


Design and Development of a Gas Coupling Unit for Trigeneration and Algae Photobioreactor Systems

April 5th , 2012

International Team

Angela Silva [1]
Felipe Merss [2]
Richard Carter [1]
Robert Rantz [1]
Wayne Weatherford [1]

Advisor:
Dr. J. Ordonez [1]
Dr. J. Vargas [2]

[1] Mechanical Eng. Dept. FAMU-FSU COE
[2] Mechanical Eng. Dept. UFPR


Outline

- **Project Description & Diagram**
- Concept Generation & Selection
- Current Concept Description
- Engineering Economics
- Life Cycle Analysis
- Results and Discussion
- Conclusion

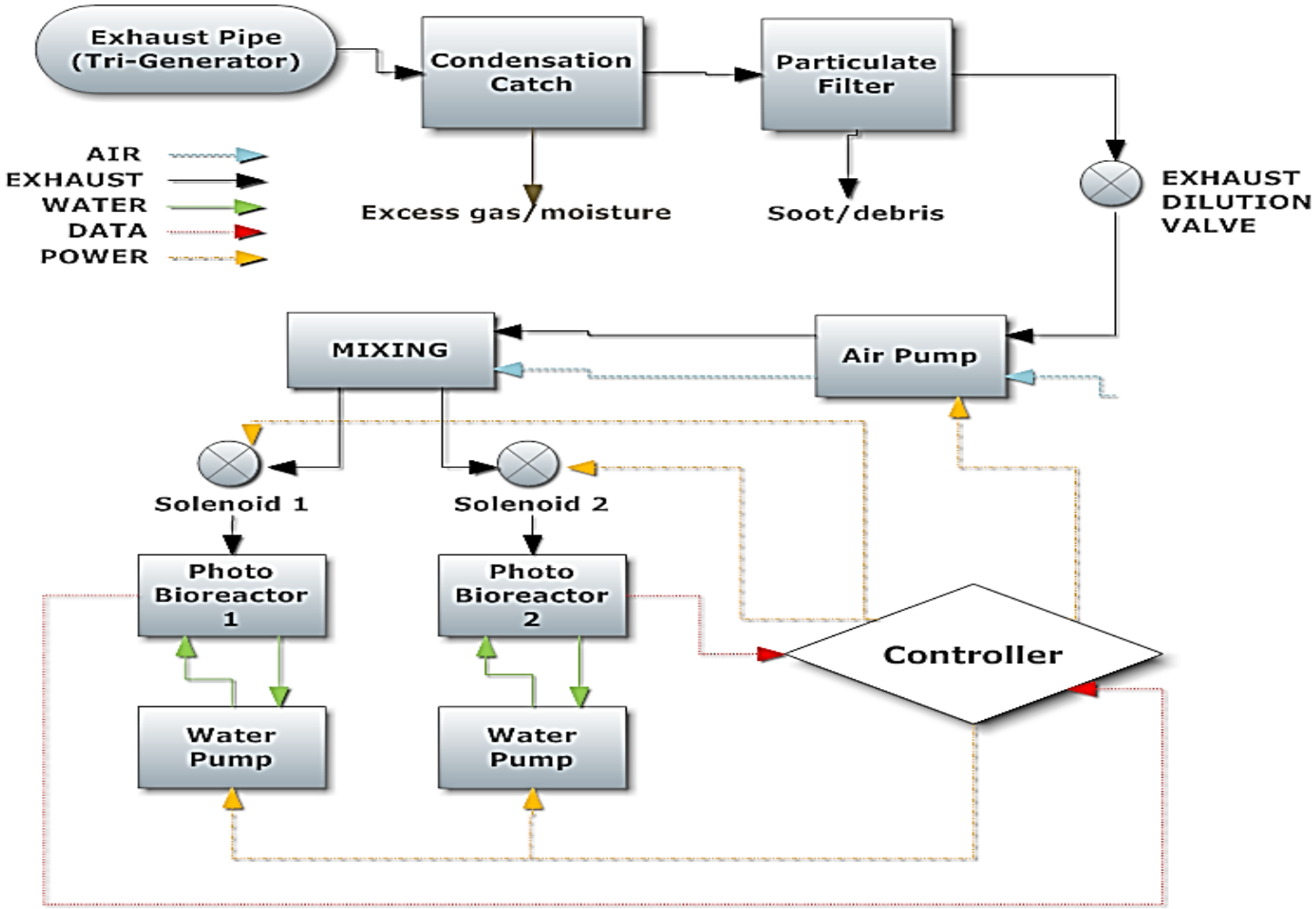
Project Description

Fuel Source vs. Land Use

Source	Oil Production (L ha^{-1})	Required Cultivation Area (M ha)*
Corn	172	1,540
Soy	446	594
Canola	1,190	223
Jatropha	1,892	140
Coconut	2,689	99
Palm	5,950	45
Microalgae [a]	70,405	7.6
Microalgae [b]	35,202	15.2

* To meet 50% of transport fuel needs in the United States of America.
[a] 40% oil in dry biomass;
[b] 20 % of oil in dry biomass. (Christi, 2007)

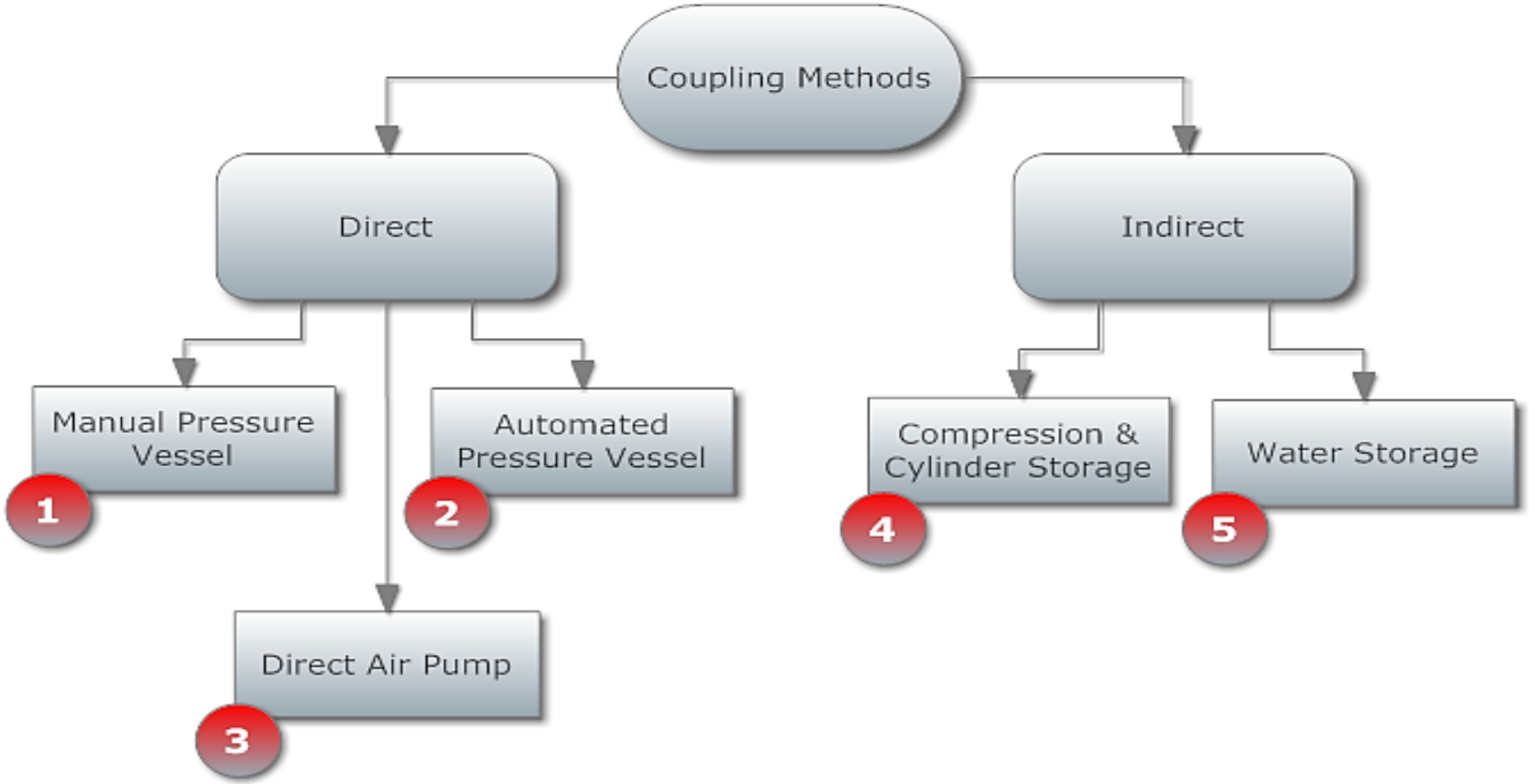
Functional Diagram



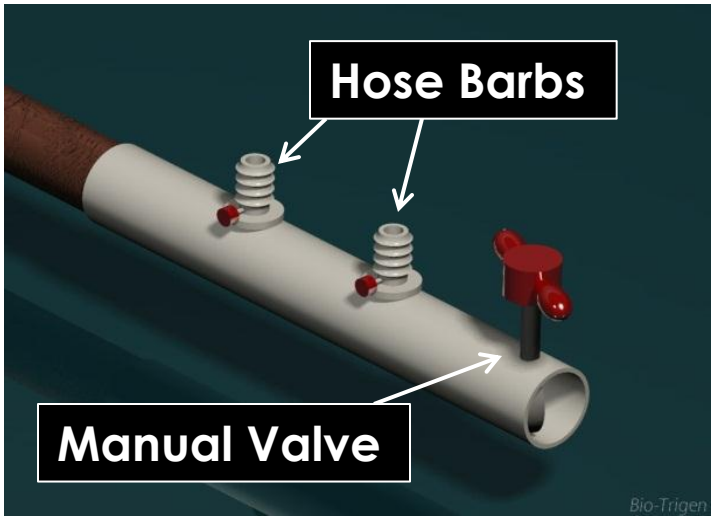

Outline

- Project Description & Diagram
- **Concept Generation & Selection**
- Current Concept Description
- Engineering Economics
- Life Cycle Analysis
- Results and Discussion
- Conclusion

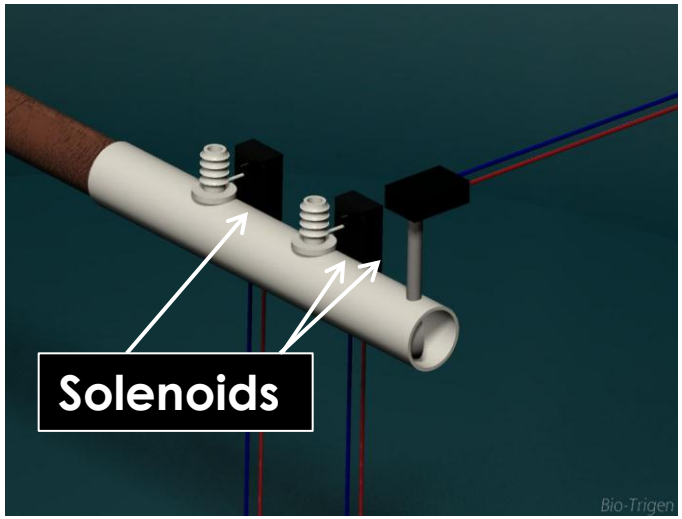
Concept Generation



Concept Generation

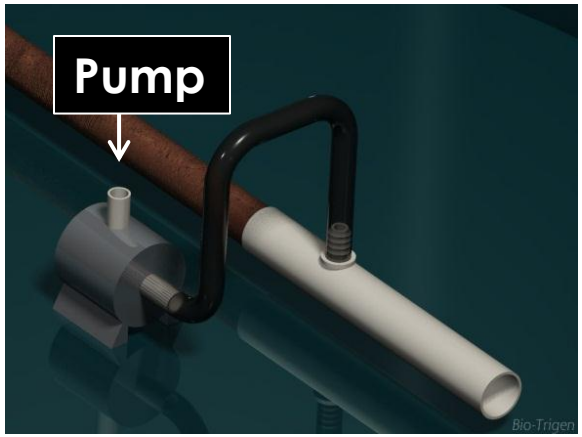


Concept 1- DIRECT Manual Pressure Vessel



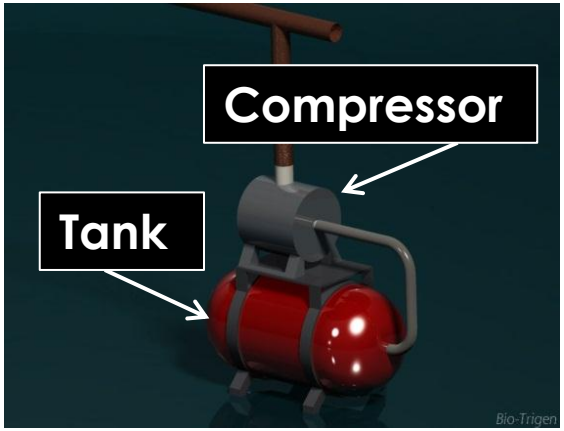
Concept 2- DIRECT Automated Pressure Vessel

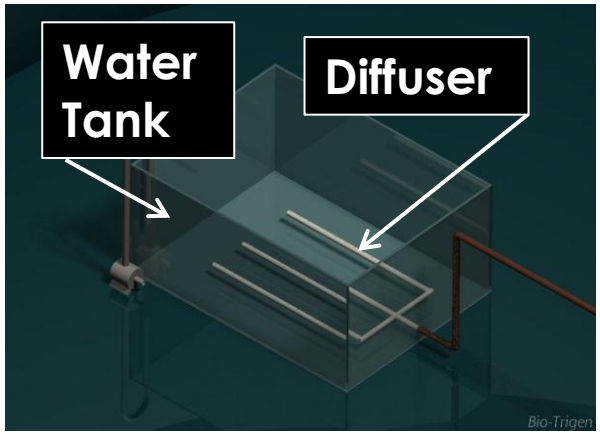
Concept Generation



Concept 3- DIRECT Air Pump

Concept 4- INDIRECT Pump to Pressure Vessel





Concept 5- INDIRECT Water Storage

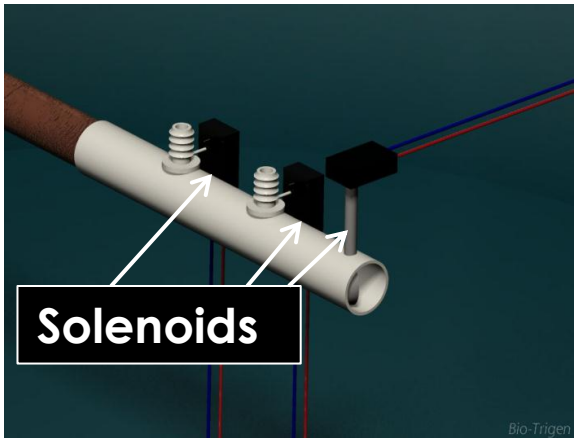
Concept Selection Matrix

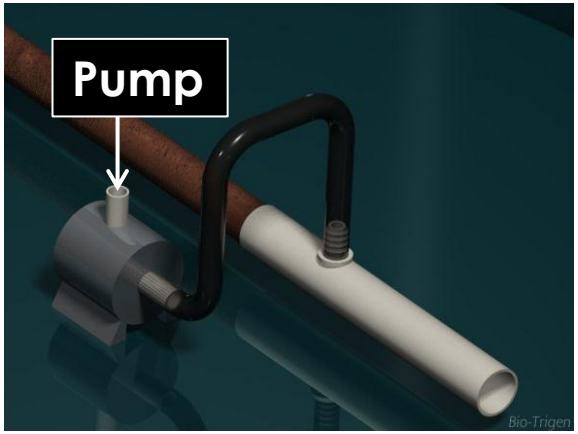
Criteria	Weight	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Capture Effectiveness	0.25	7	8	8	5	4
Power Requirements	0.2	9	9	7	4	5
Cost Effectiveness	0.2	7	8	8	5	6
Scalability	0.1	6	6	9	8	8
Controllability	0.1	7	9	9	8	7
Reliability	0.05	8	7	7	6	6
Durability	0.05	7	6	8	6	7
Adaptability	0.05	5	6	7	9	9
Total Weighted Score	1	7.25	7.85	7.9	5.7	5.8


Outline

- Project Description & Diagram
- Concept Generation & Selection
- **Current Concept Description**
- Engineering Economics
- Life Cycle Analysis
- Results and Discussion
- Conclusion

Current Concept Description

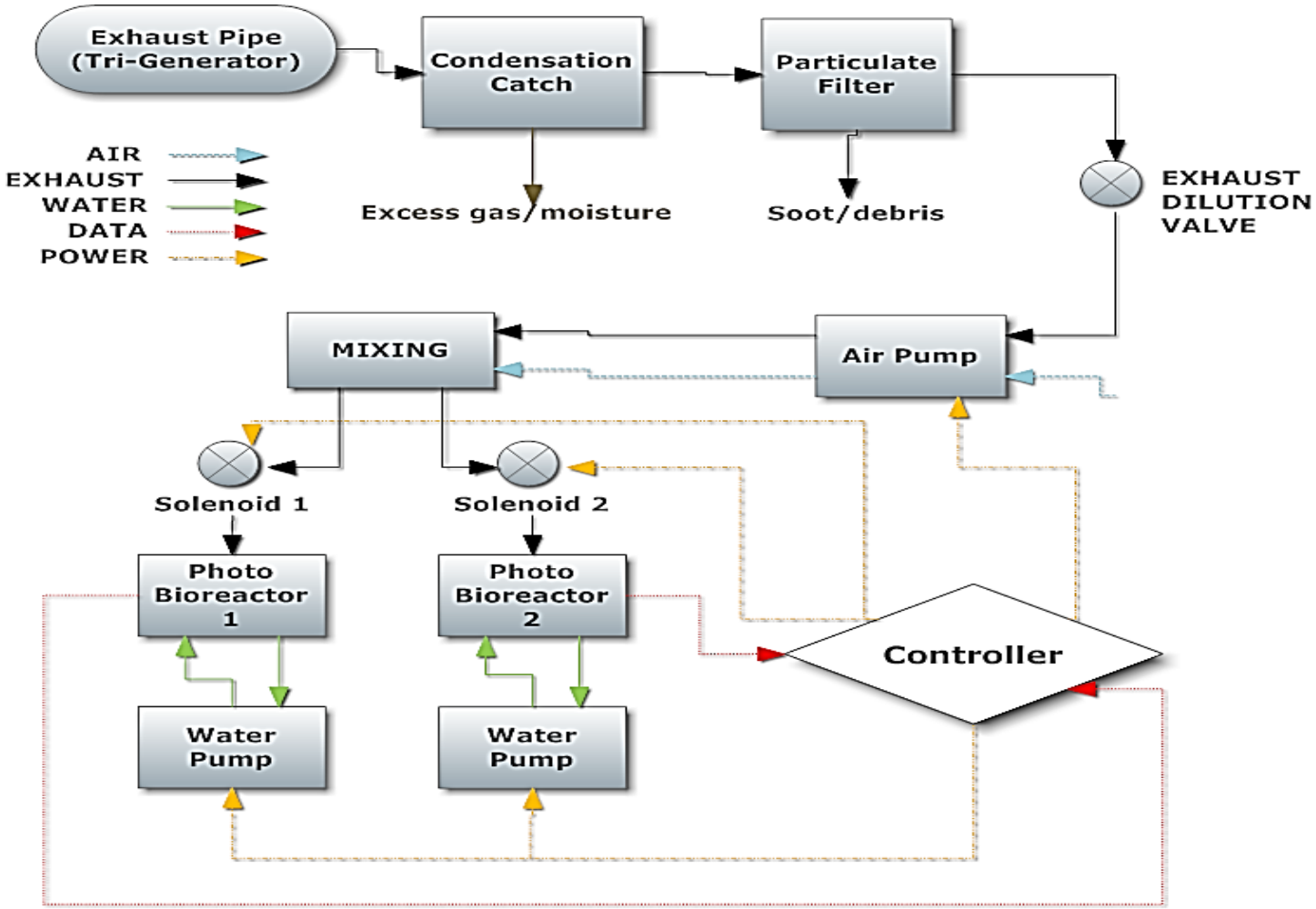




Air/Exhaust Pump

Coupling System

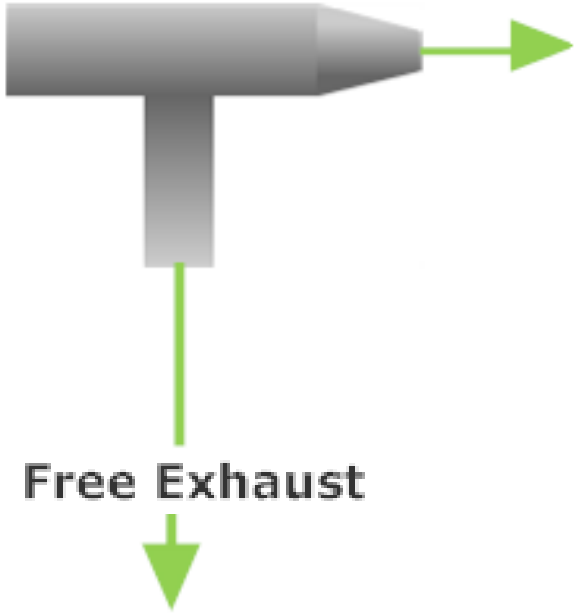
Functional Diagram



Current Concept Description

System Components- Exhaust Fitting

- A 1 in. ID CPVC fitting
- Press fit onto exhaust pipe
- Opening at bottom allows:
  - Excess exhaust escape
  - Condensate drain

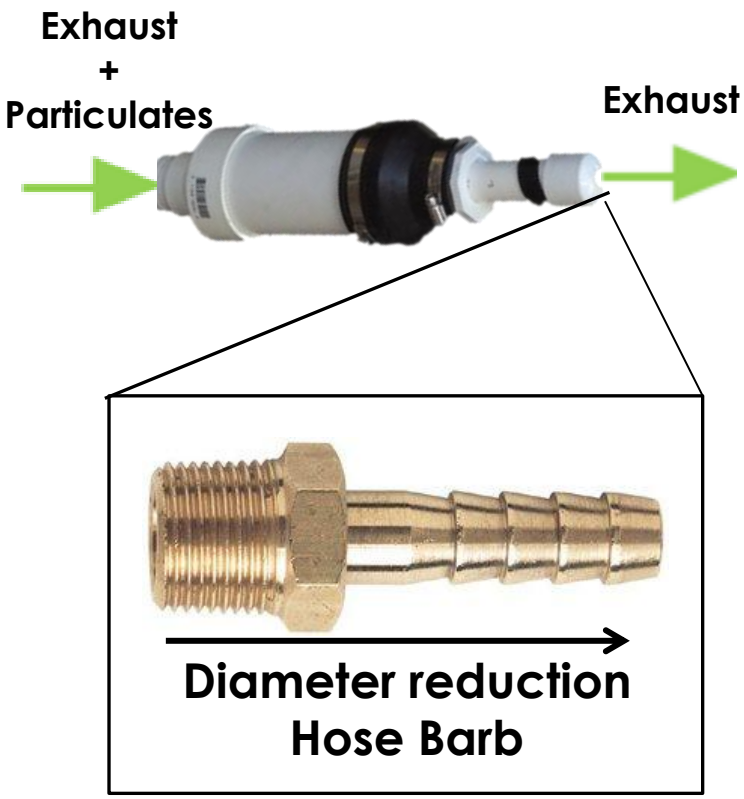


Exhaust Fitting

Current Concept Description

System Components- Filter

- Round disks
- Household smoke and particulates filter
- Placed inside CPVC piping
- Ends sealed with CPVC caps
- Ends sealed with PVC cement
- Caps are tapped for hose barb

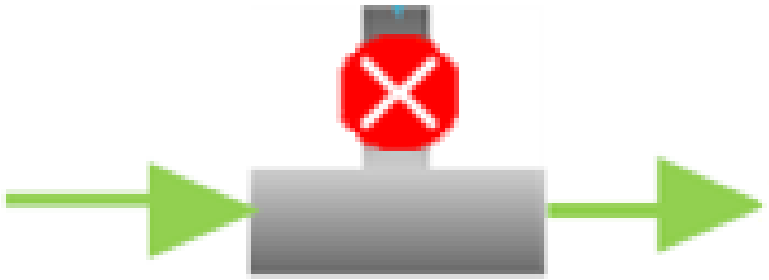


Current Concept Description

System Components- Exhaust Dilution Valve

- Simple tubing
- Flow control ball valve
- Controls exhaust and air mixture
- Doubles as air inlet if engine is not running

Open/Close Valve



Exhaust Dilution Valve

Current Concept Description

System Components- Pumps

- Water pumps provide periodic circulation

- Air pumps:
  - 2 discrete inputs
  - 2 outputs for exhaust mixing

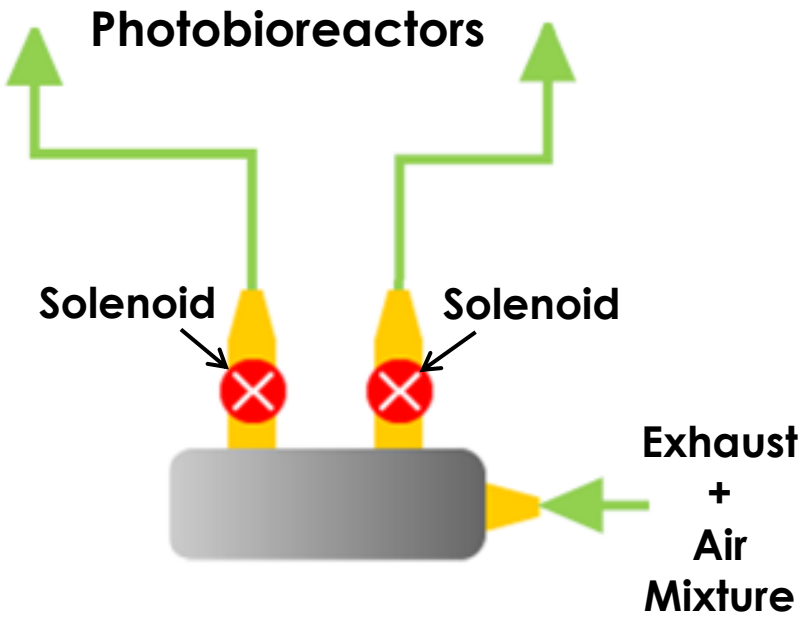
Water Pump

Air/Exhaust Pump

Current Concept Description

System Components- Distribution Manifold

- Distributes exhaust to photobioreactors
- Solenoid valves:
  - controlled
  - supply gases to photobioreactors



Distribution Manifold

Current Concept Description

System Components- Photobioreactors

- Two species :
  - *Scenedesmus quadricauda*
  - *Chlorella vulgaris*
- Two exhaust:
  - 1 *Scenedesmus*
  - 1 *Chlorella*
- Two air:
  - 1 *Scenedesmus*
  - 1 *Chlorella*
  - serve as control

Photobioreactors

Current Concept Description

System Components- Sensors

- 4 pH sensors:
  - monitor CO_2 effect on algae pH

pH Sensor

- 3 temperature sensors:
  - monitor temperature in photobioreactors

Temperature Sensor

Current Concept Description

System Components- Controllers

(a) Microcontroller controls:

- solenoids
- water pumps
- Air pumps

(a)

(b) Controlled electrical outlets:

- Specific outlet control

(b)

(c) Probe module:

- provides ports for pH and temperature sensors

(c)

(d) GUI

- Provides ease of use

(d)

Current Concept Description

System Components- Housing Unit

- Above the unit:
  - Photobioreactors are fastened
- Drawer of unit:
  - Surplus storage space
- Top shelf of unit:
  - Electronics are stored
- Bottom shelf of unit:
  - Pumps are mounted

Housing Unit


Outline

- Project Description & Diagram
- Concept Generation & Selection
- Current Concept Description
- **Engineering Economics**
- Life Cycle Analysis
- Results and Discussion

Engineering Economics

- Budget of $2,500

Item	Price
Algae and Medium	$320
Electronics and Sensors	$700
Pumps and accessories	$450
Housing Unit	$590
Miscellaneous	$60
Total	$2,120

- Available funds: $380


Outline

- Project Description & Diagram
- Concept Generation & Selection
- Current Concept Description
- Engineering Economics
- **Life Cycle Analysis**
- Results and Discussion
- Conclusion

Life Cycle Analysis

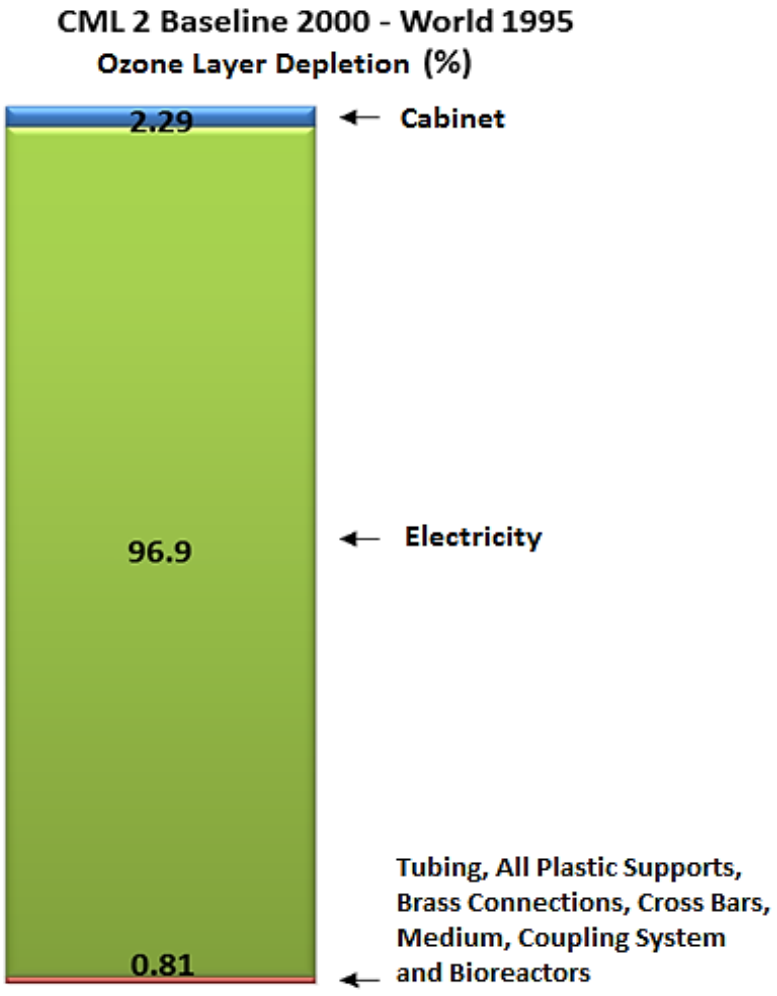
- A “cradle-to-grave” methodology
- Evaluates environmental impacts:
  - Materials used
  - Over a period of interest
- Can make a process/product greener
- Computer Applications to perform analysis (SimaPro)

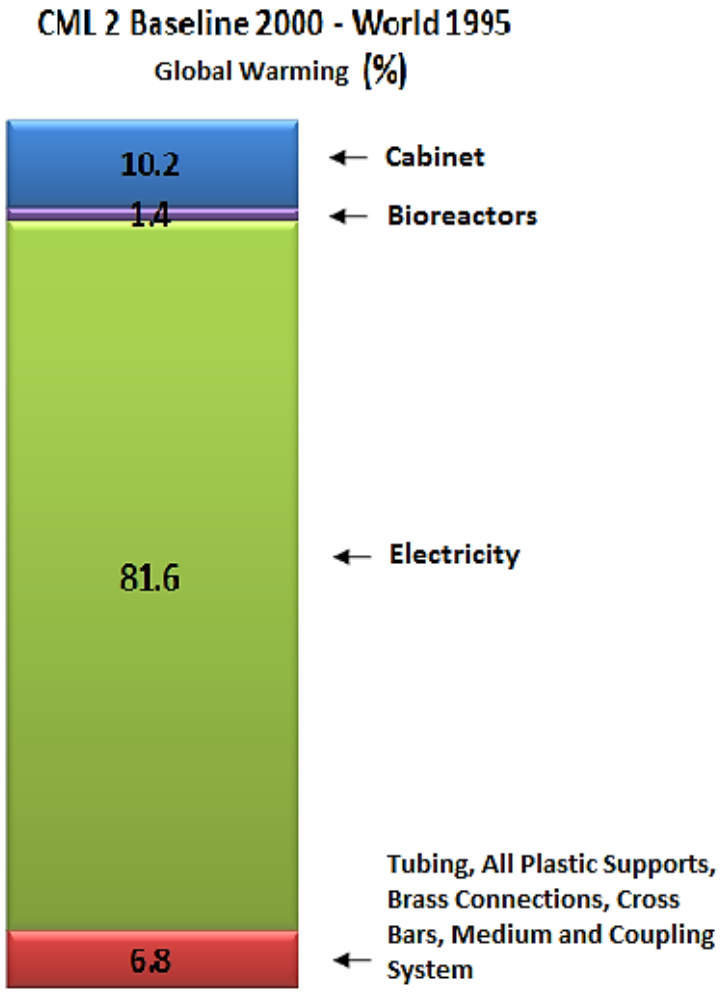
Life Cycle Analysis

SimaPro Major Input Data

Element	Weight (g)	Electricity (kWh/year)
Cabinet	26489	---
Tubing	1800	---
Bioreactors	1872	---
Coupling System (PVC)	881	---
Cross bars	332	---
Plastic Panels	576	---
Brass Connections	192	---
Distillate Water	521400	---
Water Pumps	---	473.04
Air Pumps	---	846.96
CHU Medium	1042.8	---

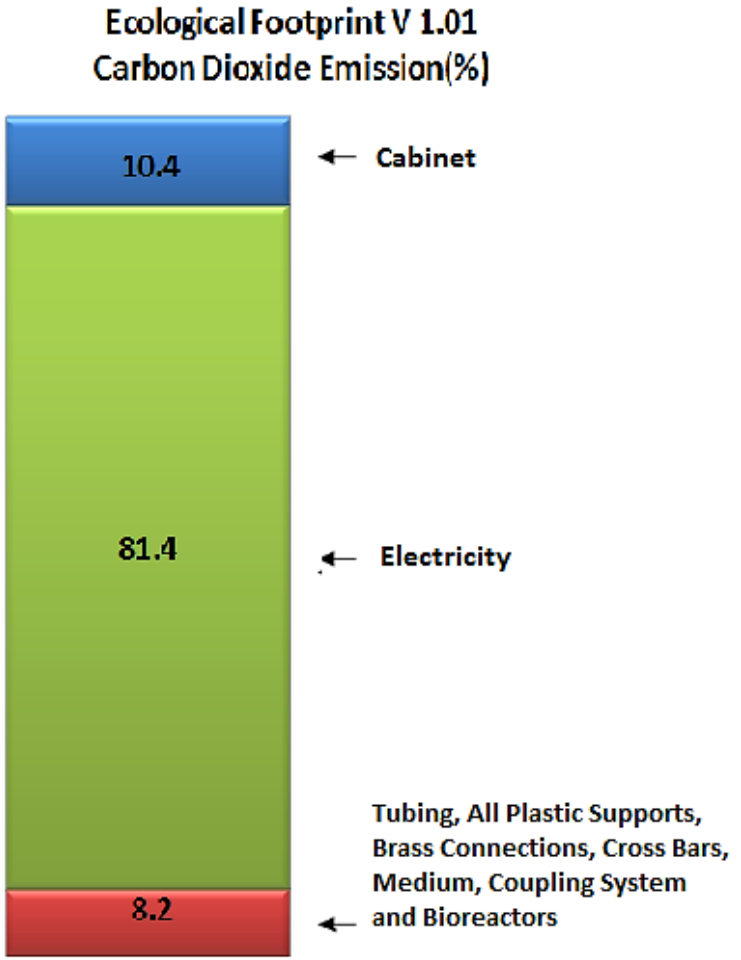
Life Cycle Analysis





Life Cycle Analysis

- Ecological Footprint method:
  - examines CO2 emitted to the atmosphere



Life Cycle Analysis

- **Biodiesel Production:**
  24 kg/yr (27.27 L/yr)
- **CO2 Sequestered:**
  187.7 kg/yr

- **Assumptions:**
  - **Batch System (10 L/wk)**
  - **20% dried biomass**
  - **20% oil extraction percentage (*Chlorella*)**
  - **30% oil extraction percentage (*Scenedesmus*)**
  - **95% efficiency in converting oil to biodiesel**
  - **Biodiesel density of ~0.88 kg/L**
  - **1 kg of dry biomass can sequester 1.8 kg of CO2**

(Global CCS Institute, 2012)

Outline

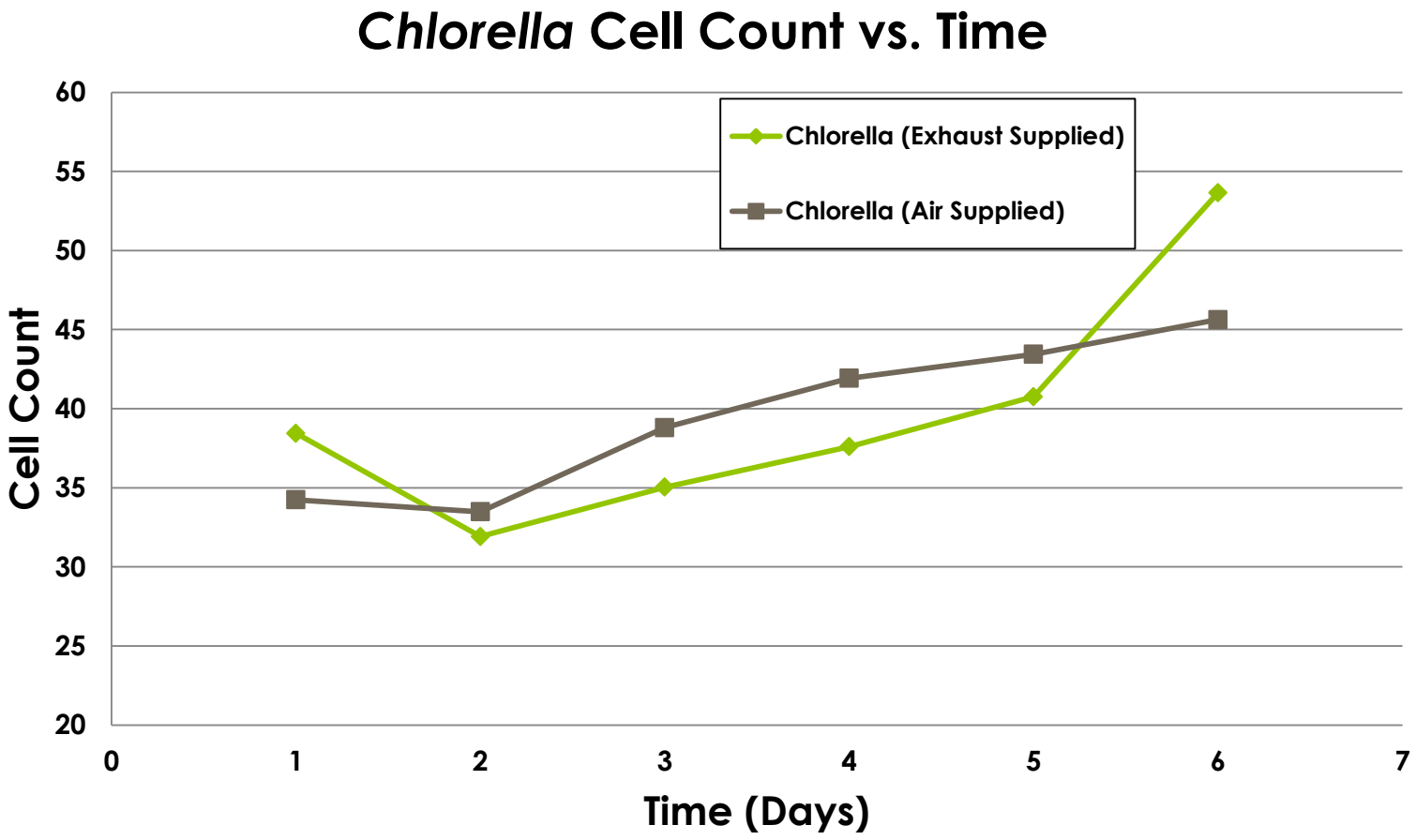
- Project Description & Diagram
- Concept Generation & Selection
- Current Concept Description
- Engineering Economics
- Life Cycle Analysis
- **Results and Discussion**
- Conclusion

Results and Discussion

- Tests conducted:
  - Trigeneration exhaust temperature test
    - Infrared temperature sensor
    - Thermocouple
  - Gas Analysis of Exhaust
  - Exhaust effect on algae growth
    - cell count
    - pH sensor data

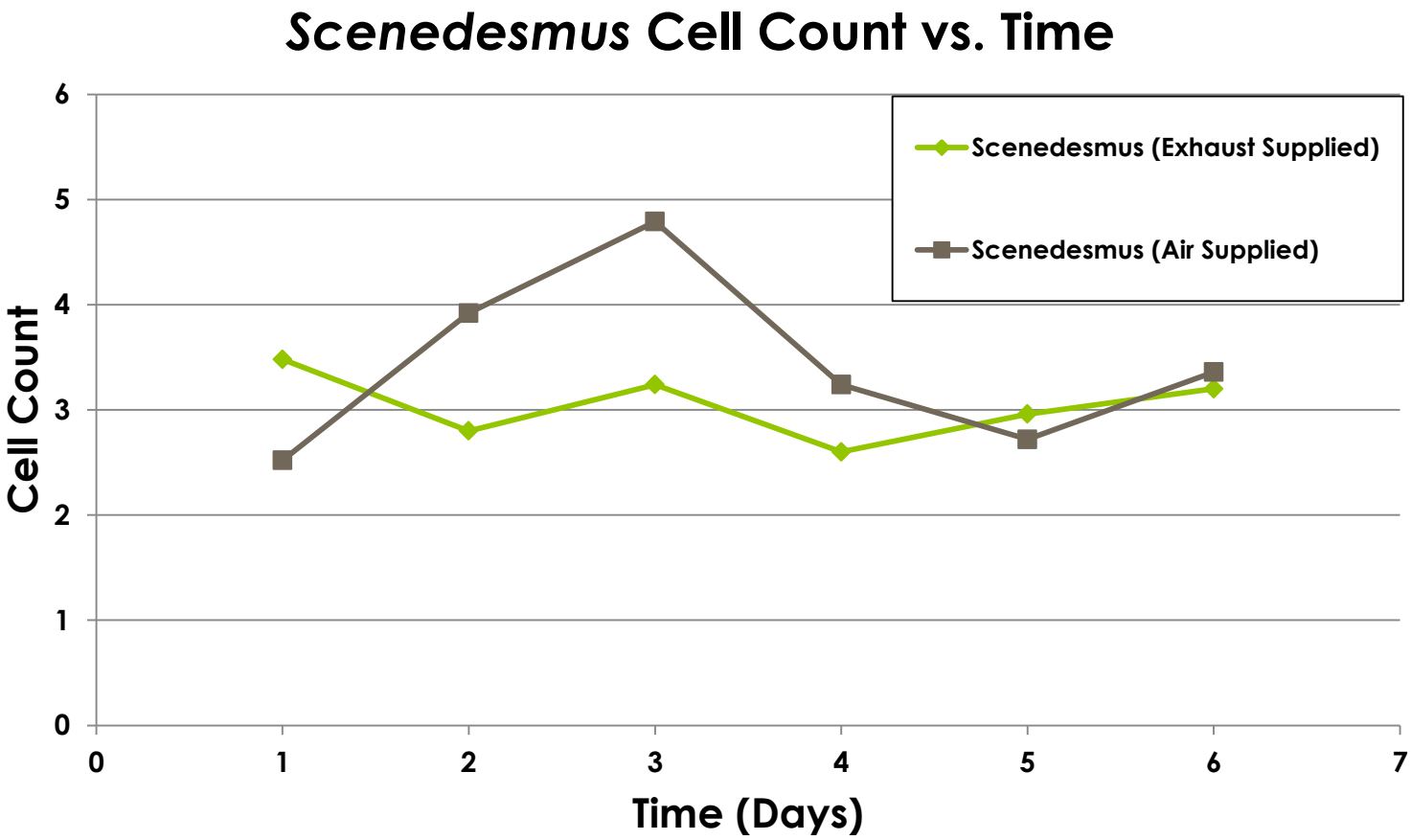
Results and Discussion

Algae Cell Count Data-*Chlorella*



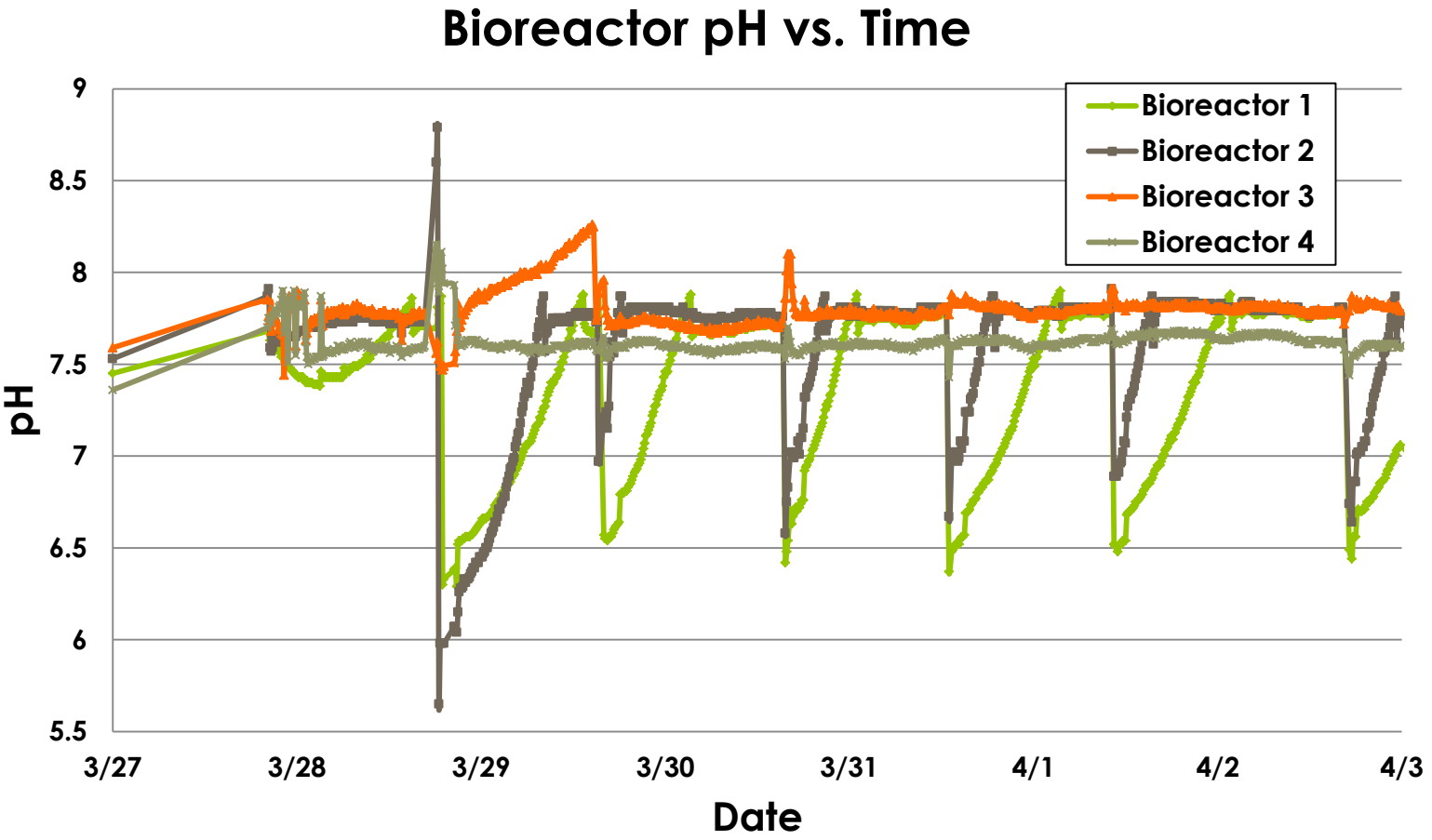
Results and Discussion

Algae Cell Count Data- *Scenedesmus*



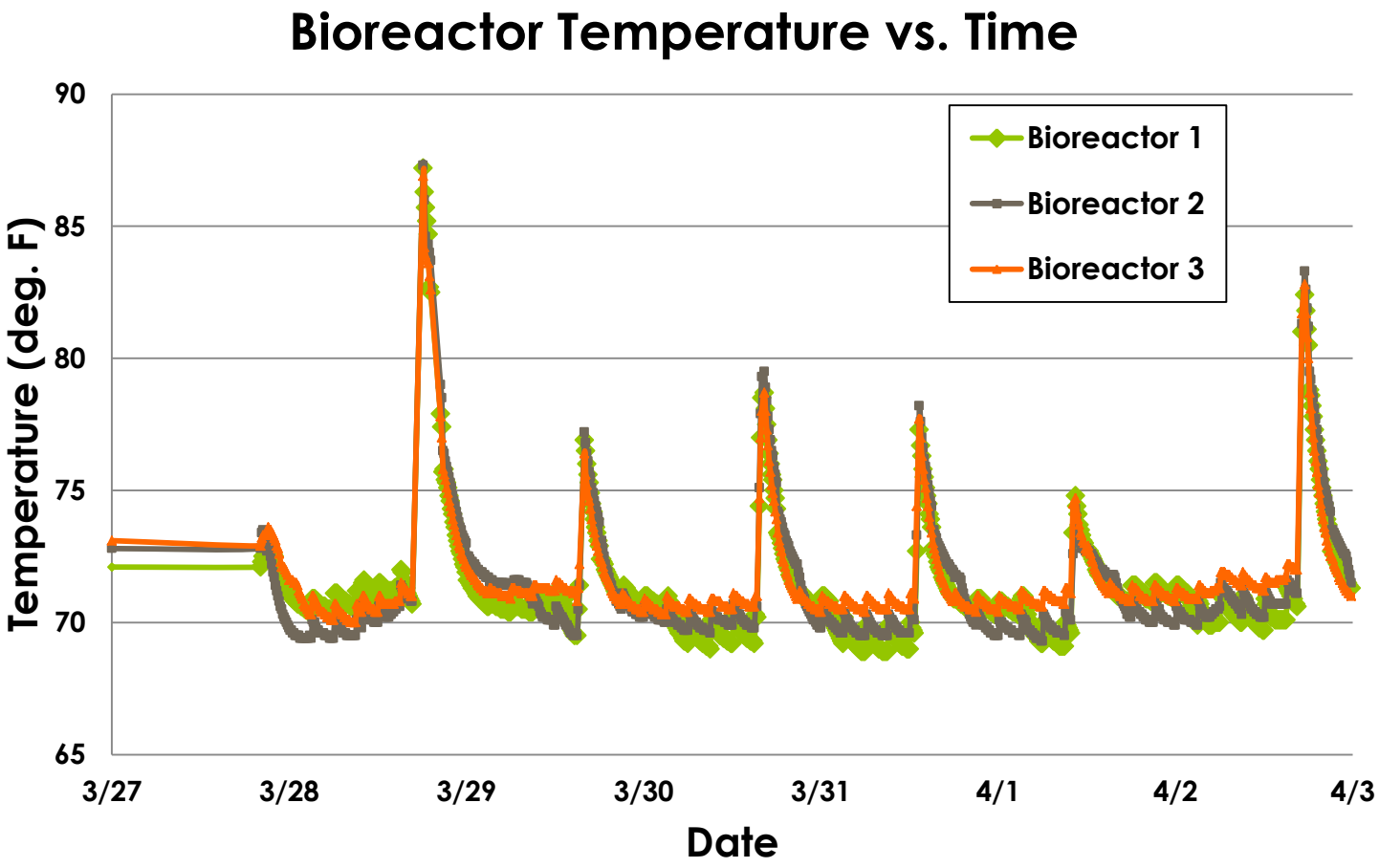
Results and Discussion

pH Sensor Data



Results and Discussion

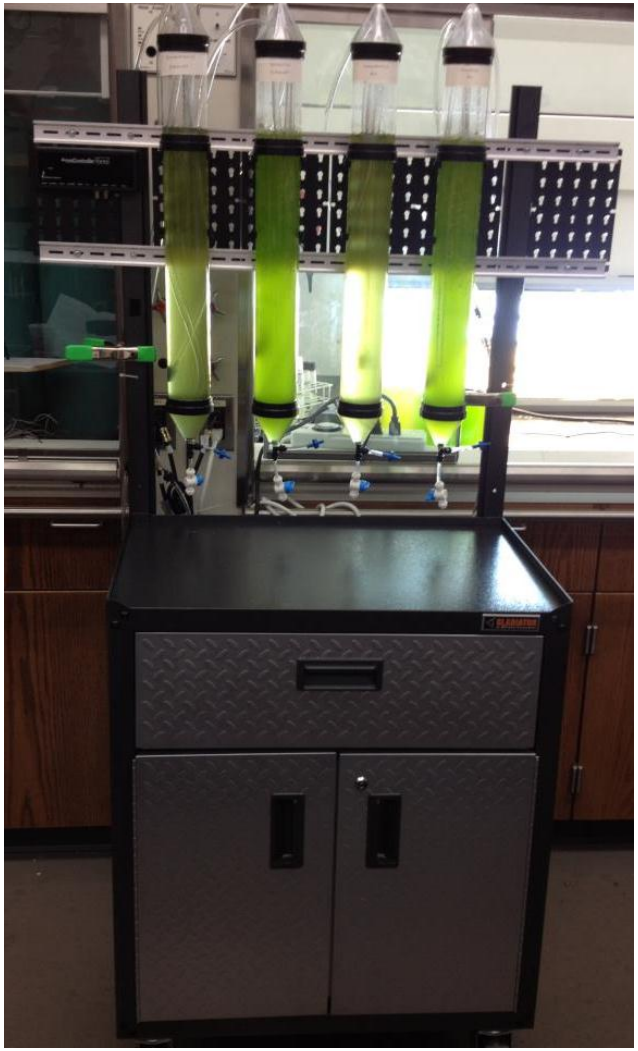
Temperature Sensor Data



Results and Discussion

Objectives Revisited

- ✓ Create a coupling device
- ✓ Deliver CO2 to Photobioreactors
- ✓ Examine growth of algae
- ✓ Complete Life Cycle Analysis




Outline

- Project Description & Diagram
- Concept Generation & Selection
- Current Concept Description
- Engineering Economics
- Life Cycle Analysis
- Results and Discussion
- **Conclusion**

Conclusion

- Coupling system supplied exhaust
- Algae can grow while fed exhaust
  - Growth was not hindered
- Improvements:
  - Larger Photobioreactors
    - Increase biomass
    - Limit temperature swings
    - More CO2 absorption
  - Creation of outdoor system
    - Continuous testing
    - Limit temperature swings

Questions?