

## Downloading the Model

I. Before using the model you must already have the following software and appropriate licensing on your computer:

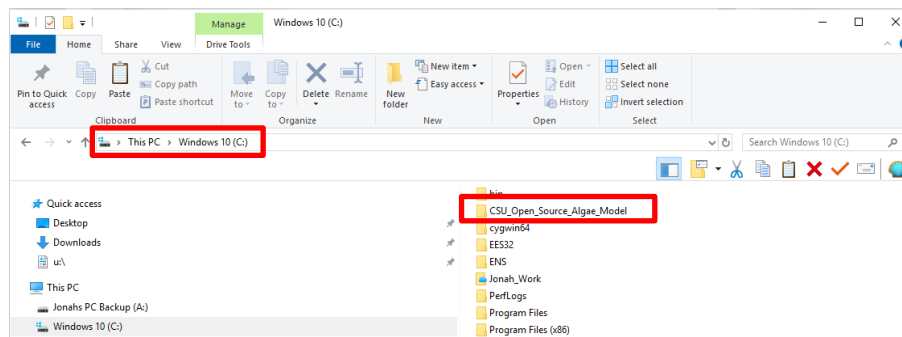
(1) **Microsoft Excel** (Purchase here: <https://www.microsoft.com/en-us/microsoft-365/p/excel/cfq7ttc0k7dx?activetab=pivot:overviewtab>)

- (i) Model most recently verified with Microsoft Office Professional Plus 2016.
- (ii) Excel must be installed on your C: drive.

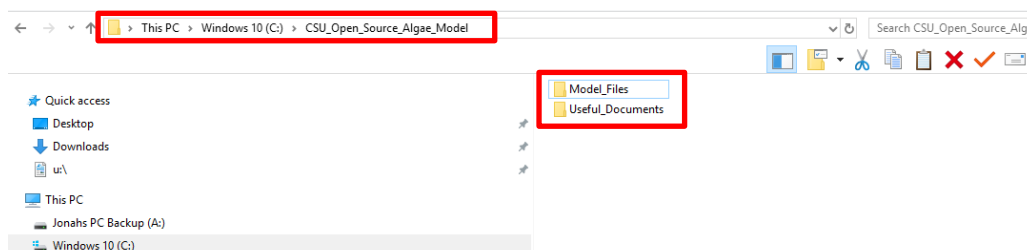
(2) **MathWorks Matlab** (Purchase here: <https://www.mathworks.com/store/>)

- (i) Model most recently verified with Matlab R2018b.
- (ii) Matlab must be installed and running from your C: drive.

II. Next, you must create the folders in your (C:) drive that the Matlab and Excel VBA codes pull from, in order to run the growth model from the User Interface in Excel. Create a new folder directly on your (C:) drive titled: “**CSU\_Open\_Source\_Algae\_Model**”



Double click the folder you just created (“**CSU\_Open\_Source\_Algae\_Model**”) and create two more folders within that folder titled “**Model\_Files**” and “**Useful\_Documents**” and ensure the file path looks like this:



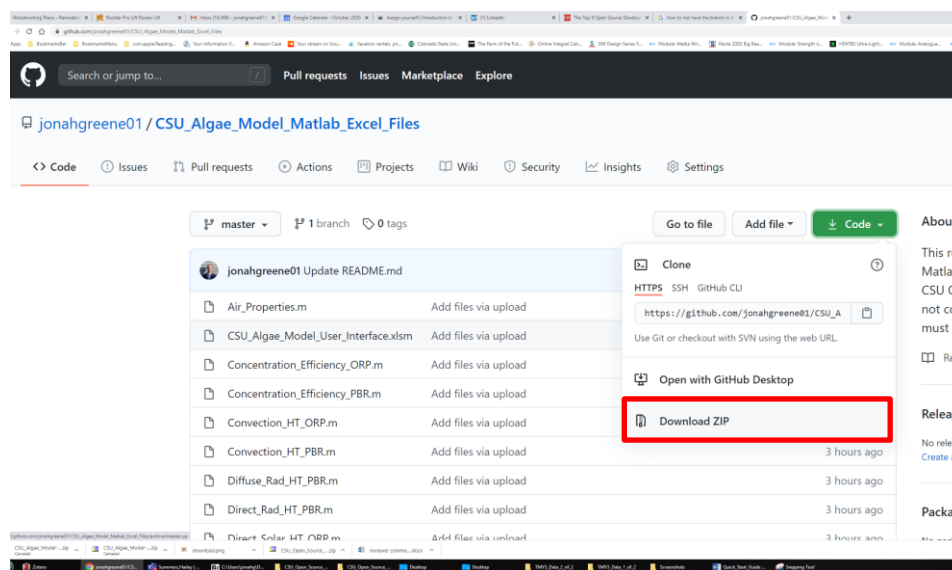
# CSU Algae Model: Quick Start Guide

Link to download the model: <https://github.com/jonahgreene01?tab=repositories>  
Please contact [jonahgreene01@gmail.com](mailto:jonahgreene01@gmail.com) with any questions!

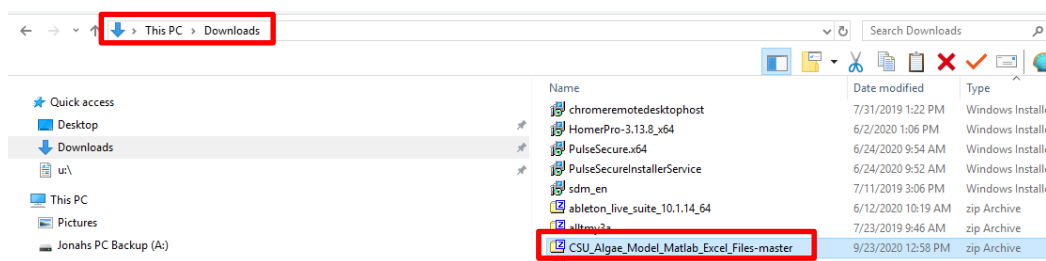
- III. With the newly created file paths, you can now download the model files from GitHub and extract them to the appropriate folders. You will need to download and extract four separate folders from GitHub: 1) Matlab and Excel Files; 2) TMY3 Data (First Half); 3) TMY3 Data (Second Half); 4) Useful Documents. The next section will cover how to download and extract each of these four folders.

## 1) Matlab and Excel Files:

[Click here](#) to be directed to the download page for the model's Matlab and Excel files. This data repository is titled "**CSU\_Algae\_Model\_Matlab\_Excel\_Files**" on GitHub and contains all the Matlab scripts, the model's Excel User Interface, and the print files for exchanging data between Matlab and Excel. Download the folder by clicking the green button labeled "**↓Code**" and then selecting "**Download ZIP**" from the drop down menu:



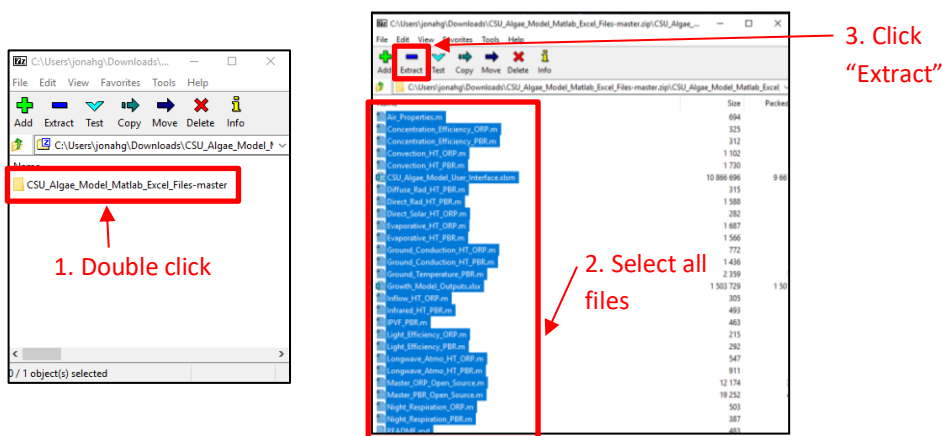
The downloaded zip file should appear in your computer's "**Downloads**" folder:



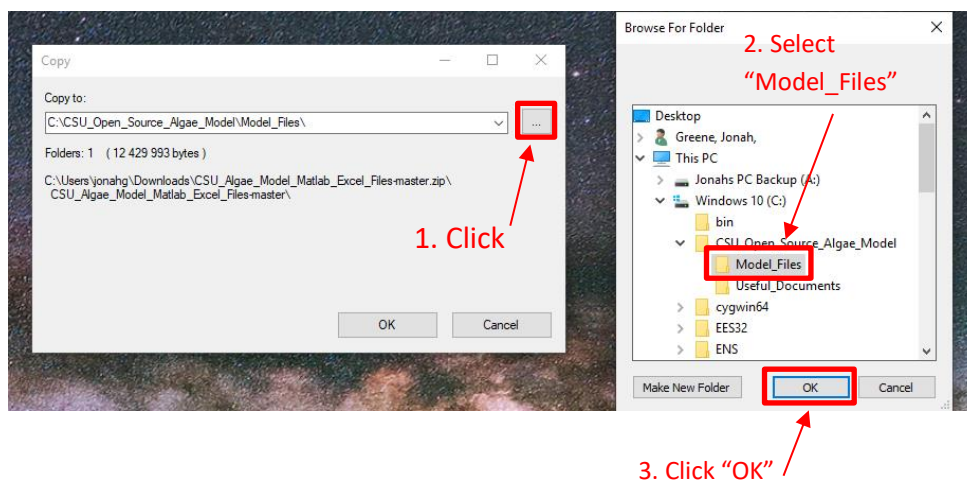
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Once you have opened the ZIP file, double click the folder titled “**CSU\_Algae\_Model\_Matlab\_Excel\_Files-master**” and ensure all files in the folder are highlighted before clicking “**Extract**”. Opening the ZIP folder and highlighting the individual files prior to extracting the files ensures that you do not extract the folder as a whole and create an additional unwanted file path.



Then select the destination folder to be the folder you created in Step II titled “**Model\_Files**”



## 2) TMY3 Dataset (First Half)

[Click here](#) to be directed to the download page for the first half of the TMY3 Dataset. On GitHub, this repository is titled “**CSU\_Algae\_Model\_TMY3\_Data\_1of2**” and will also need to be downloaded and extracted to the “**Model\_Files**” folder created in Step II. Follow the same steps outlined above for the Matlab and Excel Files. The ZIP folder downloaded from GitHub will appear in your downloads titled “**CSU\_Algae\_Model\_TMY3\_Data\_1of2 – master**”

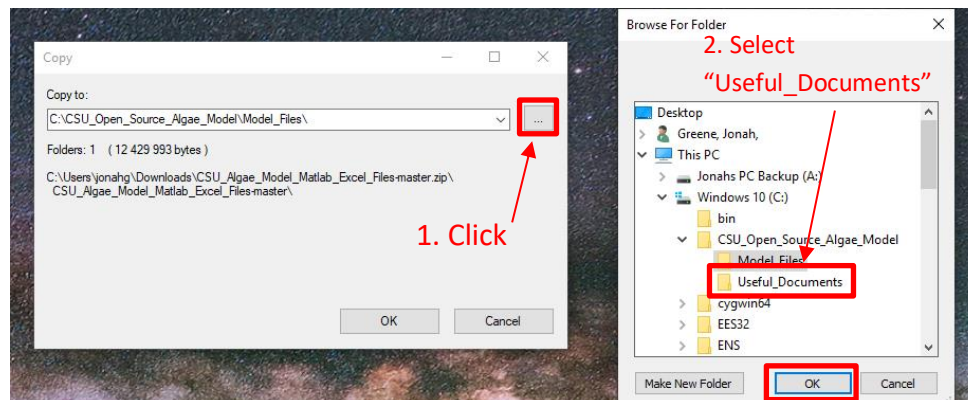
## 3) TMY3 Dataset (Second Half)

[Click here](#) to be directed to the second half of the TMY3 Dataset. Again, download the ZIP folder from GitHub and extract the contents of the folder into the folder created in Step II titled “**Model\_Files**”. The ZIP folder downloaded from GitHub will appear in your downloads titled “**CSU\_Algae\_Model\_TMY3\_Data\_2of2 – master**”

## 4) Useful Documents

[Click here](#) to be directed to the download page for the useful documents folder. This folder contains the “**Strain\_Library**”, “**Model\_Flow\_Diagram**”, and also a copy of this document, the “**Quick\_Start\_Guide**”

Follow the same download procedure used to download folders 1-3, but this time, extract the contents of the ZIP folder to the folder titled “**Useful\_Documents**” created in Step II.



With those four folders downloaded and extracted to the correct file paths, you should be able to use the CSU Algae Model with ease!

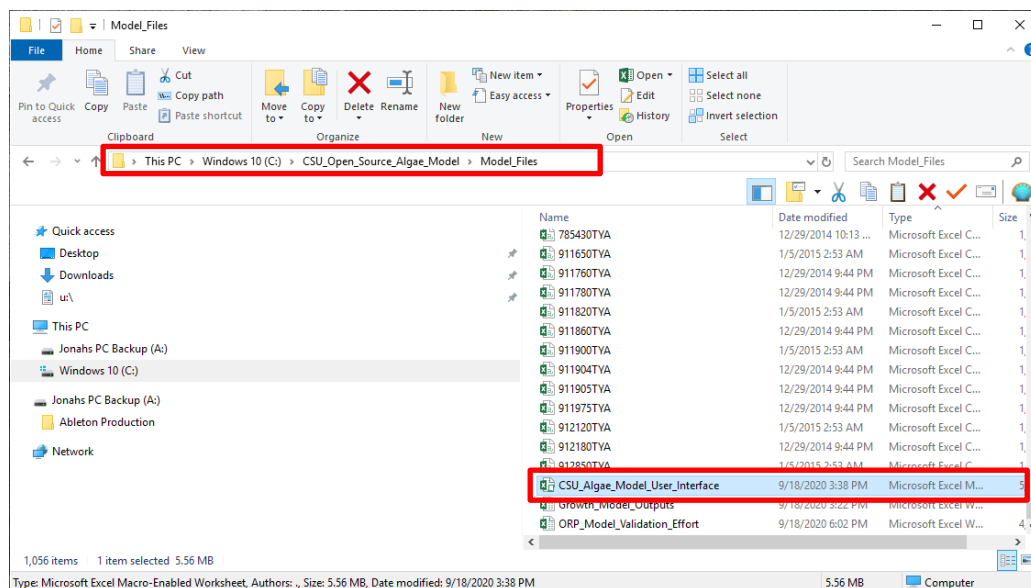
## Running the Model

I. Once the model folder are in your C: drive, open the user interface in Excel.

- (1) Double click the folder: “CSU\_Open\_Source\_Algae\_Model”
- (2) Double click the folder titled “Model\_Files”
- (3) Find and double click the file titled “CSU\_Algae\_Model\_User\_Interface.xlsm”

Before opening the “CSU\_Algae\_Model\_User\_Interface.xlsm,” make sure that the complete file path reads:

“ > This PC > Windows 10 (C:) > CSU\_Open\_Source\_Algae\_Model > Model\_Files”



II. Once you have the folder downloaded to your C: drive and have the file

“CSU\_Algae\_Model\_User\_Interface.xlsm” open in Excel, you should be able to use the model. You will never need to open Matlab to use the model. Commands written in Excel VBA will call upon Matlab and run the scripts automatically. You will not need to open Matlab but will need to ensure Matlab is running correctly on your computer and if you must connect to a third party network for your Matlab license, make sure that connection is established. To ensure you have opened the correct file, the “Home” tab in the User Interface should look like this:

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- III. Begin by choosing a location and time of year for your analysis. Location is determined by entering the latitude and longitude for the location of interest in cells “B2” and “B3.” Remember that when entering a latitude, North is positive and South is negative. When entering longitude, West is negative and East is positive. For example, when entering the latitude and longitude for Scottsdale, AZ (33.4942° N, 111.9261° W) you would enter 33.4942 into cell “B2” and -111.9261 into cell “B3.” The model will match the inputted latitude and longitude with the closest TMY3 weather station and display the correlated USAF code for that station.

- IV. Once the location has been selected, the time of year for the analysis should be selected. The drop down menu titled “**Time Period**” has several pre-programmed options including:

- (i) **Annual Analysis:** Will run the model simulation in that location for a full year

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- (ii) **Summer:** Will run the model from June 1 to August 31
- (iii) **Fall:** Will run the model from September 1 to November 30
- (iv) **Winter:** Will run the model from December 1 to February 28
- (v) **Spring:** Will run the model from March 1 to May 31
- (vi) **Custom:** When selected, the custom start and end dates will activate and allow you to choose your own start and end dates for the analysis.

**Location and Time Inputs**

Time Period: Custom

Start: *Custom (see below)*

End: *Custom (see below)*

---

Custom Start: Jul 1

Custom End: Jul 15

- V. With the location and time of year selected, the next step is to update the TMY3 dataset by clicking the “**1. Update TMY3 Data**” button. Do not close the file while the macro is running and updating the TMY3 data set. The macro usually takes 2-5 seconds to complete.

The screenshot shows the Excel interface with the 'Location and Time Inputs' section. The 'Time Period' dropdown is set to 'Custom'. Below it, the 'Start' and 'End' fields show 'Custom (see below)'. Further down, the 'Custom Start' and 'Custom End' fields are set to 'Jun 1' and 'Jun 15' respectively. To the right, a red-bordered box contains the text '1. Update TMY3 Data' and a warning: 'Warning: Updating the TMY3 data may take a couple of seconds...DO NOT CLOSE MICROSOFT EXCEL WHILE THE MACRO IS RUNNING!'.

- VI. Select your growth system of interest and adjust system parameters as needed. Growth system options in the first version of this model include Open Raceway Ponds (ORP) and vertical flat plate photobioreactors (VFP PBR). This selection is made with the drop down menu in cell “B11.”

The screenshot shows the 'Architecture Parameters' section of the Excel spreadsheet. The 'Growth Architecture' dropdown menu is set to 'Open Raceway Pond'. Other parameters include 'Number of Reactors' (set to 1), 'Width (m)' (1.5), 'Length (m)' (3.5), 'Depth (m)' (0.25), 'Panel Spacing (m)' (0.5), 'Compass Orientation (degrees)' (45.0), and 'Slope Velocity (m/s)' (0.002).



Depending on the growth system selected, the input parameter option will change. Additionally, the strain input parameters will be wiped clean and the “**Microalgae Strain**” drop down menu options will change accordingly. Strains available for the ORP system include *Chlorella vulgaris*, *Nannochloropsis oceanica*, and *Desmodesmus intermedius*. Strains for the PBR system include *Galdieria sulphuraria* 5587.1 and *Galdieria sulphuraria* Soos.

- VII. Select the microalgae strain of interest and adjust the strain parameters as necessary. The strains available in the drop down menu for each growth system have been validated against experimental data. The validation effort is presented in detail in the publication. To achieve errors similar to those reported in the validation effort, we recommend running the PBR strains in the PBR system, and the ORP strains with the ORP system due to large differences in temperature limits and light intensity parameters. For example, running *Chlorella vulgaris* (which was validated with the ORP model) in the PBR model will lead to significant error and minimal growth as the PBR system reaches temperatures far beyond the temperature limits of *C. vulgaris*. However, this suggestion can be overwritten by simply entering the six strain-specific parameters in cells “E12-E17,” and with this method virtually any strain can be tested if these six strain parameters are known.

Growth Architecture, Strain-Specific, and Harvesting Inputs (Required)		
Strain-Specific Parameters:		
Microalgae Strain:	<i>Chlorella vulgaris</i>	Initial
Optimal Temperature (°C):	27.5	
Minimum Temperature (°C):	5	
Maximum Temperature (°C):	42	
Saturation Light Intensity ( $\mu\text{mol}/\text{m}^2\text{s}$ ):	294.12	
Optical Density Coefficient ( $\text{g m L}^{-1}$ ):	0.85	
Dark Respiration Rate (% AFDW):	4.5%	

- VIII. The final required inputs are related to the harvesting sequence. Please input the “**Initial Biomass Concentration**” (also commonly called the “inoculation density” as well as the “**Max Concentration**” (maximum allowable biomass concentration in the reactor before harvesting is initiated) as well as the “**Harvesting Period**” (maximum amount of time the culture grows in the reactor before harvesting is initiated).

Harvesting Parameters (Required)		
Harvesting Parameters:		
Initial Biomass Concentration:	100	g/m <sup>3</sup>
Max Concentration:	300	g/m <sup>3</sup>
Harvesting Period:	7	days



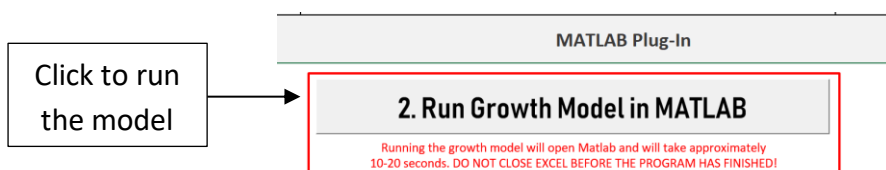
IX. Once all the required model inputs have been selected and entered, there a number of additional optional parameters which may be adjusted if these inputs are available to the user and the user would like more specific results for the consumption of CO<sub>2</sub> and nutrients (ammonia and DAP). These inputs include:

- i) **Algae Carbon Content:** The total carbon content of the algae expressed in wt% Ash Free Dry Weight (AFDW). If not entered, this parameter assumes a baseline value of 50%
- ii) **CO<sub>2</sub> Utilization Efficiency:** How efficiently the algae uptake the inputted CO<sub>2</sub>. If not entered, this parameter assumes a value of 40%.
- iii) **CO<sub>2</sub> Source % CO<sub>2</sub>:** Purity of the CO<sub>2</sub> source for the growth system. If not entered, this parameter assumes a value of 100% or totally pure CO<sub>2</sub>.
- iv) **Algae N Content (wt%):** Nitrogen content of the algae expressed in wt% AFDW. If not entered, this parameter assumes a value of 2.94% (explained in the publication).
- v) **Algae P Content (wt%):** Phosphorus content of the algae expressed in wt% AFDW. If not entered, this parameter assumes a value of 0.51% (explained in the publication).
- vi) **Nutrient Surplus:** The amount of nutrients supplied in excess (or surpassing the stoichiometric minimum requirement). If not entered, this parameter assumes a value of 20% (explained in the publication).

CO <sub>2</sub> Supply and Algal Composition Inputs (Optional)			
CO <sub>2</sub> Consumption Parameters (Optional):		Nutrient Consumption Parameters (Optional):	
Algae Carbon Content:	50.0%	Algae N Content (wt%):	2.94%
CO <sub>2</sub> Utilization Efficiency:	40%	Algae P Content (wt%):	0.51%
CO <sub>2</sub> Source % CO <sub>2</sub> :	100%	Nutrient Surplus:	20.00%
The CO <sub>2</sub> and algal composition parameters are optional. If entered, they are used in the model to calculate the total facility wide CO <sub>2</sub> and nutrient consumption rates with hourly resolution.			

X. With all the required and optional input parameters entered, you can run the model and view the results by clicking the button labeled “**2. Run Growth Model in MATLAB.**” A couple things to check before running the model:

- (1) If you have changed the location make sure to update the TMY3 Data set (explained in Step III).
- (2) If you have changed the reactor geometry, make sure you have the correct strain parameters entered as well. The strain parameters will be wiped clean if you select a different geometry.



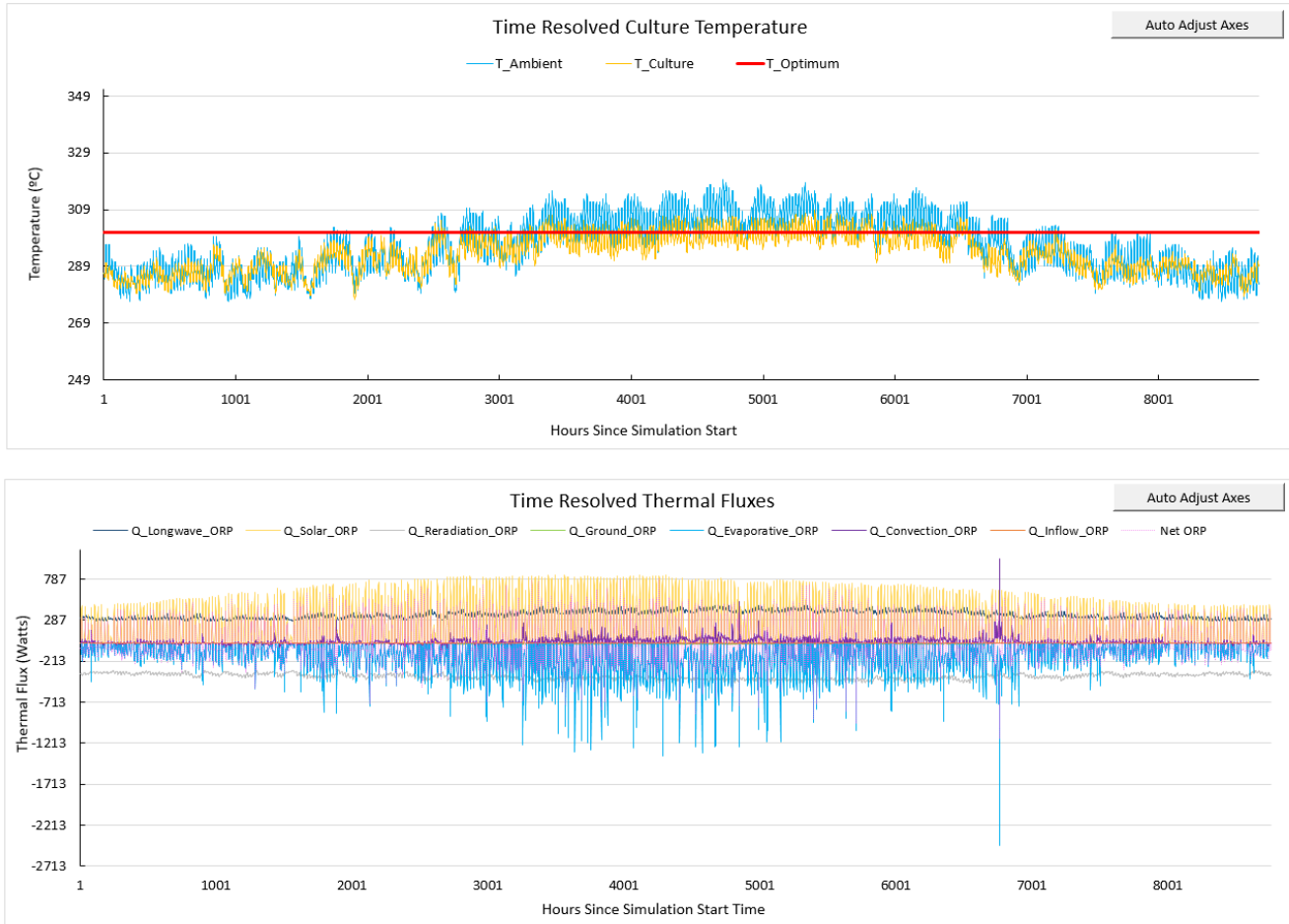
## Interpreting and Using Model Results

- I. Model results are presented in both a summary table, and a visual results section. The “**Summary of Model Results**” table shows single number outputs such as the average areal productivity (g/m<sup>2</sup>\*day) over the simulation period. Additionally, the “**Summary of Model Results**” table presents the total facility output by factoring the number and size of reactors, the total operational period, and the calculated growth rate. Example results are for an annual simulation of *Chlorella vulgaris* grown in Scottsdale, AZ.

Summary of Model Results				
Parameter	per Pond per Day	Operational Days	Facility Wide Output per Op-Time	Units (Fac. Wide)
Areal Productivity (g/m <sup>2</sup> )	8.12	365	14.120	kg per Op-Time
Volumetric Productivity (g/L)	0.032	365	14.120	kg per Op-Time
Makeup Water Demand (L)	20.89	365	7623.633	L per Op-Time
Average CO <sub>2</sub> Demand (kg)	0.05768	365	21.051	kg per Op-Time
Average Ammonia Demand (kg)	0.00144	365	0.527	kg per Op-Time
Average DAP Demand (kg)	0.00118	365	0.429	kg per Op-Time
Average Algal Concentration at Harvest (g/m <sup>3</sup> )			282.311	g/m <sup>3</sup>
Average Evaporation Rate in Reactor (cm)			0.438	cm

- II. Following the summary table, the user interface presents the time resolved culture temperature and the time resolved thermal fluxes calculated in the thermal models for each growth system. Whenever generating results, the model should auto-scale the X and Y axes of all figures. However, if the axes do not seem to be correctly scaled, this can quickly be fixed by clicking the “**Auto Adjust Axes**” button in the top right corner of each figure. Pressing this button (on any of the figures) will automatically scale all figures on the “**Home**” page.

### Reactor Temperature and Heat Fluxes

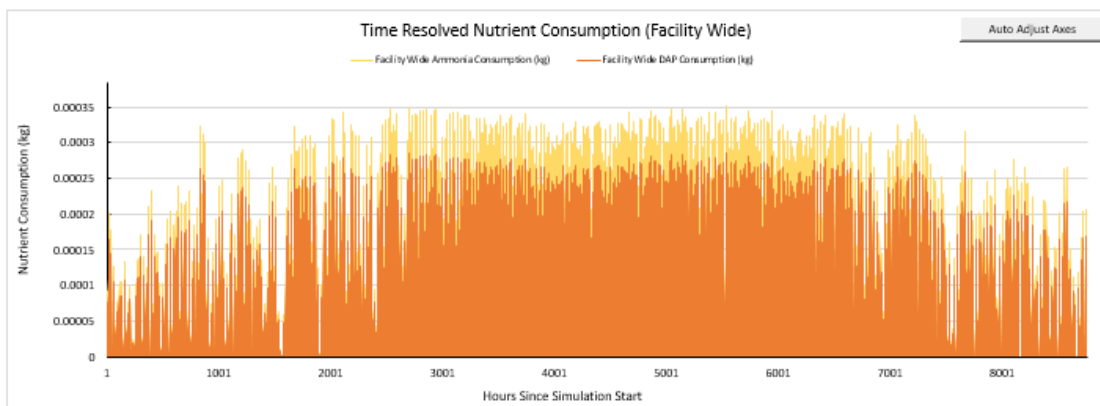
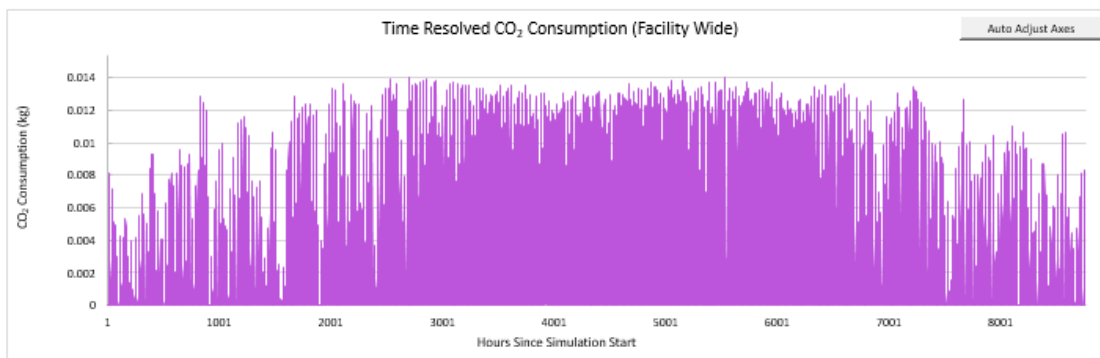
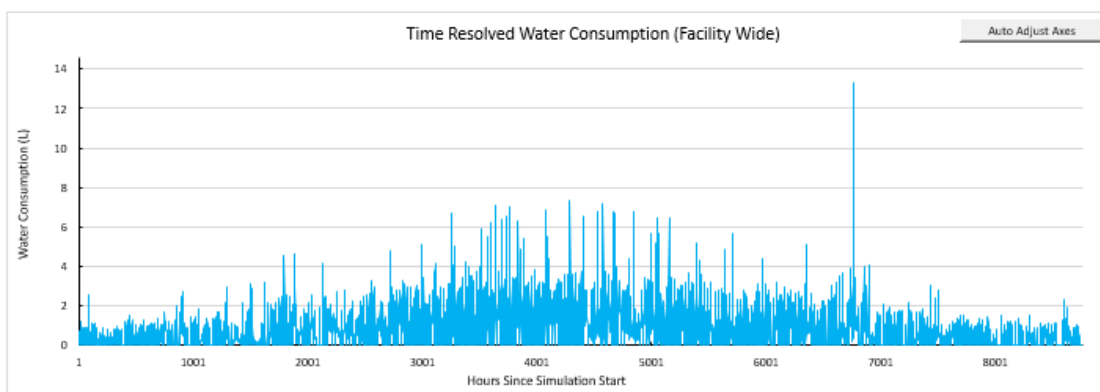
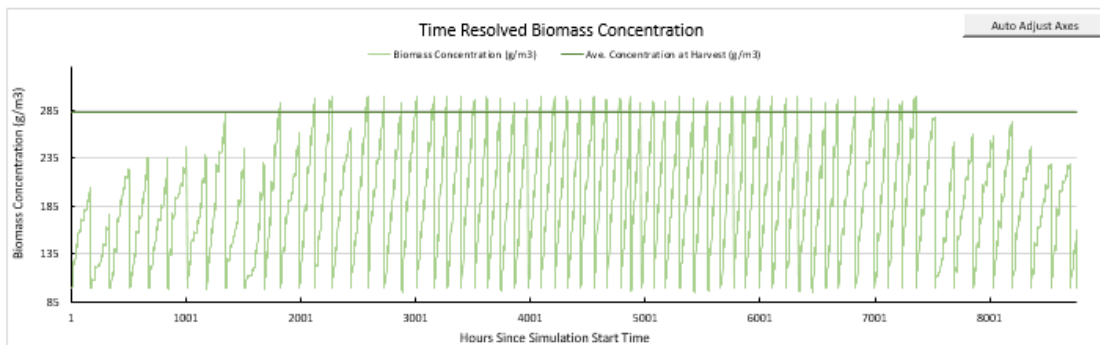


- III. Following the culture temperature and time resolved thermal fluxes, the user interface will show the time resolved algae concentration, as well as, the time resolved facility wide consumption of makeup water, CO<sub>2</sub>, and nutrients including ammonia and DAP. See the next page for example results from an annual simulation in Scottsdale, AZ with *Chlorella vulgaris*.

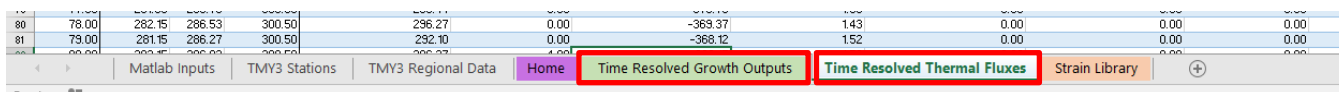
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## Biomass Concentration, Water Consumption, CO<sub>2</sub> Consumption, and Nutrient Consumption



IV. In addition to the graphical results, the hourly data informing each of the graphs can be found in the “Time Resolved Thermal Fluxes” and “Time Resolved Growth Outputs” tabs.



Time	Temperature (°C)	Light Intensity (μmol/m²s)	Optical Density (1/m)	Night Respiration Rate (% AFDW)	Growth Rate (1/d)	Respiration Rate (1/d)	Net Growth Rate (1/d)	Thermal Flux (W/m²)	Light Flux (W/m²)	Respiration Flux (W/m²)	Net Flux (W/m²)
80	78.00	282.15	286.53	300.50	296.27	0.00	-368.37	143	0.00	0.00	0.00
81	79.00	281.15	286.27	300.50	292.10	0.00	-368.12	152	0.00	0.00	0.00

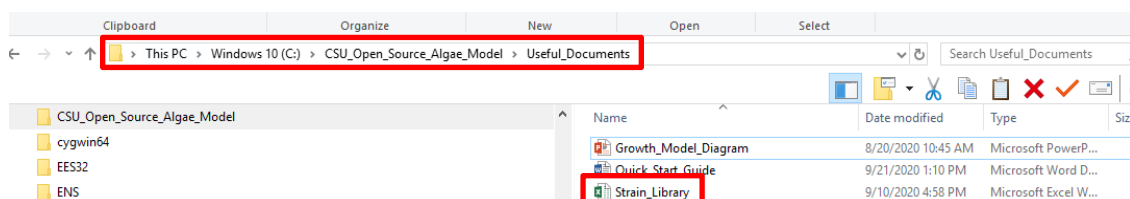
## Additional Information and Documents

### I. Strain Library

The “**Strain Library**” tab in the user interface contains the strain-specific parameters for the strains evaluated in the validation efforts for the published article. The value of each parameter, which has been adjusted empirically to match experimental data is shown in for each strain. The adjustment made to each strain-specific variable (determined empirically) relative to the value as reported in literature is shown in red next to each strain parameter. Furthermore, for a detailed derivation of each parameter and the sources used, please see the “**Strain\_Library**” document under the “**Useful\_Documents**” folder in the main folder “**CSU\_Open\_Source\_Algae\_Model**.”

Category	Model Input Parameter	Chlorella vulgaris		
		Calibrated Value	Units	(Adjustment)*
Temperature	T_optimum (°C)	27.5	°C	(+ 0)
	T_minimum (°C)	5	°C	(+ 0)
	T_maximum (°C)	42	°C	(+ 0)
Light	Saturation Light Intensity (μmol/m²s)	294.12	μmol/m²s	(+ 64.12)
Concentration	Optical Density Coefficient (1/m)	0.85	g*m/L	(- 0.19)
Respiration	Night Respiration Rate (% AFDW)	4.50%	(% AFDW)	(-0.018)

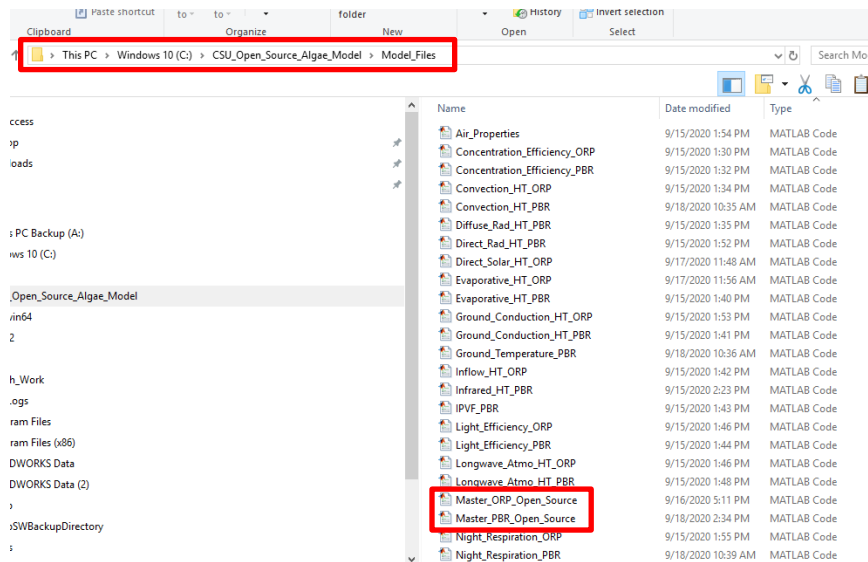
\*(Adjustment) refers to the delta between the calibrated input u



## II. Matlab Scripts

All Matlab scripts used in this model can be found in the “**Model\_Files**” folder which is in the main folder “**CSU\_Open\_Source\_Algae\_Model**.” Each of the Matlab functions used in the thermal and biological models can be found in this folder. Additionally, the master scripts for each growth system (ORP and PBR) are located in this folder:

- (1) Master Script for ORP: “**Master\_ORP\_Open\_Source**”
- (2) Master Script for PBR: “**Master\_PBR\_Open\_Source**”



**Disclaimer: It should be stressed that changing the names or locations of any of the files, functions, and documents will likely lead to errors and dysfunctionality between the user interface file and Matlab command center. For ease of operation, it is recommended to copy and paste generated results to separate documents for data manipulation and formatting. It is advised to always close the model without saving and start from scratch when evaluating a different setup.**

Thanks and happy modeling!

Please contact [jonahgreene01@gmail.com](mailto:jonahgreene01@gmail.com) with any questions, comments, or concerns!