Conceptual Design & Preliminary Engineering for Capture & Reuse of CO₂ & NOₓ for Algae Production from Stationary Engine Flue-Gas

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**Inoculation Ponds**
- 12 @ 2000-m²
- 12 @ 200-m²
- 9 @ 33-m²

**Production Ponds**
- 6 @ 20,000-m²

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**Photo-voltaic Panels**

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**Natural Gas Power Plant**
Chlorella spp.
Chlorella spp.

Spirulina (Arthrosira platensis)  Dunaliella salina

Chlorella vulgaris  Haematococcus pluvialis
Algae Pond CO$_2$ Demand

- 32 acres water surface
- 128,000 M$^2$ water surface area
- 3.0 g/m2/hr peak algae productivity (d.w.)
- 384 kg/hr peak algal productivity per module
- 50% Carbon content in algae biomass
- 192 kg carbon/hr. peak uptake rate
- 56% Carbon uptake efficiency in ponds
- 343 kg Carbon/hr – C addition rate to ponds
- 1,257 kg CO2/hr – peak addition rate to 32 acres
I.C. 2-Stroke Engine Specs.
- Natural Gas Fuel -

• 3,200 h.p I.C.-Reciprocating, 2-stroke (Cooper 8V-275)
• 30% engine efficiency (80%-load)
• 22,000 Btu/lb natural gas
• 1,007 lbs/hr nat. gas required
• 755 lbs/hr carbon in nat. gas burned
• 2,770 lbs/hr CO2 in flue-gas (3.41% CO2 vol. %)
• NOx (NO2, NO) = 102.5 ppm (average in flue gas)
• 1,259 kg/hr CO2 in flue gas
• 19 million L flue gas/hr – peak addition rate to 32 water-acres of ponds (8-10 hrs/day x 275 days/yr)
Case 1: Gravity Harvest with Settling Ponds

12 ha Raceway Ponds → Settling Ponds → Centrifuges

Blower

Make-up Water

Flue Gas

Bead Mills

Spray Dryer

Algae Product

Blowdown to Waste
# Process Assumptions

## Flue Gas Assumptions

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>% CO2 in gas (by vol.)</td>
<td>3.4%</td>
<td></td>
</tr>
<tr>
<td>% N2 in gas (by vol.)</td>
<td>87.5%</td>
<td></td>
</tr>
<tr>
<td>hrs/day of CO2 sparing</td>
<td>10 hrs</td>
<td></td>
</tr>
<tr>
<td>% Uptake of CO2 sparing</td>
<td>50%</td>
<td></td>
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</tbody>
</table>

## Site Assumptions

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<table>
<thead>
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<tbody>
<tr>
<td>Production Pond Area</td>
<td>12.0 ha</td>
<td>29.7 acres</td>
</tr>
<tr>
<td>Pumping Head for Makeup water</td>
<td>10 m</td>
<td>32.8 ft</td>
</tr>
<tr>
<td>Pumping Head for Recycle</td>
<td>5 m</td>
<td>16.4 ft</td>
</tr>
<tr>
<td>Blow down (%)</td>
<td>22%</td>
<td></td>
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</table>

## Total Biomass Produced

| Total Biomass Produced | 771 Metric tonnes/yr |
Algae Productivity Assumptions

16.0 g/m²-day Annual Average Productivity
(note: system not operated in winter months)
Case 1: Capital Costs: Total $16.6 million

- Raceway Ponds, 39%
- Harvesting Systems, 19%
- Electrical, Buildings, Contingency, etc., 17%
- Spray Dyer, 12%
- Flue Gas System, 7%
- Innoculum System, 3%
- Water piping and pumps,
Case 1: Energy Requirements* (968,000 kWh/yr)

- Water pumping, 10%
- HRP mixing, 18%
- Blowers for Flue gas, 33%
- Inoculation Raceways, 15%
- Harvesting, 12%
- Processing, 3%
- Contingency, 9%

*Additional 20,000 GJ/yr natural gas required for drying
## Case 1: Operating Expenses

<table>
<thead>
<tr>
<th>Variable Operating Expenses</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$1,040,000</td>
</tr>
<tr>
<td>Electricity (purchase)</td>
<td>$130,000</td>
</tr>
<tr>
<td>Natural gas (purchase)</td>
<td>$132,000</td>
</tr>
<tr>
<td>Consumables (Nutrients, packing, laboratory supplies)</td>
<td>$600,000</td>
</tr>
<tr>
<td>Sub Total</td>
<td>$1,902,000</td>
</tr>
<tr>
<td>Contingency</td>
<td>15%</td>
</tr>
<tr>
<td>Contingency</td>
<td>$285,300</td>
</tr>
<tr>
<td><strong>Total Variable Operating Expenses ($/yr)</strong></td>
<td><strong>$2,187,300</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fixed Operating Expenses</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance (2% of direct capital, less land)</td>
<td>$215,000</td>
</tr>
<tr>
<td>Insurance and Taxes (2% of direct capital)</td>
<td>$235,000</td>
</tr>
<tr>
<td>Depreciation</td>
<td>$610,000</td>
</tr>
<tr>
<td><strong>Total Fixed Operating Expenses ($/yr)</strong></td>
<td><strong>$1,060,000</strong></td>
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</tbody>
</table>
## Case 1: Preliminary financial summary

<table>
<thead>
<tr>
<th>Preliminary Financial summary</th>
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<tbody>
<tr>
<td>Total fixed operating expenses ($/yr)</td>
<td>$1,060,000</td>
</tr>
<tr>
<td>Total variable operating expenses ($/yr)</td>
<td>$2,185,000</td>
</tr>
<tr>
<td>Capital charge ($/yr)</td>
<td>$2,320,000</td>
</tr>
<tr>
<td><strong>Total cost of production ($/yr)</strong></td>
<td><strong>$4,508,000</strong></td>
</tr>
<tr>
<td>Other costs (marketing, rents, taxes, etc. 15%)</td>
<td>$835,000</td>
</tr>
<tr>
<td>Total dry biomass produced (kg/yr)</td>
<td>771,000</td>
</tr>
<tr>
<td><strong>Total Production Expense per kg ($/kg)</strong></td>
<td><strong>$8.30</strong></td>
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Preliminary estimate for operating costs only

$/kg-algae vs Total Wet area (ha)

- Gravity Harvest
- Centrifuge Harvest
Acknowledgements

- **Financial Support** – Southern California Gas Company:
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