Technological options and social cost considerations of woody biomass conversion

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Institute of Chemical and Engineering Sciences (ICES)
SINGAPORE
ICES – Who We Are

Ministry of Trade and Industry

Ministry of Education

Agency for Science, Technology and Research

EDB

A*STAR

Universities (NUS)

Biomedical

Science & Engineering

Exploit - commercial

ICES

IMRE

IHPC

DSI

IME

IR

SIMTech

Research areas: Chemicals, engineering & science, energy & environment, biomass utilization, LCA
LCA / LCM research

Examples LCA projects:

- National electricity generation
- Packaging materials (paper/cardboard)
- Aluminium metal supply chain
- Zinc metal recycling
- National waste management
- Waste-to-energy systems
- CO\textsubscript{2} sequestration systems (ocean and underground storage)
- LCA of Mineral carbonation (CO\textsubscript{2} sequestration with industrial residues)
- GHG intensity of plastic production
- Biomass conversion and utilization, etc
LCA Network (East Asia)

Forming collaborations:
- Biomass utilization and conversion
- Technology development
- Etc

Exchanging information/data, sharing experience, developing LCA/LCIA methodologies, etc..

[ Indra Gandhi Institute of Development Research; Thailand Environmental Institute; University of Philippines Los Banos; Joint Graduate School of Energy & Environment (King Mongkut Uni.); Konkuk University, Korea; National Institute of Advanced Industrial Science and Technology, Beijing University of Technology ... ]
• Small island with land area: 682.7 square km
• Population of 4.553 million, and rapid industrialization
• The types of identified biomass in Singapore are:
  ➢ wastepaper and cardboard (531,500 tons / year)
  ➢ food residue (1,098,600 tons / year)
  ➢ timber and scrap wood (from industry, construction & demolition and tree felling/pruning) (239,300 tons / year)
  ➢ horticultural (also from tree felling and pruning) (199,500 tons / year)
  ➢ sewage sludge (93,900 tons/year)
  ➢ animal wastes
Other sources (from the Garden City)

Trees along walkways and roads

Felling and pruning activities
Woody Biomass in Singapore

Industrial and demolition/construction waste wood

Convert into ENERGY
LCM for biomass utilization

- Growing concerns over energy security have led to the promotion of renewable energy resources: **Biomass**
- Life cycle management can be used to compare the technological options for biomass-to-energy conversion
- Taking into account: air emissions and external costs
Connecting LCM with Costs

**Standard LCA/LCM**
- ISO framework applied
- Input-output flow (inventory) according to Functional Unit
- From Inventory → impact assessment calculations
- Final results: **Total Environmental impacts**

**Integration of LCM with Costs**
- Same ISO framework applied
- Input-output flow also according to Functional Unit
- From inventory results → *connect with cost functions*
- Final Results: **Total costs**
Compare two different technologies

Waste-to-energy: wood waste $\xrightarrow{\text{Electricity}}$ Electricity

Carbonization: wood waste $\xrightarrow{\text{Charcoal}}$

Translating all LCI into costs:

- Energy inputs $\rightarrow$ costs
- Operations $\rightarrow$ costs
- Air emissions $\rightarrow$ social costs of pollution
- Worth of final product $\rightarrow$ (-ve) costs

[Diagram showing the flow of materials, energy, and air pollution through processes 1, 2, ..., X, with costs and social costs associated with each process.]
Social Costs of Air Pollution

And how to include it in LCA/LCM
Social Costs of Pollution

Studies have been carried out to quantify costs ($$) of damages to human health due to air pollution. These involve:

- specification of emissions emitted: kg pollutant of SO2, NO2, CO, PM, dioxins, etc..
- transportation and dispersion of the pollutants in the air
- impact pathways (inhalation, incidental digestion)
- monetary valuation of the damage caused (also known as externalities)


## Costs factors for each technology

<table>
<thead>
<tr>
<th>Costs and operating conditions</th>
<th>Waste Treatment Technology</th>
<th>Incinerator</th>
<th>Carbonizer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of material processed</strong></td>
<td></td>
<td>Waste wood</td>
<td>Waste Wood</td>
</tr>
<tr>
<td><strong>Main product</strong></td>
<td>Electricity</td>
<td>(940 kWh/ton)</td>
<td>Charcoal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(135 kg/ton)</td>
<td></td>
</tr>
<tr>
<td><strong>Value of product</strong></td>
<td>S$0.12/kWh</td>
<td></td>
<td>S$1.29/kg</td>
</tr>
<tr>
<td><strong>Operating costs in SGD/ton</strong></td>
<td>70</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td><strong>Electricity requirements</strong></td>
<td>70</td>
<td></td>
<td>78.37</td>
</tr>
<tr>
<td>(kWh/ton wood)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other energy requirements</strong></td>
<td>Natural gas</td>
<td>(0.23 m³/ton)</td>
<td>Kerosene</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(5.8 liter/ton)</td>
</tr>
<tr>
<td><strong>Other Costs</strong></td>
<td>S$0.7 per m³ natural gas</td>
<td></td>
<td>S$0.53 per liter kerosene</td>
</tr>
</tbody>
</table>

Thermal value of wood taken as 4.7 MWh/ton; efficiency of incinerator 20%
## Air emissions and Social costs

<table>
<thead>
<tr>
<th>Main Air emissions (kg/ton waste wood)</th>
<th>Incinerator ¹</th>
<th>Japan Carbonizer ²</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO(_x)</td>
<td>0.12</td>
<td>0.65</td>
</tr>
<tr>
<td>NO(_x)</td>
<td>1.01</td>
<td>0.43</td>
</tr>
<tr>
<td>CO</td>
<td>0.18</td>
<td>0.033</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>1280</td>
<td>43.89</td>
</tr>
<tr>
<td>Dioxins/furan</td>
<td>6.89 E-08</td>
<td>0</td>
</tr>
<tr>
<td>PM</td>
<td>0.021</td>
<td>0.015</td>
</tr>
</tbody>
</table>

| Estimated social and economic cost of emissions ³ |
|-----------------------------------|--------|--------|--------|--------|--------|
| $/kg                              | CO     | CO\(_2\) | SO\(_x\) | NO\(_x\) | PM     |
|                                  | 0.004  | 0.057   | 0.58    | 2.92    | 30.0   |
|                                  |        |         |         |         | 3.6E+07|


LCA model

Material and energy flow, and associated pollution and costs
Simple math representation for estimating total value ($P_{Total}$)

$$P_{Total} = \frac{PE}{C} - C^{EN} - C^{OP} - S^{PE}$$

Where

- $P_{Total} = \text{Total value (estimate)}$
- $\frac{PE}{C} = \text{Worth of product}$
- $C^{OP} = \text{Operating Costs}$

And

- $S^{PE} = \text{Sum of social costs of pollution}$
  - $= \sum \text{CO}_2(\text{total in kg}) \times C^{CO}_2(\$/\text{kg}) + \sum \text{SO}_2(\text{total in kg}) \times C^{SO}_2(\$/\text{kg}) + \ldots$

Where $C^{CO}_2/\text{SO}_2\ldots$ is the unit cost per pollutant

Total pollutant (kg) multiplied by cost of pollutant ($/kg) = \text{Total costs ($)}$
Results for breakdown of costs

Projected costs for 1 ton of wood treated

-200
-160
-120
-80
-40
0
40
80
120

Energy Usage | Process | Pollution (Social Costs) | Products
---|---|---|---
Incineration | Carbonization

Social costs of pollution

Worth of product

(Shown as negative costs)
Results for estimating total value of system

Total value per ton of wood waste treated

<table>
<thead>
<tr>
<th></th>
<th>Incineration</th>
<th>Carbonization</th>
<th>Incineration</th>
<th>Carbonization</th>
</tr>
</thead>
<tbody>
<tr>
<td>With social costs</td>
<td><strong>-50</strong> SGD</td>
<td><strong>-40</strong> SGD</td>
<td><strong>-30</strong> SGD</td>
<td><strong>-20</strong> SGD</td>
</tr>
<tr>
<td>W/o social costs</td>
<td>-10 SGD</td>
<td>-10 SGD</td>
<td>-10 SGD</td>
<td>-10 SGD</td>
</tr>
</tbody>
</table>

Nearly similar w/o considering social costs (pollution)
Integration of Social Costs & Economic factors with LCM

- Based on the selection of a common Functional Unit (ton woody biomass waste), all costing factors were identified and compared.

- Social impacts of pollution translated into costs ($$).

- Final results are presented in Monetary values. 
  -> provides an estimation of biomass-to-energy system in terms of product worth vs. other external cost factors.

- Limitation of gate-to-gate model: any other emissions relating to Use Stage not included in the system boundary.

- Future work should cover Capital, Commissioning and Construction.
Concluding remarks

Biomass is viewed, more important now than before, as a potentially important renewable resource

However, today’s interest in biomass as raw material for producing energy is not without precedence

Careful selection of technologies are necessary before implementation of any large scales systems for biomass utilization

Life cycle studies, along with costs and the impact of pollution on society, should be performed before any large-scale biomass conversion technology is implemented

Main conclusion: pollution is not “free” and will always impose some kind of costs – directly or indirectly – on the country and its people in the long run