Farming Algal Fuel

An Aquaculture Production Perspective

"Growing Fuel"

National Geographic
October 2007

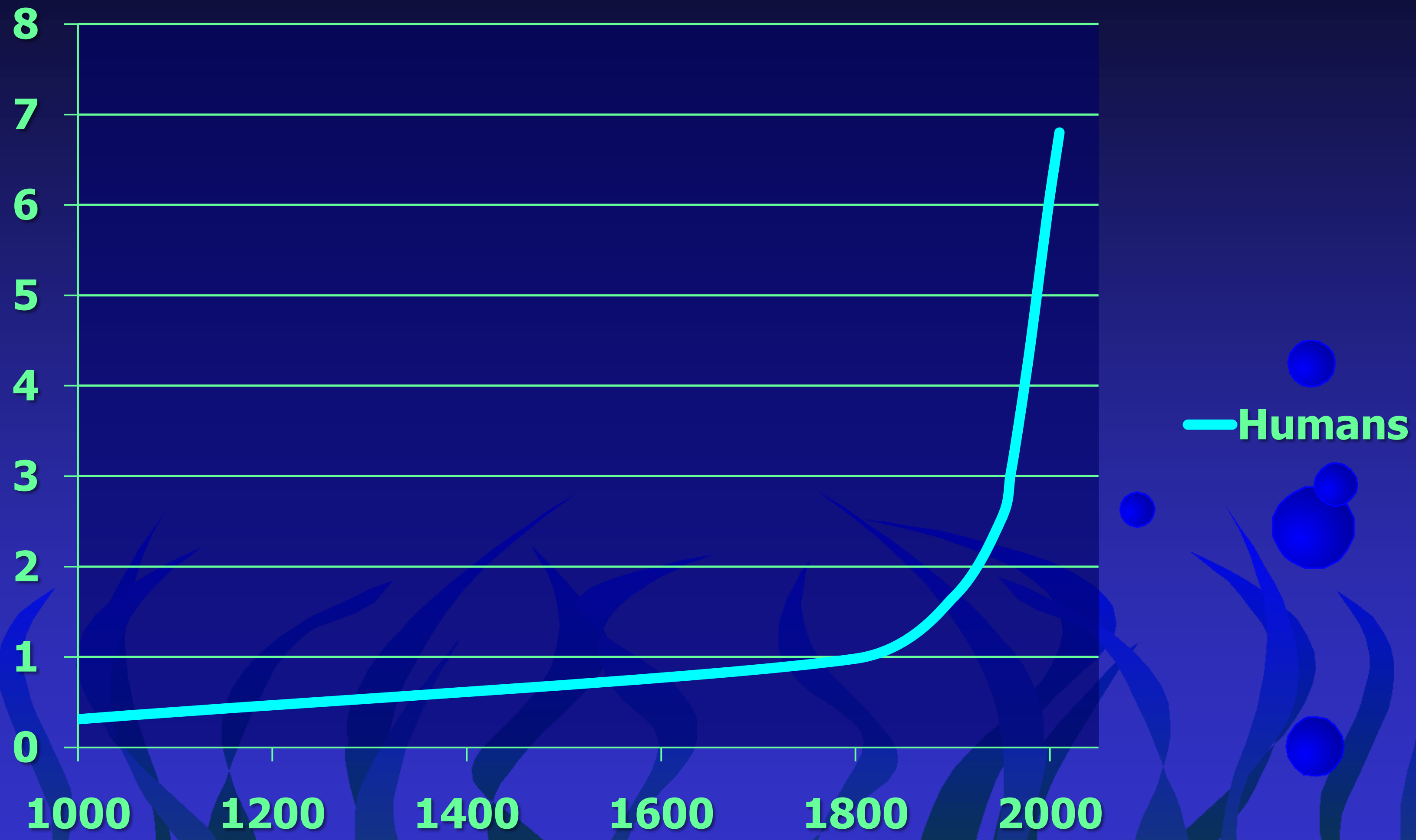
Why?
Fuel ≥ $4.00/gal

Exponential Increases

- Population: from 3 to 6.8 billion (1960-2010)
- Fossil fuel consumption

World Population Estimates

(in billions, 1000-2010 AD)



UN (1999)

http://www.census.gov/ipc/www/idb/worldpopinfo.php (2010)

U.S. Energy Shortage

- Declining world oil reserves
- US dependence on Foreign Oil
- Limited US oil reserves
- Concerns about global CO_2

Oil Reserves & Global Consumption

- **Proved World Reserves = 1.1-1.3 trillion barrels** *(DOE, 2007 & 2009)*
- **Global Oil Consumption = 85 million barrels/day** *(DOE, 2006)*
- **Proved US Oil Reserves = 21 billion barrels** *(DOE, 2007)*
- **US Oil Consumption = 7.55 billion barrels/year** *(DOE, 2006 & 2007)*

Duration of Oil Reserves

- Proved World Reserves = 1.2 trillion barrels
- Global Oil Consumption = 85 million barrels/day
- Proved World Supply = ~ 36 years (beginning in 2009)

Algal Fuel Not Currently a "Commercial" Reality

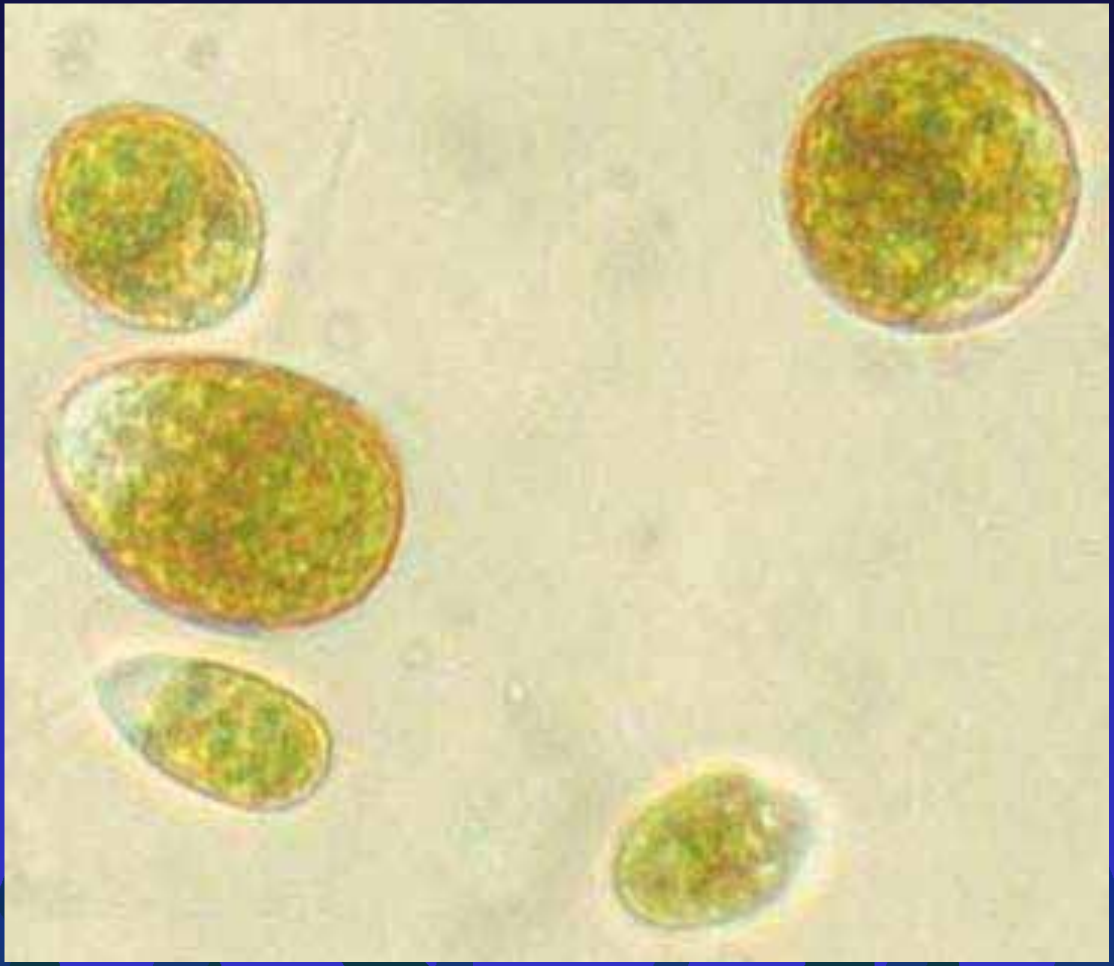
Current Production

- Nutrition/nutraceuticals
- Estimated 10,000 tons/year (photosynthetically)
- *Spirulina, Chlorella, Dunaliela, Haematococcus*
- Half in China
- Remainder in Japan, Taiwan, USA, Australia & India

Spirulina (A. platensis)

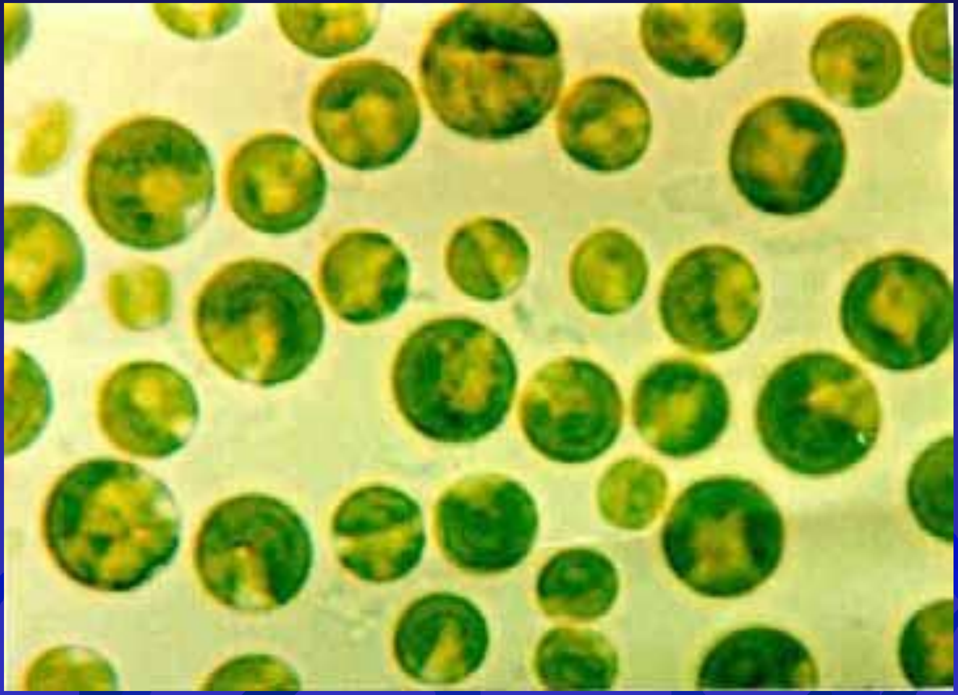
Benemann, John. 2009

Dunaliela salina



Benemann, John. 2009

Chlorella vulgaris



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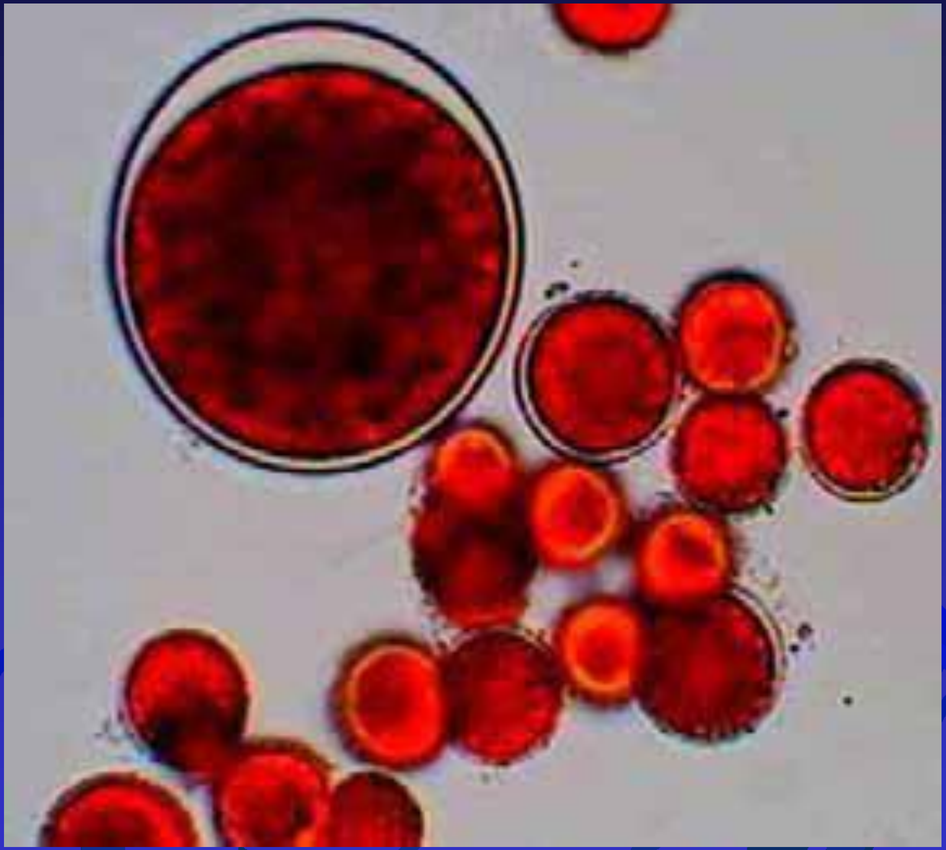
Haematococcus pluvialis



Benemann, John. 2009

Other Production

- As live aquaculture feeds (shrimp, bivalves, rotifers, etc.)
- Dark fermentation: starch & sugar vs. light (Martek omega-3 lipids, KY)

Production Systems

- Photobioreactors – small scale & more prevalent (academic & government labs)
- Ponds – large scale (98%)

NREL Photobioreactor System

Spherical Photobioreactors

Benemann, John. 2009

Tubular Photobioreactors

Benemann, John. 2009

Aquatic Species Program
NREL, Artist's Rendition (1987)

Paddlewheel Raceways/Ponds

Raceway & Circular Ponds




Benemann, John. 2009

Dunaliella Ponds
Australia

Benemann, John. 2009

Fuels from Algae

- Hydrogen -- no plausible commercial method demonstrated
- Methane -- wastewater treatment
- Oil/biodiesel -- triglycerides/lipids
- Ethanol -- starch/sugar

Algal Strain Selection

- * High lipid/oil content
- * Maximum biomass/productivity
- * Ease of harvest
- monoculture - resist contamination
- Tolerate environment (local conditions, water quality, high O_2 & temp, etc.)

Basic Resources Needed

- Available water
- Suitable pond topography (flat)
- Clay soil
- Source of CO_2 enrichment

Production

- Starter cultures (1-2% biomass) in photobioreactors
- Starter to seed intermediate pond/raceway, or
- Large ponds (one to many hectares)

Harvest

- 20-40% of volume daily
- Concentrate approx. 30-fold
- Must be low cost
- Remove from water column ("bio-flocculation" – clumping) with minimal chemicals

Oil Removal

- Cell disruption to extract
- Solvents
- Mechanical Separation
- Further processing

Problems

- Single cell starter – genetic drift
- Maintaining oil content
- Invasive algal species (esp. ponds)
- Grazers -- fungii, protozoa, rotifers, zooplankton

Advantages

- Algal generation times (hr-d)
- Terrestrial plants (mo-yr)
- More amenable to selection/GMOs
- Use soybeans and corn for food

CO_2 Removal/Abatement

- Combine with power plants
- Flue CO_2 removal
- 5000-6000 acres of ponds for 500-megawatt power plant
- Energy in vs. CO_2 removed (& energy out)

Economics

- Need low capital & operating costs
- Spirulina costs: $5K/ton
- Equivalent for 25% oil: $20K/ton
- 20-30 x higher than vegetable oil

Systems Costs

- Large scale systems costly (resources and infrastructure)
- Availability of resources – e.g. free source of CO_2
- Overall open pond costs $\geq$ \$40K/ac
- Univ. of KY researchers estimate \$18-\$30/gal oil -- before processing
- Photobioreactors too costly: like RAS (recirculating systems)

Estimated Production

- 25% useable triglycerides
- Overall open pond costs $\geq$ \$40K/ac
- Annual yield = 1.5 K gal/ac
- Fuel @ \$4.00/gal won't cover costs (capital, operating, et. al.)

Terrestrial Biofuels

- Ethanol – sugars/starch
- Bio-diesel – oils/triglycerides
- Higher plants more cost effective @ $100/barrel for crude oil

R&D Challenges

- Greater biomass
- Higher oil content
- Fast growth
- Better methods for concentrating and harvesting
- Cost effective systems

Environmental Limits

- Water
- Light
- CO_2
- pH swings/nutrients
- Temperature

Wastewater Pond
(oxidation)

Benemann, John. 2009

Combined Objectives

- Wastewater treatment/mgt
- Bio-fuel production
- By-product harvest (e.g. feed additives)

Potential vs. Reality

- Can we put a human on the moon? … Yes.
- But, how much does it cost?
- Business common sense: final product value must exceed cost.

References

- Benemann, John. 2009. Algae biofuels -- a brief introduction. jbenemann@aol.com
- Sheehan et. al. 1998. U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae; Close-Out Report. 325 pp.; NREL Report No. TP-580-24190 http://www.nrel.gov/docs/legosti/fy98/24190.pdf
- http://www.spe.org/spe-site/spe/spe/industry/reserves/GlossaryPetroleumReserves-ResourcesDefinitions_2005.pdf
- US Department of Energy (DOE):
- http://www.eia.doe.gov/emeu/international/reserves.html
- http://www.eia.doe.gov/basics/quickoil.html
- http://tonto.eia.doe.gov/dnav/pet/pet_cons_psup_dc_nus_mbbl_a.htm

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On-Line Literature & Slide Shows

www.ca.uky.edu/wkrec/Wurtspage.htm