Life cycle greenhouse gas emissions for algal biofuels: Effect of different CO$_2$ supply options

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Vehicular emission inventory modeling, Evaluation of co-benefits in transportation sector, Estimation of exhaust and non exhaust emissions from transport sector, Enhancing Production of Biodiesel from Microalgae for Environment Friendly Transport, Sustainable Transportation Systems (Prof. Bhola Gurjar)

Mapping of Dynamic Air Pollution Information to the Choices of Travelers, Transport negative externalities, Air Pollution Exposure, Transport Modelling and Simulation (Prof. Amit Agarwal)

Artificial Intelligence and Machine Learning for Environmental Data, Data Mining and Big Data Analysis (Prof. Durga Toshniwal)

Life cycle assessment of electric vehicles and biofuels, process simulation and optimization of biofuels, Integrated Assessment Modelling (IAM) of EVs and Biofuels. (Prof. Pratham Arora)
Introduction

Why make fuels from algae?

- Algae require CO2 for growth, therefore fuel is potentially low carbon.
- Possible integration to achieve low-cost CO2 sequestration and nutrient remediation.
- Uses all nutrients, minimizing eutrophication.
- Biodegradable, so minimal issues with accidental spills /leaks.
- Uses underutilized land, e.g. deserts.
- Yields >10x those for land plants, so much less land is needed.
- Certain species can grow in salty or brackish water.
CO2 supply to algal biorefinery

• A major challenge faced by algal biorefinery is the sustainable supply of carbon dioxide.
• CO2 requirements are responsible for 10-30% of biorefinery raw material cost.
• It is very important to quantify the CO2 emissions for production and transport of CO2.
• The present study compares the global warming potential (GWP) of different CO2 supply scenarios, utilizing a functional unit of 1 MJ of refined bio-crude.
CO₂ supply to algal biorefinery
Methodology

- Different CO\textsubscript{2} supply scenarios have been modelled in a steady state process simulation software \textit{ASPEN Plus}\textsuperscript{®}.

- The study considers separate day and night operations for the CO\textsubscript{2} supply cases, because algae growth only takes place during the daytime.

- A cradle-to-gate LCA study was carried out with the help of MS Excel worksheets for different process variants.
Methodology

• The different CO₂ supply scenarios that are considered in the present study utilize the flue gas from a
  ▶ Flue gas from a legacy coal-based power plant
  ▶ Flue gas from a legacy natural gas-based power plant
  ▶ Flue gas from a purpose-built natural gas combined cycle (NGCC) plant
  ▶ Flue gas from purpose-built biomass combustion plant.
  ▶ CO₂ supply from a purpose-built direct air capture (DAC) system

• The power plants are assumed to be located at a distance of 2 miles from the biorefinery.

• The standalone NGCC unit and the biomass combustion units are assumed to be constructed at the algal biorefinery.
Methodology

(a) CO$_2$e of production and utilization = X+Y

(b) CO$_2$e of production and utilization = 1+X+Y
Coal power plant flue gas
Natural gas power plant flue gas with carbon capture

<table>
<thead>
<tr>
<th></th>
<th>Natural gas-based power plant</th>
<th>Coal-based power plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_2$</td>
<td>75.6</td>
<td>65.4</td>
</tr>
<tr>
<td>$O_2$</td>
<td>11.6</td>
<td>4.1</td>
</tr>
<tr>
<td>$H_2O$</td>
<td>8.5</td>
<td>18.6</td>
</tr>
<tr>
<td>$CO_2$</td>
<td>4.3</td>
<td>11.9</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>82</td>
<td>60</td>
</tr>
</tbody>
</table>
Natural gas power plant flue gas
Standalone NGCC flue gas with carbon capture and refrigeration
Biomass combustion and gasification flue gas

Direct air capture

http://www.texasvox.org/direct-air-capture-co2-climate-solution-limitations/
Results

GHG emissions (kg CO2 eq./MJ refined bio-crude)

- Coal based power plant
- Natural gas based power plant
- NGCC with carbon capture and refrigeration
- Biomass combustion unit
- DAC

Emissions from gasoline
Conclusions

**CO₂ supply** from the combustion of **biomass** has the **lowest GHG footprint** for the delivered CO₂.

Construction of a **standalone NGCC unit** near the biorefinery has the **highest GHG footprint**. However, the GHG footprint of such a plant is very **sensitive** to the **grid electricity carbon footprint** as well as emissions from the supply chain of natural gas feedstock.

The **fossil fuel power plant** CO₂ supply has positive emissions for supplying stack gases and is expected to become **prohibitive** as the **distance** between the power plant and biorefinery increases.

The results provide a **benchmark for comparison of different CO₂ supply options** for the establishment of a sustainable algal biorefinery.