Biofuel and biogas utilization challenges in Kyoto city

Concrete Initiatives by Kyoto City to Prevent Global Warming and Build Sustainable Low Carbon Society

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Kyoto city 「Historical city」
The Cherries of the Imperial Palace in the Former Capital of Kyoto
Cherry trees at Heian Shrine
Cherry trees in front of the torii archway at Heian Shrine
Tourist boat passing by Heian Shrine
COP3 Kyoto Conference on Climate Change
Held in Kyoto City in December 1997
Environmental model city Project (2008~)

Harmony with townscapes and low carbon
“Kyoto, the city respecting culture of wood”

Forest covering three forth of city area

Street of wooden houses

Proper forest management and using thinning woods
Kyoto city aims to cut 400,000t of CO2 by 2030
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   Biodiesel fuel production from used cooking oil

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5. **A future model of the biomass utilization of Kyoto City**
1. Biodiesel production project in Kyoto City

1997: “COP3” in Kyoto

1997~: Collection of used cooking oil from household

Biodiesel fuel (BDF) supply for packer vehicle

2000~: BDF supply for city bus

2004~: BDF production plant operation

(5 kL/day, 1,500 kL/year)
Used cooking oil collection by Kyoto’s citizens

Collection points for used household cooking oil
As of December 2010, approximately 1,600 collection points
Quantity collected: approx. 190,000 liters
Biodiesel used for city buses and garbage collection trucks

Now 95 city buses
  B20 (20% biodiesel)

170 garbage trucks
  B100 (100% biodiesel)

Mobilization of the experimental city bus using high concentration biofuel by minister authorization

Approx. 150,000 liters used annually, representing a CO2 emissions reduction of about 4,000 tons
Kyoto City Technical Research Organization on Biodiesel Fuel Production (2001-)

Academic experts
Chairman: Dr. Ikegami, Professor emeritus, Kyoto University

Analysis company
Automobile manufacturer
Fat and oil producer
Fuel producer
Recycling technology company
Additives producer

Setting Kyoto City tentative standard of Biodiesel (Kyoto Standard)
## Kyoto City tentative standard of Biodiesel

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Kyoto City 2002.3</th>
<th>EU EN14214 2003.7</th>
<th>US ASTM D6751 2002.3</th>
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<tbody>
<tr>
<td>Density(15°C)</td>
<td>g/ml</td>
<td>0.86~0.90</td>
<td>0.86~0.90</td>
<td>0.88</td>
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<tr>
<td>Kinematic viscosity(40°C)</td>
<td>mm²/s</td>
<td>3.5~5.0</td>
<td>3.5~5.0</td>
<td>1.9~6.0</td>
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<tr>
<td>Pour point</td>
<td>℃</td>
<td>-7.5max</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plugging point</td>
<td>℃</td>
<td>-5max</td>
<td>-20~+5</td>
<td>-</td>
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<tr>
<td>10% residual carbon</td>
<td>%</td>
<td>0.30max</td>
<td>0.30max</td>
<td>0.50以下(100%sample)</td>
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<tr>
<td>Cetane number</td>
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<td>51min</td>
<td>51min</td>
<td>47min</td>
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<tr>
<td>Sulfur</td>
<td>ppm</td>
<td>10max</td>
<td>10max</td>
<td>500max</td>
</tr>
<tr>
<td>Flash point</td>
<td>℃</td>
<td>100min</td>
<td>101min</td>
<td>130min</td>
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<tr>
<td>Water</td>
<td>ppm</td>
<td>500max</td>
<td>500min</td>
<td>500max</td>
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<td>Monoglyceride</td>
<td>%</td>
<td>0.8max</td>
<td>0.8max</td>
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<tr>
<td>Diglyceride</td>
<td>%</td>
<td>0.2max</td>
<td>0.2max</td>
<td>-</td>
</tr>
<tr>
<td>Triglyceride</td>
<td>%</td>
<td>0.2max</td>
<td>0.2max</td>
<td>-</td>
</tr>
<tr>
<td>Free glycerin</td>
<td>%</td>
<td>0.02max</td>
<td>0.02max</td>
<td>0.02max</td>
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<tr>
<td>Total glycerin</td>
<td>%</td>
<td>0.25max</td>
<td>0.25max</td>
<td>0.24max</td>
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<tr>
<td>Methanol</td>
<td>%</td>
<td>0.2max</td>
<td>0.2max</td>
<td>-</td>
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<tr>
<td>Alkali metals (Na+K)</td>
<td>mg/kg</td>
<td>5max</td>
<td>5max</td>
<td>-</td>
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<tr>
<td>Acid value</td>
<td></td>
<td>0.5max</td>
<td>0.5max</td>
<td>-</td>
</tr>
<tr>
<td>Iodine value</td>
<td></td>
<td>120max</td>
<td>120max</td>
<td>-</td>
</tr>
</tbody>
</table>

EU regulates oxidation stability (110°C), linolenic acid methyl ester, and others
Kyoto City used cooking oil biodiesel production plant (5,000 L/day)
BDF production from used cooking oil

Alkaline catalyst, 3 tanks and 8 processes

1. Pretreatment (Dehydration)
2. Esterification (2 times, 60° Cx30~60min.)
3. Separation of glycerin
4. Recovery of methanol
5. Washing (Removal of glycerin)
6. Dehydration
7. Additives
8. Filtration (1µm)

UCO from restaurants

UCO from households

City bus

Packer vehicle

Storage tank

Cooking oil

Tank 1

Proc.1

Tank 2

KOH

Proc.2

Methanol

Proc.3

Glycerin

Proc.4

Tank 3

Proc.5

Hot water

Proc.6

Proc.7

Proc.8

Storage tank

Biodiesel fuel

B20

B100

BDF storage tank

Diesel oil

Mixing

Additives

Filtration

Glycerin
2. Experimental Biogasification project in Kyoto City

1998: Position the biogasification as a new technology in the Basic Plan for Waste Disposal

1999~: Construction of a experimental biogas plant

2000~: Biogas plant test operation using hotel kitchen

2003~: Biogas plant test operation using market garbage

2008~: Biogas plant test operation using kitchen waste (household)
Biogas system for Municipal Solid Waste

Why we need Biogas system for MSW in Japan?

past

Paper and plastic are recycled → calorific value decreasing

Containers and Packaging Recycling Law (implemented in April 1997)

current

Kitchen waste is recycled by Biogas system → calorific value increasing again

Higher efficiency of thermal recycling in incineration plant and energy from biogas

future

Recycling by AD system

Paper plastic others Kitchen waste incineration

Paper plastic recycling

Paper plastic incineration

Paper plastic incineration

Kitchen waste Recycling by AD system
100–200 Nm³-dry of biogas (methane content of at least 55%) produced from every ton of garbage

Generation of 120–240 kWh of electricity/ton of garbage by using a gas engine

Stable production of biogas from kitchen garbage and other waste
3. Overview of Kyoto Bio-Cycle Project

1. Gasification and methanol synthesis technology
   - Waste wood → Gasification → Methanol synthesis → Methanol

2. High efficiency biogasification technology
   - Waste cooking oil → Biogasification → Glycerin

3. Fuel cell utilization of biogas
   - Waste food → Biogasification → Biogas → Hyper-thermophilic hydrolysis → Biogas → Fuel cell

- BDF
- Diesel vehicle
3.1 Gasification and methanol synthesis technology

Feature of technology

- Woody biomass: various items
  Construction waste, Factory waste wood, Pruned branches, Timber residues in forests, etc.

- Practical gasifier + New type reactor for methanol synthesis
  high efficiency, energy conserving

Target of technology

Carbon conversion: 95 %, Cold gas efficiency: 65 %, Methanol yield: 30 L/day
Overview of Methanol production process

Feedstock: Wood chips
Capacity: 500 kg-biomass/day
Methanol Production: 50 L/day

Estimation at 50t/day plant
Methanol 600kg/day
Electricity 38,400kwh/day
Heat 470GJ/day

It is a technology with high efficiency and a little energy consumption
The Feature of Gasification & Methanol Synthesis Technology

One Through Synthesis

Methanol Condensation In the Reactor

Low Temperature Low Pressure

- Stability Operation By CFB Gasifier
- High Temperature Gas Filter
- Tar Cracking By Catalyst

Methanol Synthesis facility

Gas cooling unit

Gas compressor

Gas cleaning unit

Gas combustion unit

Gasification gas

Feedstock

CFB gasifier

Feeding system

Catalyst tar/gas reformer

Heat exchanger

Bag house

Wet gas scrubber

High temperature gas filter

Gasification facility

Gasification temp. 800-900 °C

Synthetic conditions (200 °C, 5MPa)

Nickel series catalyst

- Methanol synthesis reactor
- Off gas
Development of Gasification & Methanol synthesis

Biomass Methanol
(Methanol purity: about 95%)

Syngas profile
(H₂: about 15%, CO: about 8%
with steam)

Stable Composition

Demonstration test has achieved the carbon conversion ratio of 95%
and the cold gas efficiency of 65%, proving high gasification efficiency.
3.2 High efficiency biogasification technology

Feature of technology

- High temp. dry methane fermentation (55°C, TS > 20 %) + Hyper-thermophilic hydrolysis (80°C, HRT 1 day)

Improvement of decomposition rate of feed

Target of technology

- Biogas: + 20 %, Fermentation residue: - 50 % (volatile solid), Waste liquid: - 70 % (necessary to be treated)

“Biogasification system suitable for urban area”
High efficiency biogasification technology Plant

Methane fermenter

Hyper high temp. hydrolysis tank
Effect of hyper-thermophilic hydrolysis

Estimation at 60 t-wet/day plant (example data)

Attainment “+20 %” (at food waste)

Biogas (CH$_4$+CO$_2$): 14,200 ⇒ 15,600 m$^3$N

Waste food & paper: 60 t/d

Methane fermenter

Hyper high temp. hydrolysis tank

Water for dilution: 50 ⇒ 0 t

55° C methane fermenter

80° C hydrolysis (addition)

Sludge return: 0 ⇒ 90 t

Gas engine

Surplus power: 20.1 ⇒ 23.8 MWh

Heat

NH$_3$ collection: 0 ⇒ 178 kg-N

Water treatment: 63 ⇒ 16 m$^3$

Gas engine

Liquid: 13 ⇒ 16 t

Residue: 18 ⇒ 9 t

NH$_3$ collection equipment (cooling + wet scrubber)
< Points of this study >

a) Technical and Economical study of gasification and methanol synthesis technology, when the facility is installed in local village area.

b) Study of integration system of the gasification & methanol facility and the wood pellet production facility

c) Study of application possibility of short rotation crops
Gasification and methanol synthesis technology is possible to produce liquid (methanol), generation, and heat. In this study, it was aimed for the construction of an optimum system by the integration with gasification & methanol facility and wood pellet facility.
5. A future model of the biomass utilization of Kyoto City

Activation of agriculture and the forestry

Realization of sustainable society by the circulation use of various biomass and technology

Low Carbon society

Forest waste

Biodiesel facility

Recycling of forest waste

Wood pellet facility

Biodiesel facility

Used Cooking oil

Collect cooking oil

Biogas facility

Gasification & methanol facility

Sustainable society

Wooden biomass

Short Rotation Crops

Forest waste

Microalgae

garbage

Waste paper

Biogas facility

Biodiesel facility

Fuel cell by bio-methanol

Cooking Oil

Glycerin

CO₂

digestive fluid

crops

heat

electricity

Compost

Waste paper

Feed and fat

Garbage

Forest waste

Waste paper

Used Cooking oil

Collect cooking oil

Biodiesel

Bio-methanol

Biogas facility

Gasification & methanol facility

Sustainable society
## Introduction Scenarios and CO\textsubscript{2} Reduction

**Environmental Model City, Kyoto leads biomass utilization projects**

<table>
<thead>
<tr>
<th>term</th>
<th>Demonstration plant stage (until 2015)</th>
<th>The spread stage over the Kyoto city (until 2025)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification &amp; Methanol synthesis</td>
<td>◆ woody biomass : 50ton/day (country area) price: 4 billion (yen) ★ about 9,000ton-CO\textsubscript{2} (Methanol &amp; Co-generation)</td>
<td>◆ waste wood... 50ton/day × 1 plant ★ about 9,000ton-CO\textsubscript{2} (Methanol &amp; Co-generation)</td>
</tr>
<tr>
<td>Biogasification</td>
<td>◆ garbage &amp; paper : 60ton/day price: 2.8 billion (yen) ★ about 6,000t-CO\textsubscript{2} (Co-generation)</td>
<td>◆ garbage &amp; waste paper 60ton/day × 8 plant ★ about 48,000t-CO\textsubscript{2} (Co-generation)</td>
</tr>
<tr>
<td>BDF production</td>
<td>◆ cooking oil : 5kL/day 0.6 billion (yen) ★ about 4,000t-CO\textsubscript{2} (fuel supply)</td>
<td>◆ cooking oil 5kL/day × 1 plant ★ about 4,000t-CO\textsubscript{2} (fuel supply)</td>
</tr>
<tr>
<td>CO\textsubscript{2} reduction</td>
<td>19,000 t-CO\textsubscript{2}/year</td>
<td>61,000t-CO\textsubscript{2}/year total: 80,000t-CO\textsubscript{2}/year</td>
</tr>
</tbody>
</table>

If this project is carried out with nationwide, we can reduce CO\textsubscript{2} 4.5million tons a year.
Reference data
Characteristic of biomass potential in Kyoto

- Waste paper, waste timber, food waste, unused forest tree and sewage sludge were significant contributors.

Available: 2,019 kt-wet/year

340 kt-dry/year
The annual quantity of production by the willow cultivation as short rotation crops is 40 - 60 t-wet/ha.
In the national law regarding quality assurance, revision was made on the mandatory standard clause (standard needed to be legally complied) and standard value regulation of BDF mixed diesel oil, premised on the 5% of BDF mixed rate.

Eco-friendly diesel oil is expected to be commercially available.

⇒ It is expected to increase BDF sales volume.

<table>
<thead>
<tr>
<th>Items</th>
<th>Diesel with BDF</th>
<th>Diesel without BDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur</td>
<td>0.001 % by mass or less</td>
<td>0.01 % by mass or less</td>
</tr>
<tr>
<td>Cetane index</td>
<td>45 or more</td>
<td>45 or more</td>
</tr>
<tr>
<td>90% distillate temperature</td>
<td>360 ℃ or less</td>
<td>360 ℃ or less</td>
</tr>
<tr>
<td>FAME</td>
<td>5.0 % by mass or less</td>
<td>0.1 % by mass or less</td>
</tr>
<tr>
<td>Triglyseride</td>
<td>0.01 % by mass or less</td>
<td>0.01 % by mass or less</td>
</tr>
<tr>
<td>Methanol</td>
<td>0.01 % by mass or less</td>
<td>—</td>
</tr>
<tr>
<td>Acid value</td>
<td>0.13 or less</td>
<td>—</td>
</tr>
<tr>
<td>Total of Formic acid, acetic acid and propionic acid</td>
<td>0.003 % by mass or less</td>
<td>—</td>
</tr>
<tr>
<td>Acid value increase</td>
<td>0.12 or less</td>
<td>—</td>
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