Approach to Bioenergy Recovery

Shin-ichi Sakai
Kyoto University
Environment Preservation Center
Approach to Bioenergy Recovery

1. Bioenergy and green effect gas (GHG) control potential

2. Bioenergy utilization system
   1. Anaerobic digestion with energy recovery
   2. Waste incineration energy recovery

3. Biofuel production system
   1. Bioethanol
   2. Biodiesel fuel

4. Bioutilization system integration and some considerations
1. Bioenergy and green effect gas (GHG) control potential
3R Measures for Biogenic Waste

- **Feeding**: Use food residues for livestock feed. It is required that ingredients are homogeneous, essential nutrients are contained, and foreign bodies and hazardous substances should not be mixed.

- **Composting**: A biotreatment under an aerobic condition with oxygen, which brings increased temperature. Managing conditions such as a specific temperature (55 ~ 60°C), moisture, the C/N ratio and bacterial sterilization are crucial.

- **Eco-fuel**: A renewable fuel which is produced by processing biological resources. If it is substituted for fossil fuel, it contributes to reduction of the greenhouse effect gases emitted by fossil fuel, which means that it doesn’t lead to increase of CO₂.

- **Methane fermentation**: A method to recover fermentation gases including methane generated from biological decomposition of organics under an anaerobic condition. The amount of biogas recovered is about 100 ~ 200 m³ per ton of municipal solid organic waste. The methane concentration is roughly between 55% and 70%. The energy content is about 20 ~ 25 MJ/m³.

- **Thermal recovery from incineration**: A method to recover steam and electricity from waste heat in the thermogenic process of degrading carbonaceous matters with the presence of oxygen.
International Biomass Energy Potential

Energy Production (Potential)

Domestic Bioresource Potential

Estimate the domestic potential based on various statistics

⇒ The usable amount is equivalent to 31.51MkL crude oil.

<table>
<thead>
<tr>
<th>Item</th>
<th>Production (M tons/yr)</th>
<th>Usable (M tons/yr)</th>
<th>In crude oil volume (M kL/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice straw, rice chaff and barley straw</td>
<td>13.93</td>
<td>10.92</td>
<td>3.41</td>
</tr>
<tr>
<td>Livestock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Livestock excrement</td>
<td>78.93</td>
<td>78.93</td>
<td>1.36</td>
</tr>
<tr>
<td>Forest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest land residues and thinned wood</td>
<td>9.80</td>
<td>7.47</td>
<td>1.50</td>
</tr>
<tr>
<td>Unused trees</td>
<td>57.00</td>
<td>57.00</td>
<td>12.08</td>
</tr>
<tr>
<td>Waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food waste</td>
<td>29.43</td>
<td>27.41</td>
<td>1.91</td>
</tr>
<tr>
<td>Cooking oil</td>
<td>0.18</td>
<td>0.18</td>
<td>0.19</td>
</tr>
<tr>
<td>Paper waste</td>
<td>13.47</td>
<td>13.47</td>
<td>5.58</td>
</tr>
<tr>
<td>Waste timbers</td>
<td>16.79</td>
<td>10.60</td>
<td>4.61</td>
</tr>
<tr>
<td>Thinned branches</td>
<td>2.20</td>
<td>2.20</td>
<td>0.44</td>
</tr>
<tr>
<td>Sewage sludge</td>
<td>115.08</td>
<td>72.08</td>
<td>0.41</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>336.80</strong></td>
<td><strong>280.26</strong></td>
<td><strong>31.51</strong></td>
</tr>
</tbody>
</table>

Note) The “Usable” includes the compost usage, the energy usage as well as the current unused amount. It doesn’t include only the materials recycled (feed and construction materials) other than compost.

Source) National Institute for Environmental Studies: Development of technology for producing hydrogen from bio resources and waste (March 2006)

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Usable amount: 1,120 PJ/yr (P: 10^{15})

Wet: 12.3%  
Dry: 87.7%

Food waste: 6.7%  
Livestock excrement: 4.3%  
Used paper: 17.7%  
Wood waste: 16.0%  
Agricultural residue: 10.8%  
Forest land residue: 4.8%  
Sewage sludge: 1.3%  
Unused trees: 38.3%  
Wood: 76.8%

Note: Usable amount = Production – Materials recycled
Calorie calculation method: Dry: Lower calorific value (wet basis); Wet: Bio gas lower calorific value
Source: National Institute for Environmental Studies: Development of technology to produce hydrogen from bio resources and waste (March 2006)

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2. Bioenergy Application Systems

2.1 Anaerobic Digestion with Energy Recovery
# Classification of Anaerobic Digestion Systems

## Solid concentration

<table>
<thead>
<tr>
<th>Type</th>
<th>Target biomass</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet (<del>10%) / Dry (</del> 40%)</td>
<td>Food waste / Human waste / Sewage sludge / Livestock excrement</td>
<td>Advantages: Easy to manage in slurry state; and great achievements Disadvantages: Long-time fermentation and high production of digestive fluids</td>
</tr>
<tr>
<td></td>
<td>In addition to the above, paper / thinned branches / highly concentrated organics</td>
<td>Advantages: Short-time fermentation; high gas yield rate brought by higher decomposition rate of organics; and low production of digestive fluids, which leads to good sanitation Disadvantages: Necessity of a large heat quantity to heat a fermenter.</td>
</tr>
</tbody>
</table>
Wet Methane Fermentation System

Aich Expo new energy plant
(Food waste: 4.8 tons/day)

Source) NEDO: A Tour of Energy Sources of the Future
(http://www.nedo.go.jp/expo2005/energy/publication.html)

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Dry Methane Fermentation System

Kampo Recycle Plaza (Sonobe-cho, Kyoto; Food waste and woods & grasses: 50 tons/day)

Source) Material provided by Takuma Kampo Recycle Plaza (Sonobe-cho, Kyoto; Food waste and woods & grasses: 50 tons/day)

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Facilities to Introduce Methane Fermentation and Power Generation

<table>
<thead>
<tr>
<th>Target biomass</th>
<th>Power Generation</th>
<th>No Power generation</th>
<th># of Total</th>
<th>Treatment capacity (rough figure)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livestock excrement</td>
<td>42</td>
<td>28</td>
<td>70</td>
<td>1800 ton/day ~</td>
<td></td>
</tr>
<tr>
<td>Food waste (Solid)</td>
<td>28</td>
<td>19</td>
<td>47</td>
<td>2000 ton/day ~</td>
<td>Including human waste and sewage sludge mix treatment facilities</td>
</tr>
<tr>
<td>Food waste (Wastewater)</td>
<td>8</td>
<td>39</td>
<td>47</td>
<td>110000 m³/day ~</td>
<td>The actual food and plant effluents treated</td>
</tr>
<tr>
<td>Sewage sludge</td>
<td>20</td>
<td>1</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>98</td>
<td>87</td>
<td>185</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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2.2 Current Status of Waste Incineration Energy Recovery Technologies
Waste Incineration Energy Recovery Technologies

Conventional waste power generation, Flow of Conventional Type WTE (Waste to Energy)

RDF power generation
Flow of RDF Firing Type WTE

Status of Waste Power Generation Technology

• To avoid metal corrosion caused by HCl gas produced from incineration, steam conditions cannot be raised. Therefore, the power generation efficiency is low at about 10-15%.

• In waste incineration facilities, since steam is consumed in the process, some quantity of steam can be input in generator.

Use of residual heat in waste incineration facilities (2003)

<table>
<thead>
<tr>
<th>Usage</th>
<th>User</th>
<th>Non-user</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Use of hot water</td>
</tr>
<tr>
<td># of facilities</td>
<td>995</td>
<td>923</td>
</tr>
</tbody>
</table>

# of waste power generation facilities and its capacity (2003)

<table>
<thead>
<tr>
<th># of facilities</th>
<th>271</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total power generation capacity (MW)</td>
<td>1,441</td>
</tr>
<tr>
<td>Average power generation efficiency (%)</td>
<td>10.23</td>
</tr>
<tr>
<td>Total power generation (GWh)</td>
<td>7,100</td>
</tr>
</tbody>
</table>

Source) Ministry of the Environment: White paper on recycling-based society 2005
Measures for Power Generation Efficiency Improvement

- Improve the boiler steam conditions (Adopt the 4MPa x 400°C class)
- Reheat cycle (Reheat the steam after using for power generation and run the reheat turbine)
- Complex power generation (Super waste power generation and Repowering)
- Regeneration cycle (Use of extraction steam)
- Recover the turbine exhaust heat (Introduce the water-cooled condenser and district heat and cooling)

Relations between the facility completion year and its power generation efficiency

Introduction of Waste Incineration and Power Generation Technologies

The actual introduced up to 2002 is 1,460 MW and the introduction target until 2010 is 4,170 MW.

Trend of WTE installed in Japan

Note:
The electricity generated in 2003 is 8370 GWh in total, specifically, 6890 GWh from municipal solid waste and 1480 GWh from industrial waste (provided by Agency of Natural Resources and Energy). Assuming the average of electricity generated from all sources is 0.378kg-CO₂/kWh, the CO₂ reduction is equal to 3.16M tons-CO₂.

**BEP of Waste Incineration**

**Waste management practices**
3R initiative – Reduce, Reuse & Recycle
Waste inspection and characterization

**Incinerator operating and management practices**

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**BAT of Waste Incineration**

◆ **BAT of Combustion Techniques**
- Achievable performance levels: 0.01 - 0.1 ngTEQ/Nm³

◆ **BAT for Flue Gas Treatment**
- Achievable performance levels: 0.01 - 0.1 ngTEQ/Nm³
Target for Energy Recovery from Biomass and Waste

- In the plan to achieve the goals of the Kyoto Protocol (April 2005), the target for introducing new energy is 19.1M kL (crude oil equivalent) and the potential reduction in CO$_2$ emissions is equivalent to approximately 46.9M tons - CO$_2$ in 2010.

<table>
<thead>
<tr>
<th>Category</th>
<th>The amount introduced [crude oil equivalent: M kL]</th>
<th>CO$_2$ reduction [M tons-CO$_2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar power generation</td>
<td>1.18</td>
<td>2.90</td>
</tr>
<tr>
<td>Wind power generation</td>
<td>1.34</td>
<td>3.29</td>
</tr>
<tr>
<td>Waste + Biomass power generation</td>
<td>5.85</td>
<td>14.36</td>
</tr>
<tr>
<td>Use of solar heat</td>
<td>0.90</td>
<td>2.21</td>
</tr>
<tr>
<td>Use of waste heat</td>
<td>1.86</td>
<td>4.57</td>
</tr>
<tr>
<td>Use of biomass heat</td>
<td>3.08</td>
<td>7.56</td>
</tr>
<tr>
<td>(for transportation fuel)</td>
<td>0.50</td>
<td>1.23</td>
</tr>
<tr>
<td>Unused energy</td>
<td>0.05</td>
<td>0.12</td>
</tr>
<tr>
<td>Black liquor and waste materials</td>
<td>4.83</td>
<td>11.86</td>
</tr>
<tr>
<td>Total</td>
<td>19.10</td>
<td>46.90</td>
</tr>
</tbody>
</table>

Source) Conference for Eco-fuel Utilization Promotion: Spread and Expansion of Eco-fuel for Transportation (May 2006)

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3. Bio Fuel Development System

3.1 Bioethanol
Technology for Producing Ethanol from Waste Wood

Bioethanol Japan Kansai (Osaka): Produce ethanol through saccharification with dilute sulfuric acid, using two kinds of yeasts: one is a genetically modified bacterium (KO11) and the other is yeast. The plant will be completed in 2006.

Source) Osaka Eco Town Plan (http://www.epcc.pref.osaka.jp/junkan/ecotown/index.html )
Biodiesel Plant in Kyoto

- Largest capacity in Japan (5000L/day)
- High Product Quality
- KOH (potassium hydroxide) catalyst
- Three (3) major steps
  - Pre-treatment
  - Transesterification Reaction
  - Purification
- Excess MeOH can be recovered and reused
- Blending can be done between B10 and B50
Process Flow of BDF in Kyoto (1)

Used Cooking Oil

Raw Material

Vacuum Heating

Pre-treatment

Water

1st Reaction

2nd Reaction

Methanol/Catalyst

Vacuum Heating

Reaction

Methanol

Gravity separation after settling

Glycerin

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Process Flow of BDF in Kyoto (2)

Winter Only

Additive Agent
Isopropyl alcohol and/or polymer agent

Additive Agent mixing
Product
w/ Additive

B20
(20% BDF)

1st Washing
2nd Washing
Hot Water

Vacuum Heating
Water

Purifying

Gravity separation after settling
Waste Water

Product

Additive Agent mixing

Light Oil

Light Oil mixing

Product

Isopropyl alcohol and/or polymer agent

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Biodiesel Fuel Utilization in Kyoto City

- All Garbage trucks (220 trucks) were supplied B100 from Nov. 1997.
- A part of city buses (95 buses) were supplied B20 from Apr. 2000.
- 1500kL of Bio Diesel Fuel were used annually.
Collecting of the Used Cooking Oil in Kyoto City

Since 1997, there started to place collecting stations of cooking oil. 960 stations (as of end of Mar. 2005) were placed, of which 143 school districts of total 219 school districts. Total amount of collected oil was 130kL in 2005.

Collection by local garbage reduction promoting committees (64 groups), health conference and local womankind groups. (once a month, 1~2 hours)
## Eco-fuel Targets in Japan

<table>
<thead>
<tr>
<th>Target year</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transportation ecofuel input</strong></td>
<td>500,000 kL</td>
<td>About 2M kL</td>
<td>About 4M kL</td>
</tr>
<tr>
<td><strong>Gasoline substitution (Bioethanol)</strong></td>
<td>A half of the total requirement is covered by E3 and ETBE (Ethyl Tert-Butyl Ether)</td>
<td>2/3 of the total requirement is covered by E3 and ETBE</td>
<td>The total requirement is covered by E10</td>
</tr>
<tr>
<td><strong>Input amount</strong></td>
<td>Approx. 480,000 ~ 490,000 kL</td>
<td>Approx. 1.1M kL</td>
<td>Approx. 2.2M kL</td>
</tr>
<tr>
<td><strong>Input rate</strong></td>
<td>Of them, domestic production: Approx. 30,000 kL</td>
<td>Of them, domestic production: Approx. 600,000 kL</td>
<td></td>
</tr>
<tr>
<td><strong>Light oil substitution (BDF, eco-light oil and BTL)</strong></td>
<td>Input 2 ~3 times higher amount of domestic BDF</td>
<td>1/3 if the total requirement is covered</td>
<td>The total requirement is covered.</td>
</tr>
<tr>
<td><strong>Input amount</strong></td>
<td>Domestic + import: Of them, approx. 10,000 ~ 15,000 kL is produced in Japan.</td>
<td>Approx. 900,000 kL</td>
<td>約Approx. 1.8M kL</td>
</tr>
<tr>
<td><strong>CO₂ reduction potential</strong></td>
<td>Approx. 1.2M tons-CO₂</td>
<td>Approx. 4.9M tons-CO₂</td>
<td>Approx. 9.8M tons-CO₂</td>
</tr>
</tbody>
</table>

**Note:** All inputs are crude oil equivalent.

**Source:** Report of Eco-fuel Utilization Promotion: Spread and Expansion of Eco-fuel for Transportation, Ministry of Environment (May 2006)

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4. System Integration of Bioresources Utilization

4.1 Project of “Technology Development for Producing Hydrogen from Bioresources and Wastes” (2003 ~) and Kyoto Biocycle Project
Demonstration Image of Kyoto Biocycle Project

Urban area
- Waste wood (Waste lumber, construction waste and woodchips)
- Waste cooking oil

Waste
- Source expansion to various oils
- Food waste (Kitchen waste and animal & plant residues)
- Mix treatment (Paper waste and thinned branches)

Demonstration technology
- Pyrolysis gasification and methanol synthesis
- Methanol
- Electricity and heat
- Rapeseed oil
- Pressed oil
- Glycerine
- Bio gasification (High efficiency and reduction in residues)
- Residues
- Fermentation residues
- Thermal recycle
- Reforming, purification and FC use

Natural environment
- Thinned wood and unused trees

Unused resources
- Oil source plants (Ex. Rapeseed)
- Use of idle lands

4) System technology to demonstrate the spread of regenerated bio resources

3) Technologies for reforming biomass-derived gas and using for fuel cells

5) System analysis technology for evolving biomass recycling technology

2) Pyrolysis gasification and methanol synthesis technologies

1) Future bio gasification technology

Lifecycle analysis GHG such as CH_{4} & CO_{2} emissions

For diesel cars

Use secondary materials

Use hydrogen

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Core Technologies for Demonstration of Kyoto Biocycle Project

1) Future bio-gasification technology for wet biomass
   High efficiency non-slurry methane fermentation process through high temperature solubilization of residues

2) Pyrolysis gasification and methanol synthesis for dry biomass
   Synthetic gas production via high-temperature gasification and purification (dust removal and tar decomposition)
   Single-pass methanol synthesis and offgas use for co-generation system

3) Biomass-derived gas reforming and application technology for fuel cells
   Hydrogen production through biogas reforming and use for fuel cells

4) System technology for expansion of renewable bioresources
   Expansion of BDF materials and bio gasification of paper waste and waste glycerine

5) System analysis for technological evolution of biomass cyclic use
   Life cycle system analysis for biomass cycle
Domestic GHG Reduction Potential

Estimate CO₂ reduction potential based on the domestic usable amount ⇒ In case of SOFC-CGS, about 47M tons-CO₂/year can be reduced. (Equivalent to 3.5% of the CO₂ emission in 2004, 1.33B tons)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Category</th>
<th>Surplus electricity GWh/yr</th>
<th>CO₂ reduction M tons/yr</th>
<th>Surplus electricity GWh/yr</th>
<th>CO₂ reduction M tons/yr</th>
<th>Recovered CO₂ reduction 10,000 kL/yr</th>
<th>M tons/yr</th>
<th>Recovered CO₂ reduction 10,000 kL/yr</th>
<th>M tons/yr</th>
<th>Surplus electricity GWh/yr</th>
<th>CO₂ reduction M tons/yr</th>
<th>Recovered CO₂ reduction 10,000 kL/yr</th>
<th>M tons/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) GE-CGS usage</td>
<td>Agriculture</td>
<td>3656</td>
<td>4.692</td>
<td>8778</td>
<td>6.132</td>
<td>121</td>
<td>2.105</td>
<td>379</td>
<td>4.190</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Livestock</td>
<td>-1695</td>
<td>1.140</td>
<td>1059</td>
<td>1.914</td>
<td>63</td>
<td>0.319</td>
<td>196</td>
<td>0.761</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unused tree</td>
<td>9488</td>
<td>12.460</td>
<td>23218</td>
<td>16.319</td>
<td>325</td>
<td>5.547</td>
<td>1018</td>
<td>11.150</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Food waste</td>
<td>3448</td>
<td>3.798</td>
<td>7308</td>
<td>4.883</td>
<td>88</td>
<td>1.754</td>
<td>275</td>
<td>3.267</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Waste timber</td>
<td>3564</td>
<td>4.680</td>
<td>8720</td>
<td>6.129</td>
<td>122</td>
<td>2.083</td>
<td>382</td>
<td>4.188</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>23530</td>
<td>35.722</td>
<td>64291</td>
<td>47.178</td>
<td>959</td>
<td>14.994</td>
<td>2998</td>
<td>31.504</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note) The CO₂ reduction potential includes the kerosene substitution effect by heat recovery. The recent diesel oil sales is about 40M kL/yr. The FT oil recovery is equivalent to one forth of the sales. The domestic methanol consumption amounts to 1.83M tons/yr (in 2001; All amount is imported.)

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4.2 Bio Energy Recovery
Principles in Asia
Bioenergy Recovery Principles in Asia (tentative)

1. To produce bioethanol and biodiesel fuel from organic waste and waste oil as much as possible and constrain the development of new agricultural lands in developing countries.

2. To use existing agricultural lands effectively to newly cultivate sugarcanes and palms for ethanol and BDF production as much as possible.

3. To conduct the sufficient environmental assessment, when developing new agricultural lands from sheer necessity.