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Financial Analysis of Feasibility for a Heat Utilization System Using Rice Straw Pellets - Heating Energy Demand and the Collection and Storage Method in Nanporo, Japan

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Abstract**—**Rice straw pellets are a promising fuel as a renewable energy source. Financial analysis is needed to make a utilization system using rise straw pellets financially feasible, considering all regional conditions including stakeholders related to the collection and storage, production, transportation and heat utilization. We conducted the financial analysis of feasibility for a heat utilization system using rice straw pellets which has been developed for the first time in Nanporo, Hokkaido, Japan. Especially, we attempted to clarify the effect of factors required for the system to be financial feasibility, such as the heating energy demand and collection and storage method of rice straw. The financial feasibility was found to improve when increasing the heating energy demand and collecting wheat straw in August separately from collection of rice straw in November because the costs of storing rice straw and producing pellets were reduced. However, the system remained financially unfeasible. This study proposed a contractor program funded by a subsidy from Nanporo local government where a contracted company, instead of farmers, collects and transports rice straw in order to ensure the financial feasibility of the system, contributing to job creation in the region.

Keywords**—**Rice straw, pellets, heating energy demand, collection, storage.

I. Introduction

AGRICULTURAL residues such as wheat straw have been investigated as an important renewable energy source. In Asia, rice straw is abundantly available. About 9 million tons of rice straw is generated annually in Japan [1]. However, 70% of rice straw in Japan is left in paddy fields and naturally degrades into the paddy soil, following the banning of the open burning of rice straw in 1997. The degradation of rice straw results in the emission of methane and inhibits the growth of rice depending on the quality of the soil. Using rice straw as a renewable energy source would thus reduce the use of fossil fuels and the emission of methane gas as a greenhouse gas.

Although there are technologies that use the energy in rice straw, such as direct combustion, densification of rice straw to pellets or briquettes, gasification, pyrolysis, anaerobic digestion and bioethanol production [2], the present study focuses on the pelletization of rice straw because (1) rice straw needs to be stored for a long period since it can only be collected during a short period and (2) rice straw pellets can be used in popular stoves and boilers.

Financial analysis based on case studies is needed to make a utilization system using rice straw pellets financially feasible, considering all regional conditions related to the collection and storage, production, transportation, and heat utilization.

Rice straw pellets were first commercially produced (Fig. 1) in Nanporo, Hokkaido, Japan [3]. Rice straw is collected in November and stored during winter so as to dry. The rice straw pellets are used as a heat source at a public bathhouse. However, this system is not financially feasible because the bathhouse's demand for heating energy is limited and the collection and storage costs of rice straw are high owing to the need to collect a large amount of rice straw in November. These are critical factors required for the system to be financially feasible.

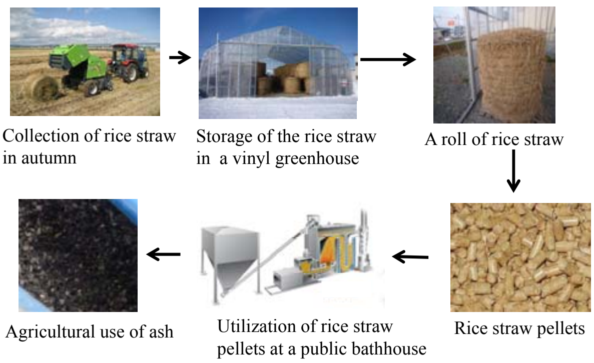

Fig. 1 Heat utilization system using rice straw pellets in Nanporo, Hokkaido, Japan

To increase the demand for rice straw pellets, the amount of rice straw pellets used by the public bathhouse needs to increase and other sources of demand need to be sought. Nanporo is planning the construction of a public heated swimming pool, which would increase the heating energy demand. Additionally, as a partial alternative to rice straw, wheat straw can be collected in August, reducing the collection and storage costs of the system. Finally, the local government of Nanporo could pay a contractor to collect and transport rice straw to improve the profitability of using rice straw pellets in heating.

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This paper reports a study on the financial feasibility of the heat utilization system using rice straw pellets in Nanporo. This study investigates the increase in profitability when increasing the heating energy demand and collecting wheat straw to partially replace rice straw as critical factors. The development of a contractor program funded by a subsidy from Nanporo local government is proposed to ensure the financial feasibility of the system. Finally, the study estimates the marginal price of heavy oil required for a subsidy to be unnecessary, considering a future increase in the oil price.

II. Methodology of Financial Analysis

A. Objectives and Boundaries of Evaluation

Fig. 2 shows that rice straw is collected as rolls and transported to a storage location (vinyl greenhouses) by farmers. As mentioned previously, because much rice straw needs to be collected in November, the use of wheat straw, which can be collected in August, is investigated in an effort to reduce collection and storage costs. A manufacturer, namely a wood processing company, manages the storage of rice straw for the drying and the production of rice straw pellets. Wood pellets are also produced from waste wood generated at the same location. The manufacturer delivers both rice straw pellets and wood pellets to users. This study assumes that the users are a public bathhouse (already existing) and a heated swimming pool (to be constructed); both use rice straw pellets (50%) and wood pellets (50%) in a pellet boiler because a clinker problem arises when burning only rice straw pellets. Ash is sold as a snow-melting material to be applied to paddy fields.

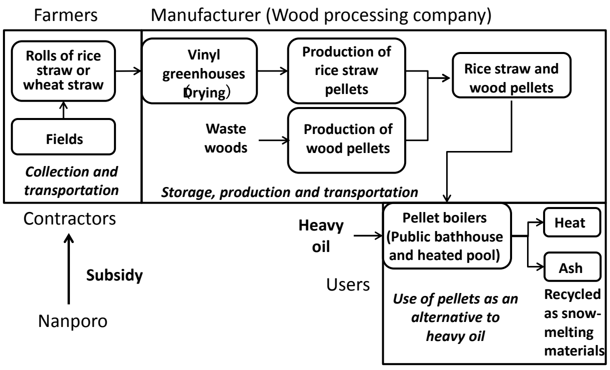

Fig. 2 System boundaries and the roles played by farmers, the manufacturer and users

B. Evaluation of Financial Feasibility

The financial feasibility of the system is evaluated under the following assumptions.

(1) Users use rice straw pellets when the total expenditure of rice straw pellets is less than that of heavy oil on the basis of the heat quantity. This study defines the critical price of rice straw pellets as the purchase price of rice straw pellets. The total expenditure includes the costs of boilers and other related equipment, maintenance costs and costs of rice straw pellets, wood pellets and heavy oil as fuels.

(2) The manufacturer sells the rice straw and wood pellets according to the purchase price of rice straw pellets to the users, which is defined as the selling price of rice straw pellets for the manufacturer. Considering all costs, from storage and production to transportation and profit, the manufacturer determines a purchase price of rice straw.

(3) Farmers determine a selling price of rice straw, considering all costs, such as costs of labor and the rental of dump trucks.

(4) This study considers the heat utilization system using rice straw pellets to be financially feasible if the selling price of rice straw for the farmers is not less than the purchase price for the manufacturer. If the selling price is less than the purchase price, a contractor program funded by a subsidy from Nanporo local government should be considered. This study estimates the size of the subsidy needed for the system to be financially feasible.

TABLE I
Setting the Heating Energy Demand

Case	Assumption	Heating energy demand GJ/y	Amount of rice straw t/y
Current situation	The existing public bathhouse uses 120 rolls of rice straw	463	24
Case 1	A third of the heating energy demand of the public bathhouse is changed from heavy oil to pellets.	4205	218
Case 2	In addition to the heating energy demand in case 1, half of the heating energy demand of the heated swimming pool is changed from heavy oil to pellets	4962	257

C. Setting the Heating Energy Demand

The public bathhouse's actual demand for heating energy from rice straw pellets is presently only 463 GJ/y, which corresponds to 24 t or 120 rolls of rice straw per year (with one roll being 200 kg). The public bathhouse cannot buy rice straw pellets because the pellets are more expensive than heavy oil. This study first considers the case that a third of the heating energy demand of the public bathhouse is changed from heavy oil to pellets (case 1), as shown in Table I. In case 1, the heating energy demand increases to 4205 GJ/y, corresponding to 218 t/y of rice straw. In case 2, in addition to the heating demand of the public bathhouse as stated in case 1, half of the heating energy demand of a heated swimming pool, which is yet to be constructed in Nanporo, is in the form of pellets, thus increasing the heating energy demand for pellets to 4962 GJ/y, corresponding to 257 t/y of rice straw.

D. Scenario Settings

Table II summarizes scenarios based on the heating energy demand and the collection and storage method. This study first evaluates the financial feasibility of the heat utilization system using rice straw pellets in case 1 described above when only rice straw is collected. This case is considered the base scenario for comparison. In scenario 1, the financial feasibility is evaluated again for case 1 but considering also the collection of wheat straw to reduce collection and storage costs. In scenario 2, the financial feasibility is evaluated for case 2 and only the collection of rice straw to determine the effect of increasing the heating energy demand. Scenario 3 investigates the marginal price of heavy oil considering the future increase in the price of oil required for the system to be financially feasible.

TABLE II
SCENARIO SETTINGS

	Base scenario	Scenario 1	Scenario 2	Scenario 3
Heating energy demand	case 1	case 1	case 2	case 1
Wheat straw utilization	-	Yes	-	-
Future marginal price of heavy oil	-	-	-	Yes

III. Estimation of Costs

A. Users (Tables III and VI)

The calculation conditions and equations for the users are given in Tables III and VI. The total expenditure for heavy oil comprises the fuel cost and the depreciation and maintenance costs of the boilers. The total expenditure for pellets comprises the costs of rice straw and wood pellets and the depreciation and maintenance costs of the pellet boilers. In the case of Nanporo, the pellet boiler was funded with a 100% subsidy from the Japanese government. The labor cost is negligible because the operator can operate the boilers while performing other duties [5].

B. Manufacturer (Tables IV and VII)

The calculation conditions and equations for the manufacturer are given in Tables IV and VII. As mentioned previously, the manufacturer sells rice straw and wood pellets at the selling price of pellets and this price is the same as the purchase price of pellets for the users. The purchase price of rice straw as a raw material is determined by subtracting the storage cost, the pellet production cost, the cost of transporting pellets to users and profit from the selling price of pellets.

C. Farmers (Tables V and VIII)

The calculation conditions and equations for farmers are given in Tables V and VIII. The selling price of rice straw is calculated considering the collection of rice straw to make rolls and transportation of rolls to the storage location and labor costs. The maintenance costs for heavy machines are considered negligible according to the results of surveys [5].

IV. Results and Discussion

The cost estimations for the users, manufacturer, and farmers are given in Tables VI-VIII. Fig. 3 shows comparison of the price based on the cost estimations. The selling price of pellets, whose unit is JPY/kg-pellets, was determined by summing the purchase cost of straw, the storage, production and transportation costs and profit. The selling price of straw and the purchase price of straw were compared after changing the unit to JPY/kg-straw, considering the residue ratio of 20%.

TABLE III
CALCULATION CONDITIONS FOR USERS

Items	Symbol	Value	Unit	Reference
Heat quantity				
Rice straw	Ca_{rice}	13.00	MJ/kg	[3]
Wheat straw	Ca_{wheat}	13.81	MJ/kg	[5]
Wood	Ca_{wood}	15.37	MJ/kg	[5]
Heavy oil	Ca_{oil}	37.1	MJ/L	[5]
Investment costs				
Pellet boiler	$C_{pellet\ boiler}$	49,320,000	JPY	[5]
Heavy-oil boiler	$C_{oil\ boiler}$	7,000,000	JPY	[5]
Other equipment related to pellet boiler	$C_{others\ burning}$	4,070,000	JPY	[5]
Subsidy for pellet boiler	$S_{pellet\ boiler}$	100	%	
Boiler capacity and efficiency				
Pellet boiler capacity	$Pe_{pellet\ boiler}$	1465	MJ/h	[5]
Efficiency	$Ef_{pellet\ boiler}$	85	%	[5]
Heavy-oil boiler capacity	$Pe_{oil\ boiler}$	2722	MJ/h	[5]
Efficiency	$Ef_{oil\ boiler}$	85	%	
Lifetime				
Pellet boiler	$Li_{pellet\ boiler}$	15	y	[5]
Heavy-oil boiler	$Li_{oil\ boiler}$	10	y	[5]
Other equipment related to pellet boiler	$Li_{others\ burning}$	15	y	[4]
Maintenance costs				
Pellet boiler	$C'_{pellet\ boiler}$	500,000	JPY/y	[4]
Heavy-oil boiler	$C'_{oil\ boiler}$	150,000	JPY/y	[5]
Ash generation ratio				
Rice straw	$Q_{rice\ ash}$	0.1489		[5]
Wheat straw	$Q_{wheat\ ash}$	0.0652		[5]
Wood	$Q_{wood\ ash}$	0.0021		[5]
Price of ash as snow-melting material	In_{ash}	6	JPY/kg	[5]
Amount of heavy oil used				
Public bathhouse	$Q_{oil\ burning}$	400,000	L/y	[5]
Heated swimming pool	$Q'_{oil\ burning}$	48,000	L/y	[5]
Price of heavy oil	C_{oil}	70.5	JPY/L	[5]
Ratio of pellets				
Rice straw	$R_{rice\ burning}$	50 or 40	%	
Wheat straw	$R_{wheat\ burning}$	0 or 10	%	
Wood	$R_{wood\ burning}$	50	%	

A. Base Scenario

The purchase price of pellets for the public bathhouse that is equivalent to heavy oil on the basis of heat quantity was 25.3 JPY/kg-pellets, as shown in Fig. 3. The purchase price of rice straw for the manufacturer can be determined as 9.3 JPY/kg-straw by subtracting the storage, production and transportation costs. However, the selling price of rice straw for the farmers was 13.4 JPY/kg-straw, which was less than the purchase price of rice straw for the manufacturer.

Although the demand for rice straw demand is 218 t/y in the base scenario compared with 24 t/y in the current situation, this was still less than the pellet production capacity of 416 t/y, and the production cost per pellet is therefore not minimal and the base scenario was not thus financially feasible.

TABLE IV
CALCULATION CONDITIONS FOR THE MANUFACTURER

Items	Symbol	Value	Unit	Reference
Investment costs				
Vinyl greenhouse	$C_{plastic\ greenhouse}$	1.5	Million JPY	[5]
Crusher	$C_{crusher}$	500,000	JPY	[5]
Pelletizer	$C_{pelletizer}$	11.8	Million JPY	[5]
Wrapping machine	$C_{wrapping}$	1.82	Million JPY	[5]
Roll splitter	C_{roll}	500,000	JPY	[5]
Other equipment	$C_{others\ manufacture}$	4.55	Million JPY	[5]
Dump truck (2 t)	C_{truck}	1.5	Million JPY	
Subsidy	$S_{pelletizer}$	100	%	
Capacity and performance				
Area required for storage of rice straw	$La_{keeping}$	0.72	m^2/roll	[5]
Storage capacity of vinyl greenhouse	$Q_{plastic\ greenhouse}$	150	roll/vinyl green house	[5]
Performance of crusher	$Pe_{crusher}$	5400	kg/h	[5]
Performance of pelletizer	$Pe_{pelletizer}$	200	kg/h	[5]
Ratio of residue	$L_{pelletizer}$	20	%	[5]
Performance of wrapping machine	$Pe_{wrapping}$	4000	kg/h	[5]
Performance of roll splitter	Pe_{roll}	200	kg/h	
Performance of hand splitting	Pe_{manual}	40	kg/h	[5]
Operating hours	$T_{manufacture}$	8	h/d	[5]
Operating days	$Day_{manufacture}$	260	d/y	[5]
Lifetime				
Vinyl greenhouse	$Li_{plastic\ greenhouse}$	14	y	[5]
Crusher	$Li_{crusher}$	15	y	[4]
Pelletizer	$Li_{pelletizer}$	15	y	[4]
Wrapping machine	$Li_{wrapping}$	15	y	[4]
Roll splitter	Li_{roll}	15	y	
Other equipment	$Li_{others\ manufacture}$	15	y	[4]
Dump truck (2 t)	Li_{truck}	4	y	
Maintenance costs				
Vinyl greenhouse	$C'_{plastic\ greenhouse}$	0	JPY/y	[5]
Crusher	$C'_{crusher}$	150,000	JPY/y	[5]
Pelletizer	$C'_{pelletizer}$	150,000	JPY/y	[5]
Wrapping machine	$C'_{wrapping}$	0	JPY/y	[5]
Roll splitter	C'_{roll}	100,000	JPY/y	
Other equipment	$C'_{others\ manufacture}$	0	JPY/y	[5]
Dump truck (2 t)	C'_{truck}	80,000	JPY/y	
Other costs				
Labor cost for storage	$P_{keeping}$	0	JPY/kg	[5]
Land tenancy	$C_{keeping}$	0	JPY/m^2	
Labor cost for production	$P_{manufacture}$	6.3	JPY/kg	
Labor cost for transportation	$P_{pellet\ transport}$	0.8	JPY/kg	
Fuel cost for transportation	$F_{pellet\ transport}$	0.15	JPY/kg	
Existing facilities				
Vinyl greenhouse	$E_{plastic\ greenhouse}$	2		[5]
Crusher	$E_{crusher}$	1		[5]
Pelletizer	$E_{pelletizer}$	1		[5]
Wrapping machine	$E_{wrapping}$	1		[5]
Roll splitter	E_{roll}	0		[5]
Other equipment	$E_{others\ manufacture}$	1		[5]
Dump truck (2 t)	$E_{2t\ truck}$	1		
Profit	$Pr_{manufacture}$	0	%	[4]

TABLE V
CALCULATION CONDITIONS FOR FARMERS

Items	Symbol	Value	Unit	Reference
Heavy machines				
Tractor	$C_{tractor}$	10.0	Million JPY	[5]
Tedder rake	$C_{tedder\ rake}$	0.98	Million JPY	[5]
Roll baler	$C_{roll\ baler}$	7.0	Million JPY	[5]
Rental of dump truck (10 t)	$C_{10\ t\ truck}$	50,000	JPY/8h	Including driver and fuel costs
Front loader	$C_{front\ loader}$	1.25	Million JPY	[5]
Rice straw roll				
Weight of roll	W_{roll}	200	kg/roll	[4]
Yield ratio of rice straw per field	Q_{gather}	4,000	kg/ha	[4]
Work efficiency of heavy machines				
Tractor	$T_{tractor}$	200	min/ha	[4]
Roll baler	$T_{roll\ baler}$	100	min/ha	[4]
Front loader	$T_{front\ loader}$	6	min/roll	
Dump truck (10 t)	$T_{10\ t\ truck}$	0.7	min/roll	
Lifetime				
Tractor	$Li_{tractor}$	7	y	[5]
Tedder rake	$Li_{tedder\ rake}$	7	y	[5]
Roll baler	$Li_{roll\ baler}$	7	y	[5]
Front loader	$Li_{front\ loader}$	4	y	[5]
Labor costs				
Collection	P_{gather}	8.89	JPY/kg	[4]
Front loader	$P_{front\ loader}$	0.81	JPY/kg	[4]

B. Scenario 1

In scenario 1, wheat straw is used to partially replace the use of rice straw, where the ratio of wheat straw to rice straw is 1:4. Fig. 3 shows that since the purchase price of rice and wheat straw for the manufacturer (10.5 JPY/kg-straw) was still less than the selling price of rice and wheat straw for the farmers (13.4 JPY/kg-straw), scenario 2 was not financially feasible, although the financial feasibility of scenario 2 was better than that of the base scenario. The collection of wheat straw in August reduces the number of vinyl greenhouses required for storage, thus reducing the storage cost. In addition, the heat quantity of wheat straw is greater than that of rice straw. This increases the selling price of pellets from 25.3 to 25.6 JPY/kg-pellets.

C. Scenario 2

In scenario 2, the heating energy demand of the heated swimming pool is added, thus increasing the use of rice straw from t/y to 257 t/y. Since the purchase price of rice straw for the manufacturer (9.8 JPY/kg-straw) was less than the selling price of rice straw for the farmers (13.2 JPY/kg-straw), as shown in Fig. 3, scenario 2 was not financially feasible. However, the financial feasibility was better than that in the base scenario because the production cost was reduced by the increase in pellet production. Pellet production should be increased to at least 416 t/y to ensure the financial feasibility of the heat utilization system using rice straw pellets.

TABLE VI
ESTIMATED COSTS FOR USERS

Items	Symbol	Rice straw		Rice + Wheat straw	Oil price 85 JPY/L	Unit
		Public bathhouse	Swimming pool	Public bathhouse	Public bathhouse	
1. Heavy oil boiler						
Number of boilers						
	C_9	1	1	1	1	
Amount of heavy oil						
	C_{10}	133.3	24.0	133.3	133.3	kL/y
	Public bath: $Q_{oil\ burning}/3$ Heated pool: $Q'_{oil\ burning}/2$					
Operational costs	C_{11}	0.85	0.85	0.85	0.85	Million JPY/y
	=Maintenance costs + depreciation cost = $C'_{oil\ boiler}*C_9+C_{oil\ boiler}/Li_{oil\ boiler}*C_9$					
Operational costs per unit of heavy oil						
	$C_{12}=C_{11}/C_{10}$	6.4	35.4	6.4	6.4	JPY/L
Price of heavy oil						
	C_{oil}	70.5	70.5	70.5	85	JPY/L
Total expenditure of heavy oil						
	$C_{13}=C_{12}+C_{oil}$	76.9	105.9	76.9	91.4	JPY/L
Total expenditure of heavy oil (based on the heat quantity)						
	$C_{14}=C_{13}/Ca_{oil}$	2.07	2.85	2.07	2.46	JPY/MJ
2. Pellet boiler						
2-1 Total expenditure of pellets						
Heat quantity supplied by pellets						
	C_5	4,205	757	4,205	4,205	GJ/y
	Public bath: $C_{10}*Ca_{oil}*Ef_{oil\ boiler}/100$, Heated pool: $C_{10}*Ca_{oil}*Ef_{oil\ boiler}/100$					
Heat quantity of pellets including rice straw, wheat straw and wood pellets						
	C_4	14.2	14.2	14.3	14.2	MJ/kg
	$= Ca_{rice}*R_{rice\ burning}/100+Ca_{wheat}*R_{wheat\ burning}/100+Ca_{wood}*R_{wood\ burning}/100$					
Amount of pellets						
	C_{20}	349	63	347	349	t/y
	$=C_5/C_4*100/Ef_{pellet\ boiler}$					
Detail amounts of pellets						
Rice straw pellets						
	C_{21}	174	31	139	174	t/y
Wheat straw pellets						
	C_{22}	0	0	35	0	t/y
Wood pellets	C_{23}	174	31	139	174	t/y
Total expenditure of pellets corresponding to heavy oil based on the heat quantity						
	$C_{24}=C_{14}*C_4$	29.4	40.5	29.6	34.9	JPY/kg
2-2 Operational costs for pellets boiler						
Number of pellet boiler						
	C_{18}	1	1	1	1	
Number of other equipment related to pellets boiler						
	C_{19}	1	1	1	1	
Operational costs	C_{25}	0.61	0.74	0.63	0.61	Million JPY/y
	= -income from selling ash + depreciation cost+ maintenance costs					
	$= -In_{ash}*(Q_{rice\ ash}*C_{21}+Q_{wheat\ ash}*C_{22}+Q_{wood\ ash}*C_{23}) + C_{pellet\ boiler}/Li_{pellet\ boiler}*(100-S_{pellet\ boiler})/100*C_{18}+C'_{pellet\ boiler}*C_{16} + C_{others\ burning}/Li_{others\ burning}*C_{19}+C'_{others\ burning}*C_{17}$					
Operational costs per unit of pellets						
	$C_{26}=C_{25}/C_{20}$	1.8	11.8	1.8	1.8	JPY/kg
2-3 Purchase price of pellets						
	$C_{27}=C_{24}-C_{26}$	27.6	28.7	27.7	33.2	JPY/kg

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TABLE VII
ESTIMATED COSTS FOR THE MANUFACTURER

Items	Symbol	Base scenario	Scenario 1	Scenario 2	Scenario 3	Unit
1. Storage						
Purchase amount of rice straw = $C_{21}/(1-L_{pelletizer}/100)$						
	B_1	218	173	257	218	t/y
Purchase amount of wheat straw = $C_{22}/(1-L_{pelletizer}/100)$						
	B_2	0	43	0	0	t/y
Number of rice straw rolls						
$B_4=B_1/W_{roll}$		1090	867	1286	1, 090	roll
Number of wheat straw rolls						
$B_5=B_2/W_{roll}$		0	217	0	0	roll
Required number of vinyl greenhouses						
	B_6	8	6	9	8	house
$=ROUNDUP(B_4/Q_{plastic\ greenhouse},0)$						
Number of new vinyl greenhouses						
	B_7	6	4	7	6	
= the required number - the existing number = $B_6-E_{plastic\ greenhouse}$						
Storage cost						
	B_{31}	0.64	0.43	0.75	0.64	Million JPY/y
= Labor costs + Land tenancy + depreciation cost + maintenance costs						
$=P_{keeping}*(Q_{rice\ keeping}+Q_{wheat\ keeping})+C_{keeping}*La_{keeping}*(B_4+B_5)+C_{plastic\ greenhouse}*B_7/Li_{plastic\ greenhouse}+E_{plastic\ greenhouse}*C'_{plastic\ greenhouse}$						
Storage cost per unit weight						
	B_{32}	3.7	2.5	3.6	3.7	JPY/kg-pellets
$=B_{31}/(B_1+B_2)/(1-L_{pelletizer}/100)$						
2. Production of pellets						
Number of required machines						
Roll splitter	B_{22}	1	1	1	1	
Crusher	B_{19}	1	1	1	1	
Pelletizer	B_{20}	1	1	1	1	
Wrapping machine	B_{21}	1	1	1	1	
Other equipment	B_{23}	1	1	1	1	
Number of new machines						
Roll splitter	B_{27}	1	1	1	1	
Crusher	B_{24}	0	0	0	0	
Pelletizer	B_{25}	0	0	0	0	
Wrapping machine	B_{26}	0	0	0	0	
Other equipment	B_{28}	0	0	0	0	
Operational costs	B_{33}	1.49	1.48	1.69	1.49	Million JPY/y
= Labor costs + maintenance costs + depreciation cost						
$=P_{manufacture}*(C_{21}+C_{22})+(C'_{crusher}*E_{crusher}+C'_{pelletizer}*E_{pelletizer}+C'_{roll}*B_{22})+(C_{crusher}/Li_{crusher}*B_{24}+C_{pelletizer}/Li_{pelletizer}*B_{25}+C_{wrapping}/Li_{wrapping}*B_{26}+C_{roll}/Li_{roll}*B_{27}+C_{others\ manufacture}/Li_{others\ manufacture}*B_{28})*(100-S_{pelletizer})/100$						
Operational cost per unit weight						
	B_{34}	8.5	8.6	8.2	8.5	JPY/kg-pellets
3. Transportation						
Number of required dump trucks (2 t)						
	B_8	1	1	1	1	
Number of new dump trucks (2 t)						
	B_9	0	0	0	0	
Transportation cost						
	B_{35}	0.25	0.25	0.28	0.25	Million JPY/y
= Labor costs + Fuel cost + maintenance costs = $(P_{pellet\ transport}+F_{pellet\ transport})*(C_{21}+C_{22})+C_{truck}*B_9+C'_{truck}*B_8$						
Transportation cost per unit weight						
	B_{36}	1.4	1.4	1.4	1.4	JPY/kg-pellets
4. Purchase price of rice straw						
Total expenditure						
	B_{37}	13.7	12.5	13.2	13.7	JPY/kg-pellets
$=B_{32}+B_{34}+B_{36}$						
Selling price of pellets						
	$B_{38}=C_{27}$	27.6	27.7	27.8	33.2	JPY/kg-pellets
Total income	B_{39}	9.64	9.62	11.4	11.6	Million JPY
$=C_{27}*(C_{21}+C_{22}+C_{23})$						
Selling price of pellets based on the heat quantity						
Rice and wheat straw pellets						
	B_{43}	25.3	25.6	25.5	30.4	JPY/kg-pellets
Wood pellets						
	B_{44}	29.9	29.9	30.1	35.9	JPY/kg-pellets
Profit	B_{45}	0	0	0	0	JPY/kg-pellets
	$=B_{43}-B_{43}/(100+Pr_{manufacture})*100$					
Purchase price of rice and wheat straw						
	B_{47}	9.3	10.5	9.8	13.4	JPY/kg-straw
	$=(B_{43}-B_{37}-B_{45})*(1-L_{pelletizer}/100)$					

D. Contractor Program Supported by a Subsidy

The difference between the selling price for the farmers and the purchase price for the manufacturer can be addressed in the form of a subsidy provided by the local government of Nanporo. Table IX shows that the subsidy required is estimated at 893,800 JPY in the base scenario and 873,800 JPY in scenario 2. Assuming that Nanporo begins a contractor program, where the collection and transportation of rice straw are carried out by the contractor instead of farmers, a new business worth between 2,900,000 and 3,400,000 JPY can be created. This program can be implemented by linking other public programs of regional promotion.

E. Effect of a Future Increase in the Price of Heavy Oil

The price of heavy oil for the public bathhouse is 70.5 JPY/L but might increase in the future. This study estimates the marginal price of heavy oil required for the selling price for the farmers to be the same as the purchase price for the manufacturer, thus making the system financially feasible. Fig. 3 shows that when the price of heavy oil is 85.0 JPY/L, the selling price of pellets increases up to 30.3 JPY/kg-pellets and the purchase price of rice straw for the manufacturer increases to 13.4 JPY/kg-straw. In this case, no subsidy is needed.

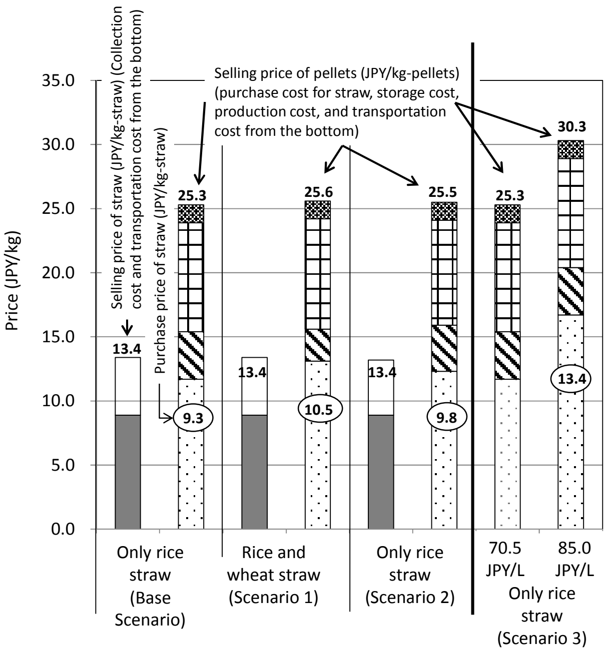

Fig. 3 Comparison of the selling and purchase prices of rice and wheat straw

TABLE VIII
ESTIMATED COSTS FOR FARMERS

Items	Symbol	Base scenario	Scenario 1	Scenario 2	Unit
1. Collection					
Area for collection					
	$A_1=B_1/Q_{gather}$	54.5	43.3	64.3	ha
Operating time of heavy machines					
Tractor	$A_4 = A_1*T_{tractor}/60$	182	144	214	h
Roll baler	$A_5 = A_1*T_{roll\ baler}/60$	91	72	107	h
Number of required heavy machines					
Time for collection	A_6	16	16	16	h
Tractor	A_7 = ROUNDUP(A_4/A_6)	12	10	14	
Tedder rake	$A_8=A_7$	12	10	14	
Roll baler	A_9 = ROUNDUP(A_5/A_6)	6	5	7	
Number of new heavy machines					
Tractor	A_{10}	0	0	0	
Tedder rake	A_{11}	0	0	0	
Roll baler	A_{12}	0	0	0	
Labor costs	P_{gather}	8.89	8.89	8.89	JPY/kg
Collection cost	$A_{20} = P_{gather}*(Q_{rice\ gather}+Q_{wheat\ gather})$	1.94	1.93	2.29	Million JPY/y
2. Transportation					
Operating time of front loader and dump truck (10 t)					
	$A_{13} = (B_4+B_5)/60*(T_{front\ loader}+T_{10\ t\ truck})$	121.1	120.4	142.9	h
Number of required heavy machines					
Front loader	A_{14}	2	2	2	
Dump truck (10 t)	A_{15}	1	1	1	
Number of rental heavy machines					
Front loader	A_{16}	0	0	0	
Dump truck (10 t)	A_{17}	1	1	1	
Days for rental					
Dump truck (10 t)	A_{19} = ROUNDUP($A_{13}/8/A_{17}$,0)	16	16	18	days
Transportation cost	$A_{22} = P_{front\ loader}*(B_1+B_2)+C1_{0\ t\ truck}*A_{15}*A_{19}$	0.98	0.98	1.11	Million JPY/y
Transportation cost per weight	A_{23}	4.5	4.5	4.3	JPY/kg-straw
3. Sum of collection and transportation costs					
Rice and wheat straw	$A_{24} = P_{gather}+A_{23}$	13.4	13.4	13.2	JPY/kg-straw
Rice and wheat rolls	A_{25}	2675	2679	2640	JPY/roll

TABLE IX
SUBSIDY REQUIRED FROM NANPORO LOCAL GOVERNMENT AND JOB CREATION

	Case 1 (Base scenario)	Case 2 (Scenario 2)
Subsidy required from Nanporo local government	4.1 JPY/kg×218×10^3 kg= 893,800 JPY/y	3.4 JPY/kg×257×10^3 kg= 873,800 JPY/y
Wages of jobs created in contracting program	13.4 JPY/kg×218×10^3 kg= 2,920,000 JPY/y	13.2 JPY/kg×257×10^3 kg= 3,390,000 JPY/y

V. CONCLUSION

(1) An increase in the heating energy demand assumed in this study was not enough to ensure the financial feasibility of the heat ut ilization system using rice straw pellets in Nanporo, Hokkaido, Japan. A subsidy of about 900,000 JPY is required from Nanporo local government.
(2) The collection of wheat straw improved the financial feasibility by reducing the storage cost.
(3) This study p roposed a co ntractor program, where a contracted company instead of farmers collects and transports rice straw. If the subsidy from Nanporo local government is used to t he finance such as the p rogram, jobs can be created with wages from 2,900,000 to 3,400,000 JPY depending on the scale of the program.
(4) A future increase in the price of heavy oil improved the financial feasibility of the system. A subsidy from Nanporo local government would not be needed in this case.

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(2) Resource recovery and storage at landfill sites
2. Development of biomass utilization systems
(1) Biogas systems using food waste, sewage sludge and manure.
(2) Heat utilization systems using wood and rice straw pellets.
3. Soil and groundwater contamination and remediation
(1) Numerical simulation of contaminant transport and fate in groundwater
(2) Development of biological treatment