Production of Algae in Conjunction with Wastewater Treatment

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Abstract

- Wastewaters are excellent algal growth media, with CO2 addition
- 2,400 acres of large WW ponds operate in No. Calif. A 10-fold increase is reasonable statewide.
- Harvesting & nutrient removal: Cal Poly research
- WWT helps in energy balance & costs of biofuel
- Wastewater algae biofuel is rapid path to market

Major Wastewater Treatment Technologies in U.S.

Activated Sludge

6,800 Facilities

25,000 million gallons per day

1.3 2.5 MWh per MG

Biofilm Systems

2,500 Facilities

6,000 million gallons per day

0.8 -1.8 MWh per MG

Major Technologies, Continued

Ponds

5,100 Facilities

2,000 million gallons per day

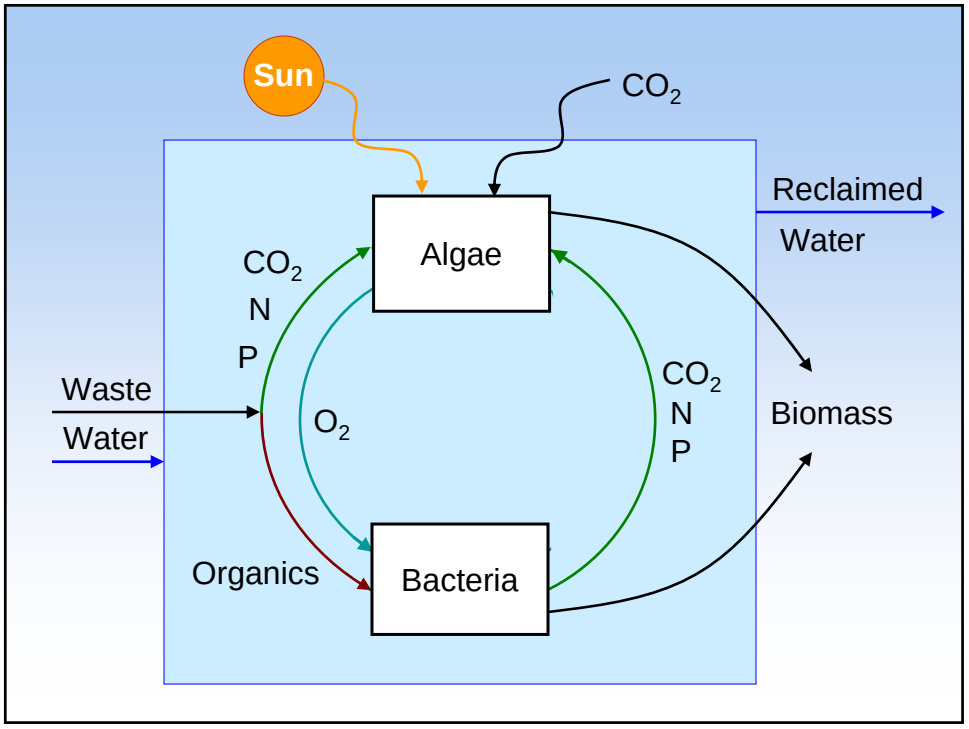
0.4 – 1.4 MWh per MG

Carbon Limited

Conventional vs. High Rate Ponds

Conventional Ponds
Little mechanical mixing
20 – 100s days residence times
C-limited

High Rate Ponds
Paddle wheel mixing
4 – 10 day residence times
C-limited with wastewater



Mechanical Systems

Drawbacks

High Energy Consumption
especially for nutrient removal

High Cost

$20 billion investment needed in next decade - ASCE

Ponds (deep or C-limited)

Drawbacks

Methane Emissions

Poor Nutrient Removal

Land Requirement

Costly Chemical Coagulation

Algae for Wastewater Treatment

Pros

- Produce oxygen with low energy input
- Remove soluble N and P
- CO2 fixed
- Biomass produced

Cons

- Rarely settle well
- Failure to meet suspended solids limits (~45 mg/L)
- Interfere with disinfection
- Biomass produced

Algae Harvesting Options

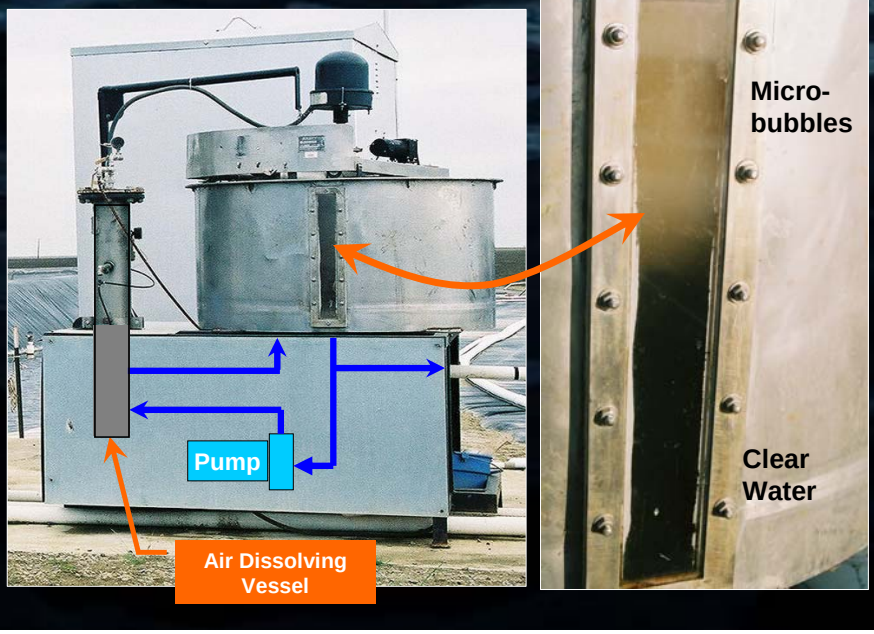
Chemical Coagulation + Flotation

Natural Settling

Chemical Coagulation & Dissolved Air Flotation

- **Metal Salts & Petroleum-based Polymers**
  - Create algae flocs
  - $300 to $600 per MG chemical costs
    vs. $1000 per MG total O&M cost avg. (AMSA 2002)
- **Dissolved Air Flotation**
  - Mechanical floc removal
  - Pressurized air and water

Flotation Harvesting



53 MGD DAF Facility in California

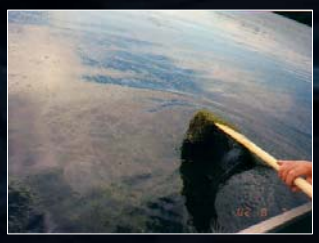
Costs

Ponds without DAF
vs. Activated Sludge

1.5 MGD basis

- **Lower capital cost for ponds**
  - $4-5 million vs. $8-10 million per MGD capacity
- **Lower operations cost for ponds**
  - 2 part-time vs. 4-8 full-time operators

Nutrient Removal:
A Growing Need but Energy Intensive



Nutrient Removal 1996

1,300 Facilities

6,000 million gallons per day

1.5 MWh per MG additional

Nutrient Removal 2016

2,200 Facilities

15,000 million gallons per day

Energy Savings Needed

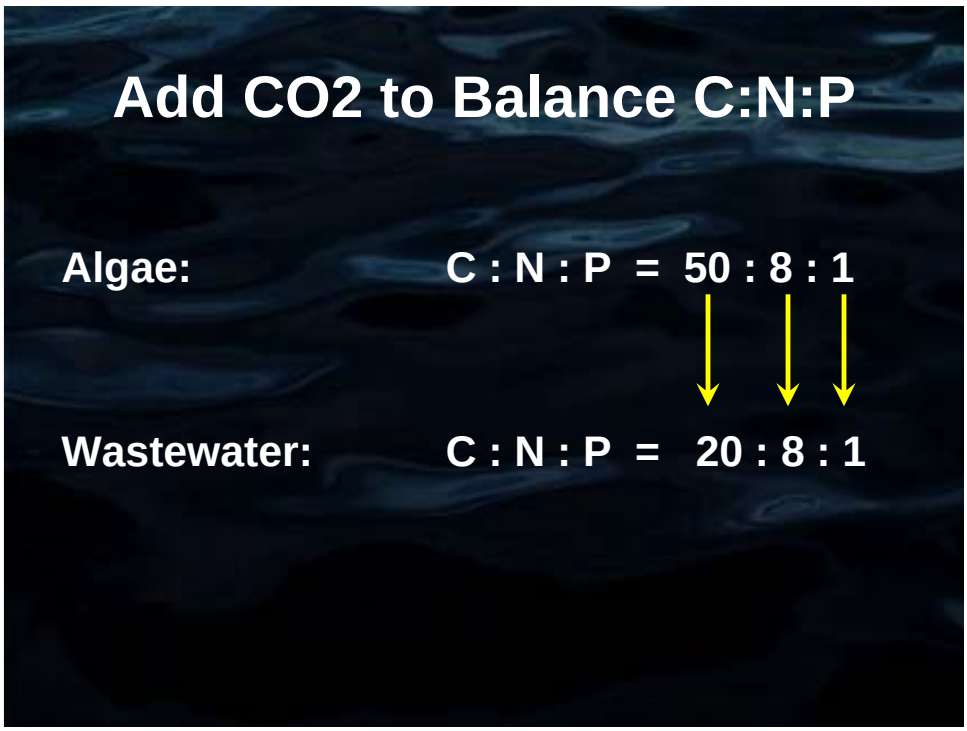
A New Approach

CO2-Enhanced Wastewater Ponds

Add CO2 to Balance C:N:P

Algae: C : N : P = 50 : 8 : 1

Wastewater: C : N : P = 20 : 8 : 1



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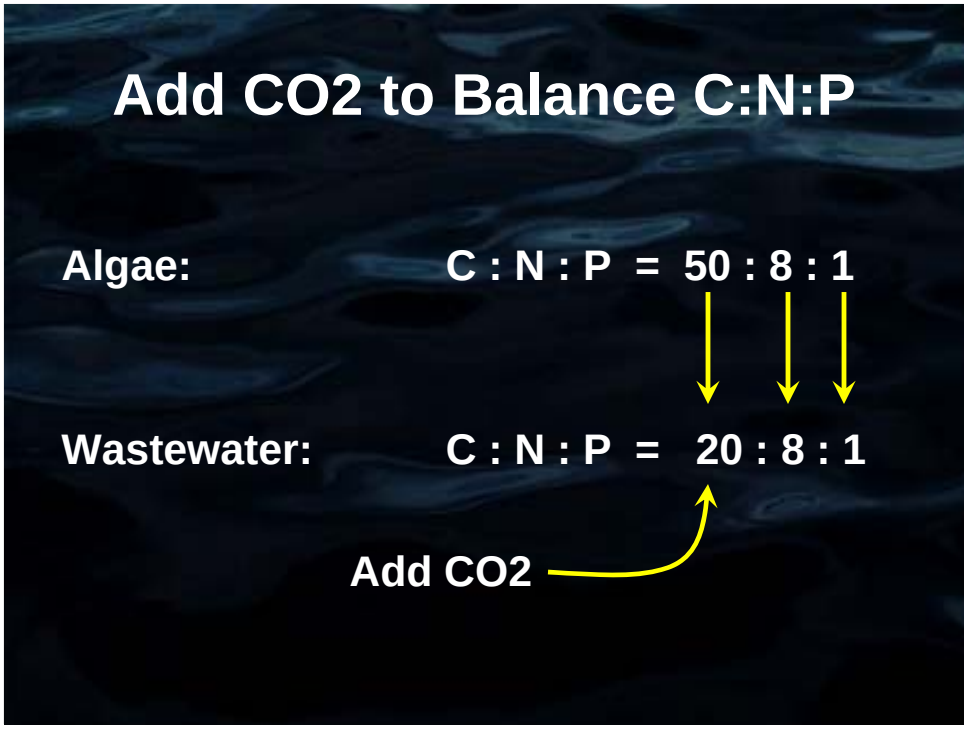


CO2-Enhanced High Rate Ponds

- Improved and accelerated treatment
- Biomass fuel provides greenhouse gas abatement
- WWT savings: ~$6 per gallon oil produced
  - Marginal oil cost is only extraction/processing
- Energy used in WW treatment decreases: 15 kWh saved per gallon oil produced
- Fuel production residual becomes fertilizer

CO2 Abatement & Offset Estimate per Volume Treated

- Biofuel Production (Methane)
  - 0.4 tons per MG
- Energy Efficiency
  - 1.2 tons per MG
- Fertilizer Manufacture Offset
  - 0.3 tons per MG
- **Total is potentially 1.9 tons per MG**

Microeconomic Potential

- Single 680-acre pond facility (existing)
- Current CH_4 emissions from algae decomposition: GhG equivalent of a ~2.8 MW natural gas power plant

With CO2 High Rate Ponds

- 18,000 metric tons algae per year (dry wt.)
- Methane electricity value: $2.5 million per year @8¢/kWh with co-digestion of high-C waste
- Or 800,000 gallons oil per year

Animal Wastes

Another source of

- Pollution
- Nutrients for algae production

Future Potential in California

- 25,000 acres of pond facilities
- Municipal and animal farm wastewaters

With CO_2 High Rate Ponds

- 660,000 metric tons algae per year (dry wt.)
- Methane electricity value: $117 million per year @10¢/kWh with co-digestion of high-C waste
- 30 million gallons oil per year

Cal Poly Research

- Lab & Pilot Plant
- N and P Removal with CO_2 Addition
- Bioflocculation & Sedimentation
  - Loading Factors
  - Low-N Stress

Pilot Plant for Sewage Treatment

Growth & Nutrient Removal Results

Day 5 of Batch Growth

CO2 Enhanced

600 mg/L VSS

<1 mg/L NH_4^+-N

<0.3 mg/L PO_4^{3+}-P

Air Sparged

130 mg/L VSS

25 mg/L NH_4^+-N

3 mg/L PO_4^{3+}-P

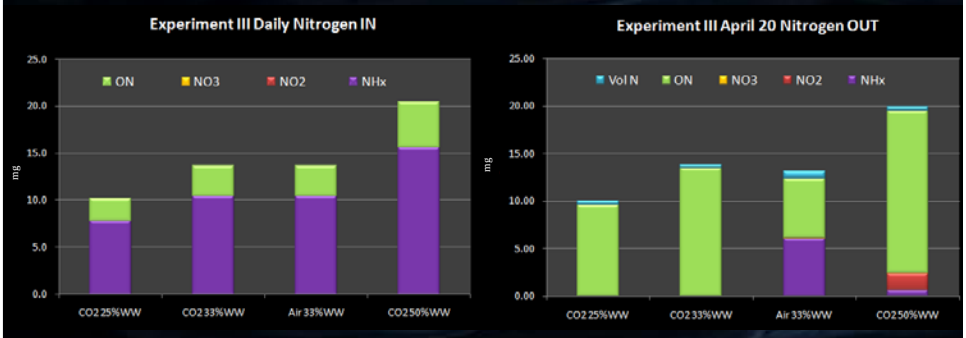
Semi-Continuous Cultures

Conditions Tested

Days	Sparging
4 Day HRT	CO_2
3 Day HRT	CO_2
3 Day HRT	Air
2 Day HRT	CO_2

Nitrogen Removal

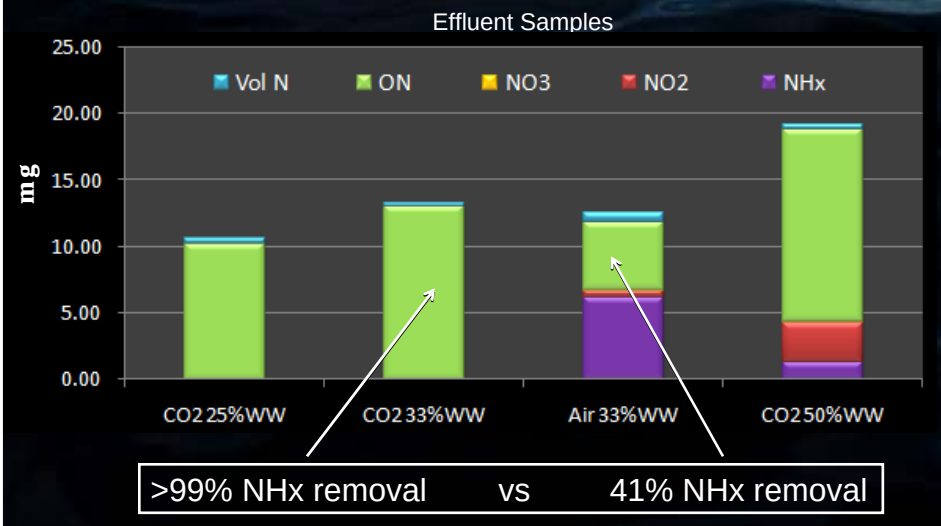
Nitrogen Balance



- Most ammonia is assimilated
- CO_2 improves removal
- Good recovery

Ammonia Removal

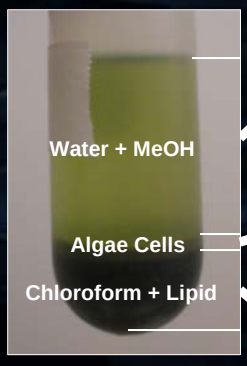
CO_2 Addition results in greater ammonia removal



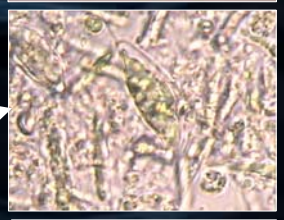
>99% NHx removal vs 41% NHx removal

Lipid Extractions

10-30% oil content



Water + MeOH 10x



Cell Layer 100x

Oil Layer 40x

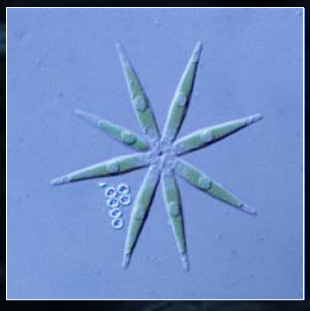
CO2-Enhanced Algae Cultures Research Results

- Low nutrient levels achieved
- Algae production accelerated
- Harvesting costs decrease due to bioflocculation
- Lipids produced
  - 30% lipid content, current maximum
  - 1500 gallons per acre per year (best est.)

Next Steps

CO2 addition at pilot scale

C:N:P ratio flexibility studies to improve range of applications



Full-scale demonstration

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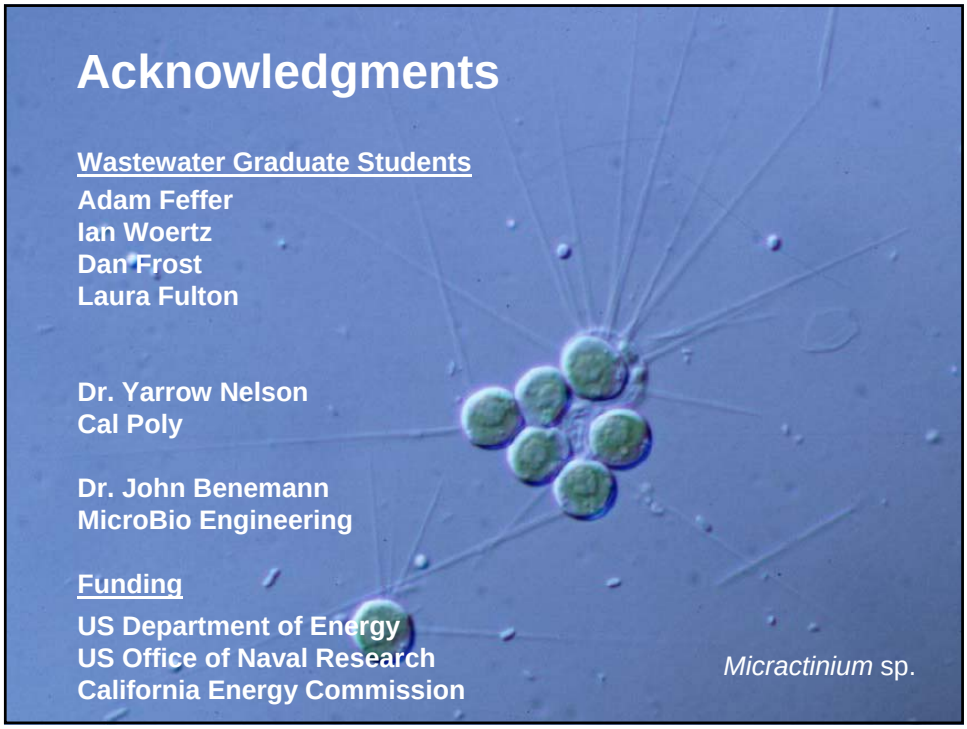

Micractinium sp.