INTEGRATED ALGAE BIOREFINERY: DESIGN, OPTIMISATION AND CONTROL

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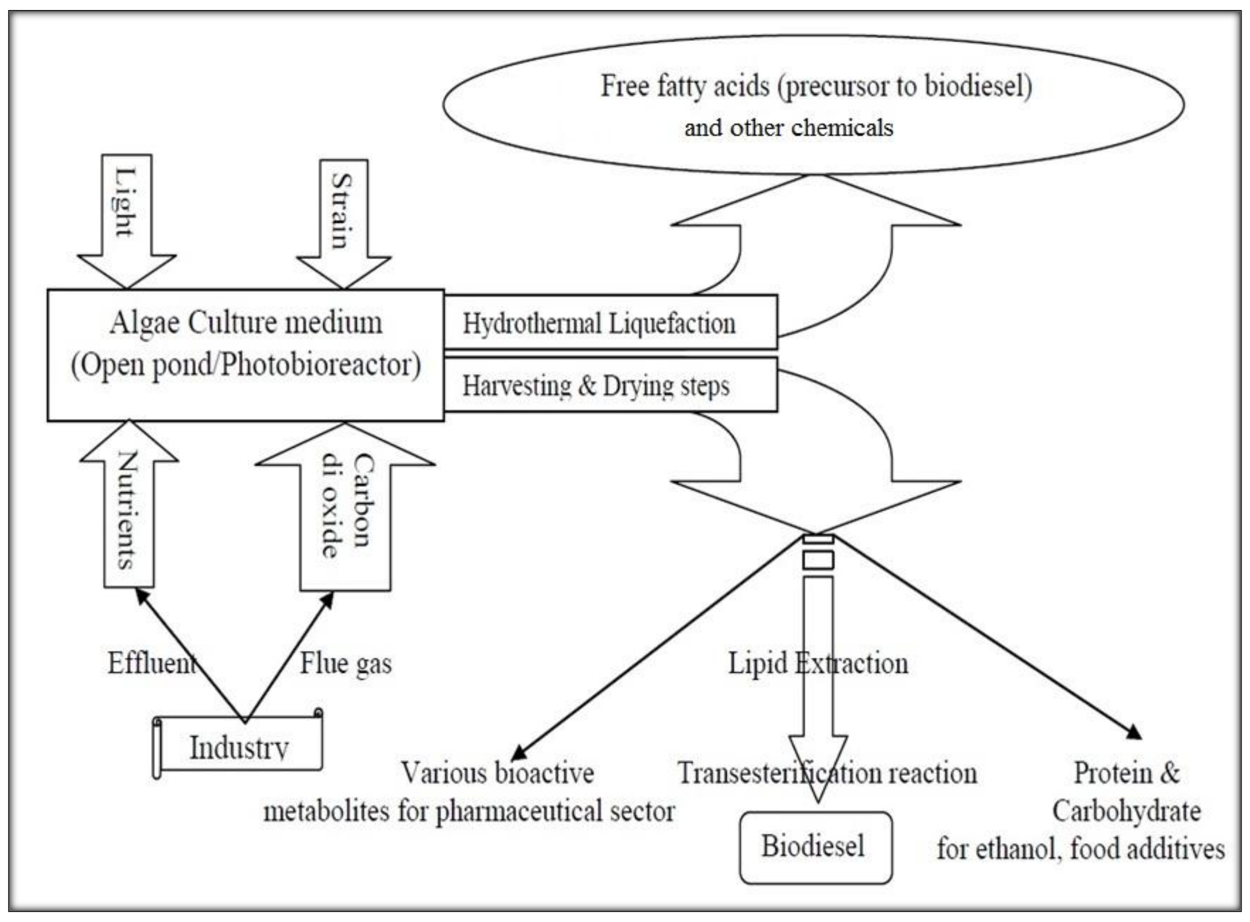
Integrated Algae Biorefinery



Advantages:

- Renewable, green, and local
- Provides higher biomass yield per unit area
- Provides various value-added co-products
- Bio-mitigates industrial effluent and flue gas

Major limitation:

- Techno-economically infeasible

Proposal: A multi-dimensional research approach using process systems engineering

- Explore novel process options: Design
- Improve existing process options: Control
- Develop optimal biorefinery: Synthesis

Hydrothermal Liquefaction

An alternative method of extracting oil from algae, using high pressure and temperature (4500 psi / 200^0-350^0C) reaction in aqueous media

Advantages

- Cost saving since water removal not needed
- Easy product recovery since byproduct converted during the reaction

Goal: Develop and validate reaction kinetics model for process design and optimisation

Model Development

$$TAG + H_2O \underset{k_2}{\overset{k_1}{\rightleftarrows}} Di + FA$$

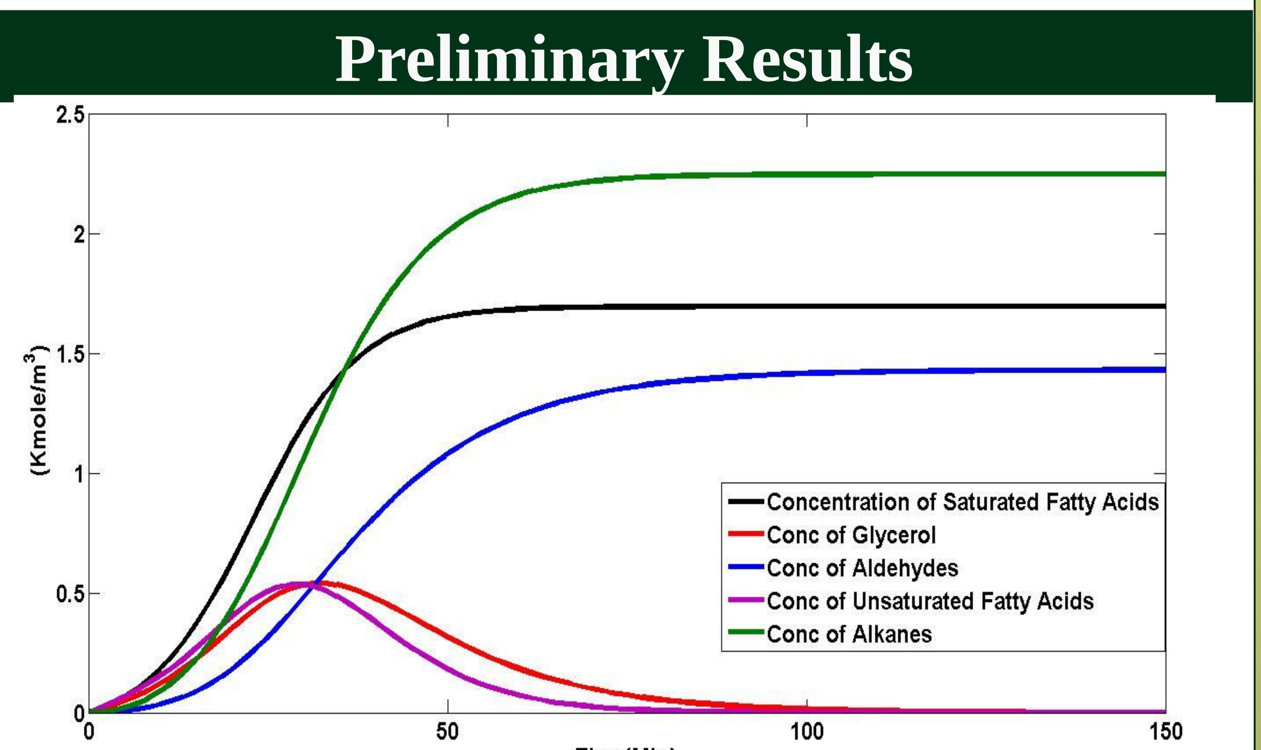
$$Di + H_2O \underset{k_4}{\overset{k_3}{\rightleftarrows}} Mono + Fa$$

$$Mono + H_2O \underset{k_5}{\overset{k_5}{\rightleftarrows}} Gly + FA$$

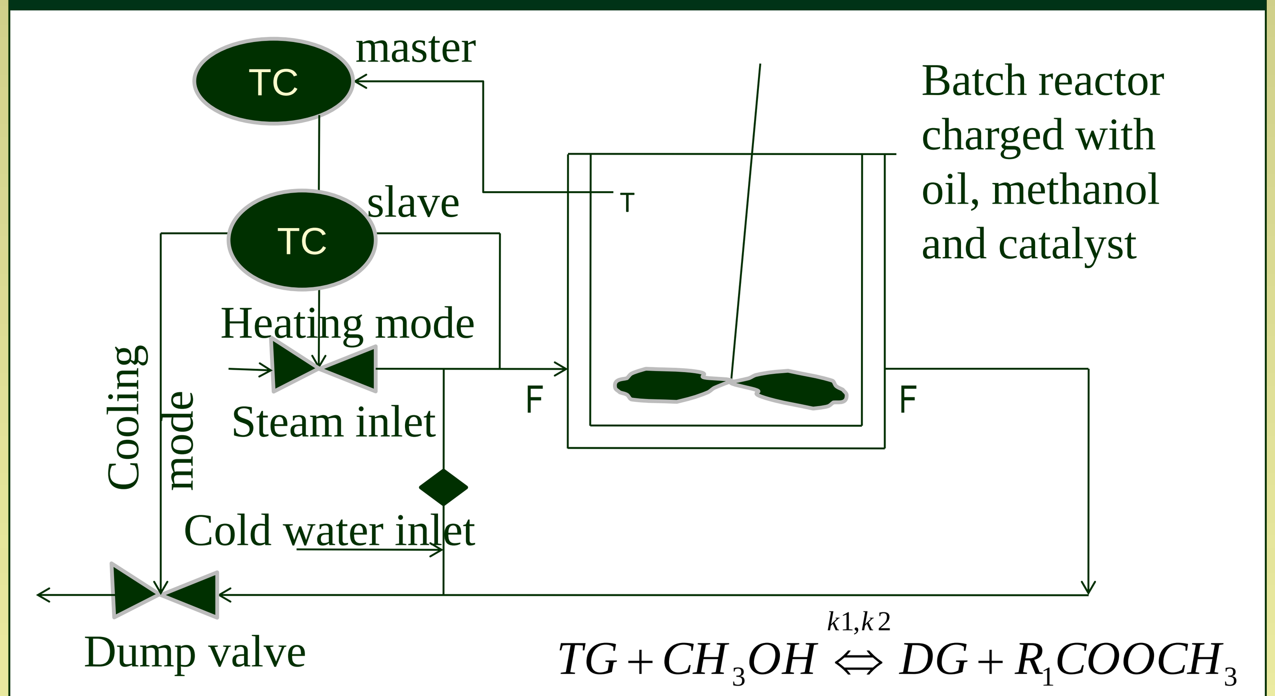
Model considerations:

- Mass balance on TAG
- Mass balance on glycerol
- Conversion of unsaturated fatty acids to alkanes

Preliminary Results



Kinetics of Transesterification Reaction



$$TG + CH_3OH \overset{k1,k2}{\Leftrightarrow} DG + R_1COOCH_3$$

$$DG + CH_3OH \overset{k_3,k_4}{\Leftrightarrow} MG + R_2COOCH_3$$

$$MG + CH_3OH \overset{k_5,k_6}{\Leftrightarrow} GL + R_3COOCH_3$$

$$\frac{dC_{TG}}{dt} = -k_1C_{TG}C_A + k_2C_{DG}C_E \quad (1)$$

$$\frac{dC_{DG}}{dt} = k_1C_{TG}C_A - k_2C_{DG}C_E - k_3C_{DG}C_A + k_4C_{MG}C_E \quad (2)$$

$$\frac{dC_{MG}}{dt} = k_3C_{DG}C_A - k_4C_{MG}C_E - k_5C_{MG}C_A + k_6C_{GL}C_E \quad (3)$$

$$\frac{dC_E}{dt} = k_1C_{DG}C_A - k_2C_{DG}C_E + k_3C_{DG}C_A - k_4C_{MG}C_E + k_5C_{MG}C_A - k_6C_{GL}C_E \quad (4)$$

$$\frac{dC_A}{dt} = -\frac{dC_E}{dt} \quad (5)$$

$$\frac{dC_{GL}}{dt} = k_5C_{MG}C_A - k_6C_{GL}C_E \quad (6)$$

$$k_j, (j = 1,\dots,6) = a_j e^{-E_a/RT} \quad (7)$$

Advanced Model Based Control of a Batch Transesterification Reactor

- Optimal control: Open loop control
- End product quality control using closed loop control
  - -Batch to batch iterative learning control
  - -Within batch on-line shrinking horizon model predictive control (SHMPC)
  - -Midcourse correction policy (MCC)

Implementation of Optimal Control

- Determination of best temperature profile of a batch reactor over a time interval $[t_0, t_f]$ such that C_E is maximized

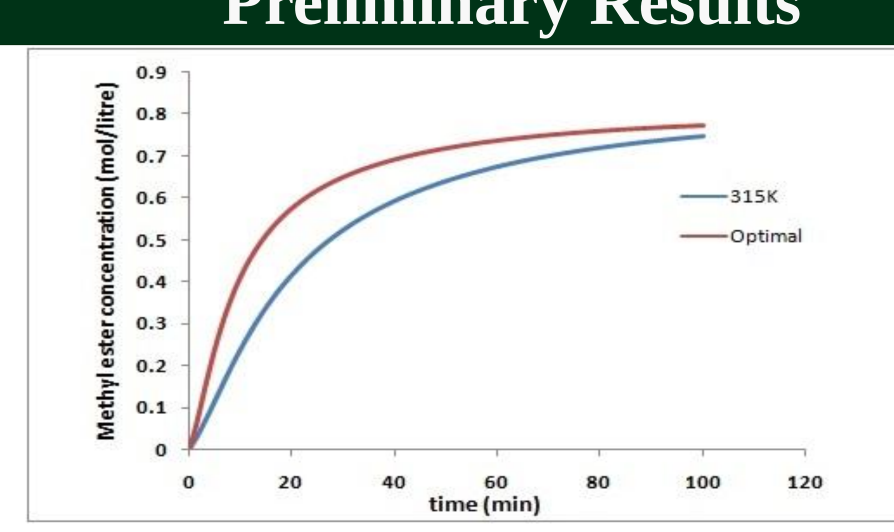
$$Min J(T) = -C_E(t_f)$$

s.t.

$$\frac{dC_i}{dt} = f(C_i, T, t); C_i(0) = C_0$$

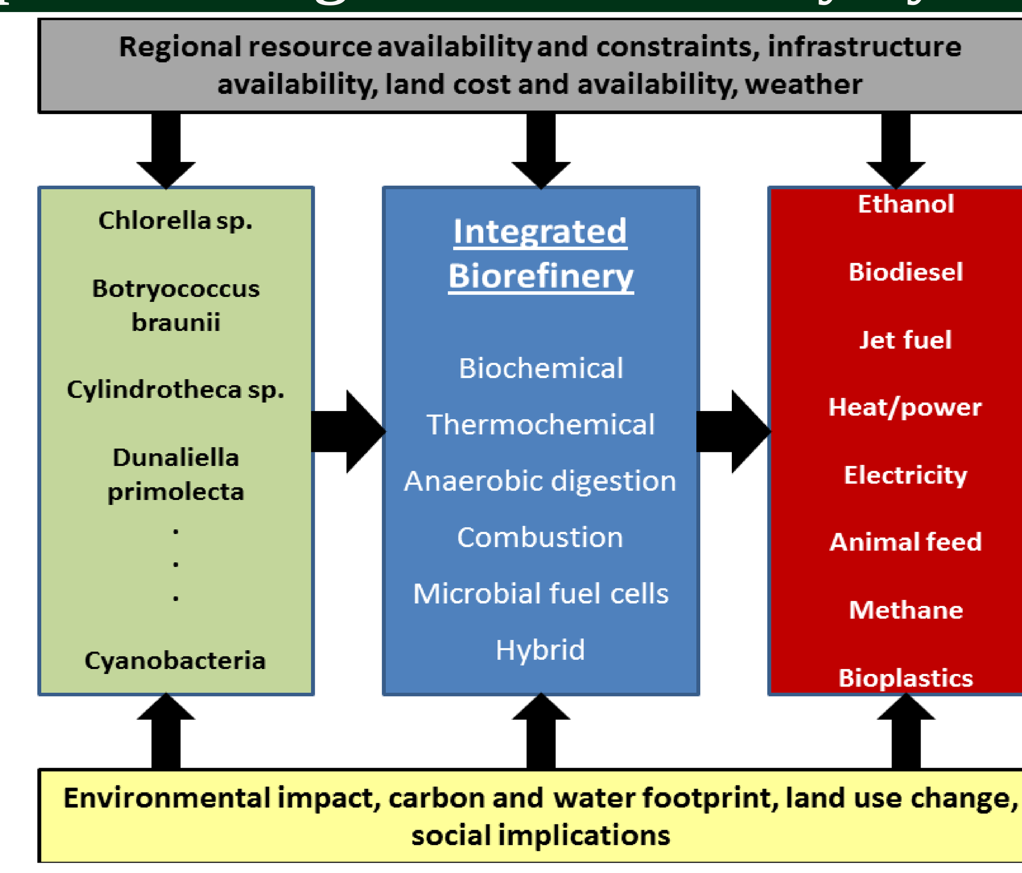
$$C_i = [C_{TG}; C_{DG}; C_{MG}; C_E; C_A; C_{GL}];$$

Preliminary Results



- Comparison of methyl ester concentration between optimal temperature profile and base temperature of 315K
- C_{315K}=0.7487 mol/L (base case); $C_{Optimal}$=0.7748 mol/L

Optimal Integrated Biorefinery Synthesis



- Development of process super-structure
- Optimisation of process flow-sheet
- Optimisation of batch process scheduling
- Integration of energy and value added products

Optimisation Model Development

- Focus on growth and harvesting
- Growth using open-pond cultivation
- Harvesting using a combination of sedimentation, and centrifugation
- Cost, efficiency and performance considerations

Equipment	Decision variables
Growth pond	Pond dimension, Growth medium, Growth duration
Settling tank	Flocculant being added, Dimension of the tank
Centrifuge	Capacity

Objective:
Minimise Annualised Life Cycle Cost

Constraints: Types of equipment used, their capacities and operating parameters

Model: MILP with 54895 equations and 74801 variables

Preliminary Results

- *Chlorella vulgaris* as algal strain
- 230.55 Mg of biodiesel per day
- Result: Cost of growth and harvesting = 0.886 $/l

Growth pond
1004 in number: each of area 100,000 m^2 (10 hectare)
Chicken waste used as nutrient
Solution grown for 20 days

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Settling tank
18 in number, capacity 25000 m^3, flocculant- ACTIPOL FB1

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Centrifuge
31 in number, capacity of 0.01009 m^3/sec. (160 gpm)

For any comments/ suggestions/ queries contact: Prof. Yogendra Shastri, Chemical Engineering Department, IIT Bombay