Bioconversion of wastes (wastewater sludge, glycerol) to biodiesel

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23/04/2015
Why biofuels? -----Energy crisis

- Fossil fuel- **80%** of world energy demand
- **50%** of available oil – exhausted
- Current consumption rate - merely **32 years!**
Why biodiesel?

- Renewable
- Sustainable
- Non-toxic
- Comparable energy density
- Bio-degradable
- Compatible with diesel engines
What is biodiesel?

Fatty acid methyl esters

**Transesterification**

- **Alcohol**: methanol (cheaper)
- **Catalyst**: base or acid (FFA)
- **Oil/fat**: vegetable oil/animal fat (expensive) and waste oil (bad quality)

![Diagram of transesterification process]

- **Biodiesel (FAMEs)**: 100 Kg
- **Glycerol**: 10 Kg

Alternatives
Problem of Glycerol?

Global glycerol production

In 2018 = 1x10^6 ton biodiesel
Alternative feedstock

Microbial oils:

- Accumulate high lipid (80% w/w)
- Rapid growth rate
- Easy to control
- Does Not require arable land

Problem

High RM cost – 70% cost
**Affordable substrates**

**Wastewater Sludge:**
- Naturally produced
- Cost free (waste)
- Rich in C & nutrients
- Disposal problem

**Crude glycerol:**
- By-product of biodiesel production
- Cost low (0.15 US$/kg) or can be free
- Simple Carbon
Process

Sterilization
121°C, 30 min

Sludge
Sludge+crude glycerol

Oleaginous microbes

Fermenter

Extraction

Biomass

Glycerol + Biodiesel

Transesterification
Process (fermentation)

Higher SS was obtained with washed sludge (31 g/L) than unwashed sludge (23 g/L).

Sterilization
121°C, 30 min

Sludge
Sludge+crude glycerol

Fermenter
Oleaginous microbes

Unwashed sludge+40 g/L glycerol

Washed sludge+40 g/L glycerol
### Sludge effect on lipid accumulation

Initial conditions: sludge SS=30 g/L; Alkaline thermal treated; 10% inoculation

<table>
<thead>
<tr>
<th>SS₀</th>
<th>Pre-treatment</th>
<th>Glucose (g/L)</th>
<th>Glycerol (g/L)</th>
<th>Washed</th>
<th>Unwashed</th>
<th>SS₁</th>
<th>Lipid (% w/w)</th>
<th>Lipid (g/L)</th>
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<td>W</td>
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<td>8</td>
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<td>40</td>
<td>W</td>
<td>-</td>
<td>48.0</td>
<td>40</td>
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<td>70</td>
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<td>10.68</td>
<td>75.8</td>
<td>8.1</td>
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</tbody>
</table>
Process

Sludge → Sludge + crude glycerol → T. oleaginous

Ultrasonication 60 Hz, 2800 W

Extraction

Biomass
Profile of biodiesel

Major:

C16 and C18
(similar as plant seed oil)

Suitable for biodiesel production
Energy balance and Greenhouse Gas Emissions
(1 tonne sludge utilized)

### Energy balance

<table>
<thead>
<tr>
<th>Process</th>
<th>Net energy gain per tonne sludge used (GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residue to landfill</td>
<td>0</td>
</tr>
<tr>
<td>Residue to land application</td>
<td>2</td>
</tr>
<tr>
<td>Residue for fermentation</td>
<td>3</td>
</tr>
<tr>
<td>Sludge fermentation</td>
<td>12</td>
</tr>
<tr>
<td>Pre-treated sludge fermentation</td>
<td>6</td>
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</table>

### GHG emissions

<table>
<thead>
<tr>
<th>Process</th>
<th>GHG generation per tonne sludge used (kg CO2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residue to landfill</td>
<td>-30,000</td>
</tr>
<tr>
<td>Residue to land application</td>
<td>-25,000</td>
</tr>
<tr>
<td>Residue for fermentation</td>
<td>-20,000</td>
</tr>
<tr>
<td>Sludge fermentation</td>
<td>-15,000</td>
</tr>
<tr>
<td>Pre-treated sludge fermentation</td>
<td>-10,000</td>
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</tbody>
</table>
Comparison of Energy Ratio
Cost of biodiesel production from sludge

260 tonnes sludge per day

1.0 US $/kg: Cost of biodiesel production

 LF= landfill
 LA=land application
Cost estimation of crude glycerol for biodiesel production

- Lipid production cost ($/kg)
- 0.4 million kg lipid/yr
- 1 million kg lipid/yr
- 1.11$/kg lipid

<table>
<thead>
<tr>
<th>Lipid content</th>
<th>Time</th>
<th>Nutrients</th>
<th>Scale</th>
<th>Methanol</th>
<th>Yield</th>
<th>Glycerol Cost (0.15$/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16%</td>
<td>0.4</td>
<td>million kg lipid/yr</td>
<td>16%</td>
<td>48%</td>
<td>40%</td>
<td>1 million 48 h 40%</td>
</tr>
</tbody>
</table>
## Conclusions

<table>
<thead>
<tr>
<th>Medium</th>
<th>Sludge</th>
<th>Glycerol</th>
<th>Sludge + glycerol</th>
<th>Washed sludge + glycerol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity used</td>
<td>1 tonne sludge</td>
<td>1 tonne</td>
<td>1 tonne sludge + 1.3 tonne glycerol</td>
<td>1 tonne sludge + 1.3 tonne glycerol</td>
</tr>
<tr>
<td><strong>Biodiesel</strong> (product)</td>
<td>198 kg</td>
<td>220Kg</td>
<td>263 kg</td>
<td>411 kg</td>
</tr>
<tr>
<td><strong>Glycerol</strong> (by-product)</td>
<td>20 kg</td>
<td>22Kg</td>
<td>26 kg</td>
<td>41 kg</td>
</tr>
</tbody>
</table>
Merci beaucoup
Energy balance of biodiesel production
(heterotrophic microalage)

Biodiesel produced from microalage cultivated in wastewater
Biodiesel production from sludge (one-step)

Wastewater Sludge → Extraction Transesterification → Biodiesel

Residual solid
Trichosporon oleaginosus

SEM images after ultrasonication (glycerol medium)

**Before**

- **Ultrasonication**
  - **520 kHz, 40 W**
  - **60 Hz, 2800 W**

**SKF-5**

- **Before**
  - **Ultrasonication**
  - **520 kHz, 40 W**
  - **60 Hz, 2800 W**
Energy balance and Greenhouse Gas Emissions
(1 tonne biodiesel produced)

Energy balance

GHG emission

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy Balance (GJ)</th>
<th>GHG Generation (kg CO2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual landfill</td>
<td>-5</td>
<td>-70000</td>
</tr>
<tr>
<td>Residual application</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Residual for fermentation</td>
<td>25</td>
<td>-20000</td>
</tr>
<tr>
<td>Sludge - extraction - transesterification</td>
<td>30</td>
<td>-50000</td>
</tr>
<tr>
<td>Sludge fermentation</td>
<td>15</td>
<td>-30000</td>
</tr>
<tr>
<td>Pre-treated sludge fermentation</td>
<td>10</td>
<td>-15000</td>
</tr>
<tr>
<td>Starch wastewater fermentation</td>
<td>10</td>
<td>-10000</td>
</tr>
<tr>
<td>Cellulose fermentation</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Starch fermentation</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Waste - fermentation - extraction - transestrification</td>
<td>-5</td>
<td>-70000</td>
</tr>
<tr>
<td>CO2 - fermentation - extraction - transesterification</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Open pond algae</td>
<td>10</td>
<td>10000</td>
</tr>
<tr>
<td>Photo-bioreactor algae</td>
<td>5</td>
<td>5000</td>
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</table>
Comparaison of Energy Ratio

Energy ratio (Output/Input)

- sunflower seed
- soybean
- canola
- microalgae (open pond)
- microalgae (photoreactor)
- microalgae from starch
- wastewater
- sludge (two-step)
- sludge (one-step)
Biodiesel from Algae
Biodiesel production from sludge (two-step)

Step 1

Wastewater Sludge → Extraction

Residual solid

Lipid

Step 2

Transesterification

Biodiesel
Different medium effect on lipid accumulation

Initial conditions: sludge SS=30 g/L; Alkaline treated; Glucose/glycerol conc.=25 g/L; 10% inocul.

Curde glycerol for lipid accumulation is comparable with glucose
Glycerol concentration effect on lipid accumulation

Initial conditions: sludge SS=30 g/L; Alkaline treated; 10% inoculation
Sludge effect on lipid accumulation

Initial conditions: sludge SS=30 g/L; Alkaline treated; 10% inoculation

Higher SS was obtained with washed sludge (31 g/L) than unwashed sludge (23 g/L).