

Energy efficiency and potentials of cassava fuel ethanol in Guangxi region of China

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Abstract

The Guangxi Zhuang autonomous region has plentiful cassava resources, which is an ideal feedstock for fuel ethanol production. The Guangxi government intends to promote cassava fuel ethanol as a substitute for gasoline. The purpose of this study was to quantify the energy efficiency and potentials of a cassava fuel ethanol project in the Guangxi region based on a 100 thousand ton fuel ethanol demonstration plant at Qinzhou of Guangxi. The net energy value (NEV) and net renewable energy value (NREV) are presented to assess the energy and renewable energy efficiency of the cassava fuel ethanol system during its life cycle. The cassava fuel ethanol system was divided into five subsystems including the cassava plantation/treatment, ethanol conversion, denaturing, refueling and transportation. All the energy and energy related materials inputs to each subsystem were estimated at the primary energy level. The total energy inputs were allocated between the fuel ethanol and its coproducts with market value and replacement value methods. Available lands for a cassava plantation were investigated and estimated. The results showed that the cassava fuel ethanol system was energy and renewable energy efficient as indicated by positive NEV and NREV values that were 7.475 MJ/L and 7.881 MJ/L, respectively. Cassava fuel ethanol production helps to convert the non-liquid fuel into fuel ethanol that can be used for transportation. Through fuel ethanol production, one Joule of petroleum fuel, plus other forms of energy inputs such as coal, can produce 9.8 J of fuel ethanol. Cassava fuel ethanol can substitute for gasoline and reduce oil imports. With the cassava output in 2003, it can substitute for 166.107 million liters of gasoline. With the cassava output potential, it can substitute for 618.162 million liters of gasoline. Cassava fuel ethanol is more energy efficient than gasoline, diesel fuel and corn fuel ethanol but less efficient than biodiesel.

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1. Introduction

In recent years, the fuel ethanol industry in China has grown rapidly, spurred by renewable energy concerns, new fuel ethanol standards and government incentives. Fuel ethanol is produced mostly from

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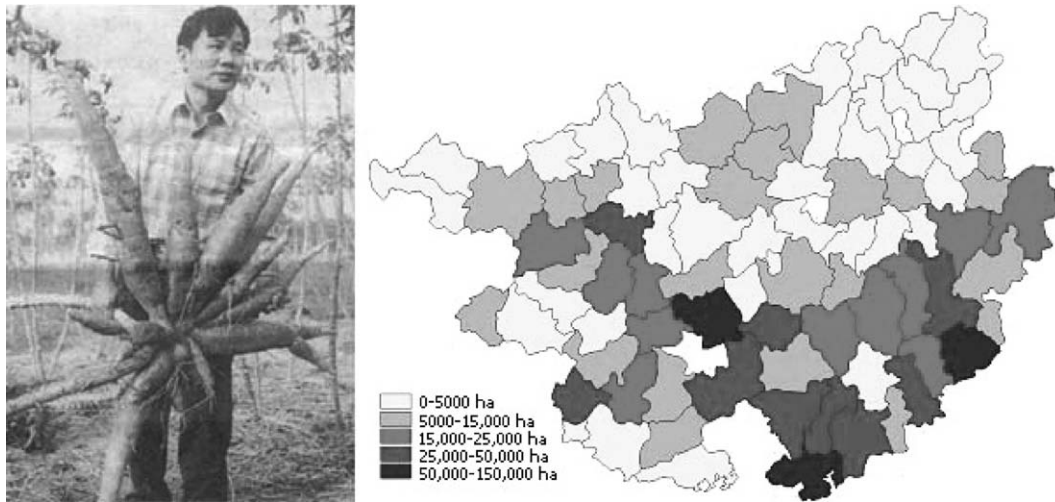


Fig. 1. High yield cassava variety and cassava plantation distribution in Guangxi region. Source: Ministry of Agriculture, PR China.

cornstarch, but cassava, a perennial woody shrub with up to 32% (fresh) starch content, has attracted more and more attention recently. As feedstock for fuel ethanol, cassava has two advantages over other feedstocks. First, Cassava can be cultivated on marginal lands where other crops, such as corn, wheat, rice and sugarcane cannot be grown well [1]. Second, cassava is not a staple food for the Chinese people. Using cassava for ethanol production would not raise major ethical and moral issues as would corn ethanol [2].

One of the most controversial issues related to fuel ethanol is whether fuel ethanol is energy efficient, or could produce a positive energy income. Disputes occurred about corn fuel ethanol in past decades. Critics questioned the rationale behind policies that promote ethanol for its energy benefits. Based on process energy analysis [3], Pimentel [2] and Hodge [4] concluded that a corn fuel program cannot produce a net energy gain, that is, the energy sources required to grow and convert corn into ethanol are greater than the energy value contained in the fuel ethanol. They suggested that ethanol use in US gasoline should be banned, not expanded. However, Shapouri et al. [5], Lorenz and Morris [6] and Wang et al. [7] insisted that corn fuel ethanol has a positive net energy output, even without considering its coproducts energy uses.

Energy efficiency also emerges as a concern in cassava fuel ethanol. The Guangxi Zhuang autonomous region is the biggest cassava production area in China, accounting for around 60% of the national cassava output (Fig. 1). The Guangxi government intends to promote cassava fuel ethanol use to substitute for gasoline. Before launching any fuel ethanol project, the government should know the feasibility of such project. The questions of most concern include energy efficiency and the potentials of a cassava fuel ethanol project.

The aims of this study were to (1) perform an energy and renewable energy efficiency analysis on a demonstration plant using cassava fuel ethanol as feedstock at Qinzhou of Guangxi, (2) calculate the energy potentials of cassava fuel ethanol and (3) compare the energy efficiency differences among typical fuels. The net energy value (NEV) and net renewable energy value (NREV) are presented to assess the energy and renewable energy efficiency of the cassava fuel ethanol system during its life cycle.

2. Methodology

2.1. System studied and boundary definition

The system studied is a combination of a cassava plantation and fuel ethanol production. General information of the cassava ethanol combination is given in Table 1. Normal cassava cultivation does not require application of fertilizers and herbicide. With fertilizers and herbicide applied and the right variety chosen, the cassava yield can reach 13,333 kg/ha on average (Table 1).

Table 1

General information of cassava fuel ethanol combination

Production site	Yield (kg ha ⁻¹)	Acreage (ha)	Moisture content (%)	Cassava starch content (%)	Ethanol conversion rate	Production scale (T)	Cassava variety
Qinzhou, Guangxi	13,333	200,000	13	75	3	100,000	ZM8639

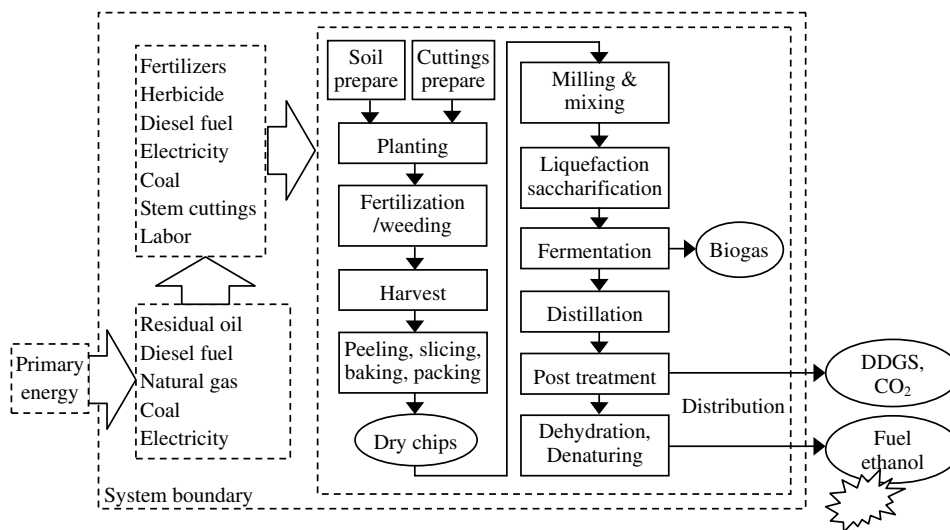


Fig. 2. Cassava fuel ethanol system and its boundary. Fertilizers, herbicide, diesel fuel, electricity, coal, stem cuttings and labor are direct inputs for cassava fuel ethanol system. Residual oil, diesel fuel, natural gas, coal and electricity are process fuel or energy feedstock of these direct inputs. With input efficiencies multiplied [9], those energy uses can be converted into primary inputs across the system boundary. Dry cassava chips, biogas, fuel ethanol, DDGS and CO₂ are system products. But cassava chips, biogas are immediately used products. The cassava chip is feedstock of ethanol conversion, and the biogas is used for cogeneration. Only fuel ethanol, DDGS and CO₂ are considered as final products.

The system boundary is the interface between the product system and its environment. The boundary definition of the cassava fuel ethanol system identifies the system studied and the energy inputs and outputs associated with the life cycle of ethanol production. The life cycle starts from preparation for cassava cutting and ends at combustion in an engine (Fig. 2). The international standards organization (ISO) recommends that the product system should be modeled in such a manner that the inputs and outputs at its boundaries are elementary flows, that is, at the system boundaries, the materials and energy inputs should be primary energy/materials and the outputs should be final products [8]. For the cassava fuel ethanol system, the final products are fuel ethanol, dried distillers' grain with solubility (DDGS) and CO₂. All the direct energy inputs are multiplied by their input efficiencies to convert them into primary energy inputs.

2.2. Direct energy and materials inputs

The cassava fuel ethanol system can be divided into five subsystems as follows:

- *Cassava plantation/treatment*: This subsystem consists of soil preparation, cuttings preparation, planting, fertilization, weeding, harvesting, peeling, slicing, baking and packing. No irrigation is needed for the Guangxi cassava plantation. The direct energy and materials required are cassava stem cuttings, diesel fuel, electricity, herbicide and nitrogen (N), phosphorus (P) and potash (K) fertilizers (Fig. 3). Cassava is planted using 7–30 cm portions of mature stem as propagules. Each hectare needs 15 kg of fresh stem cuttings as seeds. Fertilization and weeding are necessary to acquire high yield in a large scale plantation. The applied amounts of N, P and K fertilizers and herbicide are listed in Table 2. All the fertilizers and herbicide are

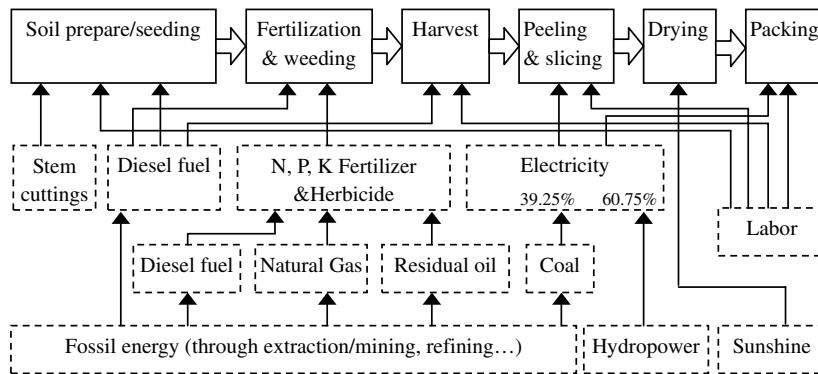


Fig. 3. Energy used in cassava plantation. Stem cuttings prepare, diesel fuel, N, P, K fertilizer, herbicide and electricity are direct materials or energy inputs. Diesel fuel, natural gas and residual oil are process fuels for fertilizers and herbicide production [9]. Electricity is from 39.25% coal burning and 60.75% hydropower in Guangxi [10]. Sunshine is regarded as free primary energy input.

Table 2
Direct energy and material inputs in cassava plantation

Item	Unit	Amount
Fertilizer		
Nitrogen	kg ha ⁻¹	100
Phosphorus	kg ha ⁻¹	100
Potash	kg ha ⁻¹	200
Herbicide	kg ha ⁻¹	30
Diesel fuel ^a	L ha ⁻¹	44
Electricity ^b	KW h yr ⁻¹	60,923
Fresh stem cuttings	kg ha ⁻¹	15
Labor		
Plantation	Hr ha ⁻¹	600
Harvest and treatment ^c	Hr T ⁻¹	40

^a Diesel fuel is used for agricultural machinery.

^b Peeling/slicing machine power is 1 kW and packing machine power is 0.1 kW. They work 3 h per day and 8 days in a harvest season.

^c 780 thousand ton fresh cassava treated.

locally produced. Diesel fuel is consumed by the agricultural machineries, including tractor, tandem disk harrow and disk plough. During the harvest season, farmers use a specially designed mechanical harvester to grab onto the stem and lift the roots from the ground. Then, they peel and slice the cassava tubers into chips with a peeling and slicing machine. Next, they dry the fresh cassava chips on the fields under the sun. At the end of harvest, the dry chips (moisture content: 13%, starch content: 75%) are collected and packed into bags, using a 0.1 kW packing machine. The labor uses in the plantation, harvest and treatment were estimated in units of man-hours per hectare and fresh tons of cassava treated (Table 2).

- **Ethanol conversion:** This subsystem includes the processes of milling, mixing, liquefaction, saccharification, fermentation, distillation, post-treatment and supplementary equipments operation (Fig. 4). After distillation, in post-treatment, anaerobic fermentation of the stillage produces biogas. All the biogas is collected for cogeneration that produces steam and electricity for in-plant use simultaneously. If the cogeneration electricity exceeds in-plant use, it may be supplied to the grid. This potential output is not shown in Fig. 2 and is not taken into account. The cogeneration steam is not enough to supply the plant. An extra 72 thousand tons of coal per year is burned to make up the thermal energy required. The efficiency of a coal fired boiler is 0.8 [11]. See Table 3.
- **Denaturing:** Ethanol is blended with conventional gasoline at 95/5 (v/v) proportion to make it non-potable with a 140 kW blending machine. Its processing capacity is 100 gallons per minute (6.3083 L/s).

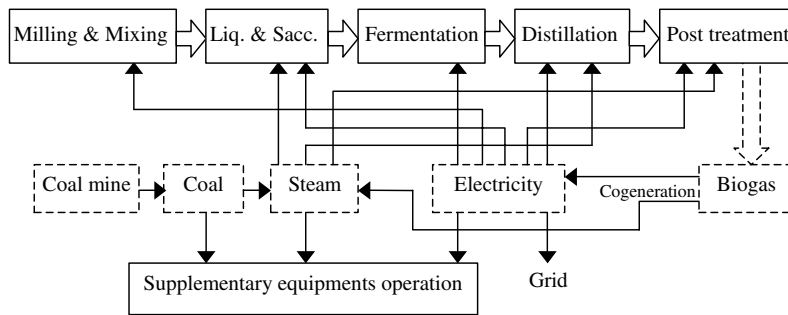


Fig. 4. Energy flows of fuel ethanol conversion subsystem. Steam and electricity are direct energy requirement for ethanol conversion process. Post-treatment produces biogas. All the biogas is collected for cogeneration that produces steam and electricity for in-plant use. The cogeneration electricity exceeds in-plant use and excess supplies grid. However, the cogeneration steam is not enough for the plant. Extra coal is burned to make up the thermal energy needed. The coal is produced from a coal mine.

Table 3
Energy inputs and outputs in ethanol conversion

Process	Electricity (kW h yr ⁻¹)	Steam (T yr ⁻¹)
Milling and mixing	3,024,000	0
Liquefaction and saccharification	1,296,000	72,000
Fermentation	4,190,400	0
Distillation	2,424,000	230,400
Post-treatment	7,047,000	79,200
Supplementary equipment operation	1,980,000	7200
Biogas cogeneration	−20,473,469	−67,609
Net energy use ^a	−512,069	321,191

^a Electricity and steam are the two energy forms used in plant. Negative electricity use represents electricity output. Excess electricity supplies the grid, and steam deficit is made up from coal burning.

- **Refueling:** The denatured ethanol is usually mixed with conventional gasoline at some blending level. It is commonly blended with 90% gasoline to make an E10 fuel that can combust in an internal combustion engine without changing its structure. In this study, the ethanol is refueled as E10 fuel. The refueling machine uses 0.07 kW power per 100 L.
- **Transports:** The materials and products in the above processes are transferred with different transporting equipments through different distances (Table 4). All the vehicles were assumed to haul other products on their return trip, so those miles were not entered into the calculations.

Table 4
Process, vehicle, capacity, and distance of transports

Process	Vehicle type	Capacity (kg)	Distance (km)
Transporting fertilizers and herbicide (including N, P, K fertilizer and herbicide) from fertilizers and herbicide plant to fields	Lorry	60,000	200
	Light truck	8000	2
Transporting fresh cassava from harvested area to collecting center	Light truck	8000	2
Transporting dry cassava from collecting center to ethanol production plant	Lorry	60,000	200
	Dump truck	12,000	50
Transporting denatured ethanol from production plant to gas station	Tank lorry	60,000	350
	Tank truck	8000	100

2.3. Primary energy uses estimation

All direct material and energy inputs were calculated at the primary energy level. A model of the greenhouse gases, regulated emissions and energy use in transportation (GREET) [9] provides the input efficiencies to convert from primary energy to process energy, such as diesel fuel and gasoline. For example, in N, P and K fertilizers and herbicide manufacturing, residual oil, diesel fuel, natural gas and electricity are process fuels (Table 5). The total energy input shall include the energy inputs required to mine, extract and manufacture the raw materials into those energy products. Multiplication by the input efficiencies converts the uses of the N, P and K fertilizers and herbicide, as well as the direct diesel fuel, electricity and coal uses, into primary energy inputs (Table 6).

The energy required for stem cuttings preparation was assumed to be 150% of the energy required to grow the cassava because the fresh stem cuttings use more energy than the regular cassava stem for additional storage and processing cost [5]. Labor inputs were regarded as calorie equivalent energy. Agricultural workers work 8 h a day, and one man-hour input is 2.3 MJ/h [12,13].

The energies required to build the ethanol facilities and produce the transportation equipment were excluded in this study because it would require a tremendous amount of data and the final result would add very little to the total energy used per liter of ethanol [5]. Moreover, the available information in this area is old and outdated, and most studies [5–7] do not include this part of energy.

2.4. NEV and NREV of cassava fuel ethanol

2.4.1. NEV calculation

The net energy value refers to the difference between the amount of total energy inputs and the amount of energy contained in the ethanol.

$$\text{NEV} = E_F - E_I \quad (1)$$

where E_F is equal to 21.185 MJ/L, the heating value of the fuel ethanol. E_I is the amount of total primary energy inputs. The solar energy absorbed by photosynthesis and fresh chips drying is excluded because solar energy is regarded as a free resource. In fact, solar energy plays an important role in the energy balance. Any energy gained in the production of ethanol is a result of the stored solar energy in the biomass feedstock. Without the solar energy introduced into the cassava fuel ethanol system, the NEV must be negative for energy depletion.

Table 5
Process energy uses for chemical production

Process fuel	N	P	K	Herbicide
Residual oil (MJ kg ⁻¹)	0	0	0	78.634
Diesel fuel (MJ kg ⁻¹)	0	2.914	1.550	78.634
Natural gas (MJ kg ⁻¹)	41.848	2.806	1.350	60.286
Electricity (MJ kg ⁻¹)	4.650	5.073	2.100	44.559

Table 6
Input efficiencies for energy sources

Item	Total energy	Fossil energy	Petroleum energy
Residual oil	1.098	1.093	1.044
Diesel fuel	1.179	1.172	1.085
Natural gas	1.064	1.063	0.004
Coal	1.020	1.018	0.014
Electricity	1.898	1.237	0.018

The cassava fuel ethanol system also produces DDGS and CO₂, which consume energy as well. Carbon dioxide is generally considered a greenhouse gas, i.e. a pollutant. However, at this plant, in the process of post-treatment, all CO₂ is captured and sold as a final product. Coproduct energy credits are energy inputs for coproducts production and are regarded as negative energy inputs to the NEV calculation. Allocating the energy uses between the main product and the coproducts is one of the most critical issues in NEV calculations. Market value and replacement methods are the most used methods in most studies [5,6]. For market value allocation, the product energy uses are in proportion to a 10 year average market value of the corresponding product. For replacement allocation, the energy credits are assumed to be equal to the energy value of a substitute product that the ethanol coproduct can replace. In this study, the DDGS was replaced by corn (replacement ratio: 1.077) and soybean meal (replacement ratio: 0.823) [9]. The CO₂ replacement value was based on the energy intensity of corn fermentation in the wet milling process. Its energy credit was 1.243 MJ/L [6].

2.4.2. NREV definition

The NEV definition only discloses the total energy efficiency. In fact, one of the greatest benefits of fuel ethanol is its renewable character and its replacement of petroleum fuel. It is necessary to indicate the renewable energy efficiency in the cassava fuel ethanol system. Similar to the NEV definition, the definition of net renewable energy value is

$$\text{NREV} = E_F - \text{NE}_I \quad (2)$$

where NE_I is the non-renewable energy input. In the cassava fuel ethanol system, that is the fossil energy inputs such as residual oil, diesel fuel, natural gas and coal. If the NREV has a negative or zero value, the cassava fuel ethanol system is not renewable, i.e. it makes no sense to acquire renewable energy from nature using this system. Only when the NREV has a positive value, is the cassava fuel ethanol system renewable.

3. Results

3.1. The NEV and NREV results

The fuel ethanol conversion was the most energy consuming subsystem among all the subsystems, making up 71.11% of the total energy inputs. The plantation was the second most energy consuming subsystem at 25.91%. The N fertilizer and herbicide application contributed the two largest energy uses in the ethanol conversion subsystem (Table 7).

The NEV of the cassava fuel ethanol system was 4.452 MJ/L without coproducts allocation. On the average results of the market value and replacement methods, 81.94% and 18.06% of the energy inputs were allocated to ethanol and its coproducts. The NEV of fuel ethanol was 7.475 MJ/L, and the NREV was 7.881 MJ/L, with coproducts allocation (Table 8).

The energy inputs can also be presented by type. In Table 9, the fossil fuels and petroleum inputs were separated from the total energy inputs. The hydropower was equal to the difference between the total energy input and the fossil energy input. Its amount was 0.406 MJ/L, 2.43% of the total energy inputs. Coal plus natural gas was equal to the difference between the fossil energy input and the petroleum energy input, which was 14.165 MJ/L, 84.65% of the total energy.

3.2. Potentials of cassava fuel ethanol

The Guangxi cassava yield (tons per hectare) has increased steadily in recent years. Although the cassava sown area declined slightly, the cassava output increased. In 2003, the cassava sown area was 244,800 ha, and the cassava dry chips output was 1.397 million tones (Fig. 5). Affected by frost in 2003, these data were less than the corresponding data in 2002.

Table 7
Energy inputs of cassava fuel ethanol system

Item	Energy input (MJ L ⁻¹)
<i>Plantation</i>	4.336
N fertilizer	0.937
P fertilizer	0.282
K fertilizer	0.255
Herbicide	1.728
Diesel fuel	0.310
Electricity	0.003
Stem cuttings	0.002
Labor	0.819
<i>Conversion</i>	11.898
Coal	11.927
Electricity output	−0.029 ^a
<i>Denaturing</i>	0.042
Electricity	0.042
<i>Transport</i>	0.452
Diesel fuel	0.452
<i>Distribution</i>	0.005
Electricity	0.005
<i>SUM</i>	16.732

^a Negative electricity input represents electricity output.

Table 8
Allocation results of energy consumption

Allocation method	Energy allocation (%)		Coproduct credit (MJ L ⁻¹)	NEV (MJ L ⁻¹)	NREV (MJ L ⁻¹)
	Ethanol	Coproducts			
Market value	82.30	17.70	2.961	7.413	7.819
Replacement value	81.57	18.43	3.084	7.537	7.943
Average	81.94	18.06	3.023	7.475	7.881

Table 9
Fossil fuel and petroleum inputs

Item	Amount (MJ L ⁻¹)	%
Fossil fuels	16.326	97.57
Petroleum	2.162	12.92
Total	16.732	100.00

Guangxi has a unique karst limestone topography, which consists of many discontinuous margin land around countless hills, which is not available for common crops such as corn, rice, wheat and sugarcane, but it is suitable for cassava plantations. Through surveying and adding up all these available areas, the ministry of agriculture of China figured out that the sum of the potentially available margin lands was around 400,000 ha (Fig. 1).

When all the potential margin land is used for cassava plantation and all the cassava is used for ethanol production, with the technological conditions in this study, the cassava ethanol can substitute for 166.107 million liters of gasoline in 2003, or potentially, 618.162 million liters of gasoline (Table 10).

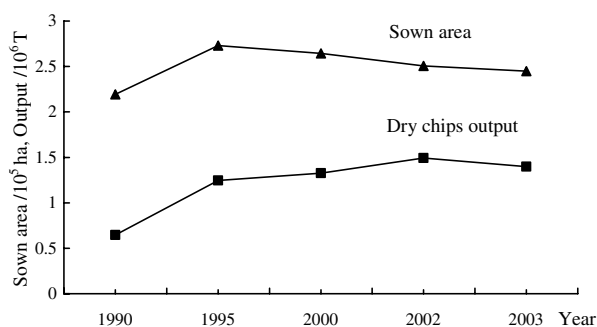


Fig. 5. Cassava sown area and output in Guangxi region in recent years [10].

Table 10

Current and potential of Guangxi cassava fuel ethanol

Item	Plantation area (ha)	Dry chip output (10 ⁶ T ^a)	Fuel ethanol output (10 ⁶ L)	Gasoline equiv. (10 ⁶ L)
In 2003	244,800	1.397	678.564	166.107
Potential	400,000	5.200	2525.253	618.162

^a Dry chip.

4. Discussions

4.1. Liquid energy conversion

Producing ethanol from cassava can provide a way to convert a non-liquid fuel into fuel ethanol, a liquid fuel that can be used for transport. In Table 9, only 12.92% of the total energy inputs are from liquid fuel. In other words, 1 J of petroleum fuel, plus the other forms of energy inputs such as coal, can produce 9.80 J of fuel ethanol. In fact, the coal contributes 71.28% of the total energy inputs directly (Table 7). The total energy contribution of coal should be greater.

China was the largest coal producer and the eighth largest oil importer in the world in 2004 [14]. On one hand, China has abundant coal reserves. Coal accounts for about 70% of fossil energy uses [15]. On the other hand, China has few domestic oil resources and has to import oil to meet the needs of transport. It was predicted that China petroleum imports would double from 2000 to 2010 [15]. How to convert coal into a liquid fuel that vehicles can use is a problem that China has faced for decades. Through fuel ethanol production, the abundant domestic coal, combined with other renewable energies, can be converted into premium liquid fuel. Thus, it provides a gasoline substitute for urban transportation and reduces oil imports.

4.2. Compare with corn fuel ethanol

Corn is a widely used feedstock for ethanol production. The NEV of cassava fuel ethanol is greater than that of corn fuel ethanol in most studies. Shapouri's NEV of corn fuel ethanol was 5.883 MJ/L [5], and Wang's NEV of corn fuel ethanol was 6.272 MJ/L [7]. Both these NEV results are less than cassava fuel ethanol's NEV. Three reasons make the NEV of cassava fuel ethanol higher than that of corn ethanol. One is that cassava ethanol productivity is higher than that of corn-ethanol. The ethanol output per hectare of corn ethanol is 3107 L/ha [5], while that of cassava ethanol is 6313 L/ha. The second reason is that cassava uses fewer fertilizers during cultivation, N fertilizer for example. Cassava uses 100 kg/ha of N fertilizer in the plantation, but corn needs 144 kg/ha [5]. The third reason is that Guangxi cassava uses more hydroelectricity, which has a higher efficiency than that of coal burning electricity generation. When outputting equal power, hydroelectricity consumes less primary energy than coal burning does.

Table 11
NEV of gasoline, diesel fuel, corn-ethanol, biodiesel and cassava-ethanol

Fuel	NEV (MJ L ⁻¹)	Energy ratio	Net energy gain or loss (%)
Gasoline ^a	−7.891	0.803	−19.69
Diesel fuel ^b	−6.765	0.841	−15.89
Biodiesel [16]	22.440	3.200	220.00
Corn-ethanol [5]	5.883	1.340	34.00
Cassava-ethanol (this study)	7.475	1.545	54.52

^{a,b} GREET model results [9] adjusted for China situation [11].

4.3. Compare with other fuels

One of the greatest benefits of fuel ethanol is its replacement of petroleum fuel. When comparing the NEV of cassava fuel ethanol with that of the other fuels, cassava fuel ethanol is more energy efficient than corn ethanol, gasoline and diesel fuel but less energy efficient than biodiesel (Table 11). During the processes of petroleum extraction, transport and refining, no extra energy enters the petroleum system, but for the cassava fuel ethanol system, during cultivation, the cassava absorbs solar energy in photosynthesis. The solar energy trapped is greater than the energy used in the processes. This explains why the NEV of gasoline and diesel fuel are negative and that of fuel ethanol is positive.

5. Conclusions

- (1) Cassava fuel ethanol production helps to convert a non-liquid fuel into fuel ethanol that can be used for transport. Through fuel ethanol production, 1 J of petroleum fuel, plus other forms of energy inputs such as coal, can produce 9.80 J of fuel ethanol.
- (2) Cassava fuel ethanol in Guangxi is energy and renewable energy efficient as indicated by positive NEV and NREV that were 7.475 MJ/L and 7.881 MJ/L, respectively. The solar energy trapped is greater than the energy used in the processes.
- (3) Cassava fuel ethanol can substitute for gasoline and reduce oil imports. With the cassava output in 2003, it can substitute for 166.107 million liters of gasoline. With the potential cassava output, it can substitute for 618.162 million liters of gasoline.
- (4) Cassava fuel ethanol has higher energy efficiency than those of gasoline, diesel fuel and corn fuel ethanol but less than that of biodiesel.

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Appendix A. Guangxi, cassava, and fuel ethanol

A.1. Guangxi

The Guangxi Zhuang Autonomous Region is located in southwest China among the Guangdong, Guizhou, Hunan, and Yunnan provinces. It shares a border with Vietnam and has a southern coastline along the Beihai Gulf (Fig. A-1).



Fig. A-1. Location of Guangxi demonstration plant at Qinzhou.

Guangxi has a unique karst limestone topography, which consists of many discontinuous margin lands around countless hills, which are not available to common crops such as corn, rice, wheat and sugarcane, but it is more suitable for cassava plantation (Fig. A-2).

A.2. Cassava

Cassava, *Manihot esculenta* Crantz, is a perennial woody shrub, which grows in tropical and subtropical areas of the world. It is also called yuca, manioc and mandioca. Cassava is divided into two groups: the sweet and the bitter types. The bitter type contains higher concentrations of cyanogenetic glucosides—poisonous plant compounds that often cause headaches in humans—than the sweet type [17]. The period from semina-tion sowing to harvest of cassava is usually 8–9 months in Guangxi (Fig. A-3).

Cassava thrives better in poor soils than any other major food plant. As a result, fertilization is rarely nec-essary. Since many cultivars are drought resistant, cassava can survive even during the dry season when soil moisture is low, but humidity is high. The starchy concentration of cassava roots is more than 30%, so it serves as a vital staple in Africa and other tropical regions around the world [17].



Fig. A-2. Karst limestone topography of Guangxi.



Fig. A-3. Cassava tuber of Guangxi.

Having sufficient sunlight, adequate temperature and ample rainfall in all seasons as well as abundant lands and hills, Guangxi has the natural predominance for growing cassava. In fact, the planted area and annual production of cassava in Guangxi accounts for 60% of that of the whole country.

A.3. Cassava based fuel ethanol

With the use of lead free gasoline in China from July 2000, the local government of Guangxi is launching an ambitious program of production of fuel ethanol from cassava. The produced ethanol will then be blended with gasoline. They set up a 100 thousand liter demonstration plant at Qinzhou of Guangxi. This plant uses local cassava as feedstock to produce fuel ethanol (Fig. A-4).

A.4. Fuel ethanol use in China

E10, a mixture of 90% gasoline and 10% (volume) fuel ethanol, is tentatively used to power motor vehicles in some of China's major grain producing regions, including nine provinces (Figs. A-5 and A-6). But Guangxi



Fig. A-4. Demonstration plant at Qinzhou, Guangxi.



Fig. A-5. Pilot regions using E10 fuel in China.



Fig. A-6. Chinese characters of “E10 fuel” on right side of a refueling machine.

is not the pilot region for some reason. Guangxi is waiting for the central government’s approval on pilot use of cassava fuel ethanol.

A.5. ASIATIC (Agriculture and small to medium scale industries in peri-urban areas through ethanol production for transport in China) program

In order to decrease the fossil fuel consumption and the greenhouse gases emission, the ASIATIC project aims to develop renewable energy in particular to promote, in a sustainable way, the production and the use of bioethanol for transportation in China. The ASIATIC project is a shared cost research and technology development financed by the EU (No.: ICA4-2002-10023). It has two case studies, one is Guangxi and the other is Liaoning. Shanghai Jiao Tong University is in charge of the Guangxi case study.

The aims of the Guangxi case study are to determine the potential of the Guangxi ethanol program to improve the living conditions in the region in order to reduce the migration to eastern regions, to evaluate the conditions of technical, social, environmental and economic viability of this program.

For more information, please visit <http://www-egc.grignon.inra.fr/ecobilan/asiatic/index.html>.

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