# OPTIMAL USE OF BIOMASS IN AN ISOLATED ENVIRONMENT: CASE STUDY AT MIYAKO ISLAND, JAPAN

By

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**KEYWORDS: Biomass, Refinery System, Conversion.**

## Abstract

THIS PAPER briefly outlines an ongoing research project and some research outcomes focusing on sugarcane. Five research topics were identified, namely 1) development of technologies for farmland application of converted biomass from sugarcane molasses such as compost, char, digestive slurry and vinasse, 2) clarification of optimal allocation of biomass and optimal operational conditions for conversion plants, 3) development of groundwater conservation technologies with biomass, mainly focusing on nitrogen, 4) development of technologies for introduction of energy crops and optimal $CO_2$ gas application to crops, and 5) clarification of favourable conditions for sugar-ethanol by-production systems using greater-biomass sugarcane. Our target biomasses are bagasse and cattle wastes. Five conversion plants, including two pyrolysis, one composting, one bio-gas and one gasification, have already been installed to properly and effectively convert biomass. Farmland application technologies for char and digestive slurry with bagasse have mainly been studied. Secondly, vinasse (bio-ethanol by-product; distilled residue) is another biomass target. We analysed vinasse for return of by-products back to the farmland as a way to achieve sustainability and devote efforts to the application of vinasse to farmland. Of course, safety to crops, the soil and water environment should be confirmed first. Previous experiments revealed vinasse does not have bad impacts on crop growth. Thirdly, we conducted studies to clarify the favourable conditions for introduction of greater biomass sugarcane to develop sugar-ethanol by-production systems. A favourable new variety of sugarcane was previously selected. In addition, a sugar-yield equation for great-biomass sugarcane was developed from observed data.

## Introduction

### Background

Japan produces an average of about 1 million tonnes of sugarcane each year. Approximately 30% of this is produced on Miyako Island in southern Japan, 1500 km from the capital Tokyo. On this island, agriculture is the major industry followed by tourism. Sugarcane is the major crop on the island with beef cattle breeding as the next most important agricultural activity.

Recently, bio-ethanol production from sugarcane molasses has been supported by the Ministry of Environment (MOE) of Japan as a special project, called ‘E3 Project’ on Miyako Island. The aim was for an integrated project, with sugarcane as the feedstock for ethanol and all by products from all industries would be returned back to the farmland to achieve sustainability. This meant that the by-products of the bio-ethanol manufacturing process were to be applied back on the fields, providing the safety of the materials could be completely assured, i.e. an absence of hazardous materials such as heavy metals, poisonous materials, etc.

### Objectives

The Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan has supported this project named ‘Rural Biomass Research Project, Biomass utilisation model, Cm6000’ for

approximately three years, commencing 2007. In this paper, the framework of the research project and some outcomes and their use are discussed.

## Methodology

Miyako Island is located in southern Japan, and was selected as the appropriate site for the project. The total area of the island is about 140 $km^2$ and the population was approximately 47 000 as of January 2001. Fifty two percent of the area is farmland. The maximum elevation on the island is only 114.6 m, land is geo-physically almost flat and there are no big rivers. The climate is semi-tropical (average temperature 23°C, average humidity 80%) with an annual precipitation of 2400 mm. Most of this precipitation is brought by typhoons and residents suffer from occasional droughts.

Agriculture is the major industry, with sugarcane production alone averaging 300 000 tonnes annually, which accounts for almost 30% of the total Japanese sugarcane production. Tobacco, vegetables and beef are also produced, but almost all other food products are imported from mainland Japan and other islands in the Okinawa region.

The main crops and typical annual biomass production for each of the islands are listed in Table 1.

**Table 1—**Main biomass on Miyako Island (2005).

| | | |
|---|---|---|
| Crop (tonnes) | Sugarcane | 173 100 |
| | Tobacco | 1217 |
| | Wax gourd | 1127 |
| | Pumpkin | 505 |
| | Sweet potato | 609 |
| | Mango | 217 |
| Pasture (tonnes) | Rosegrass | 41 138 |
| Livestock (head) | Cattle | 11 672 |
| | Swine | 923 |
| | Chicken | 23 513 |

The soil on the island is almost neutral or alkaline and has a loamy texture (Shimajiri Maji-soil). Maji soil has a high clay content but relatively high permeability ($10^{-4}$ cm/s). Because there are almost no mountains, the major water resource is groundwater. The island residents are concerned about the groundwater, not only its quantity but also its quality. Some sub-surface dams were constructed in the 1990s as a national irrigation project to effectively use the groundwater. After construction of sub-surface dams, farmers became enthusiastic about commercial and intensive agriculture.

The outcome of increased availability of water was that farmers attempted to increase productivity and increased the use of chemical fertilisers. This resulted in worsening of the groundwater quality. More recently, many farmers are attempting to reduce the amount of chemical fertilisers they apply and, in addition, they are compelled to properly manage livestock wastes (manure).

The target waste biomass for this project was determined to be sugarcane bagasse and cattle waste, as they are the two types of biomass available in large amounts. According to the Miyakojima Biomass Town Plan (2003), these two biomasses account for about 80% of the total amount of the whole island with a dry weight mass equal to 50 000 tonnes of carbon (C) each year on the island.

## Project strategies

The Rural Biomass Research Project, Biomass Utilisation Model focused on five research topics, namely:

1) Development of reuse technologies for converted biomass and vinasse from bio-ethanol production,
2) Defining optimal operational conditions for the biomass conversion facilities,
3) Development of technologies for protection of groundwater from contamination with agricultural wastes,
4) Introduction of energy crops taking into consideration sustainability,
5) Determination of installation conditions for larger biomass-sugarcane to develop sugar-ethanol by-production systems.

Pilot (test) scale conversion facilities, namely two pyrolysis systems, one bio-gas system, one gasification system and one composting system, have already been installed on the island (Figure 1). We can obtain energy and materials (charcoal, acid vinegar, anaerobic digestive slurry, compost) after conversion of biomass from these facilities. We hope to apply the materials recovered from the biomass to farmland for sustainable agriculture and to increase productivity. In addition, we hope to develop technology enabling the reuse of the vinasse, a by product of bio-ethanol production. The conversion facilities should be thought as one system. Each conversion facility should link with energy and materials already used. It is necessary for us to operate the conversion 'systems' optimally. How shall we achieve this, taking into consideration environmental issues? What is the best way to allocate biomass among the facilities?

On the island, groundwater is a unique water resource and it is crucial for residents that the quality of groundwater is conserved. Chemical fertilisers and cattle wastes are the main sources of nitrogen pollution of groundwater sources on the island (Fujie Rie *et al.*,2008)). We need to achieve water quality conservation technologies with biomass. For example, charcoal from bagasse can absorb nitrate nitrogen, reported as one of the crucial contaminants of the groundwater. The question is how to reduce contamination of the water with biomass? We need to develop technologies and scenarios.

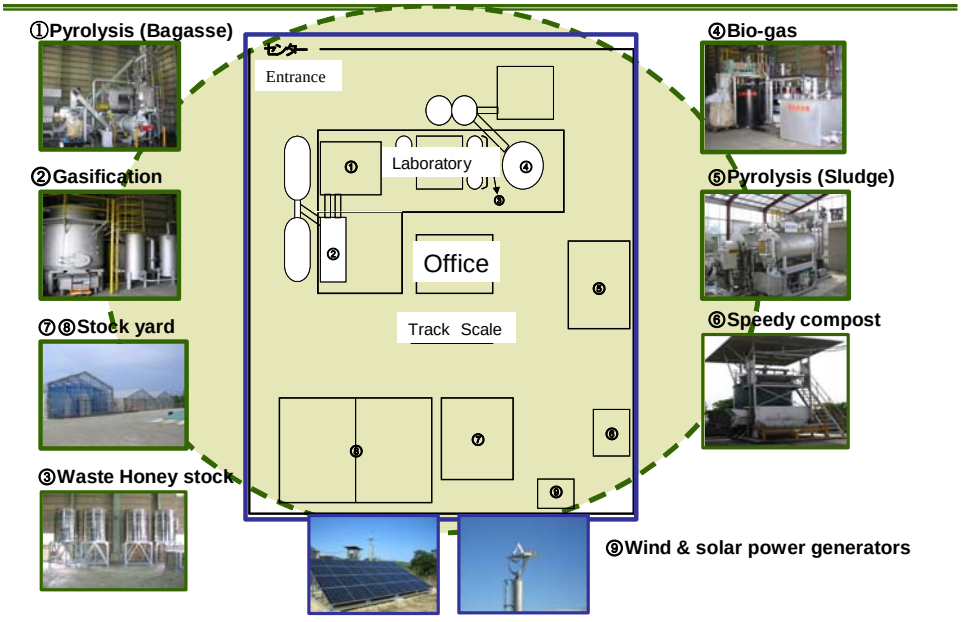


Fig. 1—Biomass refinery systems on Miyako Island, Japan.

At this point in time, sugarcane molasses is the only feedstock for bio-ethanol production. We hope to propose additional energy crops to allow the conversion facilities to operate as optimally as possible throughout the year.

From the agricultural side, it is necessary to optimise the soil and water to achieve sustainability. Sweet sorghum, sweet potatoes and cassava are favourable crops we anticipate

introducing. The issue is how to introduce these crops, taking into consideration the sustainability issue of nutrient management based on traditional agricultural machinery systems. Farmers expect additional economic benefits from growing these crops.

An additional consideration is that $CO_2$ is obtained from various conversion processes. While $CO_2$ is one GHG (Green House Gas), it is also necessary for crop photosynthesis and production. Is it possible to increase productivity with $CO_2$ application to crops from the conversion process?

The final consideration is that high-biomass sugarcanes have been developed by our group (National Agricultural Research Center of Kyushu-Okinawa; NARCKY). We hope to use these canes as the basis for a sugar-ethanol production system, with the strategies being developed for the introduction of the system.

This research project has been carried out by researchers at (NIRE), NARCKY, University of Ryukyu, Okinawa Agricultural Research Center, Non Profitable Organisations, Semi-tropic Biomass Use Research Center and Asahi Breweries Ltd. as well as scientists from various other research fields. In the NPOs, many members are from private companies in Japan. We have been exchanging various kinds of information among central (Ministry of Cabinet) and provincial governments (namely Prefecture of Okinawa and Miyakojima City). This research project is achieved by industries, institutes and governments.

**Main research outcomes**

The project is now over half way through its life, and some outcomes have already been reported in domestic publications, as well as at various domestic and international technical meetings. Outcomes to date have included:

**Nitrate nitrogen loads from chemical fertilisers and cattle wastes (Fujie Rie *et al.*, 2008)**

Nitrate nitrogen is a major contributor to groundwater contamination on the island. The main agricultural nitrogen resources are chemical fertiliser (applied to farmland) and improper cattle waste management (Miyakojima Biomass Town Paper).

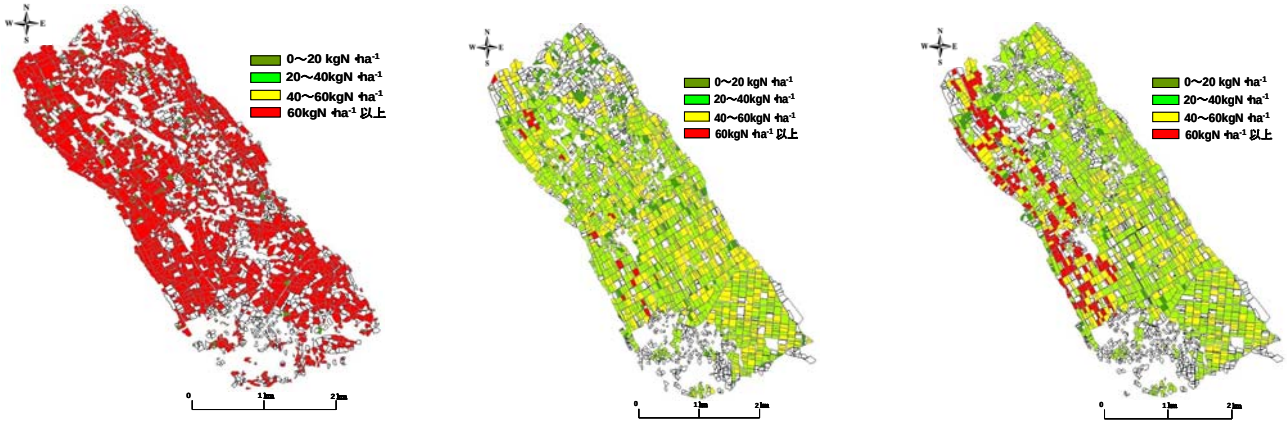


Fig. 2—Nitrate nitrogen loads at Sunagawa groundwater-basin in 1977, 1994 and 2005, respectively（Fujie Rie *et al.*, 2008）

Parameters relating to cropping and agriculture in the Sunagawa Groundwater Basin on the Island were defined and entered into a database using GIS. A **De**N**i**trification and **De** **C**omposition (DNDC) model was used to estimate the leached nitrate nitrogen from the soil associated with each crop. The estimates were used in the database to estimate the amount of nitrate nitrogen leached throughout the basin. The cropping conditions for each year studied were entered in a database, using GIS to properly identify changes.

Figure 2 shows the calculated results of leached nitrate nitrogen in 1977, 1994 and 2005, respectively. The estimations indicate that the leached nitrate nitrogen fluctuates with changes in land use and agricultural parameters such as chemical fertiliser application amount and type of crop.

Calculations of nitrogen concentrations in percolated water indicate that nitrogen can quantitatively explain the changes in groundwater quality. We can, therefore, quantify the contamination load from agriculture.

In the future, trial calculations of leached nitrate nitrogen based on various cropping conditions and agricultural performances will be carried out and applied as a basin-level management method to manage agricultural activities while considering groundwater conservation.

**1) Impacts of farmland application of converted biomass**

Anaerobic digested slurry and charcoal from bagasse were applied to farmland to assess the impact on crop growth, which was assessed from both plots and field lysimeters (Chen Yan and Shinogi Yoshiyuki, 2007; Chen Yan *et al*., 2007; Chen Yan and Shinogi Yoshiyuki, 2005).

Application of charcoal from bagasse increased the production of sugarcane and other vegetables. It improved the root-zone soil physical properties by improving soil-water holding capacity and permeability, as well as other parameters, with the improvements continuing for at least 55 months after application. In addition, charcoal absorbed nitrate nitrogen and application of charcoal from bagasse reduced nitrate nitrogen loads to the groundwater. Therefore, charcoal from bagasse may be used to reduce the bad impact of agriculture.

In other trials, digestive slurry reduces the amount of chemical fertiliser that needs to be applied by about 30%.

**Development of vinasse use technology**

**Table 2—**Main characteristics of vinasse.

| pH | Colour | BOD | $COD_{Mn}$ | $COD_{Cr}$ | TOC | $K^+$ | T-N | P |
|---|---|---|---|---|---|---|---|---|
| | | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) |
| 4.28 | 44 000 | 50 900 | 81 900 | 172 000 | 55 400 | 17 000 | 1976 | 120 |

The main characteristics of vinasse from sugarcane molasses are reported to be 1) high organic matter, 2) high COD and BOD, 3) black-colour, 4) highly acidic. The basic characteristics are shown in Table 2. Sugarcane molasses is produced from just sugarcane so there are not likely to be hazardous materials. Preliminary tests, including incubation tests, were carried out to assess the implications of farmland application. The results indicated no negative impacts on crop production. Providing the impacts on the environment, mainly groundwater contamination are monitored, it may be possible to apply vinasse to farmland. Because of the high viscosity of vinasse, it is believed that it does not percolate deeply, allowing effective use by plants. Further research is needed to confirm this.

**Other kinds of outcomes on sugarcane**

High-biomass sugarcane was developed by our group, and initial larger scale trials have been carried out. Indications are that these sugarcanes have almost the same Brix (13–16%) as other great-biomass canes, and similar to traditional commercial sucrose varieties. These sugarcanes not only produce more sugar but also higher biomass.

In addition to establishing a sugar-ethanol by-production system, our group developed an equation called Commercial Cane Sugar at n-times Crystallisation ($CCS_n$) from data collected in the laboratory. This enables us to easily estimate CCS.

**Perspectives and conclusions**

Research outcomes have been presented locally, nationally and internationally. In addition, our research projects aim to achieve real action plans and outcomes. We therefore actively communicate information to all levels of government. How can these research outcomes be utilised and, based on them, how will the residents proceed with actual action plans? The most important thing for us is the creation of real business models that use biomass on the island.

In this fiscal year, we hope to publish a manual for the application of converted biomass to farmland. In addition, we expect to transfer some research outputs to existing technologies. For

example, development of $CO_2$ application technology from the conversion facilities is expected. Proper assessment of the impacts of biomass use should also be completed. To accomplish this, integrated evaluation technologies based on the actual data and calculation tools such as Life Cycle Assessment (LCA) are necessary. Further research is required and special efforts made to approach and achieve these goals.

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# UTILISATION OPTIMALE DE LA BIOMASSE DANS UN ENVIRONEMENT ISOLE: ETUDE DE CAS DANS L'ILE DE MIYAKO, JAPON

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**MOTS CLES: Biomasse, Système de Raffinerie, Conversion.**

## Résumé

CE PAPIER décrit brièvement un projet de recherche en cours et quelques résultats de recherches sur la canne à sucre. Cinq sujets de recherche ont été identifiés, notamment 1) le développement de technologies pour l'application biomasses converties de la mélasse de canne à sucre, tels le compost, la cendre, le lisier et la vinasse sur les terres cultivées. 2) La clarification de l'allocation optimale de biomasse et des conditions d'opération optimales pour les usine de conversion. 3) Développement de technologies de conservation de l'eau souterraine avec la biomasse, avec emphase sur l'azote. 4) Développement de technologies pour l'introduction des cultures d'énergie et d'application optimale de $CO_2$ gazeuse aux cultures. 5) Clarification des conditions favorables pour la production simultanée de sucre et d'éthanol en utilisant la canne à sucre a fort biomasse. Nos biomasses cibles sont la bagasse et les déchets d'élevage. Cinq usines de conversion, incluant deux par pyrolyse, une de compostage, une de biogaz et une de gazéification ont déjà été installées afin de convertir correctement et efficacement la biomasse. Deuxièmement, la vinasse (sous-produit de bio-éthanol, résidu de distillation) est une autre cible de biomasse. Nous avons analysé la vinasse pour le retour des sous-produits à la terre cultivée comme un moyen d'atteindre la durabilité et avons consacré nos efforts à l'application de la vinasse à la terre arable. Bien sûr, la sécurité aux cultures, à l'environnement du sol et de l'eau doivent d'abord être confirmés. Les essais précédents ont démontré que la vinasse n'a pas d'effet négatif sur le développement de la culture. Troisièmement, nous avons mené des études afin de clarifier les conditions favorables pour l'introduction de canne à sucre à fort biomasse pour développer les systèmes de production sucre-éthanol. Une nouvelle variété de canne à sucre favorable fut préalablement sélectionnée. De plus, une équation de rendement sucre pour la canne à fort biomasse fut développé à partir des données observées.

# EL USO ÓPTIMO DE LA BIOMASA EN UN ENTORNO AISLADO: ESTUDIO DE CASO EN LA ISLA DE MIYAKO, JAPÓN

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**PALABRAS CLAVE: Biomasa, Sistema de Refinería, Conversión.**

## Resumen

ESTE DOCUMENTO describe brevemente un proyecto de investigación en curso y algunos resultados de investigación en caña de azúcar. Fueron identificados cinco temas de investigación, a saber: 1) desarrollo de tecnologías para la aplicación en tierras agrícolas de biomasa procesada a partir de melazas de caña de azúcar tales como: compost, char, purines digestivos y vinazas, 2) definir la localización y condiciones operacionales óptimas de las plantas de conversión de biomasa, 3) desarrollo de tecnologías de conservación de aguas subterráneas basadas el uso de biomasa y enfocadas principalmente en nitrógeno, 4) desarrollo de tecnologías para la introducción de cultivos energéticos y aplicación óptima de $CO_2$ gaseoso a los cultivos, y 5) definición de las condiciones adecuadas para que los sistemas de producción dual azúcar-etanol usen una alta proporción de la biomasa de la caña de azúcar. Nuestra biomasa objetivo son el bagazo y los excrementos vacunos. Cinco plantas de conversión, entre ellas dos de pirólisis, una de compostaje, una de bio-gas y una de gasificación, ya han sido instaladas para realizar una efectiva y apropiada conversión de la biomasa. Se han estudiado principalmente tecnologías de aplicación de char y purines digestivos con bagazo a tierras agrícolas. El segundo lugar lo ocupa la vinaza (sub-producto del bio-etanol; residuo de la destilación) que es otro objetivo de uso de biomasa. Analizamos el retorno de la vinaza a las tierras de cultivo como una forma de lograr la sostenibilidad y dedicar esfuerzos a su aplicación en tierras agrícolas. Por supuesto, la seguridad para los cultivos, para el ambiente edáfico y acuático debe ser confirmada primero. Experimentos anteriores revelaron que la vinaza no tiene impactos negativos en el crecimiento de los cultivos. En tercer lugar, llevamos a cabo estudios para caracterizar las condiciones favorables para la introducción de caña de azúcar con mayor producción de biomasa para desarrollar sistemas duales para la elaboración de azúcar-etanol de caña. Previamente se seleccionó una nueva variedad de caña de azúcar. Adicionalmente, a partir de datos observados se desarrolló una ecuación de rendimiento de azúcar para caña de azúcar de alta producción de biomasa.