Municipal Organic Solid Waste as an Alternative Urban Bioenergy Source

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Energy, energy, and energy

- Increasing energy demand due to rapid urbanization (especially mega cities) and industrialization
- Depletion of fossil fuel resource and rising oil price
- Oil, gas, and coal would still continue to be important components of global energy supply (~80%)
- Alternative energy sources such as solar energy, wind energy, and bioenergy will gain more attention
- In South and Southeast Asia, more than 1 billion population has no grid connected electricity

Decentralized bioenergy

Southeast Asia Map

- Rice husk, Wood residues
- Rice husk, Sugar bagasse, Palm oil, Pulp & paper
- Rice husk, Wood residues
- Rice husk, Sugar bagasse, Pulp & paper, Wood residues
- Rice husk, Sugar bagasse, Palm oil, Pulp & paper, Wood Residues
- Rice husk, Palm oil, Wood residues

(Industrial Power Technology)
Biomass in Singapore?
Very Rich

PAPER WAR
Good news for ‘karung-guni’ men?

As three new newspapers hit the streets soon, the people who may be smiling all the way to the bank could be the rag-and-bone men who collect old newspapers for recycling.

(The Straits Times)

- Food waste: 498,000 tonnes (19.4%)
- Paper/Cardboard waste: 544,900 tonnes (21.3%)
- Plastic waste: 579,000 tonnes (22.6%)
- Wood/Timber waste: 142,000 tonnes (5.5%)
- Horticultural waste: 144,000 tonnes (5.6%)
- Total organic waste available as Resources = 1.91 M tonnes (74.4%)

PUB’s dewatered sewage sludge = 270,000 tonnes/year

(National Environment Agency of Singapore, 2006)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Conversion Process Type</th>
<th>Major Biomass Feedstock</th>
<th>Energy or Fuel Produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Combustion</td>
<td>thermochemical</td>
<td>wood, agricultural waste, municipal solid waste, residential fuels</td>
<td>heat steam, electricity</td>
</tr>
<tr>
<td>Gasification</td>
<td>thermochemical</td>
<td>wood, agricultural waste, municipal solid waste</td>
<td>low or medium–Btu producer gas</td>
</tr>
<tr>
<td>Pyrolysis</td>
<td>thermochemical</td>
<td>wood, agricultural waste, municipal solid waste</td>
<td>synthetic fuel oil (biocrude), charcoal</td>
</tr>
<tr>
<td>Anaerobic Digestion</td>
<td>Biochemical (anaerobic)</td>
<td>animal manure, Agriculture waste</td>
<td>Medium Btu gas (methane)</td>
</tr>
<tr>
<td>Ethanol Production</td>
<td>biochemical (aerobic)</td>
<td>sugar or starch crops, wood waste, pulp sludge, grass straw</td>
<td>ethanol</td>
</tr>
<tr>
<td>Biodiesel Production</td>
<td>chemical</td>
<td>rapeseed, soy beans, waste vegetable oil, animal fats</td>
<td>biodiesel</td>
</tr>
<tr>
<td></td>
<td>thermochemical</td>
<td>wood, agricultural waste, municipal solid waste</td>
<td>methanol</td>
</tr>
</tbody>
</table>
### Key Challenges and Opportunities

<table>
<thead>
<tr>
<th>Output</th>
<th>Feedstock</th>
<th>Preparation</th>
<th>Key transformation</th>
<th>Refining</th>
<th>Distribution / Usage</th>
<th>Co-products</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transportation</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ethanol (starch)</td>
<td>Designer crop</td>
<td>De-watering</td>
<td>Continuous flow</td>
<td>Mostly resolved</td>
<td>Sediment</td>
<td>Market for DDG</td>
</tr>
<tr>
<td>Ethanol (cellulose)</td>
<td>Beyond clean production to waste cellulose</td>
<td>Acid and enzyme</td>
<td>Pre-treatment</td>
<td>Mostly resolved</td>
<td>Sediment</td>
<td>What to do with CS sugars</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>Beyond food crops</td>
<td>Particulate mass consistency of non-virgin oils</td>
<td>De-watering</td>
<td>Higher efficiency</td>
<td>Catalyst standards</td>
<td>Water contamination</td>
</tr>
<tr>
<td><strong>Heat and Electricity</strong></td>
<td></td>
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</tr>
<tr>
<td>Biogas (Anaerobic Digestion)</td>
<td>Beyond manure and SRM recoveries</td>
<td>Particle size</td>
<td>De-watering</td>
<td>Well understood</td>
<td>Microbial efficiency and nutrition</td>
<td>Generator efficiency and robustness</td>
</tr>
<tr>
<td>SNG (Gasification)</td>
<td>Beyond homogeneous feedstock</td>
<td>Sorting technology</td>
<td>Moisture removal</td>
<td>Heat transfer</td>
<td>Material handling</td>
<td>Generator efficiency and robustness</td>
</tr>
<tr>
<td>Bio-Oil (Pyrolysis)</td>
<td>Beyond homogeneous feedstock</td>
<td>Particle size</td>
<td>De-watering</td>
<td>Mostly worked through</td>
<td>Chemical characterization and extraction</td>
<td>Generator efficiency and robustness</td>
</tr>
</tbody>
</table>

### Biomass-to-Energy Application in Singapore

- Bio-diesel using used cooking oil (2006)
- Four bio-diesel plants to be established on Jurong Island (2006); palm oil (3) and Jatropha (1)
- Mixing 5% bio-diesel in the regular diesel
- Clean energy hub (S$170M): solar, biomass / biofuel and hydrogen/fuel cell
- Food waste to compost and methane (2007)
NTU’s Waste to Bioenergy Research

- Co-production of bio-hydrogen and bio-methane using a three-phase hybrid anaerobic solid-liquid digestion system
- Bioconversion of green waste to sugars for bio-ethanol production
- Organic waste degradation and electricity generation using microbial fuel cells
- Energy recovery from post-consumer plastic waste using pyrolysis
- Algae biofuel production using photobioreactors
- Biomass Derived Fuel (BDF)
Acidogenic from Rm Effluent
Methanogenic Production Biogas

Hybrid Anaerobic Solid-Liquid (HASL) System

Effluent from Rm
Biogas Production

Gas Meter
Peristaltic pumps

Methanogenic Reactor (Rm)
Acidogenic Reactor (Ra)

HASL Bioreactor Vs Conventional Anaerobic Digesters

HASL system
single pass reactor (right) leachate recycle reactor (left)
HASL BIOREACTOR Vs CONVENTIONAL AD REACTORS

Semi-continuous HASL System

The semi-continuous HASL system
HASL Bioreactor vs Conventional Anaerobic Digesters

The mini pilot-scale HASL system

The enhanced HASL system with submerged biofilter
HASL Bioreactor vs Conventional Anaerobic Digesters

Effects of lipid on HASL performance

Experimental setup
Effects of lipid on HASL performance

Methanogenic bacteria

methanogenic bacteria with autofluorescence under epifluorescence microscope
Effects of salt on HASL performance

Control

1% NaCl

2% NaCl

3% NaCl
Effects of food waste fertilizers added in different dosages to subsoil on Kang Kong growth

HASL Pilot Plant @ NTU
The demo-plant for co-generation of hydrogen and methane with a capacity of 3 tonnes of food waste per day.

NTU Research Activities (waste)

**NTU unleashes energy hidden in food waste**

- Feeding and shredding
- Aeration and sedimentation
- Submerged bio-filter
- Acidogenesis
- Equalization
- Methanogenesis
- Discharge
- Reuse
- Methane
- Hydrogen

Food waste

The residue is fertilizer.

NTU unleashes energy hidden in food waste.
Three-phase AD for co-production of Bio-H₂ and Bio-CH₄

Complex Starch-rich materials

Glucose → Acetate → Acetate → H₂ and CO₂

Acidogenesis by Clostridia

Acetate → Butyrate → H₂ and CO₂

Acetogenesis + Methanogenesis

Acetate → H₂ → CH₄ and CO₂

The proposed three-phase AD system for co-production of Bio-H₂ and Bio-CH₄ from food waste
NTU Research Activities (Waste)
Bio-ethanol Production from Green Wastes

In the proposed bio-production process, the biopolymers of green waste are converted into ethanol due to the simultaneous activities of hydrolyzing and ethanol-producing microorganisms.

Anaerobic hydrolyzing microorganisms are isolated from natural sources and guts of tropical wood-eating insects, like termites and caterpillars, to convert green waste into sugars as substrate for ethanol production.

(unknown net source – thanks)

Termites and their Intestinal Microbes
Gram staining

Isolation from 1yr compost (x3000)
Isolation from 3-4 M compost (x3000)
Isolation from termite guts (x3000)
Isolation from aerobic sludge (x3000)
Isolation from garden soil (x3000)

NTU Research Activities (waste)

Waste to Electricity with Microbial Fuel Cell

- Innovations: Mediator-less, membrane-less, electrode with big surface area
- Using naturally-occurring microorganisms or facultative anaerobic iron-reducing bacteria
- Changing bioreactor design configuration to avoid the use of membranes
- Using an electrode with very large surface area to enhance electron transfer

(unknown net source – thanks)
NTU Research Activities (Waste)

Energy Recovery from Plastics Waste using Pyrolysis

- Recover energy from plastics waste with thermal treatment
- Products (gas, liquid, solid) with high potential for reuse
- Good for waste minimization

Liquid products from pyrolysis

Ash collected

Pyrolysis diagram

Experimental setup

NTU Research Activities (Waste)

Algae Biofuel

- As primary producers, algae presents a great potential for converting sunlight into chemical energy. This project explores the potential of biofuel production from algae in Singapore.

- Alpha Synovate Pte. Ltd.
  Alpha Biofuels Singapore

Benoit Guieysse, Wang Jing-Yuan, Tan Hai Woon and Allan Lim
NTU Research Activities (Waste)

Biomass Derived Fuel (BDF)

I had a dream....
Thank You

Energy Resource Management
(Diversification)

(unknown net source – thanks)
Energy Resource Management
(Integration)

Energy Resource Management
(Decentralization)
Energy Resource Management (Conservation)

开源 · 节流