Design of Scaleable Photobioreactors for Mass Production of Algae for Biofuel Production

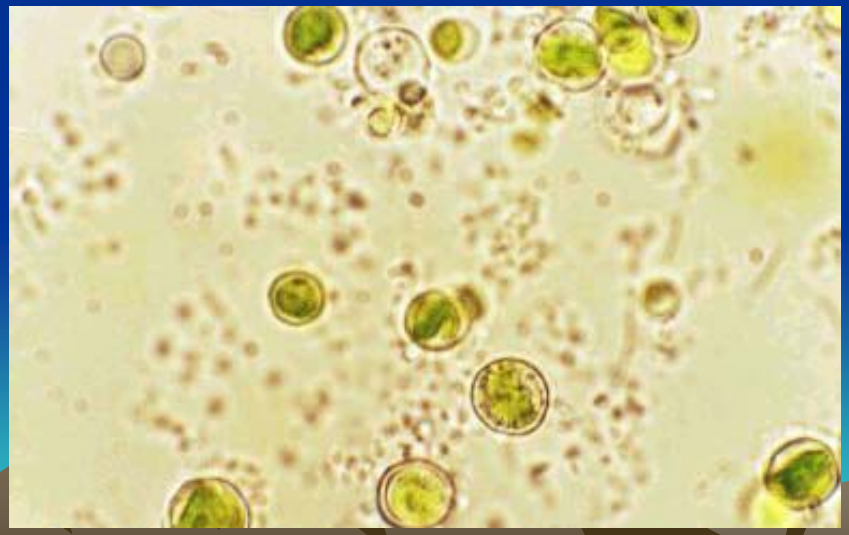
Joel L. Cuello,
Michael Mason and Michael Kazz
The University of Arizona

Critical Need for Other Biomass Feedstocks

Algae!

Nostoc sp.

Chlorococcum littorale



Chlorella sp.

Spirulina sp.

Why Algae?

- Some accumulate hydrocarbons
- Some accumulate fatty acids
- Some accumulate starch
- Some produce hydrogen gas

Algae: Major Advantages

(1) renewable energy source

(2) potential for reduction of emissions from power plants

(3) much higher productivity than traditional fast-growing energy crops

(4) less area required than traditional crops when grown in photobioreactors

Algae: Major Advantages

(5) production in photobioreactors prevents potential degradation of soil and groundwater

(6) non-potable water can be used, aiding in wastewater treatment and utilizing non-productive areas

(7) production of economically valuable chemicals

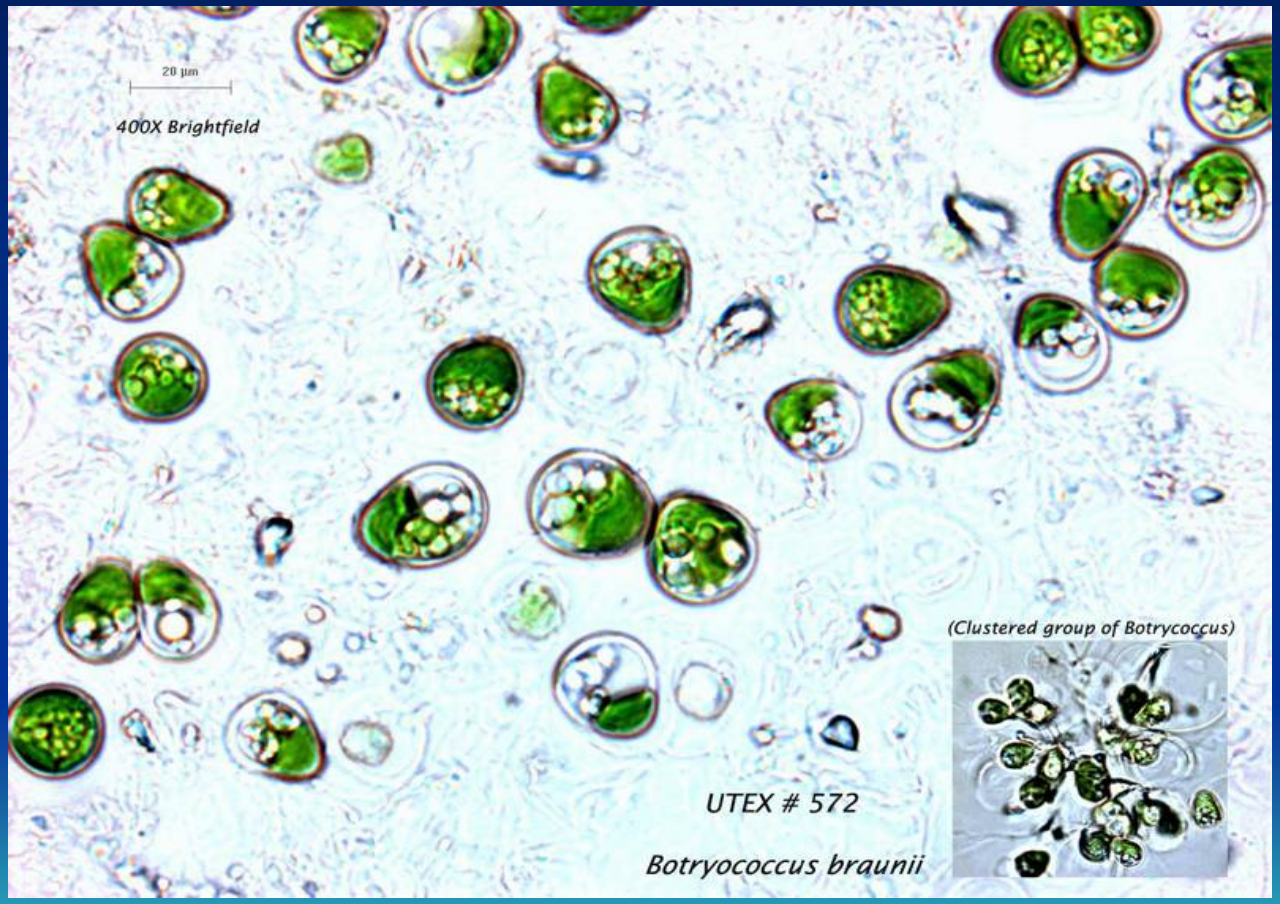
Algae: Major Advantages

(8) Energy feedstock that does not compete with food or feed!

Algae: Biodiesel Yield (L/ha-yr)

Soybeans	446
Rapeseed	119
Mustard	1300
Jatropha	1892
Palm Oil	5950
Algae (Low)	45000
Algae (High)	137000
Ours (High)	132,300!

Botryococcus braunii for Hydrocarbon Production



Biofuel Production from Algae

1) Species/Strain Selection

2) Mass Production of Algae

3) Downstream Processing

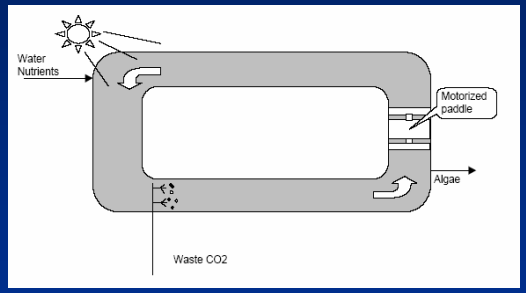
Mass Production of Algae

Optimization of Environmental Parameters for Algae Culture

Design of Scaleable Photobioreactor

Two Ways to Mass Produce Algae

Open Ponds



Photobioreactors

Criteria for Algae Open Ponds

Delivery of Light

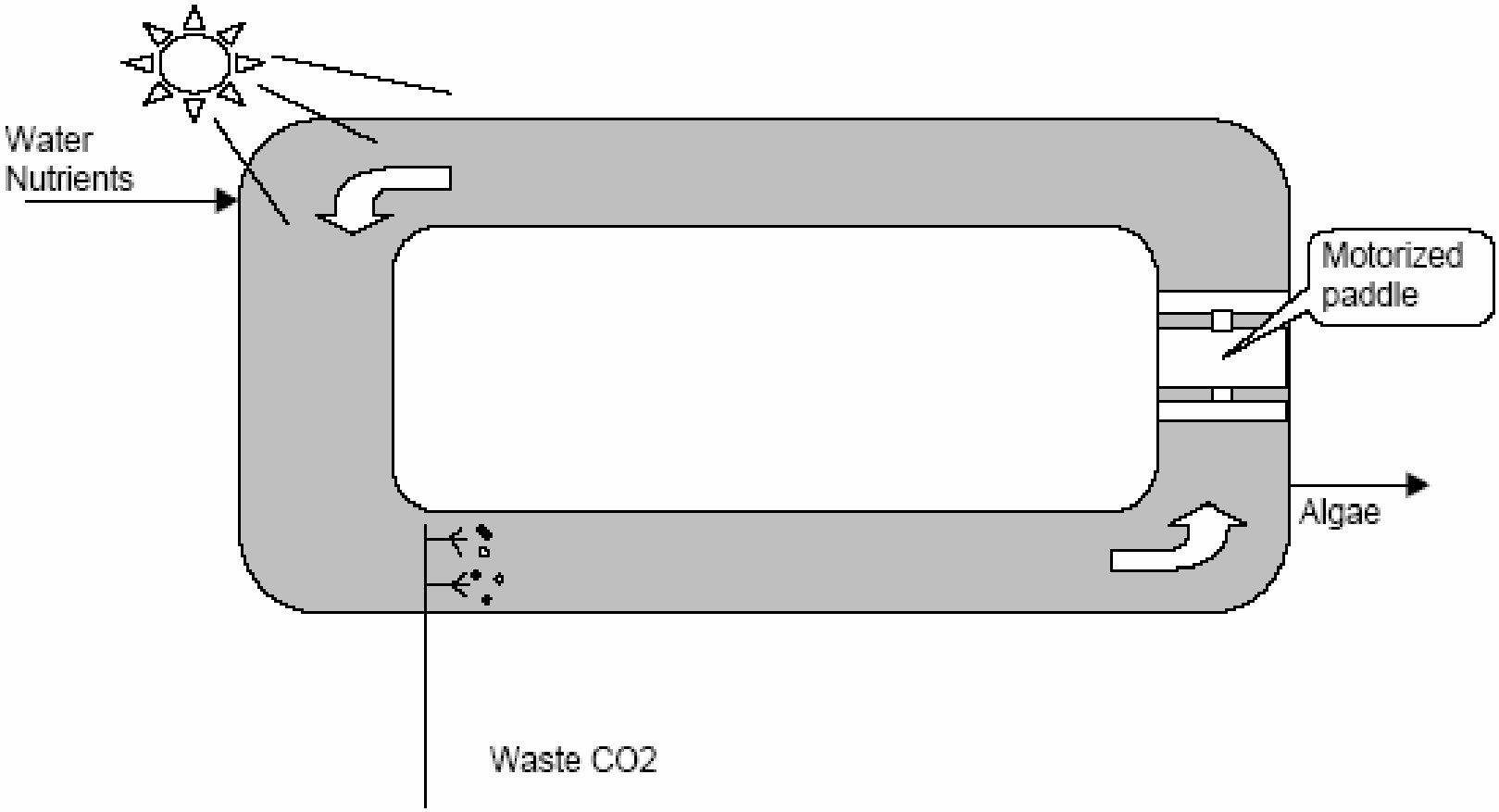
Delivery of CO_2

Delivery of Nutrients

Adequate Mixing

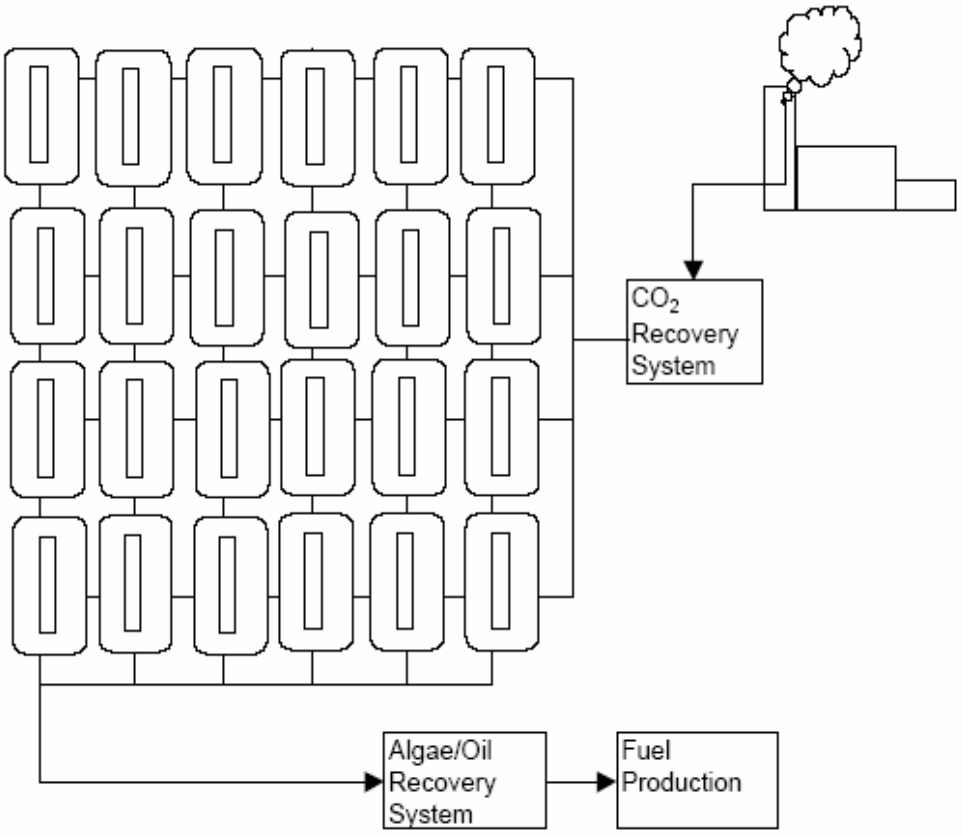
Optimal Culture density

Open Pond System



http://www.veggievan.org/downloads/articles/Biodiesel%20from%20Algae.pdf

Open Pond System



http://www.veggievan.org/downloads/articles/Biodiesel%20from%20Algae.pdf

Open Pond Cultivation Challenges

- **Pollution**

-- Soot flakes from furnaces of sugar factory

-- Heavy metals

-Algae can accumulate heavy metals

-Intracellular concentration of heavy metals of 1000x higher than the surrounding medium has been observed

-Could come from air pollution by industries (Cd from fertilizer)

Open Pond Cultivation Challenges

- **Infection**

  -- parasites, protozoa, insect larvae, unwanted algae species

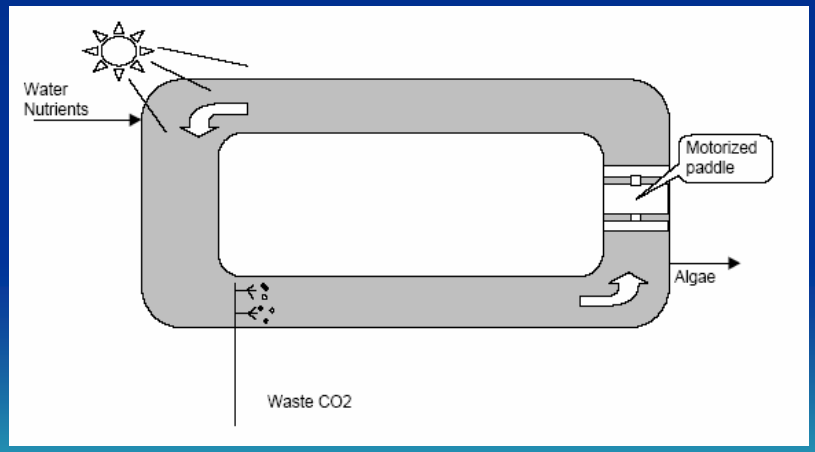
  -- causes loss of culture

  -- e.g., in India, infestation by Ephydra fly of 30 insect larvae/L in Spirulina culture reduced algae yield by 30%

Open Pond Cultivation Challenges

- **Poor CO_2 usage**

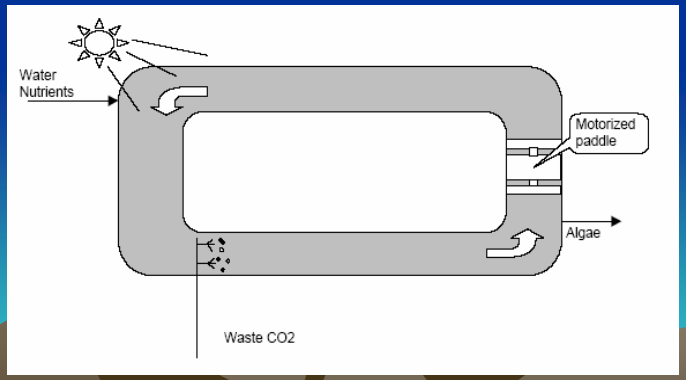
  -- most of the CO_2 bubbled into the pond is lost into the atmosphere



Open Pond Cultivation Challenges

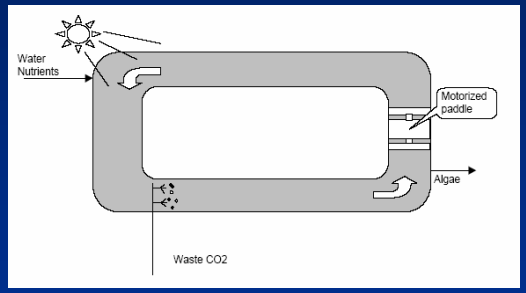
- **Sub-optimal use of land area**

  -- Requires strictly two-dimensional surface area expansion for large-scale operation (as opposed to three-dimensional volume expansion)



Two Ways to Mass Produce Algae

Open Ponds



Photobioreactors

Criteria for Algae Photobioreactors

- Delivery of Light
- Delivery of CO_2
- Delivery of Nutrients
- Adequate Mixing
- Optimal Culture density

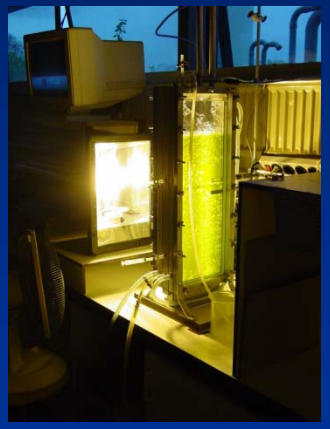
Photobioreactor

Controlled

Light
Nutrients
CO_2
Mixing
Culture Density
pH
Temperature
Flow Rate
etc.

Scaleable Photobioreactor Design

Scaleable Photobioreactor Design

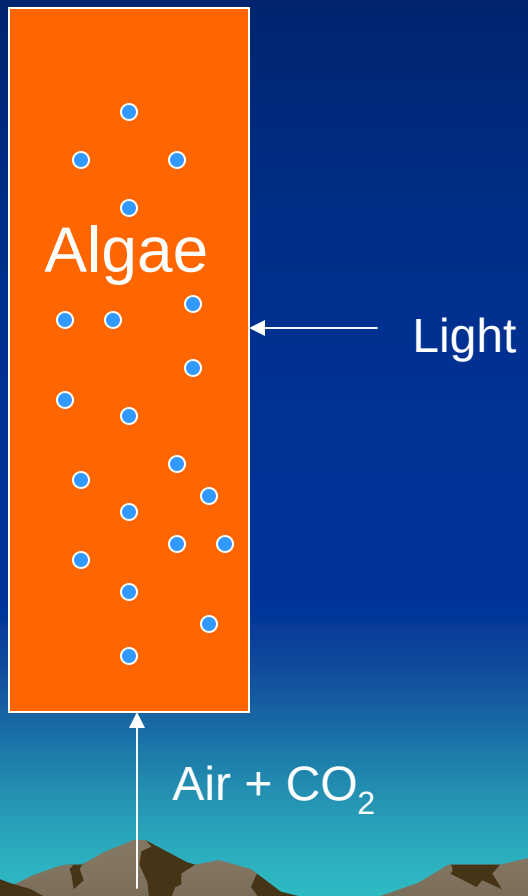


Photobioreactor Design

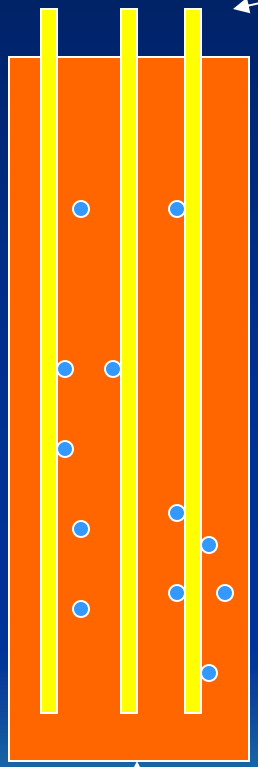
All Bioreactor configurations will work in small scale, but not all will work in large scale!

And then there is also the capital cost.

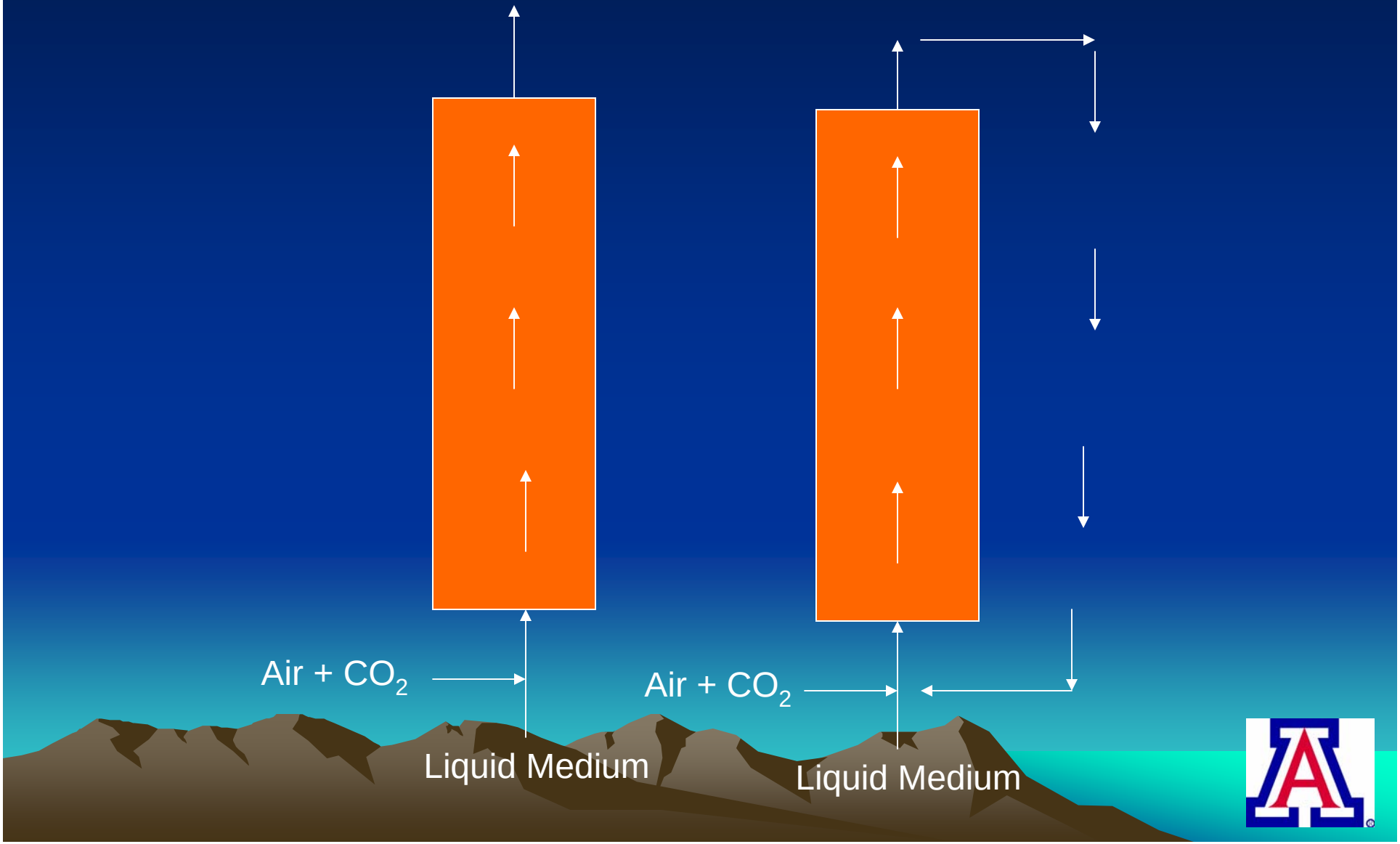
Bubble Column



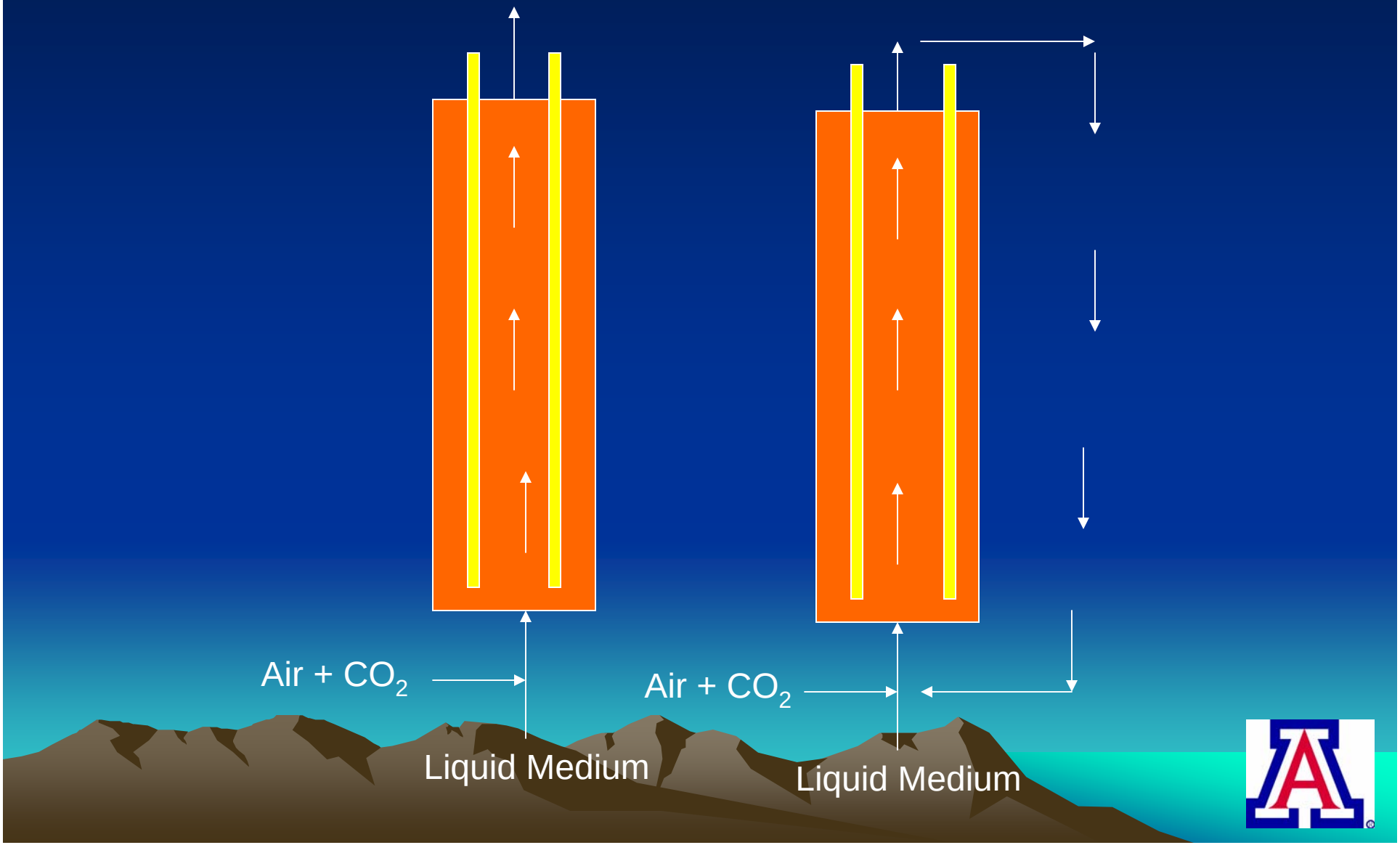
Bubble Column



Convective Flow Column



Convective Flow Column



Objective: Design Column Photobioreactors

Scale Up Investigations:

H/D

Flow Velocity

Bubble Size

kla

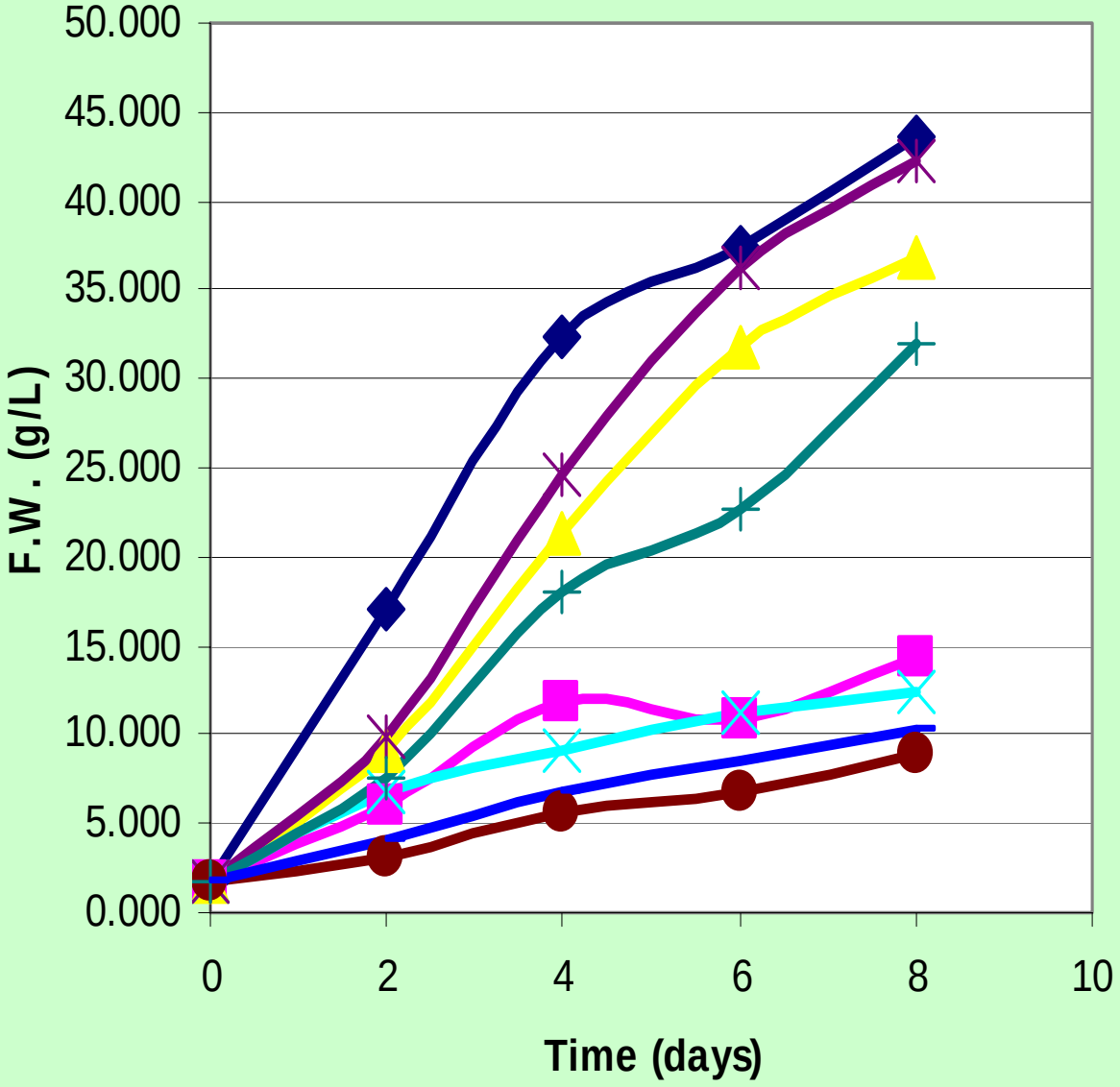
Mixing Rate

Initial Density

Light Levels

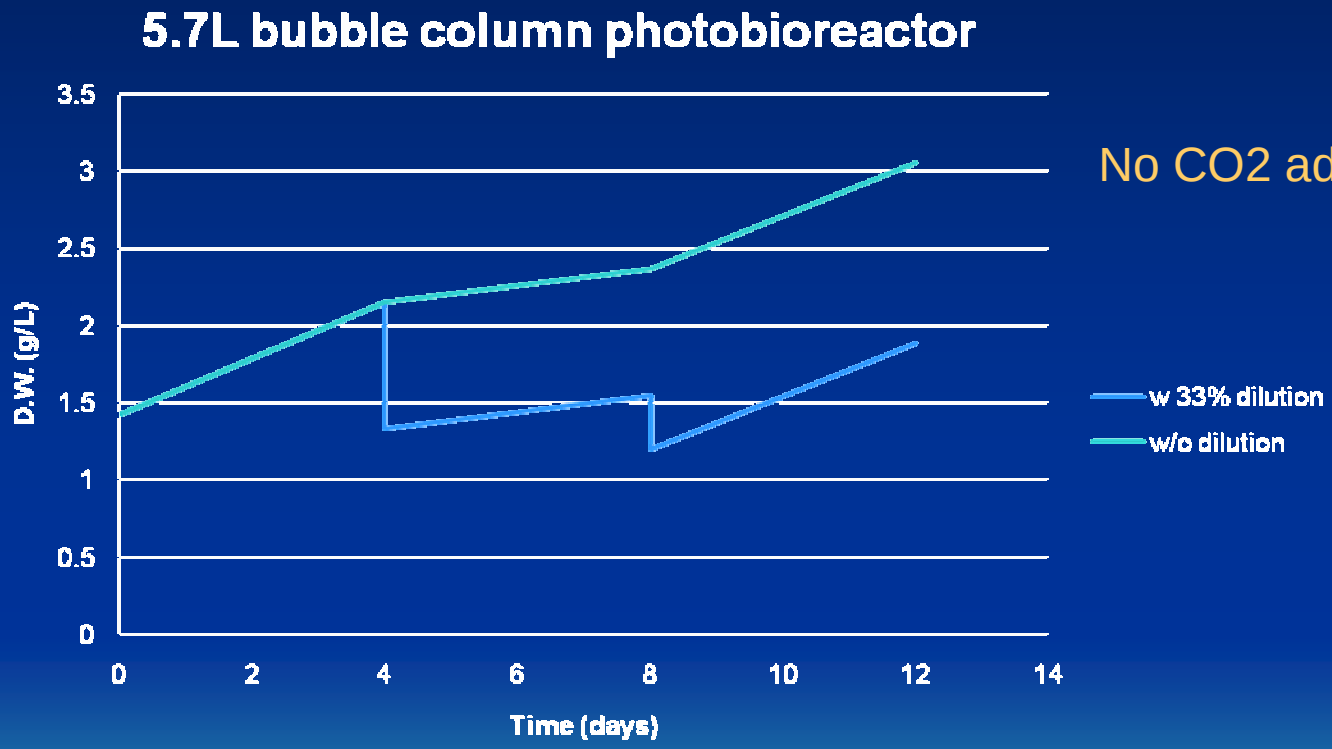
Photobioreactor Design

B. braunii growth optimization



- mix., CO2, 200umol
- mix, no CO2, 200umol
- mix., CO2, 150umol
- mix., no CO2, 150umol
- no mix., CO2, 200umol
- no mix., no CO2, 200umol
- no mix., CO2, 150umol
- no mix., no CO2, 150umol

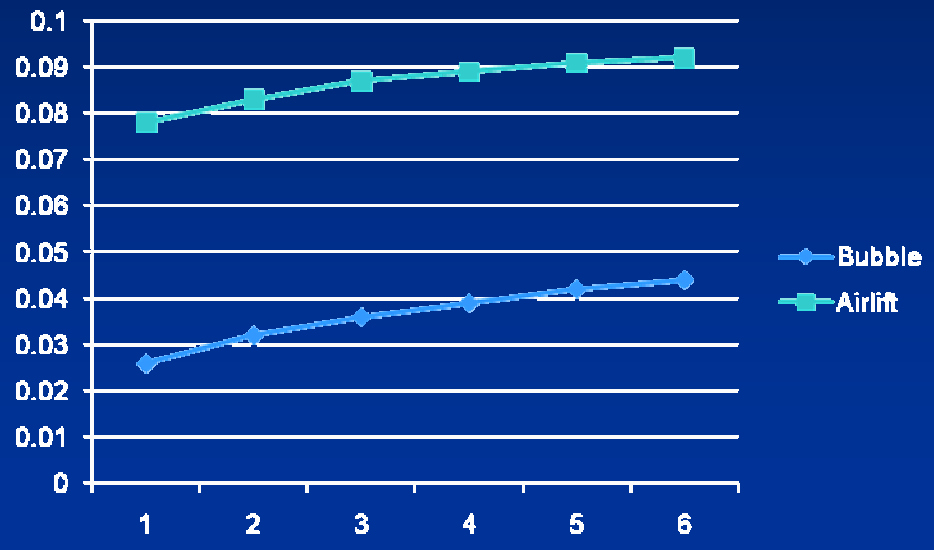
Bubble Column Photobioreactor



No CO2 added

Column Photobioreactors

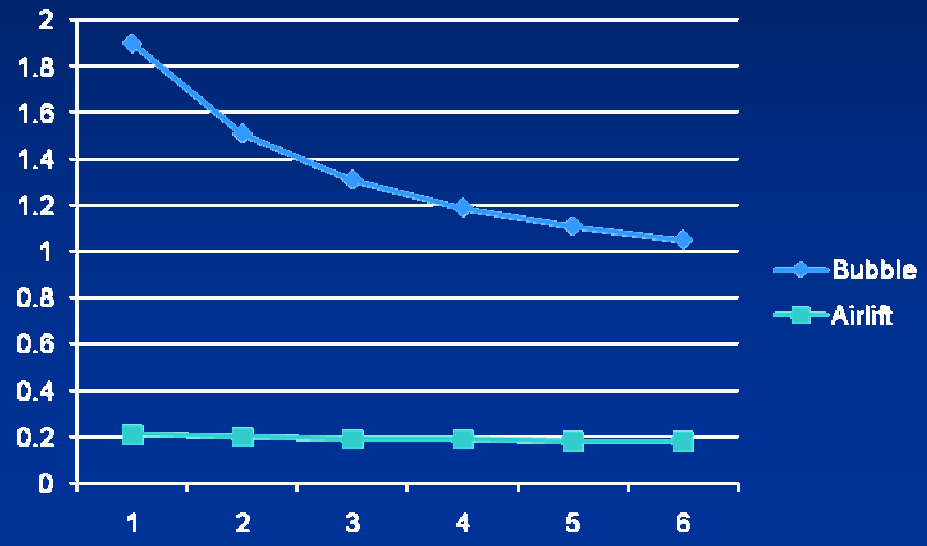
Axial Dispersion Coefficient (m2/s)



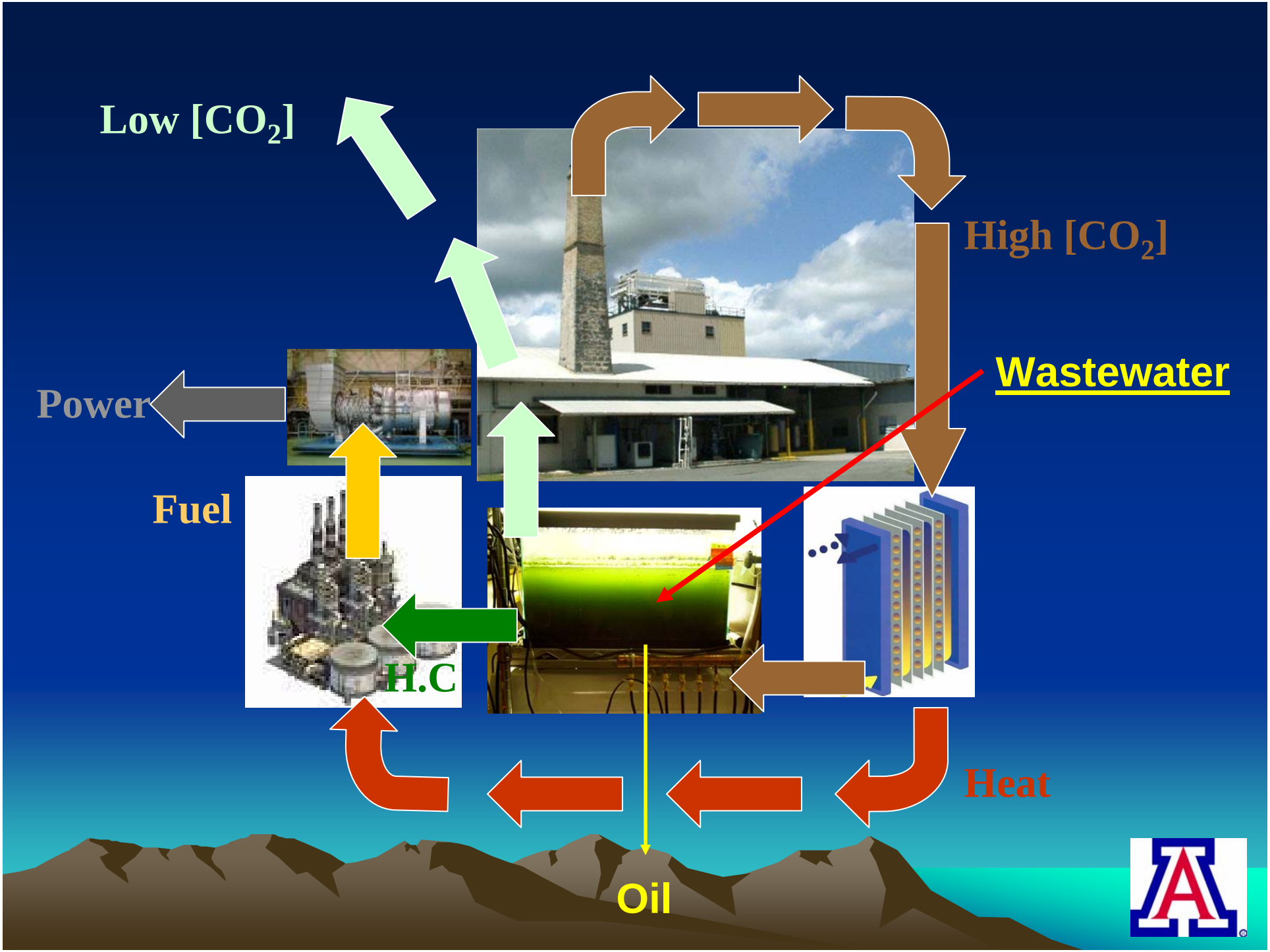
vvm (per min / 10)

Column Photobioreactors

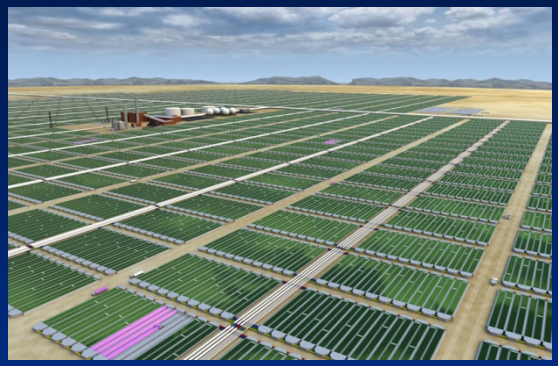
Mixing Time (min)



vvm (per min / 10)


Low [CO_2]
High [CO_2]
Wastewater
Power
Fuel
H.C
Heat
Oil

Further Work



- Correlating hydrodynamic characteristics with growth rate and oil production
- Pilot scale
- Use of waste CO2 and wastewater