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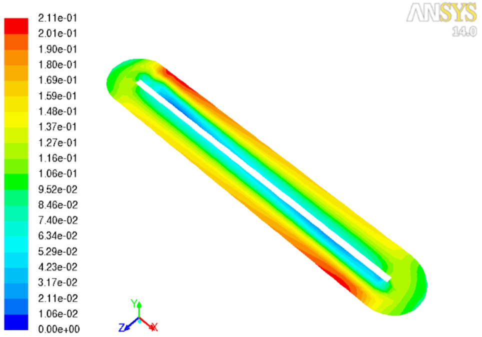


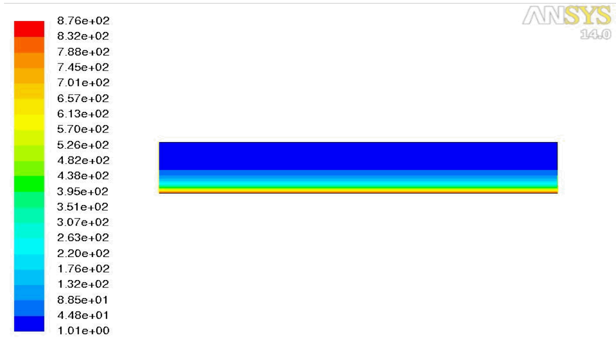


# A Computational Model of Algal Growth

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NNSA National Nuclear Security Administration

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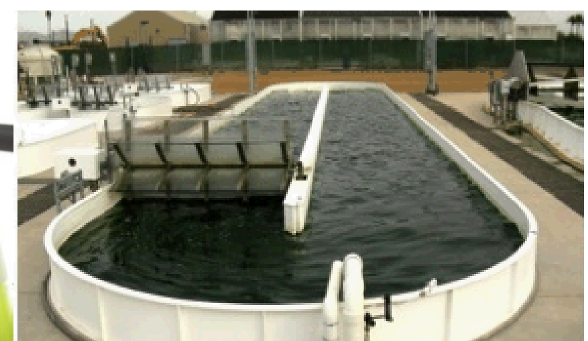
# Algal Biofuels

- Alternative to petroleum based fuels
- Can be grown on non-arable land
- Can be grown using wastewaters such as municipal and industrial effluent and saline waters.
- Can consume carbon dioxide from waste sources such as power and ammonia plants





# Goals of Computational Models

- Make accurate predications of algal growth
- Reduce experimentation on large scales which is costly and time consuming
- Optimize existing systems for higher yields

# Current Models

**Photobioreactor Models**

- Typically control over one or more environmental parameters
- Small fluctuations of parameters can be important due to small volumes

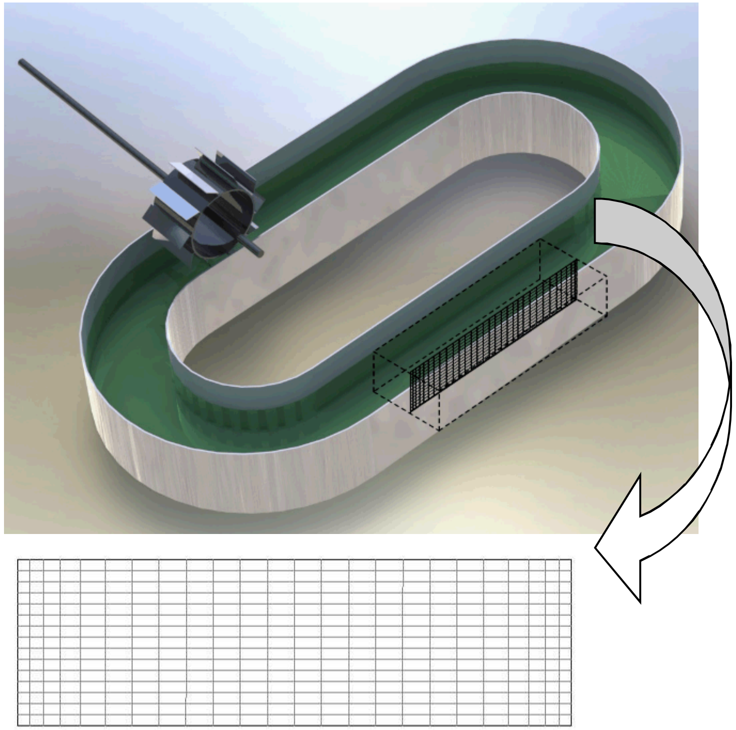
**Water Quality Models**

- Model large systems
- No control over environmental parameters
- Small fluctuations of parameters typically not important due to large volumes

# Computational Fluid Dynamics

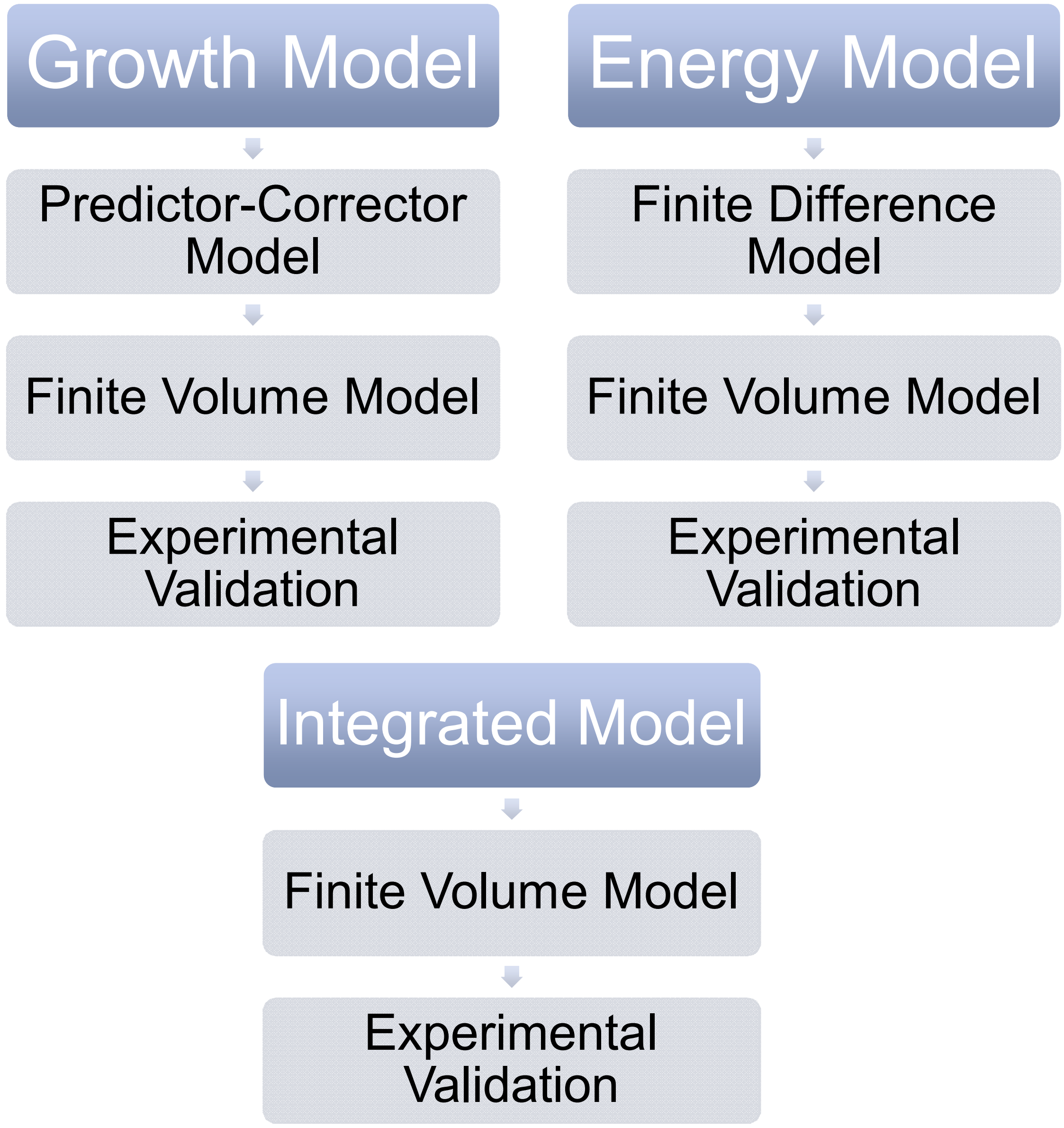
Numerical solution and visualization of mass, momentum and heat transfer equations.

- Calculate the distribution of light, temperature, and species within the pond with high accuracy
- Integrate all aspects of algal growth through user defined functions (UDF)



# Objectives

- Identify key parameters of algal growth
- Develop a computational fluid dynamics (CFD) model of algal growth based on:
  - Species
  - Environmental conditions
  - Water quality conditions
- Develop and validate a CFD model of pond temperature based on:
  - An energy balance
  - Weather station data
- Validate the CFD model with more simple numerical models and experimental data


Growth Model
Predictor-Corrector Model
Finite Volume Model
Experimental Validation
Energy Model
Finite Difference Model
Finite Volume Model
Experimental Validation
Integrated Model
Finite Volume Model
Experimental Validation

# Growth Model

[illegible]

[illegible]

$$\square = \begin{cases} \exp\left(-\square_1\left(\square_{,1} - \square\right)^2\right) & \square < \square_{,1} \\ 1 & \square_{,1} \le \square \le \square_{,2} \\ \exp\left(-\square_2\left(\square - \square_{,2}\right)^2\right) & \square_{,2} < \square \end{cases}$$

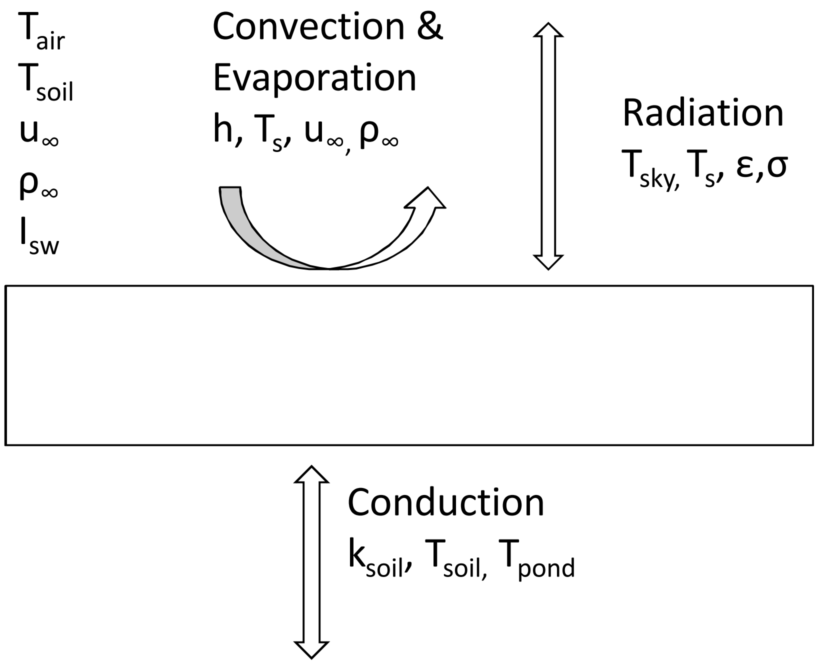
[illegible]

[illegible]

[illegible]

# Energy Model

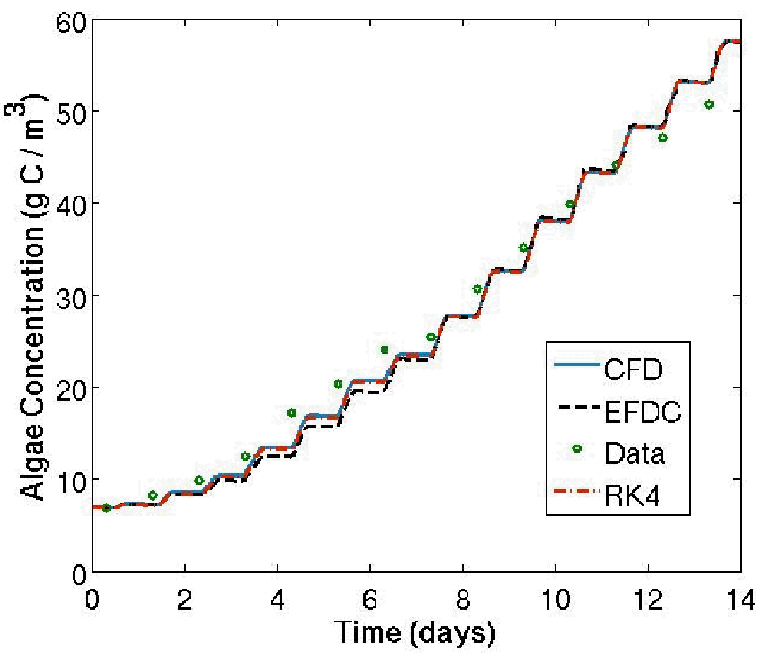
- $q''_{lw} = \varepsilon\sigma(T^4_{sky} - T^4_{surface})$
- $q''_{conv} = \bar{h}(T_\infty - T_s)$
- $q''_{evap} = h_{fg} h_m (\rho_{sat} - \rho_\infty)$
- $q''_{cond} = k(T_{pond} - T_{soil})$
- $q''_{sw}$, from weather data



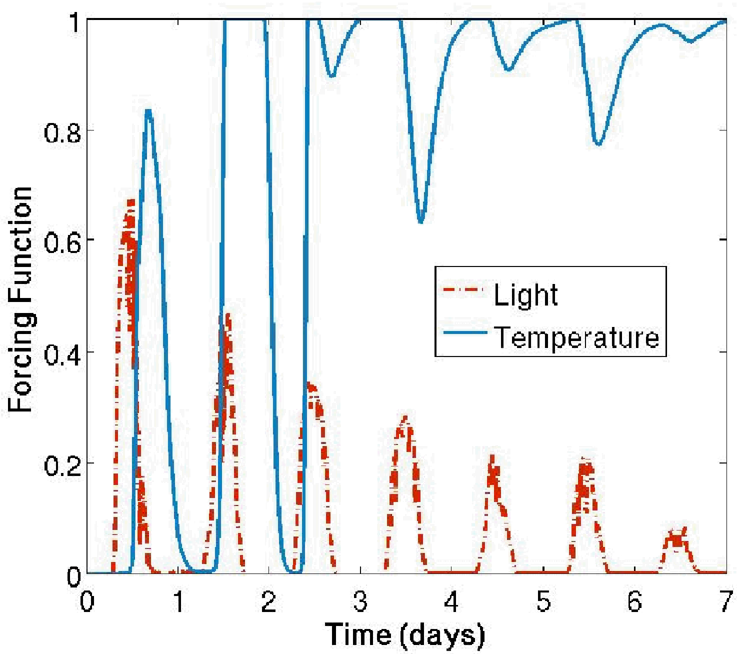
# Greenhouse Experiment

- Pond type
  - Open tank
- Dimensions
  - 0.211 m deep
  - .53 $m^3$ volume
- Location
  - Sandia National Labs (Albuquerque, NM)
- Species
  - *Nannochloropsis salina*
- Data Collected
  - Algae concentration
  - Nutrient concentration
  - Pond Temperature
  - Solar intensity
  - pH

# Validation



Algae Concentration (g C / m$^3$)
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14
Time (days)
CFD
EFDC
Data
RK4

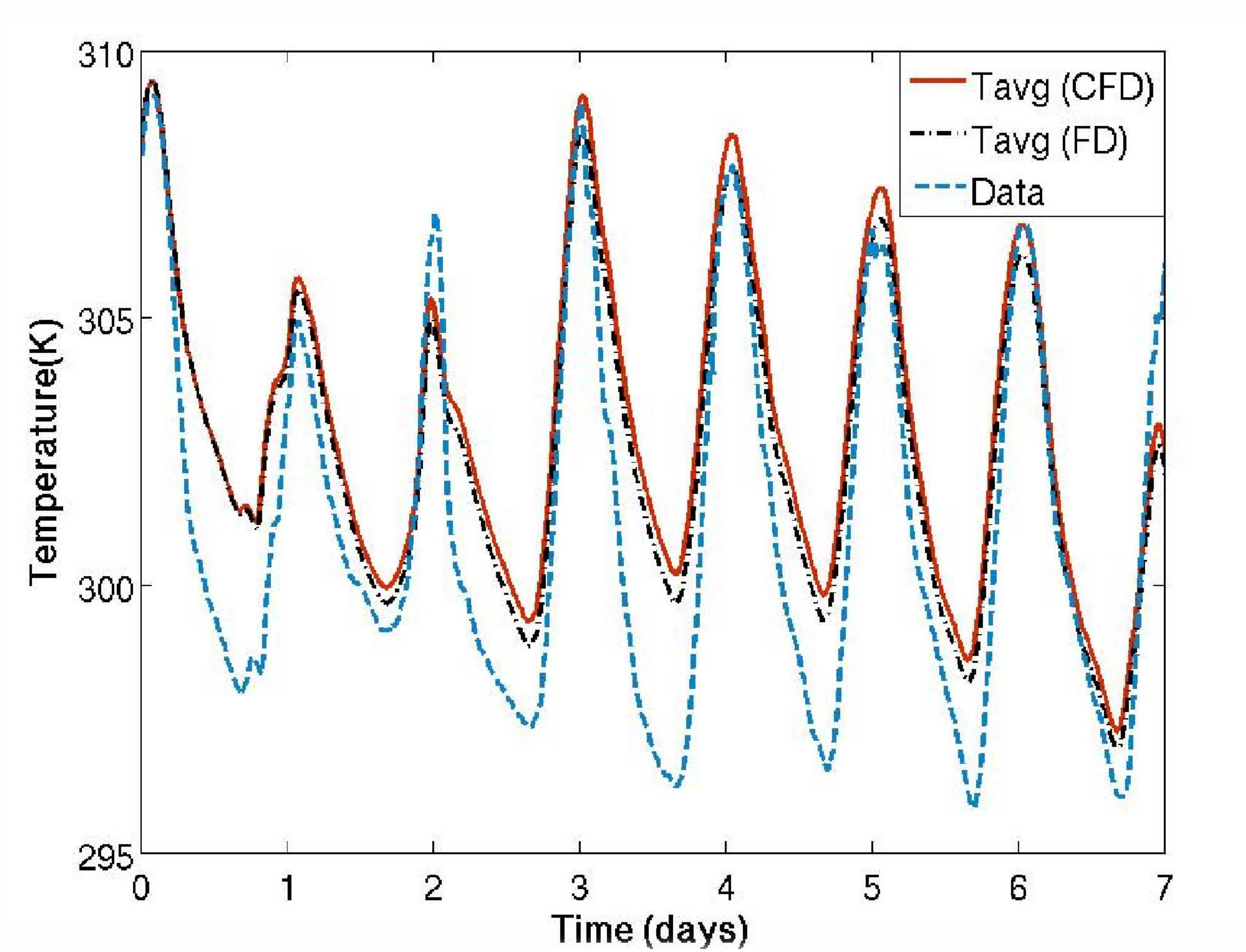



Forcing Function
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
6
7
Time (days)
Light
Temperature

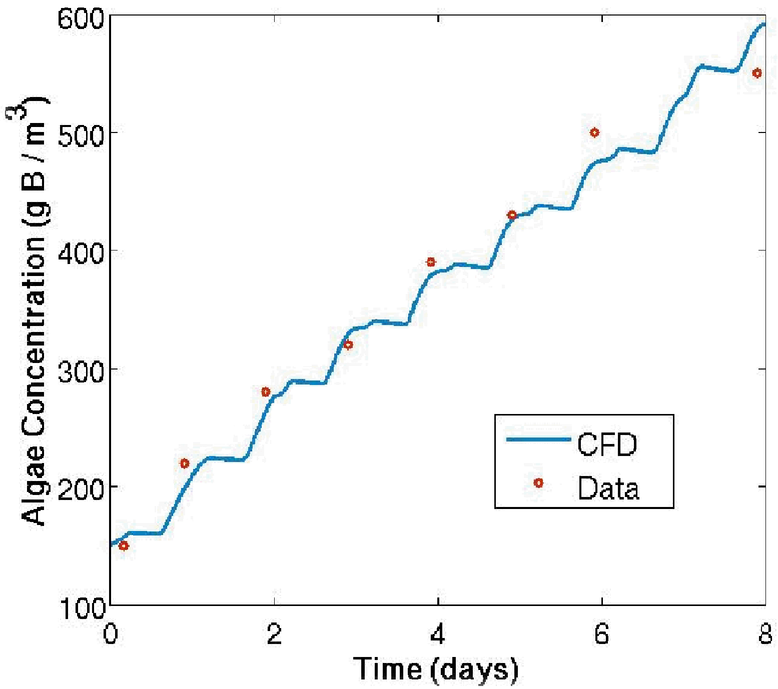
# Raceway Experiment

- Pond type
  - Open raceway
- Dimensions
  - 0.2 m deep
  - 59.3 $m^2$ surface area
  - 12 $m^3$
- Location
  - Arizona State University (Mesa, AZ)
- Species
  - *Nannochloropsis granulata*
- Data Collected
  - Algae concentration
  - Nutrient Concentration
  - Pond Temperature

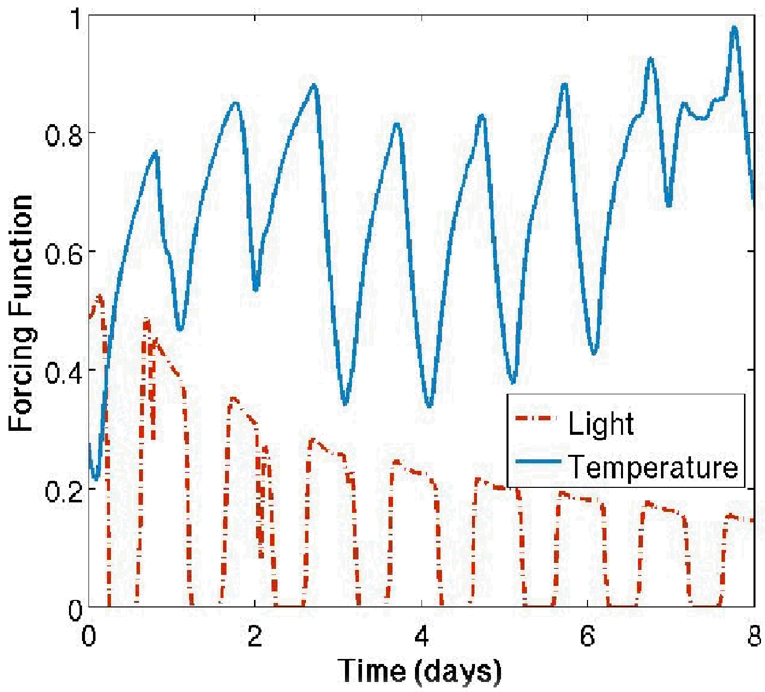
# Energy Balance Validation



# Validation



Algae Concentration (g B / m^3)
600
500
400
300
200
100
0
2
4
6
8
Time (days)
CFD
Data

Forcing Function
1
0.8
0.6
0.4
0.2
0
2
4
6
8
Time (days)
Light
Temperature

# Conclusion

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- Upon initial validation, the model is able to predict pond temperature and algal biomass with no modification of the parameters
- The model can be easily adapted to a variety of locations and pond sizes
- Once validated, can serve as a predictive tool for modeling biomass yields

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