Modeling Algae Pond Cultivation – Canada (and global)

SUMMARY: Powerful analytic model predicts your algae biomass production. Use ambient conditions or conduct “what if” analysis around temperature, light, inoculum concentration and harvesting frequency to optimize production for ponds and PBRs. Improve accuracy by re-calibrating for your algae species using site specific experimental data.

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Research Objectives
- To model and predict algae autotrophic growth in Canada and other parts of the world using primarily solar energy.
- Of particular interest would be the ability to predict cultivation growth yields at different latitudes and geographic locations for techno-economic analysis for applications involving ponds and/or photo-bioreactors (PBRs).

Hypothesis
- LIGHT and TEMPERATURE are the two most important geographic related variables affecting the growth of algae.
- The hypothesis is that an analytic model can be developed to predict growth for different geographic regions based on experimental results at one location (base case) and correlate these results to credible solar Global Horizontal Irradiance (GHI), length of day and temperature data sets.
- Once achieved, the model can extrapolate outcomes for other geographic areas.

Procedure
- Access ATP3 experimental data sets to establish experimental base case.
  - Mesa AZ for the period Jun-Jul 2014
  - Compile data sets for processing
  - Validate model calculations statistically (including use of standard deviations)
  - Calculate K, Biomass growth production coefficient
  - Apply light dependence model: (Beer – Lambert)
  - Apply two temperature dependence models: Arthenius, Ras
    - Model 1 \( f(T) = \frac{a}{1 + e^{c(T-\text{opt})}} \)
    - Model 2 \( f(T) = \frac{a}{1 + e^{c(T-\text{opt})}} \)
    - Biomass production (Jayaraman 2015)
      \( \frac{\text{d}B}{\text{d}t} = K_B f(T) \)
      \( B = B_0 + K_B \frac{\text{d}t}{f(T)} \)
- Correlate experimental data to NASA satellite GHI data sets for solar energy, ambient temperature; daylight for same dates and location.
- Validate correlation including statistical standard deviations
- Upload data sets for selected locations
- Analyze results

Definitions
- Algae growth...exponential model
  - Model parameters:
    - Maximum initial biomass concentration
    - Maximum growth rate
- Assumptions
  - \( f(t) = \frac{a}{1 + e^{c(T-\text{opt})}} \)
  - \( B = B_0 + K_B \frac{\text{d}t}{f(T)} \)

Assumptions
- \( f(t) = \frac{a}{1 + e^{c(T-\text{opt})}} \) except for \( T \) where \( T_{\text{opt}} \leq T < T_0 \)
- Model parameters:
  - \( a = \text{maximum initial biomass concentration} \)
  - \( K_B = \text{maximum growth rate} \)
- \( K_B \text{ is} \text{ constant} \) (growth rate is constant)
- \( T_0 \) is constant and \( T_0 = T_{\text{opt}} + T_0 \)

References

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Conclusions
- Model predicts significant algae cultivation can take place in Canada
- Incremental improvements with respect to media temperature and initial biomass concentrations, etc. have profound, increasing positive effects the further north the cultivation takes place.
- Given the potential access to low grade waste heat and an abundance of CO\text{2} from industrial / oil sands activities in northern Alberta, these may be utilized to both enhance algae production and reduce cultivation costs.

Future Work
- Conduct techno-economic analysis to determine the feasibility and impact of utilizing waste CO\text{2} and low grade heat at various locations to be able to provide a comprehensive, comparative cost analysis between cultivation sites.
- Conduct techno-economic analysis based on utilizing alternative cultivation and processing technologies including open ponds, photo-bioreactors and downstream processing of biomass via pyrolysis, hydrothermal liquefaction, etc. and the production of diluent and hydrogen for oil sands applications.
- Determine the impact of changes on the delivered cost of algae biomass / T
- Conduct life cycle assessments based on site specific inputs / outputs and environmental impacts.

Highlights
- Model predictions to produce 1000 T biomass / year:
  - With Mesa AZ algal cultivation growth as the base case, only 7.56 kWh/m\text{2}/day average to achieve similar results in other geographic locations.
  - Starting each cultivation cycle at 0.15 g/L biomass, requires 22.6 H of pond at Mesa AZ and 94.7 H at Great Slave Lake NWT.
  - Raising the avg. media temperature by 1°C reduces the amount of land required from 97.0 H to 91.4 H at Great Slave Lake NWT (8.1%) and from 24.4 to 23.5 H (9.8%) at Mesa AZ.
  - Doubling the initial media biomass concentration (inoculum) from 0.15 (g/L) to 0.3 (g/L) reduces the land requirement for ponds from 22.6 H to 11.3 H at Mesa AZ and from 94.7 H to 47.4 H at Great Slave Lake

Assumptions
- Overview of important Assumptions:
  - \( K_B \) is constant and \( T_0 = T_{\text{opt}} + T_0 \)
  - \( K_B \text{ is constant} \) (growth rate is constant)
  - \( T_0 \) is constant

Assumptions
- Overview of important Assumptions:
  - \( f(t) = \frac{a}{1 + e^{c(T-\text{opt})}} \) except for \( T \) where \( T_{\text{opt}} \leq T < T_0 \)
  - Model parameters:
    - \( a = \text{maximum initial biomass concentration} \)
    - \( K_B = \text{maximum growth rate} \)
  - \( K_B \text{ is} \text{ constant} \) (growth rate is constant)
  - \( T_0 \) is constant and \( T_0 = T_{\text{opt}} + T_0 \)