Anaerobic digestion and Algae Farming: Energy and Nutrients for Small Farms

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Anaerobic digestion

- AD is the microbial degradation of organic material under anaerobic conditions
- Produces biogas as an energy source
- Nutrients remain in effluent as source of "biofertilizer"

On-farm feedstocks

- Manure
- Crop waste/culls
- Spoiled prepared food
- Diseased plants
- Carcasses
- Energy crops
- Bioethanol/biodiesel by-products

Uses of biogas

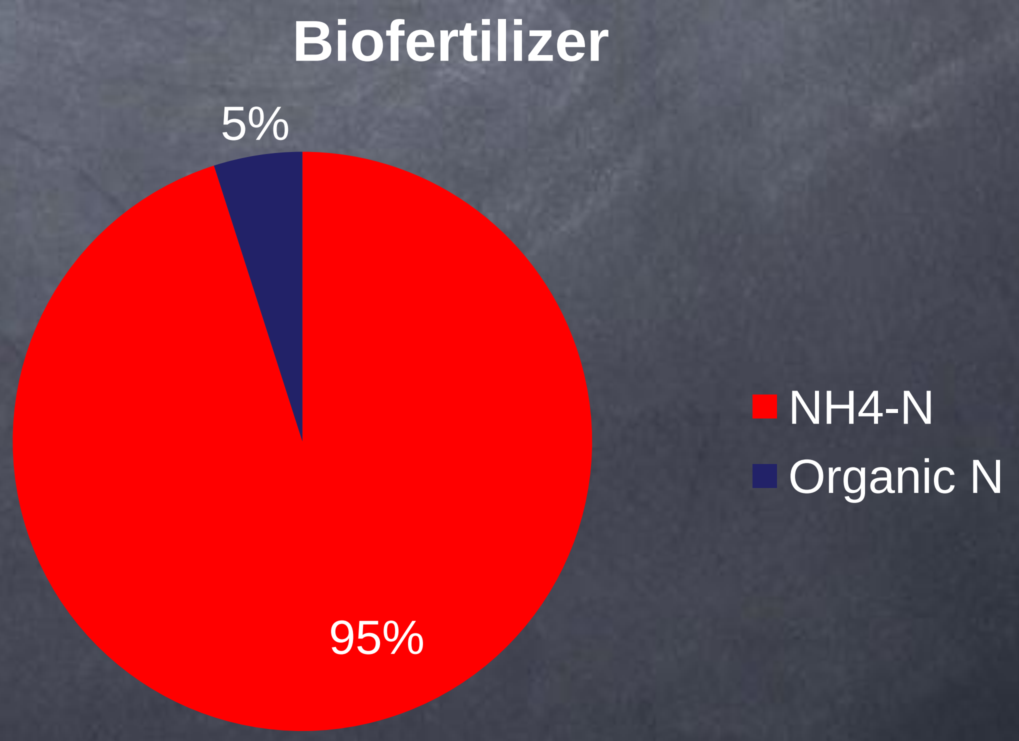
- Cooking
- Heating (water/air/greenhouse)
- Electricity
- Gas lighting
- Vehicle fuel





Biofertilizer- nitrogen form

- Organic nutrients are mineralized during digestion process
- Organically-derived replacement for synthetic chemical fertilizers



Integration with composting

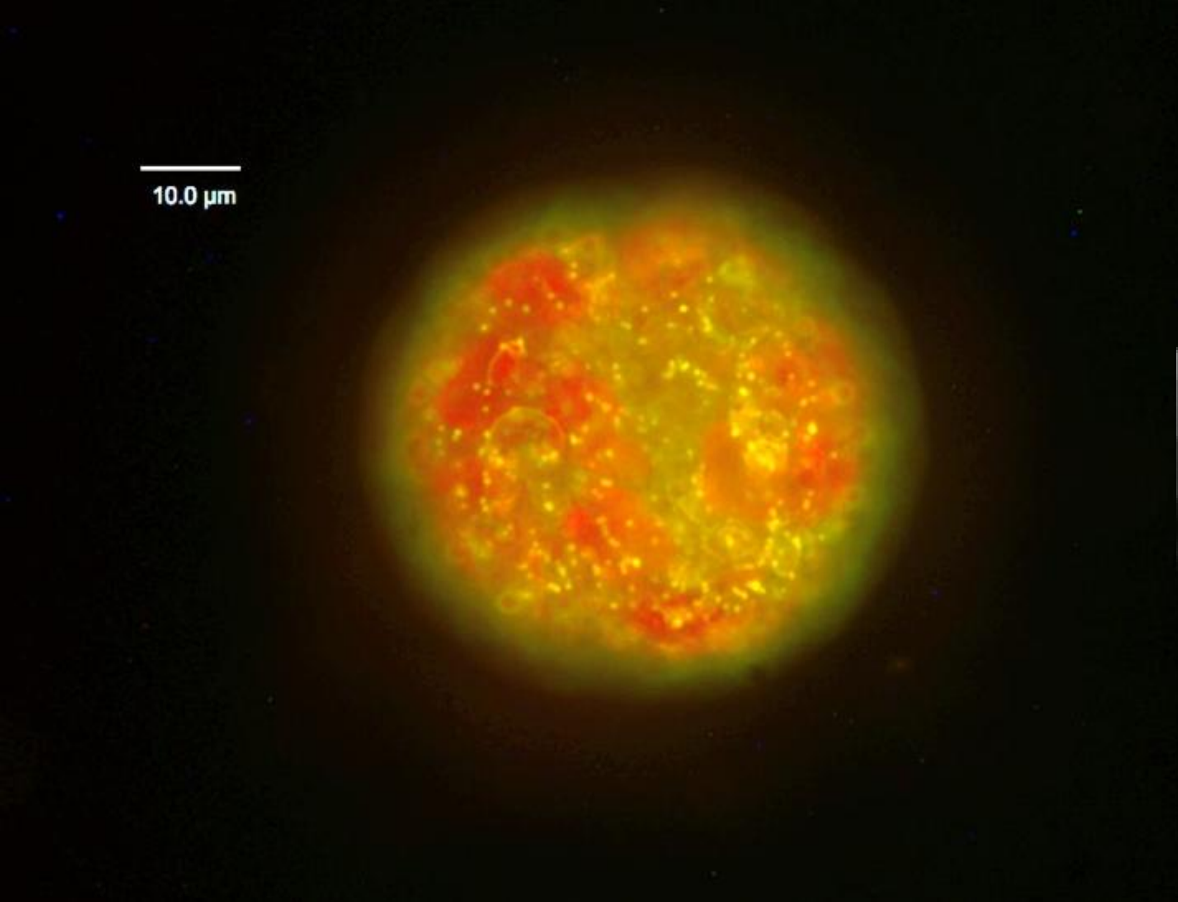
- Biofertilizer can be incorporated into existing composting systems
- Low C:N ratio of biofertilizer improves biodegradability of high carbon material (e.g. woody waste, paper)
- Helps return carbon to soil

Advantages of biofertilizer

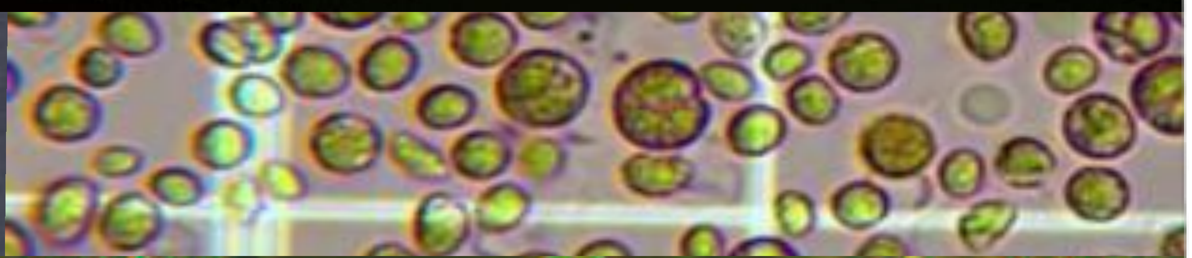
- Nutrients converted to plant-available form
- Can be injected into existing fertigation systems
- Avoids need for spreaders

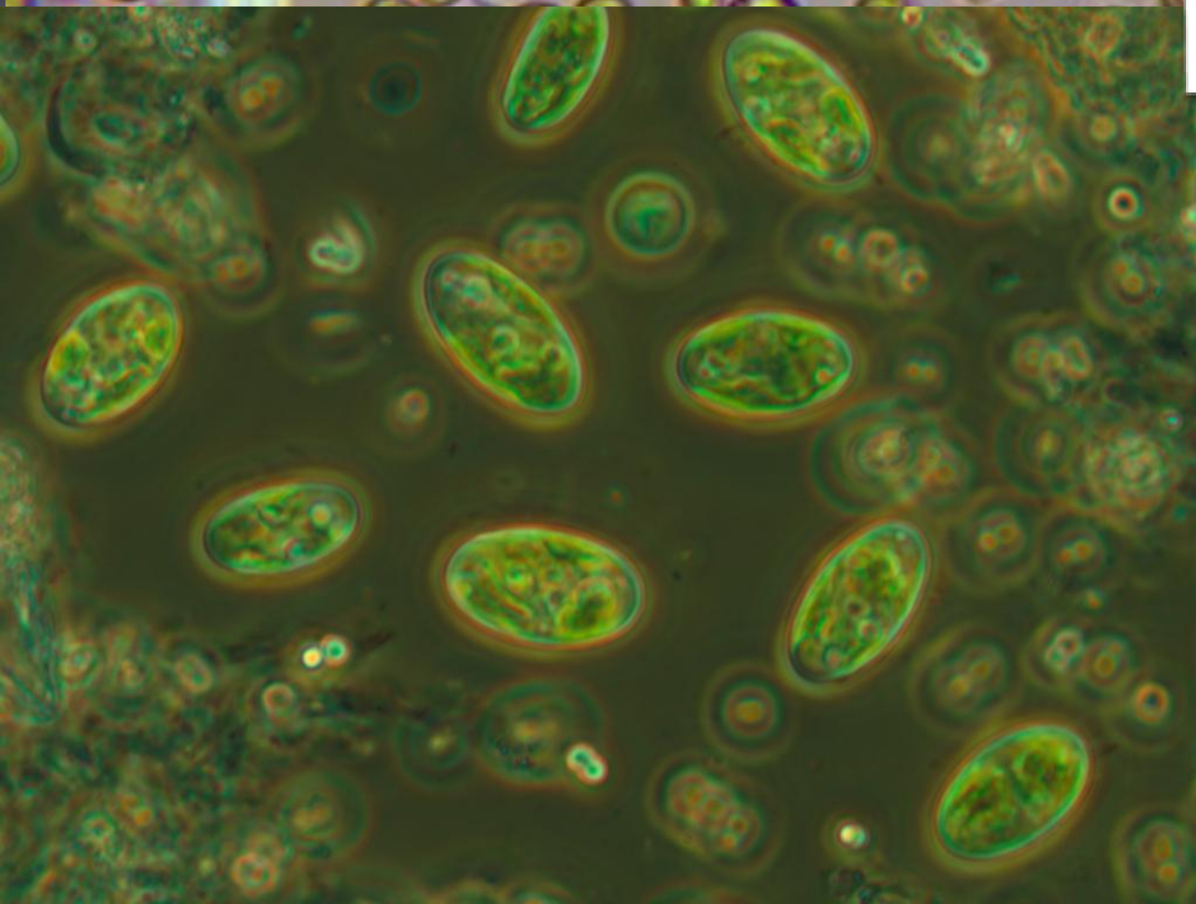
Advantages of biofertilizer

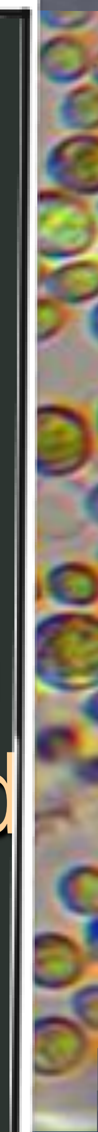
- Can be diluted to required concentrations
- Ideal for small farms implementing organic agriculture
- Facilitates urban agriculture
- Nutrients available for algal cultivation

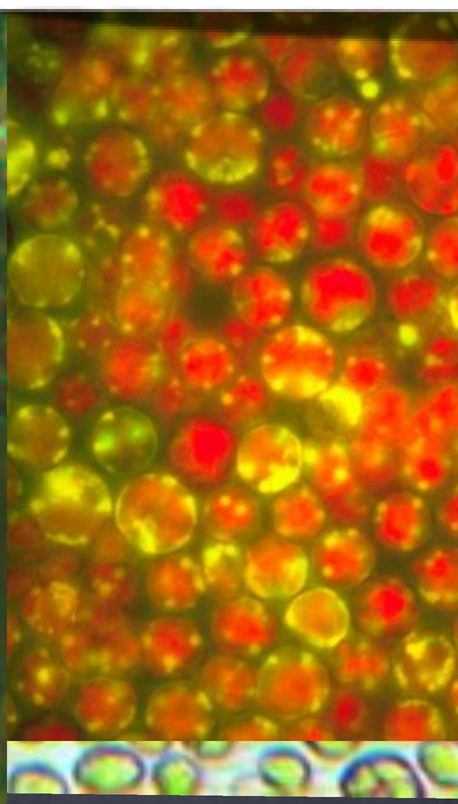


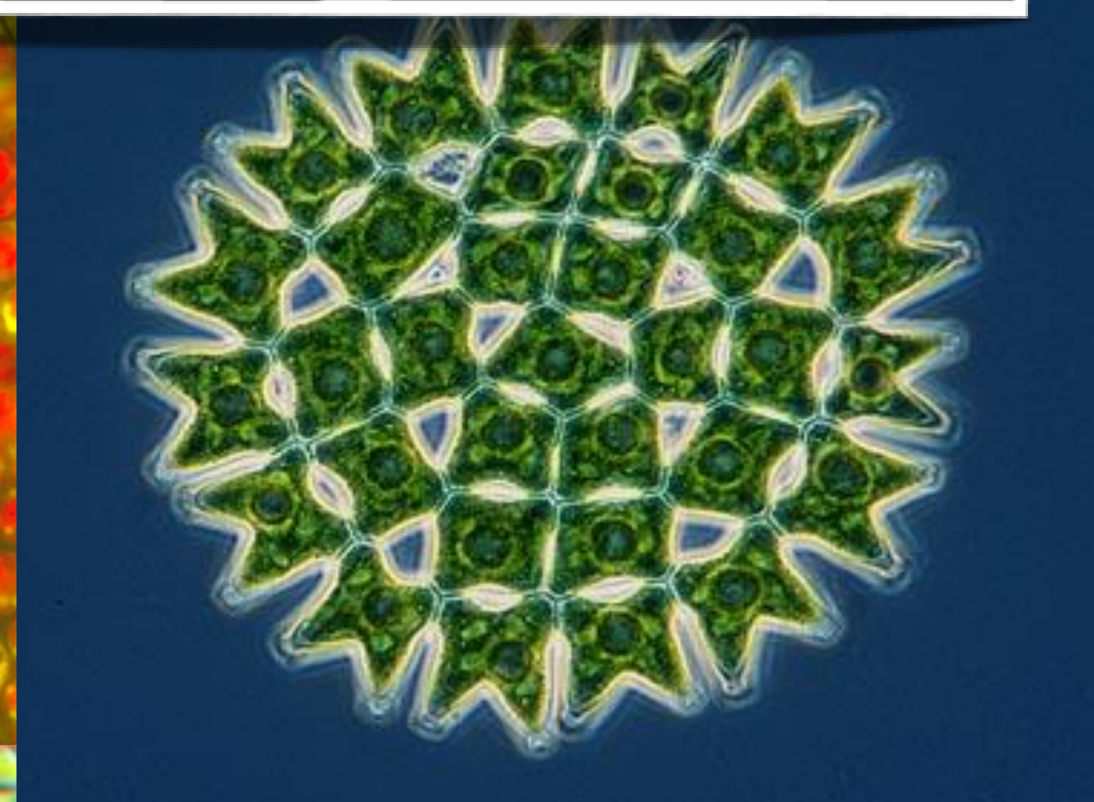
Algae : a catch-all phrase referring to any of the micro and macroscopic plants that lack true leaves, roots, and stems. Ranging in size from single-cells to giant kelps and including both prokaryotic and eukaryotic organisms.











The Botanical Diversity of Algae

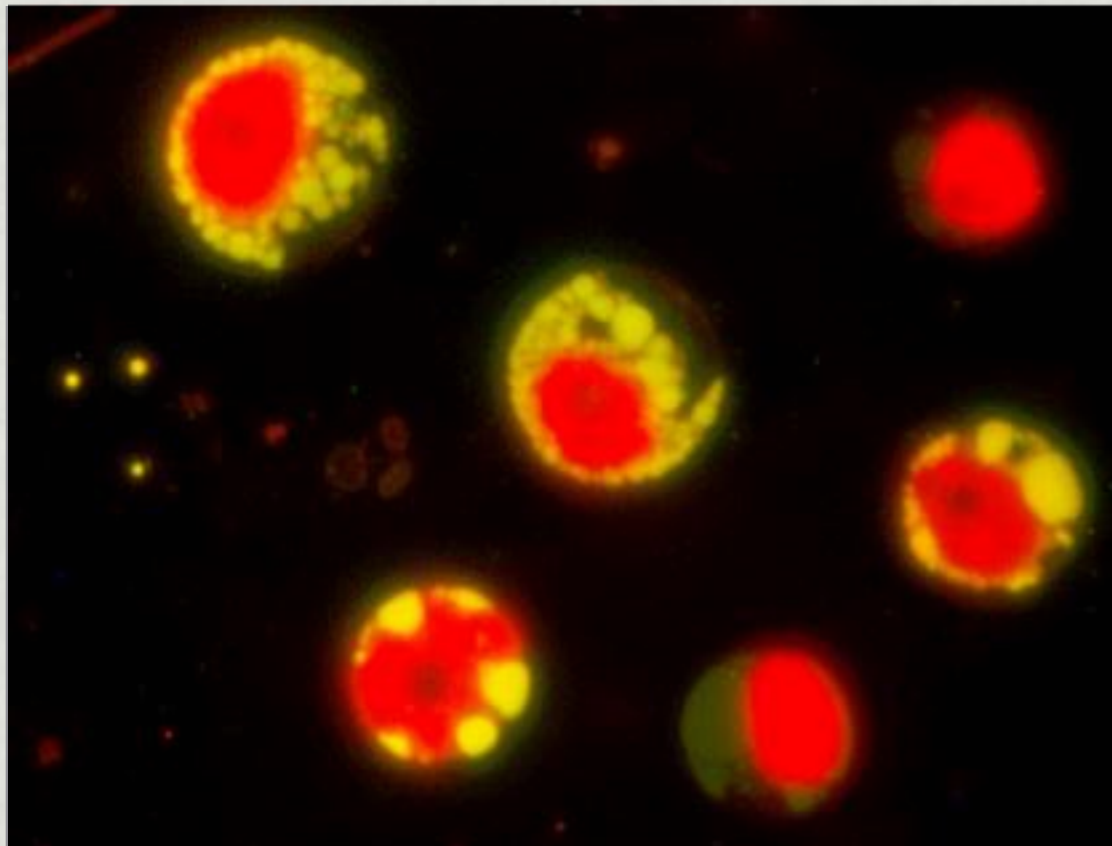
- Algae are a diverse polyphyletic group of organisms
  - 40,000 recognized species
  - 10,000,000 yet to be described (Andersen 1991)
- Nine major taxonomic Divisions (always changing)
- Ubiquitous, found on every continent and in every ocean.

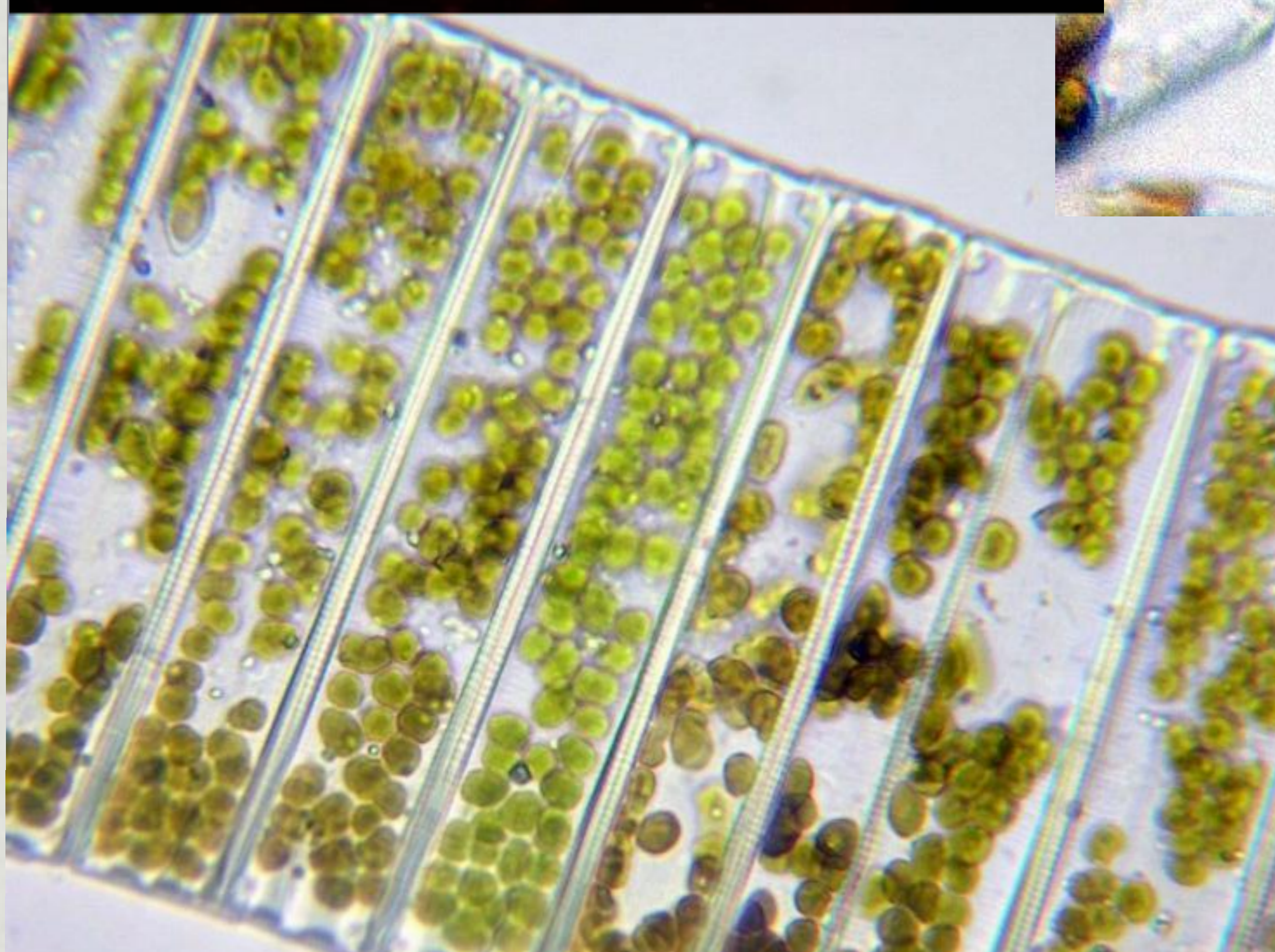
Why Algae?

- Algae produce lipids that can be used as a fuel!
    - Some algae can store up to 50% of their dry weight as oils
- Algae can be grown on non-arable land, where food crops simply cannot grow- rooftops, deserts, oceans, wastewater treatment plants, effluent lagoons, etc.

Photo: Tim Devarenne (Texas A&M)

Algal Lipids



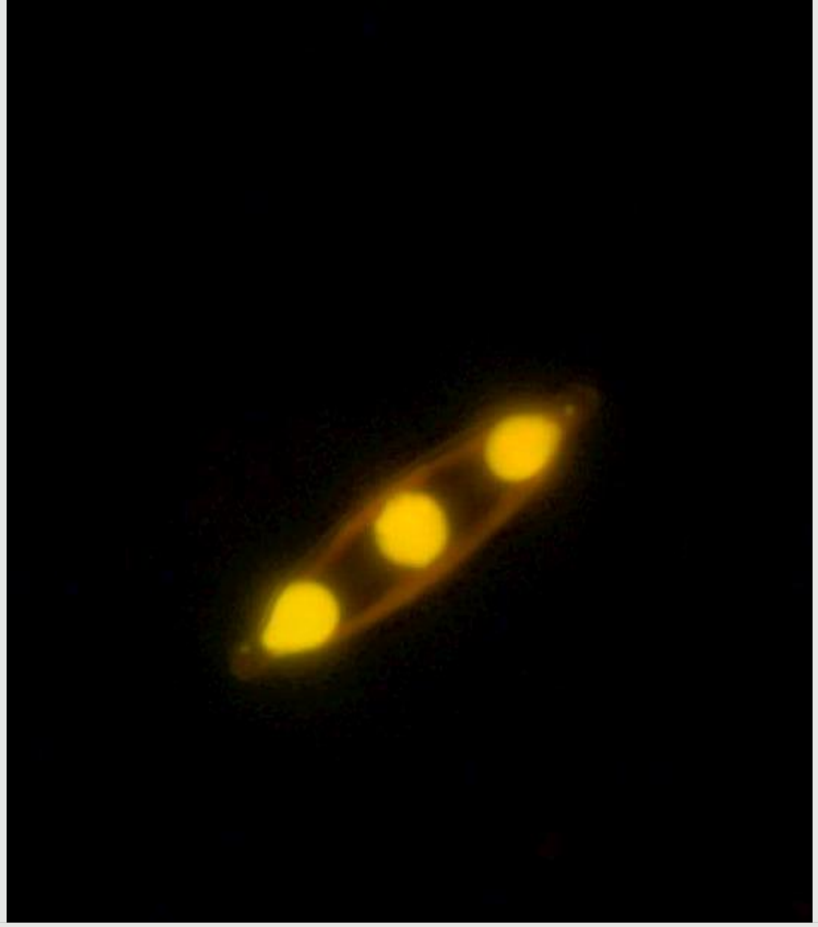


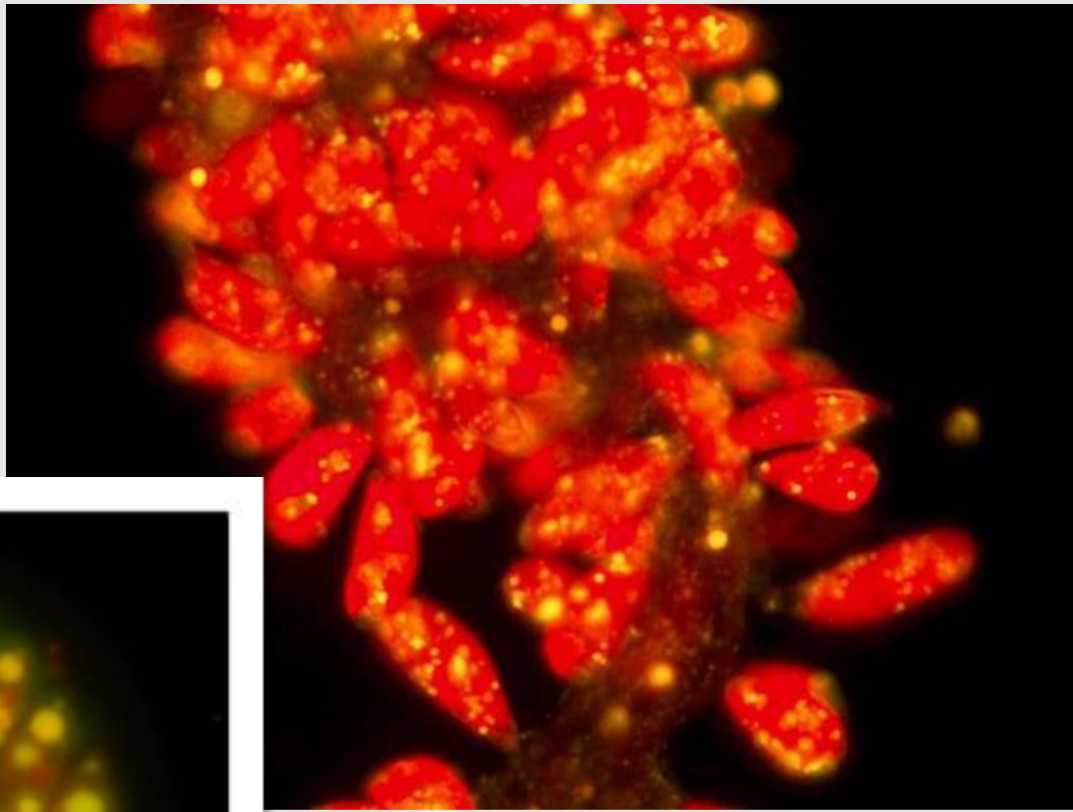
Phycoprospecting

- Crop Discovery!

- Utilizing the fluorescent stain Nile Red (9-diethylamino-5H-benzo[α]phenoxazine) for oil staining

- Local algae are collected and evaluated for the to store photosynthetic energy in energy-dense oils.





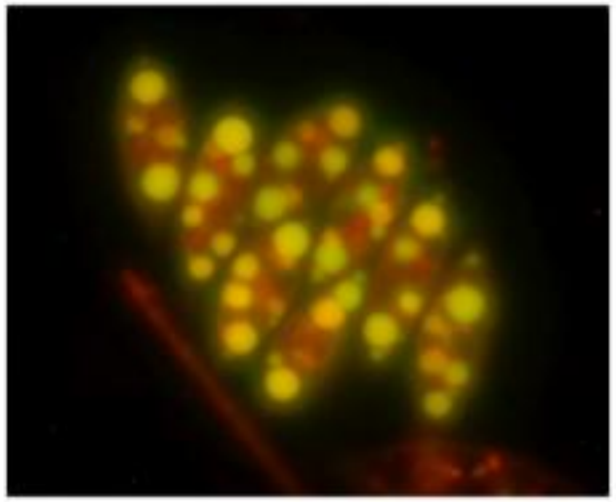


Table 1

Products synthesized by microalgae

Product	Microalgae	Price (USD)	Producer
β-Carotene	*Dunaliella*	300–3000/kg	AquaCarotene (Washington, USA) Cognis Nutrition & Health (Australia) Cyanotech (Hawaii, USA) Nikken Sohonsha Corporation (Japan) Tianjin Lantai Biotechnology (China) Parry Pharmaceuticals (India)
Astaxanthin	*Haematococcus*	10,000/kg	AlgaTechnologies (Israel) Bioreal (Hawaii, USA) Cyanotech (Hawaii, USA) Mera Pharmaceuticals (Hawaii, USA) Parry Pharmaceuticals (India)
Whole-cell dietary supplements	*Spirulina* *Chlorella* *Chlamydomonas*	50/kg	BlueBiotech International GmbH (Germany) Cyanotech (Hawaii, USA) Earthrise Nutritionals (California, USA) Phycotransgenics (Ohio, USA)
Whole-cell aquaculture feed	*Tetraselmis* *Nannochloropsis* *Isochrysis* *Nitzschia*	70/L	Aquatic Eco-Systems (Florida, USA) BlueBiotech International GmbH (Germany) Coastal BioMarine (Connecticut, USA) Reed Mariculture (California, USA)
Polyunsaturated fatty acids	*Crypthecodinium* *Schizochytrium*	60/g	BlueBiotech International GmbH (Germany) Spectra Stable Isotopes (Maryland, USA) Martek Biosciences (Maryland, USA)
Heavy isotope labeled metabolites	N/A	1000–20,000/g	Spectra Stable Isotopes (Maryland, USA)
Phycoerythrin (fluorescent label)	Red Algae Cyanobacteria	15/mg	BlueBiotech International GmbH (Germany) Cyanotech (Hawaii, USA)
Anticancer drugs	N/A	N/A	PharmaMar (Spain)
Pharmaceutical proteins	*Chlamydomonas*	N/A	Rincon Pharmaceuticals (California, USA)
Biofuels	*Botryococcus* *Chlamydomonas* *Chlorella* *Dunaliella* *Neochloris*	N/A	Cellana (Hawaii, USA) GreenFuel Technologies (Massachusetts, USA) LiveFuels, Inc. (California, USA) PetroAlgae (Florida, USA) Sapphire Energy (California, USA) Solazyme, Inc. (California, USA) Solix Biofuels (Colorado, USA)

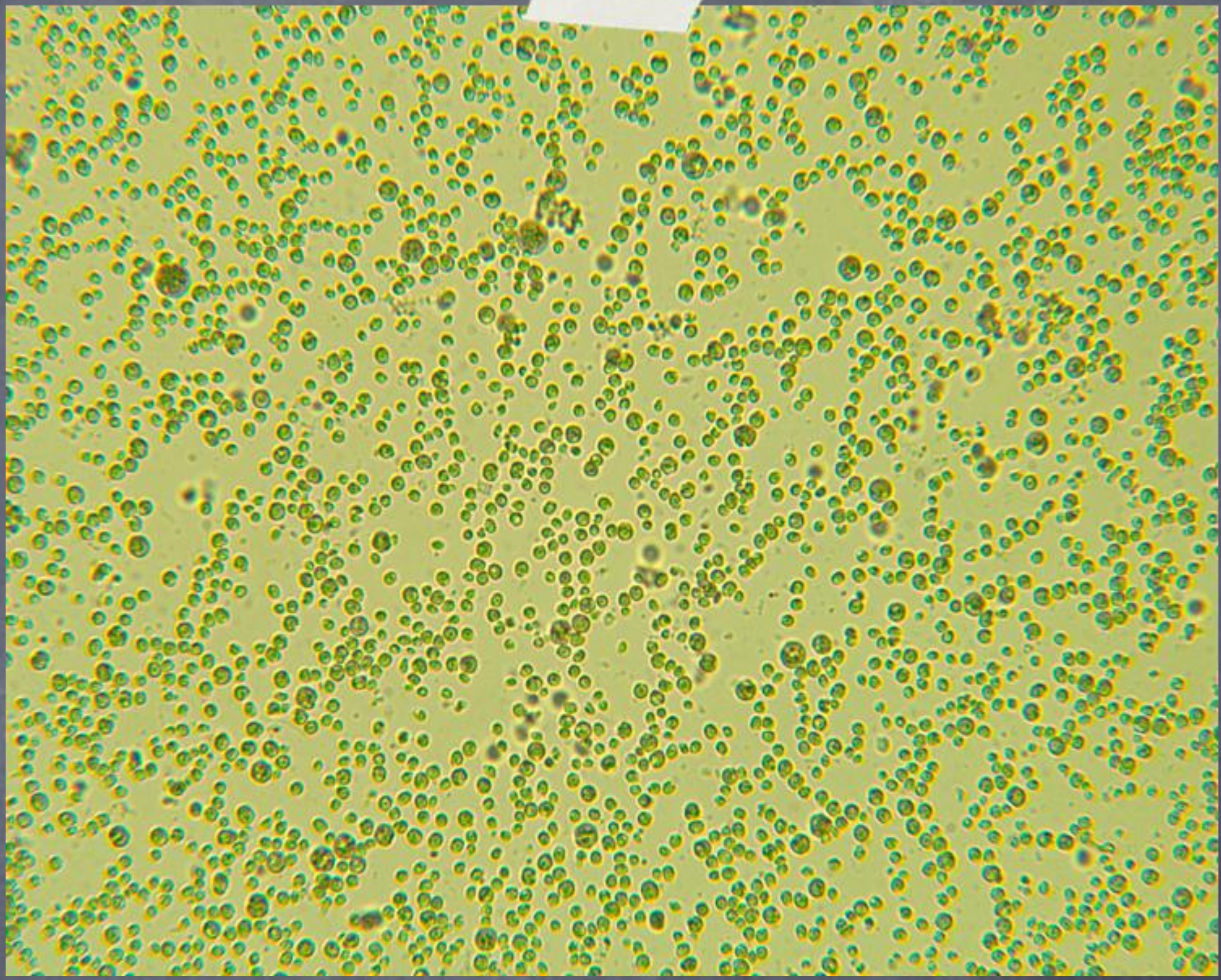
Over the years, algal biotechnology companies have brought a number of products to market, ranging from aquaculture feed to specialty chemicals. Currently, the development of pharmaceutical compounds and biofuels is a priority of the industry.

A green light for engineered algae: redirecting metabolism to fuel a biotechnology revolution

Julian N Rosenberg[1], George A Oyler[1], Loy Wilkinson[2] and Michael J Betenbaugh[1]

Abundant Growth

- Aquatic Advantage
  - Efficient ionic exchange
  - No complex support structures
- Cellular Multiplicity
  - Daily doublings
- Biomass Production Potential
  - Daily Biomass Harvesting



Strain	Genus	Family	Growth Rate (doublings·day^{-1})
OSCIL2	*Oscillatoria*	Cyanophyceae	**4.23**
OSCIL3	*Oscillatoria*	Cyanophyceae	**3.50**
AMPHO46	*Amphora*	Bacillariophyceae	**2.81**
NANNO13	*Nannochloris*	Chlorophyceae	**2.78**
CHLOR23	*Chlorella*	Chlorophyceae	**2.66**
SYNEC3	*Synechococcus*	Cyanophyceae	**2.51**

Adapted from: Sheehan J, Dunahay T, Benemann J, Roessler P (1998). A Look Back at the U.S. Department of Energy's Aquatic Species Program—Biodiesel from Algae. U.S. Department of Energy's Office of Fuels Development Prepared by: the National Renewable Energy Laboratory

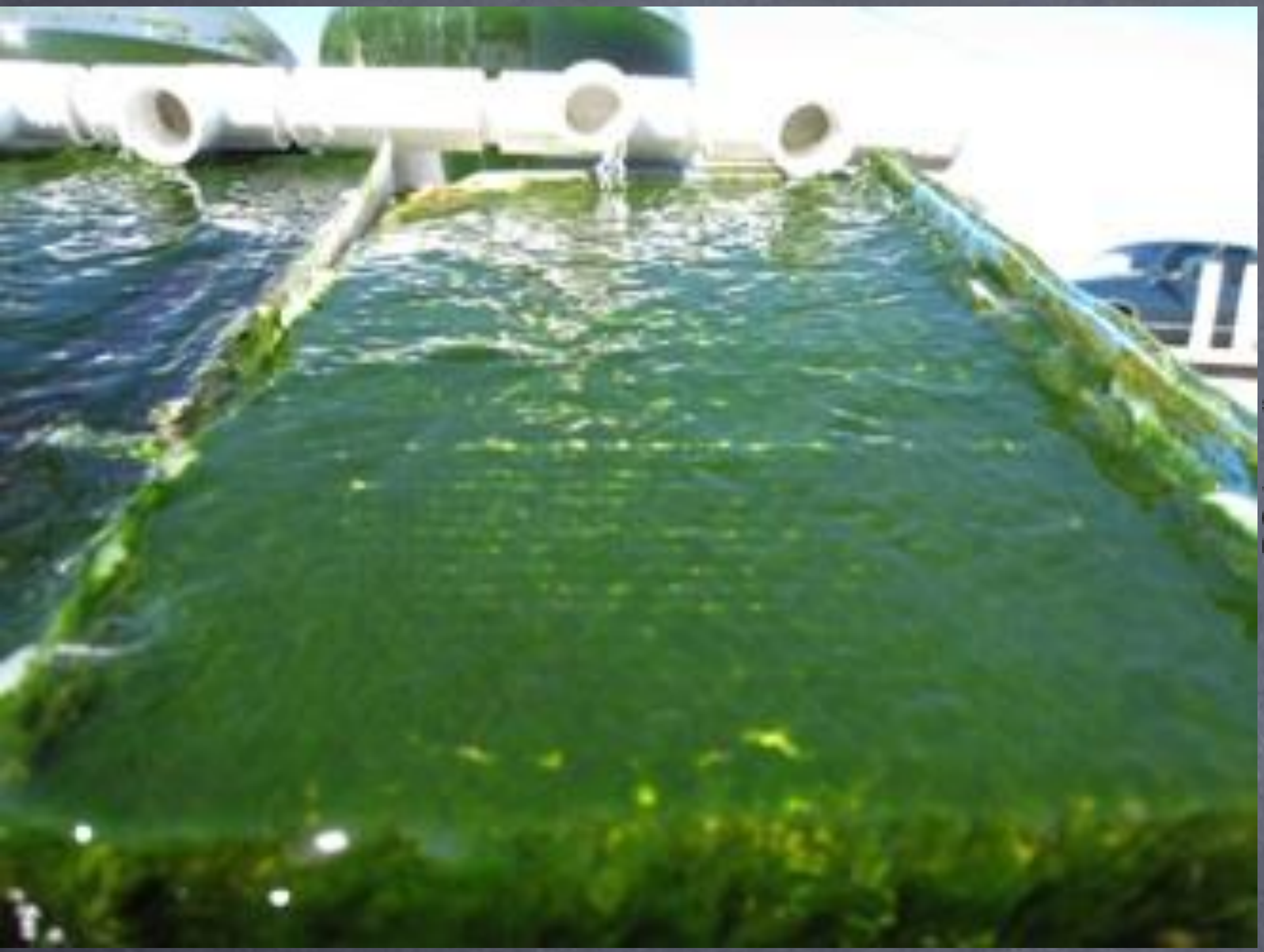
Energy Crop Comparison

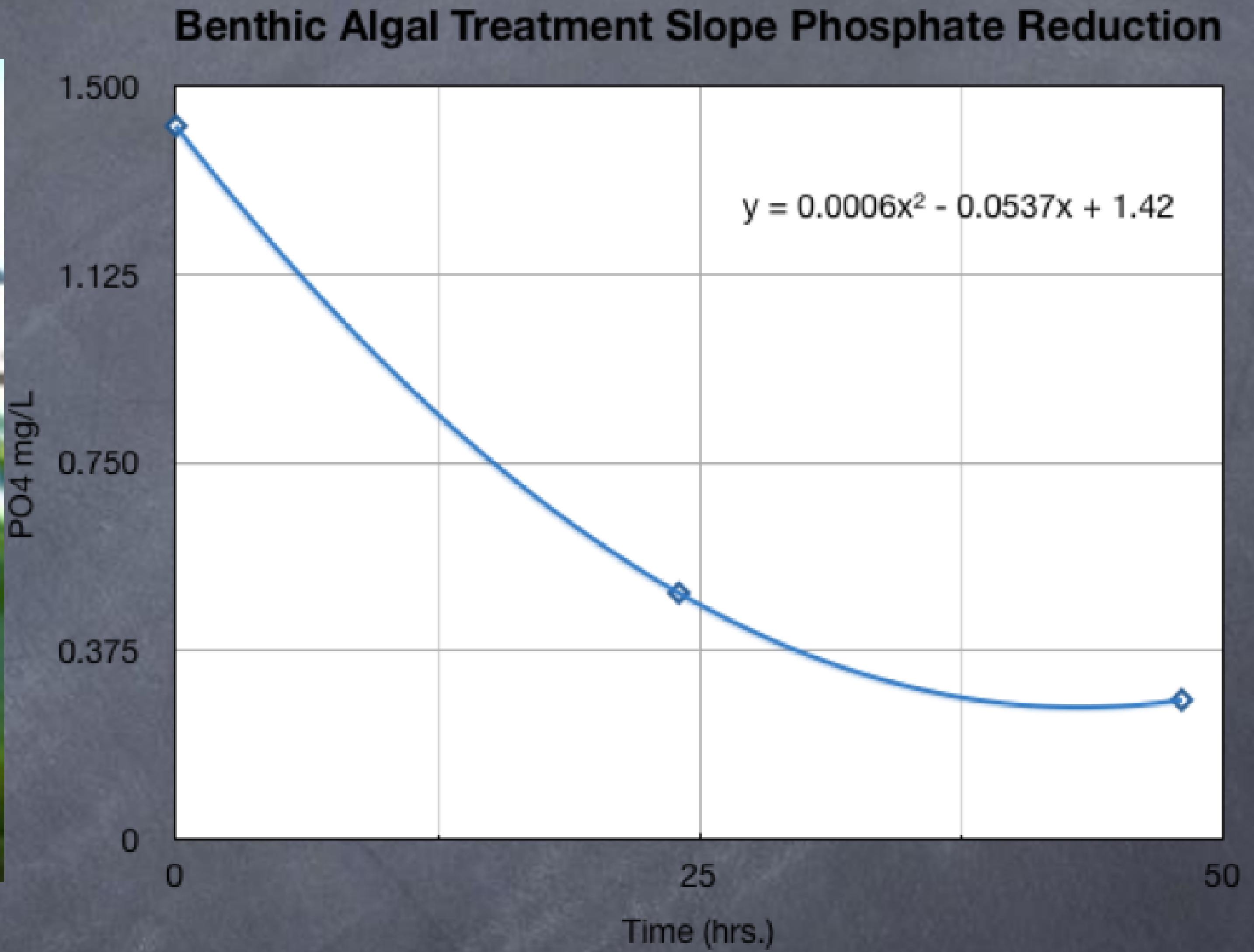
Energy Crop	Approx. Daily Biomass Production g/m2	Approx. Annual Biomass Production tons/acre
Maize grain (*Zea mays*) [1]	2.93	4.77
Grain *Sorghum* [1]	2.05	3.34
Soybean (*Glycine max*) [2]	0.797	1.29
Sugarcane (*Saccharum* sp.) [3]	13.5	22
Energycane (*Saccharum*) [3]	12.89	20.5
Elephant grass (*Miscanthus*) [3]	12.58	21
Sweet *Sorghum* [4]	7.98	13
Erianthus [4]	36.85	60
***Stigeoglonium* spp.** [5]	42.4	69 (estimated)
1) Mason, S.C. et *al.* 2008.		
2) Egli, D.B. 2008.		
3) Prine, G.M. et *al.* 1990		
4) Mislevy, P. et *al.* 1989		
5) Preliminary results		

Algae can utilize wastes

- Algae have been used successfully to treat N and P excess of sewage/manure wastes generated by animals and human activities (Nurdogan and Oswald 1995, Lincoln *et al.* 1996, Wilkie and Mulbury 2002).
- Algae can significantly reduce farm waste environmental impacts, while creating useful products.

Preliminary findings





Benthic algal treatment slopes using a cultivated algal polyculture

SWANKY Farm Refinery