Bio-coal briquettes and planting trees as an experimental CDM in China*

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Abstract

China faces mutually exclusive choices: to reduce CO_2 but to keep coal consumption. Our results suggest that it is possible to meet both choices, improving thermal efficiency by bio-coal briquette, using ashes of the briquettes to improve soil, and promoting forestation in semi-desert and desert. The cost of CO_2 reduction (from 5 US dollar/t-C to 279 US dollar/t-C) is within the cost of the existing AIJ projects in the US, and the prices of bio-coal briquettes (210~228 Yuan/t) is comparable to the prices of conventional coal briquettes (180~240 Yuan/t), but expensive compared to domestic coal (100~170 Yuan/t). The project is suitable for a portfolio CDM, it has strong need from the local participants as well as its additionality of reducing CO_2, SOx, and dusts.

1 Introduction

CO_2 reduction and increase of coal consumption are mutually exclusive. China faces these two exclusive choices: to reduce CO_2 but to keep coal consumed. Our results suggest that it is possible to meet both to some extent, improving thermal efficiency by bio-coal briquette, recycling ashes of the briquette to improve soil, and planting trees in the improved soil of semi-desert and desert. This paper will explain the results and consider possiblity of the project as a CDM.

China has increased CO_2 emission around 600 million ton-CO_2 in the last decade. It is mainly due to China's heavy coal dependence, though China has rapidly increased oil consumption.[2] Considering the world oil and natural gas market, it is not desirable or realistic that China is increasing oil and natural gas consumption at this speed for decades.[3] Coal consumption in the industry is necessarily for its relatively cheap cost. For the household, especially in rural area, China's coal dependence will continue.[4]

[2]According to EIA *International Energy Outlook*, 1998–2001, Chinese CO_2 emissions were 2.27 billion t-CO_2 in 1990, and 2.93 billion t-CO_2 in 1997. But after 1996–7, China has decreased energy consumption, especially coal direct consumption, extremely rapidly. The causes have not yet been fully explained, but see, for example, Sinton and Fridley [2000], Müller [2001].

[3]Martinot [2001] reviews the world bank energy projects in China, which promote energy efficient coal-fired power generation, natural gas-fired, wind power, and hydro power, but no oil-fired power generation. Though natural gas fired power generation is included, Zhang et al. [2001] describes the price of natural gas is quite uncertain.

[4]Qiu et al. [1990], Smith, Gu and Qiu [1993] and Qiu and Gu [1996] introduce improved biomass stoves that diffused in rural area in early 1990s, but eventually households tend to use coal stoves or LPG stoves, due to increased per capita income. Sun [1996] estimates rural residential energy consumption not reported in the statistics, i.e. non-commercial energy consumption, which includes raw coal.

CO_2 reduction for the global warming is important for China but much more urgently for Japan, because as a member of Annex I countries, Japan must decrease CO_2 emission to 6% less than the 1990's level. It is hard for Japan to reach at the level solely by increase of energy efficiency or decrease of energy consumption. Japan has to apply the clean development mechanism (CDM) to obtain carbon credit in order to implement the reduction of CO_2, for example, introducing the new alternative technology as a foreign direct investment, or planting trees in non-forested land.

It is reasonable that Japan will invest in China to improve coal combustion efficiency and to plant trees. It is also reasonable that China consumes coal, because of its cost and the coal industry's employment. But in reality it is difficult to maintain and promote such a project by participants of the local communities and enterprises. Thus, we first examine the previous political process of Japanese official development aids briefly, and try to find how to maintain incentives of the local participants.

Secondly, we must consider technical characteristics of the project, because coal consumption produces CO_2, SOx and dusts. It is necessary for SOx and dusts to remove sulphur contents and to produce perfect combustion. And bio-coal briquette is one of the best choices for these purposes. It reduces SOx and dusts as we shall see below.

Thirdly, there are two obstacles to promote bio-coal briquette, one is its price and the other is CO_2 generated by bio-coal briquette. We consider the scale effect of production of bio-coal briquette equipments on the price. As to the price of bio-coal briquette, it might be reduce by mass production, by which decreases construction cost of the equipments per unit of briquette.

In addition, ashes of bio-coal briquettes are suitable for soil improvement for desert. And ashes of the briquette can be produced and use almost at the same place. Forestation is best to prevent desertification and to absorb CO_2. Under these desirable technical conditions, we must consider the economic sustainability, and competitiveness for alternative choices.

We finally investigate possibility of the project to be as a clean development mechanism, which will promote any incentive to investment from Japan and the other Annex I countries.[5] If CO_2 reduction cost lies within a reasonable level, the projects for bio-coal briquette and for planting trees have advantage not only technically but also economically.

[5]Quian and Zhan [1998] present only Japan has interested in SOx reduction projects in China, projects of the other developed countries have concentrated to reduction of the global warming gases or energy savings. We have interests in reduction of both SOx and CO_2 (see T Kojima ed. [2000] and T Yamada ed. [2001]), but here our description is mainly concerned with CO_2.

2 Political processes and maintaining incentives of the local participants

Japan's foreign aid to China starts from 1979, and it has been successful in a way, for example, through its yen loan, constructions of fired and hydro power generation plants are now supplying 3% of total generated electricity in China, construction of facilities for electric railway are amount to 38% of total electricity railway in China.[6] The Japanese government's ODA loans are increasingly environmental oriented since the 4th program 1996, as in Table 1.

One of the early Japan's aids to China constructed "China-Japan Centre for Friendship and Environmental Protection" (Chu-Nichi Yuko Kankyo Hozon Senta) (CJCFEP), 1990–94. Chinese government purchased land for the centre, and Japan's aid was 10.5 billion yen. After establishing the centre, every environmental aid under the Grass Roots projects has been managed by CJCFEP. CJCFEP is a direct organisation under the Environmental Protection Agency of the central government.[7]

In 1998, the Grass Roots projects consisted 71 projects, and 5 of them were related to environmental improvement. This number is not high compared to the amount of loan aid for the environmental investment. Iechika [2000] explains that this is because all the environmental grant aid are through CJCFEP, and due to the pattern of the Japanese government's policy to China in the environmental grant aid. The policy consists of (1) promoting China's own activities to improve the environment, (2) human resource development for China's environment protection, and technology cooperation for reducing pollution, which should improve the China's environment effectively in the short run, and (3) allocation equally to every region, which shall help to reducing regional differences.

Projects related to the item (3) are provided from the loan aid, while the Grass Roots projects are corresponding to the item (2) human resource development and technology cooperation. According to initial purposes of the Grass Roots projects, an important characteristics of it is quick response to local or regional demand for environmental improvement. But actually, all environmental projects of the Grass Roots projects are through CJCFEP, that is, the central government.

The authors have heard that, roughly speaking, half of project's fund through the central government is attributed to the central government as commission, half of the rest is to the local government as commission, and in the same way, usually half of the rest is provided as commission of intermediate organisations. As a result, people or a body who actually take part in a project can receive only a fraction of the total fund. This might be just a rumour, and certainly there is no evidence or

[6] Ministry of Foreign Affairs [2000].

[7] See Iechika [2000].

document to prove the procedure. But if this situation is true, it is understandable that local people do not want to participate in a project through the central government, therefore they would not propose their needs to the local government. No proposal from locals means no project, because the Japanese government starts to react when the Chinese central government accepts a proposal from the local government. After tens of procedures, the Grant Aid starts. These processes are indeed necessary to prevent from failure, but it might also prevent from revealing what is actually necessary to local people in China.

As for our projects, we approached directly to the city government's environmental bureau. As a result, we could save procedures required to the central government and parts of the local governments. And we can discuss and negotiate directly with actual, not intermediate, counterparts of the project. This process is extremely important to promote and appreciate incentives of local partners of the project.

Table 1: ODA to China by the Japanese government

billion yen

year	Total Loan Aid	Loans: Environmental Project	Donations: Technology cooperation
–1990	993.4	— (–%)	41.48
1991	129.6	10.4 (0%)	6.86
1992	137.3	0.0 (0%)	7.53
1993	138.7	0.0 (0%)	7.65
1994	140.3	0.0 (0%)	7.96
1995	141.4	2.5 (2%)	7.37
1996	170.5	50.7 (30%)	9.89
1997	202.9	29.5 (15%)	10.38
1999	206.6	44.7 (22%)	9.83
1999	192.6	34.7 (18%)	7.33

	Donations (Bilateral Grant Aid)		
year	Total Grant Aid	Environmental Project	Grass Roots Project
–1990	63.11	—	— (– cases)
1991	6.65	0.302	0.036 (9 cases)
1992	8.24	1.914	0.050 (13 cases)
1993	9.82	4.221	0.066 (12 cases)
1994	7.80	3.819	0.106 (14 cases)
1995	0.48	0.000	0.151 (25 cases)
1996	2.07	0.000	0.310 (39 cases)
1997	6.89	0.104	0.439 (56 cases)
1998	7.65	1.247	0.502 (71 cases)
1999	5.91	1.940	0.560 (78 cases)

Sources: Ministry of Foreign Affairs, *Japan's ODA Annual Report*, 1999, 2000, Iechika [2000].

3 Two experimental projects on bio-coal briquettes

As explained in Introduction, we have not chosen a cutting-edge technology, but chosen a product with a relatively out-of-date technology for Japan, but we think important for China, bio-coal briquette. Bio-coal briquette is a high pressured mixture of powdered coal and biomass, added with either powdered $Ca(OH)_2$, or CaO to remove sulphur. Bio-coal briquette has three desirable characteristics: firstly it is made from coal. China has plenty reservation of coal. Nevertheless, coal industry in China has been seriously declined in this decade, and recently China began to import coal from Australia. Bio-coal briquette can be produced from either high quality coal or low quality coal; typically low quality coal in China contains ashes at 20% ∼ 45% in terms of weight (Mizoguchi [2001] in Yamada ed. [2000] page 11). If bio-coal briquette production develops, demand for Chinese coal increase, *ceteris paribus*. In addition, needless to say, China's consumption for domestic coal is also preferable for the world energy market.[8]

Secondly, bio-coal briquette burns nearly perfect, therefore the flame has significantly higher temperature than simple coal burning. Energy efficient coal consumption is good for environment in every respect. As a result, dust from burning bio-coal briquette is much less than from burning coal directly (see the second line in Table 2). High temperature flame of bio-coal briquette results in high thermal efficiency compared to coal (see the last line in Table 2).

Thirdly, its ash is also beneficial to improving soil in the desert and semi-desert area northwest Shenyang (Nitta et al. [2001] in Yamada ed. [2001] Chapter 8). Table 3 shows that its chemical components of bio-coal briquettes ash. It contains higher silica and alumina but lower calcium compounds such as CaO, $CaCO_3$ and $CaSO_4$, in general similar to gypsum. According to Nitta et al. [2001], the experiment using gypsum produced from sulphur scrubber in Shenyang presents that the gypsum improve soil and actually it helps corn growth significantly (See the pictures at Chapter 8 in Yamada ed. [2001].). Nitta et al. [2001] concludes that ash of bio-coal briquettes should have a similar effect to soil improvement, although it is not so successful as gypsum but effective, because it contains less calcium compounds than gypsum. Because sulphuric by-products in bio-coal ash is generated from sulphur in coal, bio-coal briquette with higher sulphur might produce more effective soil improver.[9]

The bio-coal briquettes examined above were produced by the two experimental equipments installed in Chengdu and Shenyang in Table 4. The capacity of equipments are small (1/20 ∼ 1/5) compared to that of the equipment suggested as

[8] See footnote 3.

[9] In 2001, not yet fully reported, much more significant improvement of corn growth has been observed by bio-coal briquette ash as a soil improver.

Table 2: Experiments on bio-coal briquettes

() the reduction ratio of a pollutant

Shenyang			
	Coal	Bio-coal briquettes	
Dust mg/Nm^3	112~121	42~ 46 (63%)	
SO_2mg/Nm^3	742~976	307~314 (64%)	
Gross calorific	15,355~	16,700	
value kJ/kg	23,012	16,700	
Thermal efficiency	100	111	
Chengdu in average			
	Coal	Type A bio- -coal briquettes	Type B bio- -coal briquettes
Dust mg/Nm^3			
SO_2mg/Nm^3	2,007	654 (67.4%)	601 (70.1%)
Gross calorific value kJ/kg	20,188	16,207	16,207
Thermal efficiency	100	104	107

Notes: Type A bio-briquettes denote compounds of coal(72.5%), biomass (sawdust (13%), straw (1.5%)), CaO (7%). The numbers in parentheses () are the compounded ratio in terms of weight.
Type B bio-briquettes denotes the type A bio-coal briquettes added activators, for example, iron oxide (3), potassium manganate (2) as oxidising agents, and NaCl (1).

The number in parentheses () is the reduction ratio compared to coal under the same consumption of fuel in terms of weight.

Thermal efficiency is measured by the time required to boil the same amount of water, using stove and pan. (See for detail Kim et al. [2001] in Yamada ed. [2001], pages 67–70. and Hashimoto et al. [2001] in Yamada ed. [2001], page 101.)

Sources: Yamada ed. [2001], Chapters 1, 3 and 5.

Table 3: Chemical analysis on bio-coal briquette ash

	Gypsum from de-sulphurdization	Bio-coal briquette ashes
$Ca(OH)_2$	2%	1%
CaO	31%	9%
$CaSO_3$	2%	1%
$CaCO_3$	29%	5%
$CaSO_4 \cdot 2H_2O$	32%	10%
SiO_2	9%	27%
Al_2O_3	4%	19%

Notes: Gypsum from the de-sulphurdization is derived by an equipment in Shenyang China, which does not consume water, blowing dry powdered limestone into the boiler.

Sources: Nitta et al. [2001] in Yamada ed. [2001], page 170.

optimal 1~2 t/hour in Yoshioka et al. [2001] in Yamada ed. [2001] Chapter 7. The production of bio-coal briquettes requires at least 7 peripheral equipments other than the installed bio-coal briquette equipment that is a machinery for the formation of briquette with high pressure.

3.1 Cost calculation for the bio-coal briquette production

Cost calculation for the briquette production is not easy. As to variable cost for the production, Yang [2000] and Hashimoto et al. [2001] report for Chengdu and Liu [2000] reports for Shenyang, on material cost and labour cost for unit production of bio-coal briquette. Table 5 presents the unit cost of briquette production for 1 metric ton. Even for the variable cost, Hashimoto et al. [2001] reports different unit cost for electricity, transportation and labour. Economies of scale for these cost items reduce unit cost of production significantly. Figures in parentheses in Table 5 are cost for the experimental equipment, of which capacity is 843.8 t/year, and the other figures are based on the assumption that the plant capacity is 10,000 t/year.

Figures for Shenyang are based on the assumption that the plant capacity is 30,000 t/year. The plant capacity does not necessarily present capacity of a equipment, it can present multiple equipments in a single plant.

Yoshioka et al. [2001] considers optimal capacity of equipment and production of equipments given the market size of bio-coal briquette. As the market size increases, the optimal capacity of equipment increases. But due to the economies of scale on equipment production, the optimal capacity of equipment increases diminishingly.

Table 4: The installed bio-coal briquette equipments

Chengdu	
Production capacity	200~250kg/hour
Electricity consumption	303.7kW
Annual production at full employment	843.8 t/year
	$= 225$kg/h$\times$15hours/day$\times$250days/year
Shenyang	
Production capacity	50kg/hour
Electricity consumption	10kW
Annual production at full employment	187.5 t/year
	$= 50$kg/h$\times$15hours/day$\times$250days/year

Sources: For Chengdu, Yang [2000] in Kojima ed. [2000], Chapter 12, page 221, for Shenyang, Nitta [2000] in Kojima ed. [2000], Chapter 10, page 188.

Table 6 shows equipment costs for the two projects. Yang [2000] and Hashimoto et al. [2001] describes equipments for experimental briquette production of annual 200~ 250 t and for hypothetical production of annual 10,000 t in Chengdu. The main equipment was imported from Japan for experimental production, as a result, the cost of the main equipment is very expensive. On the other hand, the main equipment for hypothetical production is assumed to be made in China. Therefore, the cost of the main equipment is relatively cheaper than that of experimental.

Liu [2000] describes the equipments for hypothetical production of annual 30,000 t in Shenyang. Liu assumes the main equipment is made in China. And he estimates depreciation for the main equipment and the other peripheral equipments, but further details are not available.

Table 7 is the summary of unit cost of briquette production. The price of normal coal briquette in Chengdu is about 180 ~ 240 Yuan/t. Hashimoto et al. [2001] describes that bio-coal briquettes of the prices 260 ~ 280 Yuan/t have been sold in several places. Hashimoto et al. [2001] expects that the bio-coal briquette should be competitive when the price becomes 180 ~ 200 Yuan/t.

In Shenyang, Liu [2000] describes that bio-coal briquettes of the prices 230 and 250 Yuan/t have been sold in two places.

As to the experimental bio-coal briquettes, the fixed cost is extremely high compared to the market prices of the other briquettes. When the bio-coal briquette's main equipment is to be produced in China, the price of bio-coal briquette can be low enough to have competitiveness.

Yoshioka et al. [2001] suggests the following cost function to determine the number and the capacity of bio-coal briquette equipment for a given market size.

$$C(q,n) = aq^{b} + n^{\alpha} \exp(c + d \ln q + \frac{e}{2} \ln q^{2}),$$

and

$$a = 0.26,\ b = 0.71,\ c = -1.62,\ d = 0.34,\ e = 0.25,\ \alpha = 0.6,$$

where q is capacity of equipment (t/hour), n is the number of equipments. Substituting these values into the parameter, we can calculate the total production cost of briquette equipments.

Since these parameters are based on Japanese data, we first apply the production of the experimental equipment, which produces 843.8 t/year or 225 kg/hour.[10] And resulting cost is adjusted to 2 million Yuan as shown in Yang [2000], that is

$$C(0.225t/hour, 1) = 0.26607 \sim 2,000,000 Yuan.$$

Next we can calculate the optimal capacity and number of equipments using this cost function for the cost calculations of Chengdu and Shenyang. According to this cost function, the optimal number of equipments is 4 and the capacity of an equipment is 0,667t/hour operating 3,750 hours per annum, if the market demand for bio-coal briquette equals to annual 10,000 t.

$$C(0.667t/hour, 4) = 0.60263 \sim 4,530,000 Yuan.$$

4,530 thousands Yuan means the depreciation cost for per ton of production using this equipment is 45.3 Yuan/t·year. The depreciation from the other fixed cost is 0.93 Yuan/t·year. Therefore the total production cost equals to 192.67 Yuan/t·year. Hashimoto et al. [2001] estimates 170,000 Yuan if the equipment can be produced in China. And she obtains the total cost of 150.44 Yuan/t. But even if the equipment is produced in Japan, the price of bio-coal briquette 192.67 Yuan/t is not so expensive as the experimental production.

When the market demand for bio-coal briquette is annual 30,000 t, the optimal number of equipments is 8 with the capacity of 1.00 t/hour operating 3,750 hours per annum.

$$C(1t/hour, 8) = 0.94912 \sim 7,134,000 Yuan.$$

7,134 thousands Yuan for annual 30,000 t means the depreciation cost for per ton of production using this equipment is 23.78 Yuan/t·year. Depreciation for the other

[10] Yoshioka et al. [2001] assume that annual operating hours are 7,000 hours. But it seems impossible that annual working hours are 20 hours × 350 days, and labour cost for the above data is not counted shifted work schedule and over-time payments. We follow Nitta [2000] who assumes 15 hours × 250 day = 3,750 hours/year.

peripherals equals to 8.63 Yuan/t, then the total production cost equals to 237.55 Yuan/t. Liu [2000] estimates 3,000,000 Yuan if the equipment can be produced in China. And he obtains 223.77 Yuan/t. The total cost 237.55 Yuan/t is just a little expensive, but its difference is not so significant.

We can use this cost function to estimate the price of bio-coal briquette to meet demand for the briquette in Shenyang.

3.2 Potential demand for bio-coal briquette and reduction of CO_2 emission

In the following sections, we shall calculate the unit cost of bio-coal briquette and CO_2 emission for Shenyang. Because Chengdu city determined that coal consumption in the city was prohibited and the city substituted natural gas for coal. Therefore, there is no incentive to consume bio-coal briquette in Chengdu city, though the other places in the Sichuan district might demand for bio-coal briquette.

On the other hand, Shenyang does demand for bio-coal briquette. The main equipments and the other peripheral equipments in Chengdu have been transported to Shenyang this spring.

Coal consumption of the Liaoning district was 97.324 million ton in 1999. But bio-coal briquette is not suitable to metal furnace, coal mining and products, chemical, and power generation. Excluding these industries, the coal consumption amounted to 22.5735 million ton in the Liaoning district.

Industry's coal consumption in Shenyang was 5.54 million ton in 2000, 2.54 million ton was consumed for power generation, and the rest 3.00 million ton of coal was for industrial production. But sectoral allocation of coal consumptions is not available for Shenyang. Household coal consumption in Shenyang was 3.97 million ton in 2000. Half of the coal consumption for industry excluding electricity and household are to be maximum substitutable amount of bio-coal briquette for coal.

For alternative substitution ratio for bio-coal briquette, we simulate five possible cases, i.e. 1%, 5%, 10%, 20% and 50%. Table 8 presents coal consumption and its equivalent amount of bio-coal briquettes in terms of calorific value. In this case, calorific value for bio-coal briquette is assumed to be 16,700 kJ/kg. The bio-coal briquette that Liu [2000] assumed for Shenyang uses Fushun coals with high calorific value, 23,012 kJ/kg. As a result, the suggested mixture of bio-coal materials shows higher than 16,700 kJ/kg. Because of this and possible errors in estimation of calorific values for bio-coal briquette, we examine several other cases.

Shenyang consumes 16 kinds of coals in 2000. We use the same estimates of carbon contents obtaining CO_2 from conventional coal consumption (the baseline carbon emission) in Shenyang. Total coal consumption of 9.51 million ton generates around 19.9 million t-CO_2 in Shenyang, and its average carbon contents of coal is estimated as 0.571 in terms of weight.

Carbon contents of bio-coal briquette is estimated using Table 9, and carbon originated from biomass is excluded.

We can calculate the cost of the main equipments for bio-coal briquette production from the potential market demand, the unit cost of bio-coal briquette, and expected CO_2 emission for unit consumption of bio-coal briquette and for average coal in Shenyang.

Table 10–12 shows the potential market demand for the three bio-coal briquettes with different calorific value and material cost, the cost required to meet production of the bio-coal briquette corresponding to the market demand, CO_2 emission from consumption of the bio-coal briquette, reduction of CO_2 emission from the baseline (coal consumption), price of the different bio-coal briquettes, and estimated CO_2 reduction cost for the project of installing the new production equipments for bio-coal briquette.

The CO_2 reduction cost is estimated as follows: First, calculate the average price of coal consumed in Shenyang, using estimated price and actual price if available. The average price of coal in Shenyang was 127 Yuan/t in 1999. Second, calculate the CO_2 emission reduction; difference of CO_2 emission between bio-coal briquette consumption and coal. Higher thermal efficiency of bio-coal consumption and smaller CO_2 emission factor of bio-coal briquette consumption by eliminating CO_2 originated from biomass consumption, these two factors are attributable to CO_2 reduction of bio-coal briquette compared to coal consumption. Third, calculate cost of the project installing the new equipments for bio-coal briquette production, and calculate the price of bio-coal briquette. Fourth, calculate the additional cost of production, that is, difference between coal purchasing cost (the average price of cost times coal consumption assumed to be substituted to bio-coal briquette that corresponds to the substituted coal consumption) and bio-coal total production cost (the price of bio-coal briquette times potential market demand for it). Finally, divide the additional cost of bio-coal production by the amount of CO_2 reduction. Thus, CO_2 reduction cost of the project represents the unit (additional) investment cost per ton of CO_2 reduction.

Table 5: Variable cost of bio-coal briquette production

Chengdu

Item	Inputs per 1 ton of briquettes		Unit price of materials	Unit cost of production
Materials				109.26 Yuan
Powdered coal	664.0	kg	0.095 Yuan/kg	63.08 Yuan
Powdered limestone	170.0	kg	0.150 Yuan/kg	25.50 Yuan
Sawdust	124.5	kg	0.150 Yuan/kg	18.68 Yuan
Straw	41.5	kg	0.050 Yuan/kg	2.08 Yuan
Electricity	30.0	kWh	0.570 Yuan/kWh	17.10 Yuan
Transportation				10.00 Yuan
Labour cost				10.00 Yuan
Total variable cost				146.44 Yuan
(Following costs are derived from the experimental production.)				
(Electricity	131.0	kWh	0.570 Yuan/kWh	74.67 Yuan)
(Transportation				35.73 Yuan)
(Labour cost				30.00 Yuan)
(Total variable cost				249.66 Yuan)

Shenyang

Item	Inputs per 1 ton of briquettes		Unit price of materials	Unit cost of production
Materials				142.43 Yuan
Coal	423.7	kg	0.170 Yuan/kg	72.02 Yuan
Coal	464.3	kg	0.120 Yuan/kg	55.72 Yuan
Limestone	51.5	kg	0.050 Yuan/kg	2.58 Yuan
Straw	132.0	kg	0.080 Yuan/kg	10.56 Yuan
Drying materials			10 Yuan/t	8.60 Yuan
Electricity	32.0	kWh	0.600 Yuan/kWh	19.20 Yuan
Transportation			15 Yuan/t	16.20 Yuan
Labour cost			1040 Yuan/month	8.33 Yuan
Administration				10.40 Yuan
Total variable cost				205.14 Yuan

Table 6: Cost of the bio-coal briquette equipments

Chengdu		
For experimental production		
The main equipment	1	2,000,000 Yuan
Peripheral equipments		
Conveyor belt	1	30,000 Yuan
Magnetic separator	1	8,000 Yuan
Grinder for biomass	1	10,000 Yuan
Grinder for limestone	1	9,000 Yuan
Grinder for coal	1	8,000 Yuan
Dryer	1	200,000 Yuan
Mixer	1	34,000 Yuan
Sieve: vibrating screens	1	30,000 Yuan
Dust collector	1	12,000 Yuan
Total		2,341,000 Yuan
Unit fixed cost per annum		277.44 Yuan/t·year
For annual 10,000t production		
The main equipment	1	170,000 Yuan
Peripheral equipments		
Conveyor belt	1	11,000 Yuan
Magnetic separator	1	12,000 Yuan
Grinder for biomass	1	17,000 Yuan
Grinder for coal	1	12,000 Yuan
Dryer	1	13,000 Yuan
Mixer	1	17,000 Yuan
Sieve: vibrating screens	1	11,000 Yuan
Total		263,000 Yuan
Total including installation cost		400,000 Yuan
Unit fixed cost per annum		4.00 Yuan/t·year

Notes for Table 6: The main equipment is for formation of briquettes with high pressure.

Estimated costs are based on Chinese prices in 1999 and 2000.

The main equipment for experimental production is expensive because it was made in Japan. And annual production capacity is assumed to be 843.8 t

The other equipments are assumed to be made in China.

Depreciation is calculated as the purchase value divided by duration.

Source: Yang [2000] in Kojima ed. [2000] Chapter 12, Hashimoto et al. [2001] in Yamada ed. [2001] Chapter 5.

Table 6: Cost of the bio-coal briquette equipments (Continued)

Shenyang For annual 30,000t production	
The main equipments	3,000,000 Yuan
Depreciation for the main equipments	300,000 Yuan/year
Depreciation for the peripheral equipments	259,000 Yuan/year
Unit fixed cost per annum	18.63 Yuan/t·year

Notes for Table 6: The main equipment is for formation of briquettes with high pressure.

Estimated costs are based on Chinese prices in 1999 and 2000.

The main equipment for experimental production is expensive because it was made in Japan.

The other equipments are assumed to be made in China.

Depreciation is calculated as the purchase value divided by duration.

Source: Liu [2000] in Kojima ed. [2000] Chapter 11.

Table 7: Total unit cost of bio-coal briquette production

Chengdu bio-coal briquette	Experimental production	527.10 (Yuan/t)
Chengdu bio-coal briquette	Annual production 10,000 ton	150.44 (Yuan/t)
Shenyang bio-coal briquette for boiler	Annual production 30,000 ton	223.77 (Yuan/t)
Shenyang bio-coal briquette for stove	Annual production 30,000 ton	200.00 (Yuan/t)

Notes: Duration for the equipments of ‘Chengdu Annual 10,000 production’ is assumed to be 10 years.

Liu [2000] also estimates the unit cost of bio-coal briquette for stove, in that case the material cost is cheaper than for boiler.

Sources: Tables 5 and 6

Table 8: Coal and equivalent bio-coal briquette consumption: Shenyang in 2000

	Coal consumption		Equivalent bio-coal briquette		
	t	TJ	million t		
Thermal efficiency	1.00		1.00	1.04	1.11
Total*)	6,970,000	123,882	7.418	7.133	6.683
1%	69,700	1,239	0.074	0.071	0.067
5%	348,500	6,194	0.371	0.357	0.334
10%	697,000	12,388	0.742	0.713	0.668
20%	1,394,000	24,776	1.484	1.427	1.337
50%	3,485,000	61,941	3.709	3.566	3.341

Notes:*) Total coal consumption is excluded power generation.
Thermal efficiency is from Table 2.
Calorific value for bio-coal briquette is assumed to be 16,700 kJ/kg from Table 2.

Source: Coal consumption in Shenyang is due to Shenyang Environmental Protection Bureau.

Table 9: Estimated carbon contents and calorific values for bio-coal mixtures, and the price of coal: Shenyang in 1999

	J/g	Price	Carbon contents in weight
Fushun coal	23,012	170	0.7618
Hongyang coal	21,757	140	0.7237
213 Lignite	15,355	100	0.4855
Lignite Shenbei	12,970	110	0.3922
Tiefa coal	15,481	120	0.4905
Xima coal	22,175	130	0.7368
Biomass	15,086	80	0.4950
Limestone		50	0.1220

Notes: Carbon contents for coals are estimated by the authors using the available data for calorific values and carbon contents.
Carbon contents for biomass is due to Kim et al. [2001] in Yamada ed. [2001], Chapter 3.
Carbon contents for limestone is from Asakura et al. [2001].
We assume that CO_2 originated from biomass is excluded in estimation for the carbon contents of bio-coal briquettes.

Source: Liu [2000] in Kojima ed. [2000], Chapter 11.

Table 10: The price, capacity, and CO_2 emission for bio-coal briquette: 16,700 kJ/kg

Thermal efficiency to coal Coal=1.00	Market Size t	The number of the main equipments	Cost of the main equipment's production Yuan	CO_2 from bio-coal briquette t-CO_2	CO_2 reduction from the baseline t-CO_2	The price of bio-coal briquette Yuan/t	CO_2 reduct -ion cost Yuan/t
1.11	66,827	15	10,259,191	118,875	27,055	223.60	225.12
1.04	71,325	16	10,580,002	126,876	19,054	223.08	370.49
1.00	74,178	16	10,777,212	131,951	13,979	222.78	548.90
1.11	334,136	56	22,964,569	594,374	135,277	215.12	204.17
1.04	356,639	59	23,771,195	634,404	95,247	214.91	340.03
1.00	370,905	61	24,271,758	659,780	69,871	214.79	506.76
1.11	668,297	103	33,361,327	1,188,793	270,509	213.24	199.58
1.04	713,279	109	34,575,576	1,268,808	190,495	213.09	333.22
1.00	741,810	113	35,329,675	1,319,560	139,742	213.01	497.30
1.11	1,336,594	194	49,044,913	2,377,585	541,019	211.92	196.31
1.04	1,426,557	206	50,879,384	2,537,615	380,989	211.81	328.43
1.00	1,483,619	213	52,018,844	2,639,120	279,484	211.75	490.63
1.11	3,341,485	459	82,737,777	5,943,963	1,352,547	210.72	193.36
1.04	3,566,393	489	85,910,637	6,344,038	952,473	210.66	324.09
1.00	3,709,048	507	87,881,578	6,597,799	698,711	210.62	484.60

Notes: Thermal efficiency is from Table 2.

Market size is derived from total calorific value of coal consumption and of bio-coal briquette.

The number of the main equipments and the cost of the main equipment's production are estimated from the cost function Yoshioka et al. [2001].

CO_2 bio-coal briquette is calculated from the estimated carbon contents and the market size (consumption of the briquette).

CO_2 reduction from the base line is the difference between CO_2 emission from bio-coal briquette and CO_2 emission from coal consumption in Table 8. CO_2 contents of coal is estimated as 0.571.

The price of bio-coal briquette is price of per ton of bio-coal briquette, which is derived from fixed cost, variable cost using the cost of the main equipment production, and from Tables 5 and 7.

CO_2 reduction cost Yuan/t is the unit (additional) investment cost per ton of CO_2 reduction, using the average price of coal 127 Yuan/t. See the text for detail.

Table 11: The price, capacity, and CO_2 emission for bio-coal briquette: 18,095 kJ/kg

Thermal efficiency to coal Coal=1.00	Market Size t	The number of the main equipments	Cost of the main equipment's production Yuan	CO_2 from bio-coal briquette t-CO_2	CO_2 reduction from the baseline t-CO_2	The price of bio-coal briquette Yuan/t	CO_2 reduct -ion cost Yuan/t
1.11	61,676	14	9,880,736	121,708	24,222	227.62	214.12
1.04	65,827	15	10,187,535	129,900	16,030	227.07	380.25
1.00	68,460	15	10,376,376	135,096	10,835	226.75	615.78
1.11	308,378	52	22,012,982	608,539	121,112	218.74	191.51
1.04	329,135	55	22,782,153	649,499	80,152	218.52	345.12
1.00	342,300	57	23,259,673	675,479	54,173	218.39	562.94
1.11	616,757	96	31,928,385	1,217,078	242,224	216.77	186.51
1.04	658,269	101	33,086,203	1,298,997	160,305	216.62	337.34
1.00	684,600	105	33,805,134	1,350,957	108,345	216.53	551.21
1.11	1,233,514	180	46,880,513	2,434,157	484,447	215.40	183.01
1.04	1,316,539	191	48,629,215	2,597,994	320,610	215.29	331.87
1.00	1,369,200	198	49,715,372	2,701,914	216,690	215.23	542.95
1.11	3,083,785	425	78,994,921	6,085,392	1,211,119	214.16	179.85
1.04	3,291,347	453	82,018,924	6,494,986	801,525	214.09	326.93
1.00	3,423,001	470	83,897,376	6,754,785	541,725	214.05	535.49

Notes: Thermal efficiency is from Table 2.

Market size is derived from total calorific value of coal consumption and of bio-coal briquette.

The number of the main equipments and the cost of the main equipment's production are estimated from the cost function Yoshioka et al. [2001].

CO_2 bio-coal briquette is calculated from the estimated carbon contents and the market size (consumption of the briquette).

CO_2 reduction from the base line is the difference between CO_2 emission from bio-coal briquette and CO_2 emission from coal consumption in Table 8. CO_2 contents of coal is estimated as 0.571.

The price of bio-coal briquette is price of per ton of bio-coal briquette, which is derived from fixed cost, variable cost using the cost of the main equipment production, and from Tables 5 and 7.

CO_2 reduction cost Yuan/t is the unit (additional) investment cost per ton of CO_2 reduction, using the average price of coal 127 Yuan/t. See the text for detail.

Table 12: The price, capacity, and CO_2 emission for bio-coal briquette: 18,00 kJ/kg

Thermal efficiency to coal Coal=1.00	Market Size t	The number of the main equipments	Cost of the main equipment's production Yuan	CO_2 from bio-coal briquette t-CO_2	CO_2 reduction from the baseline t-CO_2	The price of bio-coal briquette Yuan/t	CO_2 reduct -ion cost Yuan/t
1.11	61,041	14	9,833,349	122,070	23,860	228.35	213.20
1.04	65,149	15	10,139,028	130,287	15,644	227.81	382.88
1.00	67,755	15	10,325,750	135,498	10,432	227.48	628.96
1.11	305,203	52	21,893,776	610,352	119,299	219.42	190.34
1.04	325,745	55	22,658,295	651,433	78,218	219.20	347.03
1.00	338,775	56	23,132,770	677,491	52,160	219.07	574.33
1.11	610,406	95	31,748,427	1,220,704	238,598	217.45	185.30
1.04	651,491	100	32,899,240	1,302,867	156,435	217.29	339.10
1.00	677,550	104	33,613,739	1,354,982	104,320	217.21	562.20
1.11	1,220,811	178	46,608,814	2,441,408	477,196	216.06	181.76
1.04	1,302,981	189	48,346,768	2,605,734	312,870	215.96	333.52
1.00	1,355,100	196	49,426,237	2,709,963	208,641	215.89	553.67
1.11	3,052,028	421	78,525,134	6,103,521	1,192,990	214.82	178.57
1.04	3,257,453	448	81,530,445	6,514,335	782,176	214.75	328.49
1.00	3,387,751	465	83,397,306	6,774,908	521,602	214.71	545.97

Notes: Thermal efficiency is from Table 2.

Market size is derived from total calorific value of coal consumption and of bio-coal briquette.

The number of the main equipments and the cost of the main equipment's production are estimated from the cost function Yoshioka et al. [2001].

CO_2 bio-coal briquette is calculated from the estimated carbon contents and the market size (consumption of the briquette).

CO_2 reduction from the base line is the difference between CO_2 emission from bio-coal briquette and CO_2 emission from coal consumption in Table 8. CO_2 contents of coal is estimated as 0.571.

The price of bio-coal briquette is price of per ton of bio-coal briquette, which is derived from fixed cost, variable cost using the cost of the main equipment production, and from Tables 5 and 7.

CO_2 reduction cost Yuan/t is the unit (additional) investment cost per ton of CO_2 reduction, using the average price of coal 127 Yuan/t. See the text for detail.

Table 10–11 present the following findings:

(1) The market size contributes price reduction around 13 Yuan/t of bio-coal briquette.

(2) Thermal efficiency of bio-coal briquette significantly affects CO_2 reduction cost. As the market demand for bio-coal briquette increases, bio-coal briquette with higher thermal efficiency reduces CO_2 reduction cost more than briquette with lower thermal efficiency. Thermal efficiency makes difference of CO_2 reduction cost wide, when the market demand increases.

(3) CO_2 reduction cost is varying rather wide from 629 Yuan/t to 178.57 Yuan/t, from 9,213 Yen/t to 2,616 Yen/t, or from 75.97 US dollar/t to 22.57 US dollar/t. The highest CO_2 reduction cost is due to low thermal efficiency for bio-coal briquette, which is assumed to equal to that of coal. In fact, independent studies show there is at least 4% increase of thermal efficiency for bio-coal briquette. 4% increase of thermal efficiency contributes to reduce the CO_2 reduction cost to 382.88 Yuan/t, 5,608 Yen/t, or 46.24 US dollar/t.[11]

It is still expensive CO_2 reduction cost, because the average price of coal is rather cheap, 127 Yuan/t. If bio-coal briquette substitutes more expensive or high quality coal, for example, 150 Yuan/t, the unit cost of CO_2 reduction shall be 111 Yuan/t (11% increase of thermal efficiency) or 280 Yuan/t (4% increase of thermal efficiency). High thermal efficiency and substituting medium and higher quality coal are necessary for the success of this project as a CDM. The price of conventional briquettes is 180 – 230 Yuan/t in 1999. Therefore bio-coal briquette can easily substitute for the coal briquettes.

4 Planting trees in Kangping-xian, border to the Inner-Mongolia desert

Bio-coal briquette is beneficial not only to CO_2 reduction, but also to soil improvement because of its ash, as we mentioned earlier. Northwest Shenyang faces with invasion of the Inner-Mongolia desert due to its strong wind and its alkali salt soil. Soil improvement and forestation prevent from further desertification and from strong wind. This project starts planting trees at Kangping-xian in Shenyang city, and experiments of soil improvement and CO_2 absorption by growth of trees.

[11] The exchange rate for Chinese Yuan is assumed to 8.28 Yuan/US dollar, 14.65 Yen/Yuan.

We have already planted 405,000 trees for three years, and observed their healthy growths. Table 13 shows the planted area for each year, the expected products and CO_2 absorption.

Table 14 presents cost and CO_2 reduction cost for planting trees. We did not consider the expected revenue of timber sales, because it should pay for maintenance threes for twenty years. As a result, cost of the project is purchasing cost of infant trees and labour cost for planting activities. We assume that it takes about 2 hours for planting 4 trees. Actually all the trees were planted as one of the activities of the green festival in China, thus all workers were volunteers. Even if we include labour cost, the CO_2 reduction cost is 12.22 Yuan/t (1.48 US dollar/t, 179 Yen/t). It is much cheaper than that of the bio-coal briquette project.

Table 15 shows some comparison with the other AIJ projects in the United States. The cost of CO_2 reduction varies from 1.58 US dollar to 487.57 US dollar per ton in terms of carbon. Our projects (Keio-Research for Future Projects) are within the range 5.43~278.54 US dollar/t-C. It is rather expensive for planting trees (forestation) compared to Rio Brabo Carbon Pilot Project, but rather cheap compared to the power generation projects.

The size of our projects is uncertain for bio-coal briquette, because it depends on volume of demand for bio-coal.[12] As the price of bio-coal is not expensive compared to the other briquette, it can substitute at least the other coal briquette. The project of planting trees is small because it has started for three years. It will continue to satisfy needs of the local participants. There are strong supports from the local participants, the project is to be classified as a portfolio approach of the CDM project (Wake et al. [2001]).

5 Concluding remarks: as an experimental CDM

This paper shows that our research projects can be a CDM project in terms of CO_2 reduction cost, compared to the other AIJ projects. At the same time, the price of bio-coal briquette is well competent with the other coal briquette, but it is not enough to substitute for coal. This is also an important point for the project as a CDM. If there is no CO_2 credit, the investment will not occur spontaneously.

Certainly, there is a possibility of failure. We have learned from the project in Chengdu, because the Chengdu city has quickly changed energy consumption from coal to natural gas. It is possible because Sichuan has plenty of natural gas reserves,

[12] According to Xu and Wang [2001], the potential of wind energy in east China is about 2.57 million ton in terms of CO_2. Maximum amount of CO_2 reduction by bio-coal briquette will reach 1.3 million ton in terms of CO_2. Wind power is more suitable for the Inner Mongolia than in Shenyang as Lew [2000] describes.

Table 13: Planting trees in Kangping-xian

Period	Planted area		The number of trees
First year 1999	8km × 100m	80.0ha	85,000
Second year 2000	7km × 100m	66.7ha	70,000
Third year 2001	24km × 100m	240.0ha	250,000
Total	39km × 100m	386.7ha	405,000
Expected timber production	20 years after		76,800 m^3
Price timber per cubic meters			300 Yuan/m^3
Expected revenue	after 20 years		23 million Yuan
Expected CO_2 absorption	for 20 years		78,880t-CO_2

Notes: Expected timber production is derived from the fact that annual production of trees per 6.667 are is at least 0.8 m^3 in average according to Mr Wang and the Forestry Bureau of the Shenyang city council. For 20 years, this produces 92,800 m^3. About 17% are assumed to be disposed as rim.

Expected CO_2 absorption is derived using the facts as follows:

Tree growth in 20 years amounts to 92,800 m^3, its density is assumed to be 0.5, and timber carbon (in terms of CO_2) contents 1.7 g-CO_2/g.

The kinds of trees are willow, birch, and poplar of China origin. Sources: Yamada ed. [2001], page 170 and the private letter from Mr Wang Kezhen, the economy and trade attaché of Shenyang city government.

Table 14: Cost of Planting trees and CO_2 reduction in Kangping-xian

Item	Total	Unit cost	Total cost
Tree	405,000	@1.5 Yuan	607,500 Yuan
Farm labour force	95,000	@15 Yuan per day	356,250 Yuan
City council and army officials	1,000		
CO_2 reduction cost of the project			12.22 Yuan/t

Notes: Wages for farm labour force are obtained from the local average wage. The actual workers for this project were volunteers in the nation's annual planting festival. It is reasonable to assume that one can plant four trees in 2 hours. City council and army officials are mainly transporting trees, water supply, and initial digging with machinery.

The cost of farm labour force is estimated from 2 hours $\times$ 95,000 $\times$ 15 Yuan/8 hours

CO_2 reduction cost is calculated as $(607,500 + 356,250)/78,880$ Yuan/t-CO_2.

We neglect expected revenues from selling timber after 20 years. It will reach 23 million Yuan, 1.2 million Yuan/year.

Sources: The private letter from Mr Wang Kezhen, the economy and trade attaché of Shenyang city government.

for the other district in the north, cold, and hence needing more energy, such as Shenyang, it is impossible to change energy consumption to natural gas or to oil so quick and so completely. But even if Shenyang would change energy pattern to oil or to natural gas, the cost of failure of the project is not significant. Because the price of bio-coal briquette shows relatively mild economies of scale when the production exceeds just 1% of the total coal consumption in Shenyang. Therefore, we can start relatively small sized plant for producing bio-coal briquette. The project of planting trees has almost no risk, but trees do not grow well. As the local participants can receive the product of forestation, they have reasonable incentives to take care of their forest. Furthermore, trees prevent wind from desertification of their cropping fields sited behind the forests close to the city.

Our calculation of bio-coal briquette is based on Shenyang's coal consumption. It can be extended to the whole Liaoning district. The results could be several times greater than those we have. Nevertheless, we should point out three issues to be remained for future research.

(1) Our results of CO_2 emission for bio-coal and for coal do not reflect retrospective effects of the emission included in the life cycle analysis. (2) The base line of CO_2 emission is based on the current coal consumption. People may consume higher quality coal, then the demand for bio-coal briquette will be different, and the cost of CO_2 reduction will change. If people would like to consume more LPG than

Table 15: Comparison to the other AIJ project in the US

Type	Country	Project	Duration Years	CO_2 reduction t-C/year	Reduction cost US$/t-C
Planting trees	Belize	Rio Bravo Carbon Pilot Project	40	41,072	1.58
Re-planting trees	Panama	Commercial re-forestation in the Chiriqqui Province	25	629	235.37
Wind power	Costa Rica	Tierras Morenas Windfarm Project	14	5,781	389.20
Hydropower	Costa Rica	Dona Julia Project	15	3,828	487.57
Geothermal power	Nicaragua	El Hoyo-Monte Galan Geothermal Project	38	101,336	39.24
Energy transformation	Czech Republic	City of Decin: Fuel-Switching for District Heating	27	6,133	48.31
Bio-coal briquette	China	Keio-RFP	–	—	82.76~ 278.54
Planting trees	China	Keio-RFP	20	1,076	5.43

Sources: Wake et al. [2001]

coal, the amount of bio-coal briquettes substituted for coal will be decreased. (3) There is uncertainty for thermal efficiency of bio-coal briquette. It will depend on type of stoves or kettles, which people usually use.

In spite of the remained issues, we hope that the project will continue and extend to a practical activity from an experiment. If there is no practical activity, CO_2 and SOx emissions in China shall not be reduced.

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