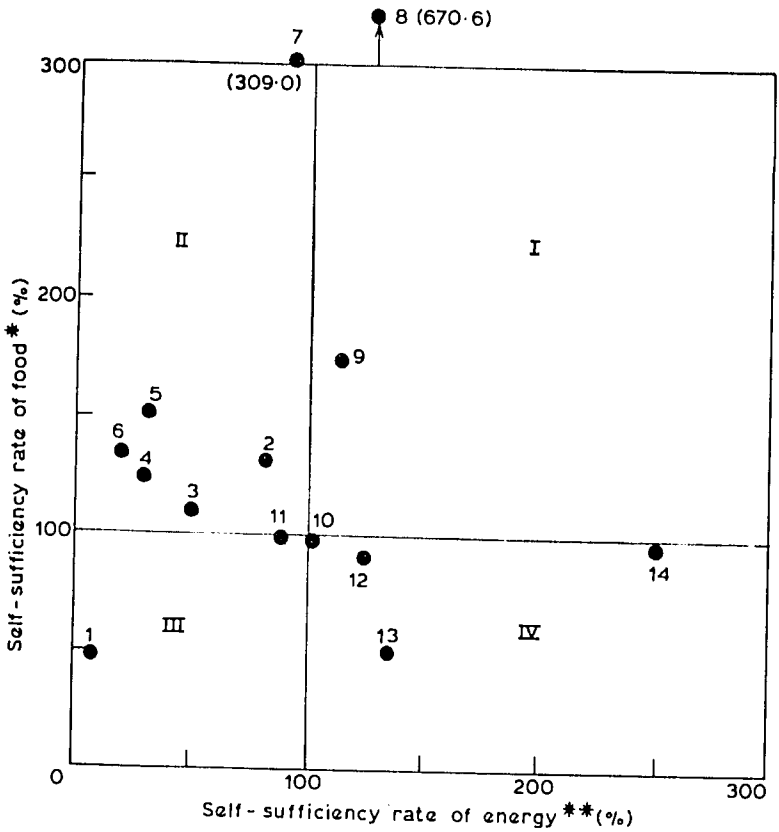

Fig. 4. Self-sufficiency rates of food and energy in various countries. The figure was originally presented by Rask;[12] here plots are limited to countries of current interest and the values are those for 1979.

Countries: 1, Japan; 2, USA; 3, Brazil; 4, Philippines; 5, Thailand; 6, France; 7, Argentina; 8, Australia; 9, Canada; 10, China; 11, India; 12, USSR; 13, Malaysia; 14, Indonesia. Self-sufficiency rate = Quantity of domestic production/Quantity of domestic consumption. The total amount* of grains, roots and sugar was taken as the quantity of food. * Original data by FAO;[9] ** original data by United Nations.[11]

become much smaller or even negative, and as a result most countries will be almost on the horizontal axis. In other words, energy conversion of agricultural products is expected to make little contribution towards energy supply as long as the current state of energy conversion is assumed.

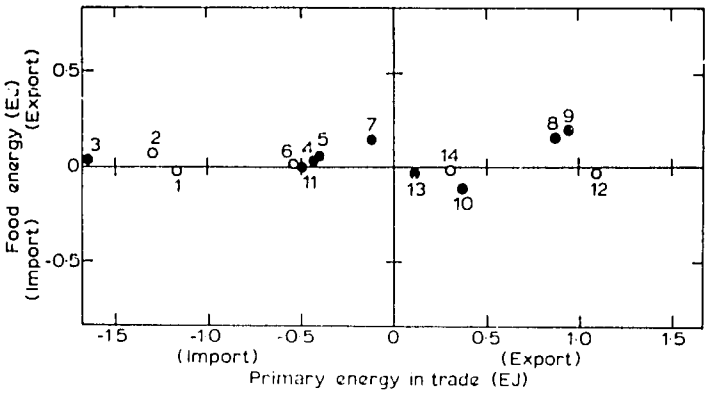

Fig. 5. Primary energy in trade and food energy in various countries. The correspondence between number and country in this figure is the same as in Fig. 4. Food energy is the sum of the High Heat Value of grains, roots and sugar exported and/or imported. The scale for open circles (○) is one tenth of the original scale (i.e., the unit of energy of open circles is 10 EJ).

ENVIRONMENTAL IMPACTS

A tropical climate with a high temperature and abundant rainfall is certainly a desirable condition for growth of plants. Production of crops on a large scale, however, requires the development of vast new areas of arable land. Even if this can be achieved by making farmland from idle cropland and forest, it is likely to cause severe disturbance in the present ecosystem. The feasibility of alcohol production should not be discussed without examining the environmental and social impacts. A quantitative evaluation of such aspects is difficult, due to many uncertain factors. Hence, only a qualitative description of the problems is attempted here.

First, it should be pointed out that the ecosystem of field agriculture, except paddy culture, is quite unstable in the tropical region. The degradation rate of organic components in the soil is very fast due to high temperature, and then the accumulation rate of organic nutrients is relatively low. A rapid loss of the soil accompanied by a loss of soluble nutrients is apt to occur due to heavy rainfall. The soil is likely to cake because of the lack of mineral components and will become

barren if field crops are harvested every year. The present manner of field agriculture, the swidden (cut/burn) agriculture, seems to be not only a means of minimizing the use of fertilizers, but also a reasonable way of farming under such conditions.

A large-scale farm project of feed corn in Sumatra, Indonesia, constructed on a vast wasteland and developed with a great deal of machinery and financial support provided by Japan, is now being terminated as unsuccessful, in spite of considerable efforts over the past ten years. This failure suggests to us the inevitable danger of large-scale development in these areas without regard for the natural harmony of the ecosystem. It has been pointed out by Nart[13] that in Thailand the replacement of complex natural ecosystems with monocultures, single-crop cultivation, has resulted in the appearance of such pests as locust plagues on an unprecedented scale.

Conversion of forestland to farmland may involve more serious problems. In the tropics, forests are capable of high primary productivity of biomass but are unable to recover their original form once they are destroyed. As a result of the forest-to-farmland movement now being promoted to increase production of crops for exports in the non-oil producing countries, frequent flood occurrences have been reported. These floods will in turn accelerate soil erosion and the rate of sedimentation in reservoirs, rivers and streams, thereby increasing the severity of subsequent floods.[13]

Treatment of wastewater from ethanol plant will be another difficult problem. There may be no economical and effective method to treat huge amounts of wastewater containing more than 20 000 ppm of BOD from the fermentation process. One possible method is methane fermentation (which should be capable of generating energy) followed by activated sludge treatment. But since complicated and expensive facilities are required for this, the investment may exceed the cost of construction of the ethanol plant.

RESPONSIBILITY OF DEVELOPED COUNTRIES ON FUEL POLICY

Hence, it is clear that the alcohol production projects in Southeast Asian countries will make little contribution to their energy supplies or economies, and still less contribution to the supply of high-grade fuel to

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the developed countries. Financial and technological aid to the projects by the developed countries should be carefully examined because if the plans end in failure, assistance will have resulted only in the export of alcohol plants, irrespective of the original aim. In fact, it has been pointed out[14] that people in the Southeast Asian countries involved tended to be concerned that all the developed countries were interested in was to sell the equipment.

Referring to the responsibility of the developed countries, the depressing effects of oil prices on the economies of developing countries would be effectively reduced if these prices could be stabilized through decreasing energy consumption in the developed countries, where more than 80% of the fossil fuel of the world is consumed. As stated above, consumption of fossil energy in Southeast Asian countries is only about 1% of world consumption. Nevertheless, increased oil prices do have a great influence on their economies. Therefore the advanced countries have the opportunity as well as the responsibility of giving 'indirect' assistance to them in this aspect.

At the same time, other productive plans which will take the place of alcohol production projects should be developed. For example, a feasibility study of other crops which will bring much more profit than that derived from the raw materials of alcohol fermentation should be researched. But the use of large amounts of chemical fertilizers and fuels, which consume a lot of oil, in order to increase the productivity per unit land area should be carefully avoided. As far as self-sufficiency in food is concerned, the Southeast Asian countries are blessed with favorable conditions. Thus the broad possibilities remain of developing industries which will really contribute to the improvement of the life of their people without increasing energy consumption. It is in the lifestyle of low energy consumption that the use of biomass as a local energy source, such as fuelwood production and use of logging residues or forest stand improvements, will have some significance. When developed countries intend to make technological assistance, sensible efforts from such a standpoint will be required.

CONCLUSION

There are many negative factors for fuel-alcohol production projects from crops containing sugars or starch in Southeast Asian countries. In most cases a net positive energy balance can scarcely be obtained. Low-

cost ethanol production cannot be expected unless low farm labor cost sustains it. The contribution of the planned alcohol production to the total energy supply is too small. Ample land reclamation to cultivate raw crops for ethanol conversion would make important environmental impacts on tropical ecosystems. Judging from these findings, we conclude that there is little justification in pursuing the energy-production agriculture concept through the production of ethanol from crops in Southeast Asian countries.

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