Demonstration of Biofuel Production Technology from Non-Edible Biomass Resources at AIST for Sustainable Biomass-Asia Strategy

Kinya Sakanishi
Biomass Technology Research Center (BTRC), AIST, Hiroshima 739-0046, Japan

“Green Biomass for Blue Earth”
Research Bases of AIST

AIST Chugoku (Biomass Technology Research Center, 1/10/2005 started, and relocated to Higashi-Hiroshima in 1/4/2010)

AIST Hokkaido
AIST Kansai
AIST Tohoku
AIST Tsukuba
AIST Tokyo Waterfront
AIST Chubu
AIST Shikoku
AIST Kyushu

Tokyo Headquarters
Challenges in the 21st century

1) Energy
2) Environment
3) Food

Collaborations (Agriculture & Engineering etc.) in the Asian Countries

keyword: Biomass

Trilemma!
Political and Social Needs

Political Need;
- Biomass Nippon Strategy (2002 & 2006 renewed)
- Japan-China-Korea Science & Technology Collaboration
  Ministry Meeting (2007)
- East Asia (ASEAN+E3) Summit: Cebu Island Declaration (2007)

Social Need and Impact;
- Mitigation of Global Warming
- Substitution of Fossil Fuels
- Activation of Agriculture
- Suppression of Desertification
- Demonstration of Sustainable Development Scenario
Asian region has abundant biomass resources.
(87EJ corresponds to 2.3 billion kl-petroleum)

Unit: EJ ※1EJ=2.6×10^7kl-petroleum

Ref. “Study on energy conversion technology for Biomass”
(RITE, 1998~2000)
Potential Collaboration Projects on Utilization of Non-Edible Biomass

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Target Technology</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sewage Sludge</td>
<td>Hydrothermal Pretreatment, &amp; Carbonization</td>
<td>Methane &amp; Hydrogen</td>
</tr>
<tr>
<td>Food Wastes</td>
<td>Two-stage Fermentation, &amp; Waste-water treatment</td>
<td>Fertilizer, Animal feed</td>
</tr>
<tr>
<td>Agricultural Waste (rice husk &amp; straw, bagasse etc.)</td>
<td>BTL, Flash pyrolysis &amp; Gasification</td>
<td>MeOH, DME, Synthetic Fuels, Olefins Hydrogen</td>
</tr>
<tr>
<td>Energy Crops (Cassava, Sugar Cane, Oil palm, Jatropha, Sago Palm etc.)</td>
<td>Extraction &amp; Catalysis etc.</td>
<td>BDF</td>
</tr>
<tr>
<td>Aquatic Biomass Forestry Products, Old palm trunk etc.</td>
<td>Plant Growth, Clone Identification Non-acidic Pretreatments (Hot-compressed Water &amp; Mechano-chemical milling)</td>
<td>Bioplastics, Bio-chemicals, Bioethanol, Bio-ethylene, Bio-propylene</td>
</tr>
</tbody>
</table>

Technical and Post Doctoral Training (JICA/JST, NEF, AIST fellowship etc.)

Standardization in Asia & JIS, and ISO
BTRC ethanol production process
(One-batch concept)

- Pretreatment
  - Wood, Rice straw, Bagasse etc.
  - Requirement of pretreatment without separation of cellulose and hemicellulose fraction
- Pretreated sample
  - Requirement of cellulase and hemicellulase to hydrolyze both components
- Cellulase & Hemicellulase
- Recombinant yeast
- Ezymatic hydrolysis and ethanol fermentation (including xylose utilization)
  - Requirement of glucose- and xylose-fermentable recombinant yeast

Ethanol
Mini plant (0.2 t/batch) (pretreatment process)

① Coarse pulverizing processes:
Raw materials (wood chips or straw) are crushed and milled to under several mm.
② Hydrothermal process:
The milled materials are softened by hot-compressed water.

③ Fine pulverizing processes:
The softened materials are finely fibrillated to several microns by wet disc-milling. The milled sample (5-7% w/v) are centrifuged to make a dewatered cake (20% w/v).
Current approaches for cost effective nano-fibrilation

- Enzymatic saccharification
- Fermentation
- Continuous mechanical treatment
- Mechanical pulverization + Hot-compressed water + Chemical modification

Lignocellulosic biomass

Cellulose affinity additives

Water

Conversion rate of cellulose into glucose (%)

Nano-fibrillation by continuous mechanical treatment

Ball mill treatment (4 hours)

Fine pure cellulose <20μm

Enzymatic saccharification time (h)

× 30000

1μm

5μm
BTRC ethanol production process: Enzymatic hydrolysis process

Reduction of enzyme costs is the most important factor for enzymatic saccharification.

☆ Development of cellulase-producing fungus, *Acremonium cellulolyticus*
  → Analysis of cellulase and hemicellulase components
  → Heterologous expression of hemicellulase in *A. cellulolyticus*
☆ Development of hemicellulase-producing fungi to combine with *A. cellulolyticus*
☆ On-site production of cellulase and hemicellulase using pretreated biomass
Necessity of hemicellulose supplements

Supplemental hemicellulase enzymes to Acremonium cellulase are required for higher sugar recoveries from hemicellulose.

Enzymatic hydrolysis of ball-milled Douglas-fir

Cypress
Douglas-fir
Beech
Eucalyptus

Mannan-degrading enzymes
Xylan-degrading enzymes

Glucose  Mannose  Xylose

Sugars (mg/g DM)

0  200  400  600  800

AC (10FPU/g-sub)
AC (10FPU/g-sub) + 1 U/g-sub Mannosidase
+100 U/g-sub Mannanase

Man  Glc

0  100  200  300  400  500

AC (10FPU/g-sub)
Saccharification and fermentation processes:
The pretreated materials are hydrolyzed (48-72 h) and then fermented (24 h) by fungal enzymes and yeast cells, respectively. The enzymes and yeast cells are produced on-site.
⑤ Distillation and dehydration processes:
The fermentation liquor is directly distilled without separation of the residue. Pure ethanol (99.5%v/v) is obtained by 2-nd distillation and dehydration processes.
Future Needs for Alternative Transportation Fuel

2000-2010
Fuel technologies for urban environment

*PM, NOx reduction
*Advanced end-of-pipe technologies

2010-2020
Fuel technologies for minimizes fuel consumption

*CO2 reduction
*New engine system/new fuel

Petroleum

Energy security

S-free gasoline
S-free diesel

S-free, low-aroma, low-olefins and high octane gasoline
S-free, low-aroma diesel

Designed fuel

Natural Gas
Biomass
Heavy Oils
Coal

Syngas CO/H2

FT Synthesis etc.

H2

GTL / BTL
DME
Methanol
H2 for Fuel Cell

*PM, NOx reduction
*Advanced end-of-pipe technologies

S-free, Aroma-free
Combined BTL by Bio- and Chemical- Conversion

Biomass → CO/H₂ → SNG, Diesel/Gasoline, Alcohols/DME, ETBE

2000-2030

Bio-based Conversion

Chemical conversion

S-free & Aroma-free Fuels, and Hydrogen

Further contribution for environmental issues

(NEDO 2t/d Plant, MeOH production)
Photograph of bench-scale BTL plant

Wood → Gasifier → Scrubber → Desulfurization tower

CO₂ removal tower

Compressor & Gas holder → FT synthesis reactor → Liquid fuel
Research Target in Upgrading of Primary FT Products

- **Hydrocracking/isomerization catalysts**

  - Naphtha ($C_{10-}$)
  - Middle-distillate ($C_{10-C_{20}}$)
  - $C_{20+}$ wax

**Targets in $C_{20+}$ wax upgrading:**
- Conversion $> 80\%$
- Selectivity to MD $> 75\%$
- Iso-paraffins in MD $> 65\%$

**Quality of MD:**
- Sulfur $< 1$ ppm
- Aromatics $\sim 0$
- Cetane No. $> 70$

**R&D of hydrocracking/isomerization catalysts:**
- Solid catalyst preparation and in depth characterization of catalysts.
- Hydrocarbon fuel analyses for elucidating the reaction mechanism.
- High-pressure continuous flow reactors (micro, bench) operation.
- Thermodynamic analyses the for hydrocarbon reactions and for the catalysts deactivation.
BTL (Biomass to Liquid) Process Scheme;
Biomass gasification with FT Synthesis via Hot Gas Cleaning => Design of “Mobile BTL Plant”

Pressurized Gasification of biomass (1 ~ 3MPa, ~ 900 °C)

H₂, CO
Tar
H₂S, COS
NH₃, HCl etc.

Removal of Catalyst Poisons at 300 - 400 °C for Direct Coupling

FT Synthesis DME synthesis (1 ~ 3MPa, ~ 250 °C)
**Biomass System Analysis and Simulation**

**Objectives:**

1. To develop biomass system simulation technology, Ground database (DB) should be constructed.
2. To design economic feasible total system for biomass. The simulator can be used for optimization, economic & environmental analysis.

**INPUT**

- **Wood DB**
  - Structures
  - Molecules
  - Elements
  - …..

- **Thermo DB**
  - Calorie
  - Moisture
  - Enthalpy
  - Entropy
  - …..

- **Cost DB**
  - Devices
  - Processes
  - Products
  - …..

- **Process DB**
  - Separation
  - Fermentation
  - Chemical
  - Thermal
  - …..

**Simulation**

**Analysis**

- Mass & energy analysis
- Cost analysis

Ex.: Process model for ETBE & BTL

**OUTPUT**

- Carbon balance
- Energy balance
- Efficient
- Impact (LCA)
- Economics
- Cost recovery
How much CO$_2$ can Biofuel mitigate?
Project Scheme on Sustainable Asian Biomass Strategy

Best Practice Scenario and System for Sustainable Biomass Utilization Models in East Asian Countries

Total Promotion of Biomass Asia Strategy
Extensive Win-Win Collaboration in Asia
International R&D Joint Projects on Biomass, Especially agriculture and engineering fields

Technology, IP, Human resources

Resources, Economical development, Technology transfer

Energy, Materials, CO₂ reduction: CDM ⇒ Sustainable Development
## Estimated Biomass Yields as Main Product and Residues

(million tons)

<table>
<thead>
<tr>
<th>Crops</th>
<th>Biomass</th>
<th>Thai-Land</th>
<th>Vietnam</th>
<th>Indonesia</th>
<th>Malaysia</th>
<th>Philippines</th>
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<tbody>
<tr>
<td><strong>Oil Palm (Coconut Palm)</strong></td>
<td>Main Product 33</td>
<td>1</td>
<td></td>
<td>13 (1)</td>
<td>16</td>
<td>(2)</td>
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<td></td>
<td>Factory Residue 38</td>
<td>1 (1)</td>
<td></td>
<td>10 (8)</td>
<td>11</td>
<td>(7)</td>
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<td></td>
<td>Field Residue 71</td>
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<td>26 (6)</td>
<td>31</td>
<td>(5)</td>
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<tr>
<td><strong>Sugar-cane</strong></td>
<td>Main Product 15</td>
<td>7</td>
<td>2</td>
<td>3</td>
<td></td>
<td>3</td>
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<tr>
<td></td>
<td>Factory Residue 44</td>
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<td>6</td>
<td>8</td>
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<tr>
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<td>5</td>
<td>8</td>
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<td><strong>Cassava</strong></td>
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<td>5</td>
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<td>6</td>
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<td>Field Residue 20</td>
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<td>2</td>
<td>9</td>
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<tr>
<td><strong>Rice</strong></td>
<td>Main Product 74</td>
<td>15</td>
<td>20</td>
<td>31</td>
<td></td>
<td>8</td>
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<tr>
<td></td>
<td>Factory Residue 34</td>
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<td></td>
<td>Field Residue 84</td>
<td>17</td>
<td>23</td>
<td>35</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td><strong>Timber (Wasted Trunk)</strong></td>
<td>Main Product 18</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>6</td>
<td>1</td>
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<tr>
<td></td>
<td>Factory Residue 18</td>
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<td>1</td>
<td>8</td>
<td>6</td>
<td>1</td>
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<tr>
<td></td>
<td>Field Residue 32</td>
<td>1 (1)</td>
<td>1</td>
<td>6 (9)</td>
<td>4 (7)</td>
<td>(3)</td>
</tr>
</tbody>
</table>

For 2003 or 2004
Proposal Content (draft)

1. Hybrid Agricultural Refinery Model (ex. China)
   Corn, Rice, Wheat, Sugarcane, Cassava etc.

2. ASEAN Continental Model;
   Rice & Sugar Energy Complex Model
   (ex. Thailand, Viet Nam etc.)

3. ASEAN Islands Model;
   Palm Oil Energy Complex
   (Malaysia, Indonesia etc.)

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Proposal of Efficient Recovery and Utilization Model of Agricultural Wastes

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1. Sustainable Biomass-Refinery
   (1) Bio-Fuels
      1-1. Bio-ethanol
      1-2. Bio-diesel fuel (BDF)
   (2) Bio-chemicals

2. Evaluation & Design of Biomass Utilization System
   (1) Life cycle assessment (LCA)
   (2) Demonstration plant projects
   (3) Design of optimized local models

3. Research and Development for Sustainable Biomass Production
Ethanol Production from Palm Wastes

- Oil Palm
- Fresh Fruit Bunch
- Fruit
- Trunk waste
- Empty Fruit Bunch
- Fiber, Shell
- Crude Palm Oil
- Palm Kernel

Lignocellulosic Biomass

- Pretreatment
- Saccharification
- Fermentation
- Purification

ETHANOL
New Materials from Oil Palm Biomass

Oil Palm

Palm Oil

Palm oil industry

BDF

Crude glycerol

Bio-waste

trunk  EFB  shell

- lignocellulosic materials
- Ethanol production
- lignin etc.

Development of polymer materials

Standardization for Biodegradable plastics in AIST

- ISO 14855-2 (Aerobic biodegradation test)
  - participated International Round-robin test (RRT)
- ISO/AWI 10210 (Preparation method of test materials for biodegradation tests)
  - proposed by AIST
- ISO 15985 (Anaerobic biodegradation tests)
  - participated RRT
- ASTM D6866 (Measuring method of biomass carbon ratio)
  - on research work in order to propose as ISO in future
Collaborative Research for Palm Industry Complex

November, 2007
Joint Research Agreement (JRA) among University Putra (UPM) Malaysia, Kyushu Institute of Technology (KIT), and Biomass Technology Center (BTRC), AIST

April, 2008
Collaborative research on bioethanol production from palm residues by collaboration of UPM, KIT, and BTRC

November, 2008
Collaborative laboratory (Biomass Technology Centre) in UPM

Signing ceremony of JRA at UPM
Opening ceremony of Biomass Technology Center at UPM
Fruitful Collaborations Using Biomass

Technology Transfer
Investment
CDM

CO$_2$ Reduction
Local Energy Supply
Forest Restoration

Credit
Liquid Fuels
Bulk Chemicals
Small- & Large-scale Biomass Utilization System!!

As small as possible

Bio-fuel Cell!

As large as possible

High efficiency and convenience

Local Energy Supply

Industrial Utilization

High economical viability

Stable law material supply, High demand in product
Summary & Proposals for Effective Biomass Utilization

1) Palm Energy&Chemicals Complex;
   - Combined production of bio-fules and bio-carbons by optimizing bio-conversion and thermochemical routes

2) Sugar and Rice Energy&Food&Chemicals Complex;
   - Large-scale bio-ethanol production from agricultural wastes for simultaneous supply of food and bio-fuels

3) Wood Refinery Complex for Fuels and Chemicals;
   - Total multi-production system of timber, paper pulp, ethanol, and bio-chemicals including lignin-derivatives
Thank you very much for your attention!

“Green Biomass for Cool Earth”