Year-round production of microalgae for biodiesel supported by waste industrial CO$_2$ and heat emissions

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Microalgae biofuels & industrial off-gas mitigation

- Sunlight
- Initial microalgae
- Nutrients (e.g., N, P)
- CO₂
- Controlled stress in an industrial environment (pH, temperature)
- Increased microalgal lipids (at levels 2-5 times higher than without stress)
- Increased biomass (1.8 kg CO₂ = 1 kg biomass)
- Industrial off-gas

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Global temperatures lead to large zones traditionally considered unsuitable for outdoor algae cultivation.
Capturing industrial waste heat & CO$_2$ provides a solution

Sudbury Integrated Nickel Operations: A Glencore Company smelter

Off-gas from the smelter contains:

- 60 MW of waste heat
- 100,000 tons of CO$_2$ per annum
Current smelter off-gas diagram

Feed → Roaster

Roaster → Gas cleaning

Gas cleaning → Gas cooling

Gas cooling → SO₂ removal & sulphuric acid production

Converter

Converter → Gas cleaning

Gas cleaning → Furnace

Furnace → Gas cleaning

Gas cleaning → 650°C

650°C → 50°C

50°C → SO₂ removal & sulphuric acid production

SO₂ removal & sulphuric acid production → H₂SO₄

H₂SO₄

Cleaned off-gas discharged to atmosphere

Cleaned off-gas discharged to atmosphere

Off-gas

350°C

Off-gas

650°C

50°C
Smelter-coupled process: CO$_2$ & waste heat utilization

- **Feed**
- **Roaster**
- **Gas cleaning**
- **Heat exchanger**
- **Off-gas discharged to atmosphere**
- **SO$_2$ removal & sulphuric acid production**
- **Furnace**
- **Gas cleaning**
- **Converter**
- **Closed loop**
- **Direct off-gas injection for pond heating, agitation and CO$_2$**
Is cold climate production using off-gas feasible?

We have modeled cultivation of algae in cold climates, by using a “standard production tank” of 50 m long, 5 m wide and 1 m deep.

The tank with insulated sides is sunk into the ground and covered with a clear polyethylene roof (similar to used in greenhouses).

The smelter’s the annual ambient temperature profile
Model results: microalgae production

<table>
<thead>
<tr>
<th>Month</th>
<th>Ambient Temperature (°C)</th>
<th>Energy per tank</th>
<th></th>
<th>15°C (kW)</th>
<th>30°C (kW)</th>
<th>15°C (kW)</th>
<th>30°C (kW)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Furnace Roaster</td>
<td>Furnace</td>
<td>Roaster</td>
<td>Furnace</td>
<td>Roaster</td>
</tr>
<tr>
<td>February</td>
<td>-11.4</td>
<td>12</td>
<td>27</td>
<td>10</td>
<td>51</td>
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<td></td>
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<tr>
<td>May</td>
<td>11.3</td>
<td>12</td>
<td>1</td>
<td>10</td>
<td>25</td>
<td></td>
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<tr>
<td>August</td>
<td>17.7</td>
<td>12</td>
<td>4</td>
<td>10</td>
<td>4</td>
<td></td>
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<tr>
<td>November</td>
<td>-1.5</td>
<td>12</td>
<td>2</td>
<td>10</td>
<td>26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The limit is 180 tanks which is determined by the volume of furnace off-gas required to provide CO₂ and agitate the tanks.

Whereas, the available roaster off-gas is enough to heat as many as 240 tanks.
Potential biodiesel production

*Calculations can be done with values based on any industrial operation and our research outcomes:*

For the smelter, using the 180 tank maximum - algae productivity will be 810 000 kg/year.

This is a system which achieves similar volumetric productivities as published values, but has a significantly decreased footprint due to the greater tank depths.

Using a conservative 30% lipid content - 227 000 L of biodiesel per annum.
Biodiesel for mining

Biodiesel is ideal for the mining sector – use in underground diesel powered equipment.

Combustion of biodiesel, compared to diesel, results in:

- 100% reduction in SO$_2$
- 90% reduction in unburned hydrocarbons
- 75-90% reduction in polycyclic aromatic hydrocarbons
- 17.1% less CO
- 22.5% reduction in smoke density

A cleaner working environment could reduce the level of very expensive mine ventilation.
Unique pilot plant facility

Tanks (1 m³) on the smelter roof and connected to furnace off-gas (6-7% CO₂)

Study impact on microalgae growth & lipid production from:

- off-gas flow rate, composition and mixing
- pH levels
- water temperature
- single and mixed cultures
- CO₂ uptake/mitigation
Microalgae biodiesel from the pilot plant
Conclusions

Synergy between modeling, laboratory and pilot plant work has allowed for extensive research and development that covers the complete microalgae and biodiesel production process.

As a result, production of microalgae for biofuel is possible outdoors in Canada and other cold climates utilizing an industrial process-coupled approach to make positive use of otherwise waste CO₂ and heat.
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