Biofuel Production from Microalgae: A Viable Alternative?

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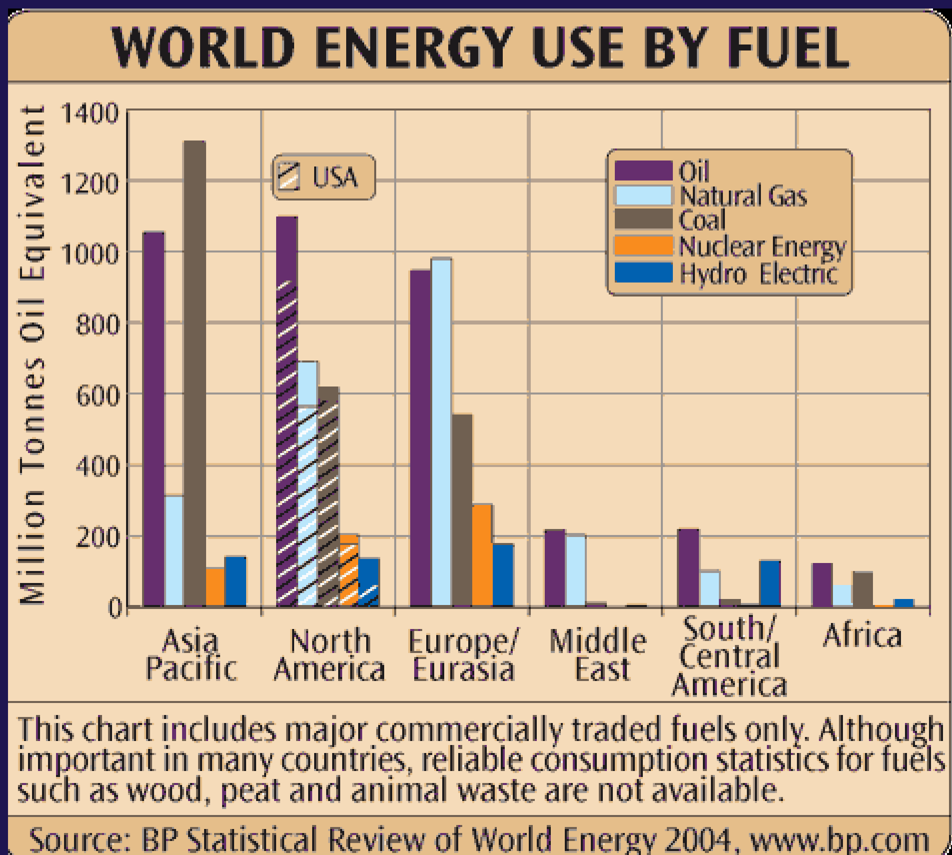
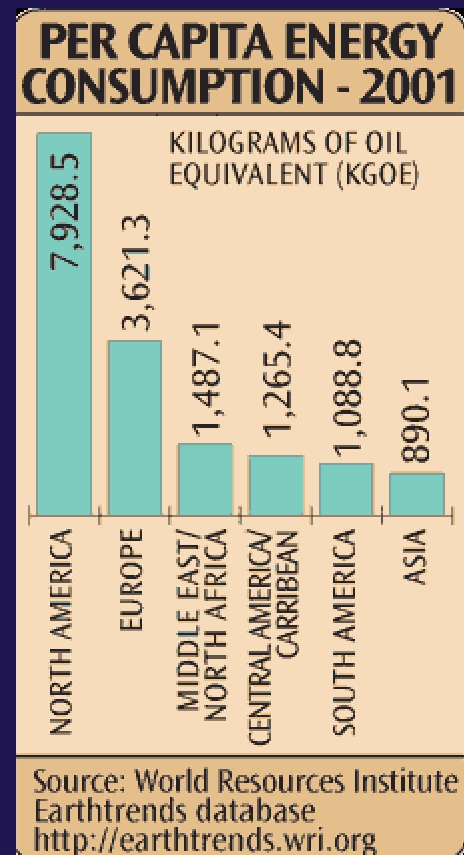
Current Petroleum Dependence

US has 1.6% of the world's oil reserves

US utilizes 24% of the world's production

Energy Consumption





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Current Petroleum Dependence Ohio

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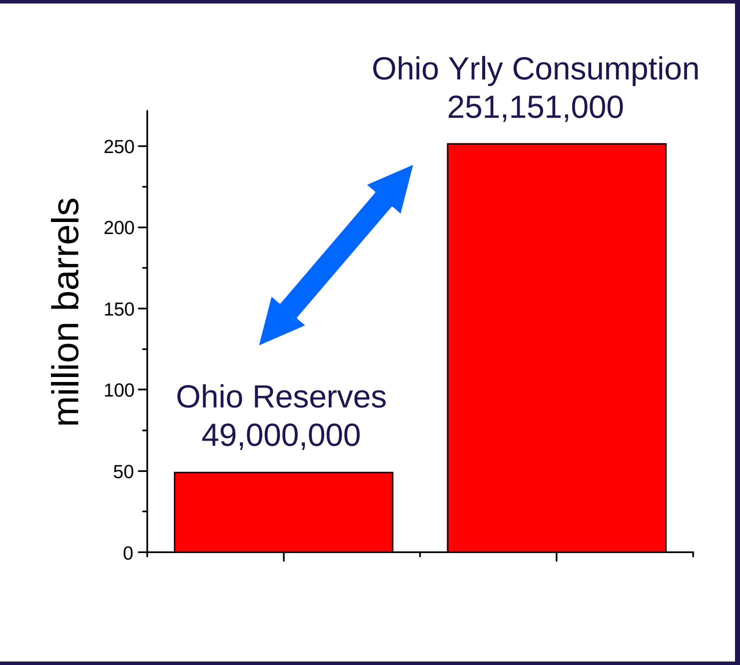


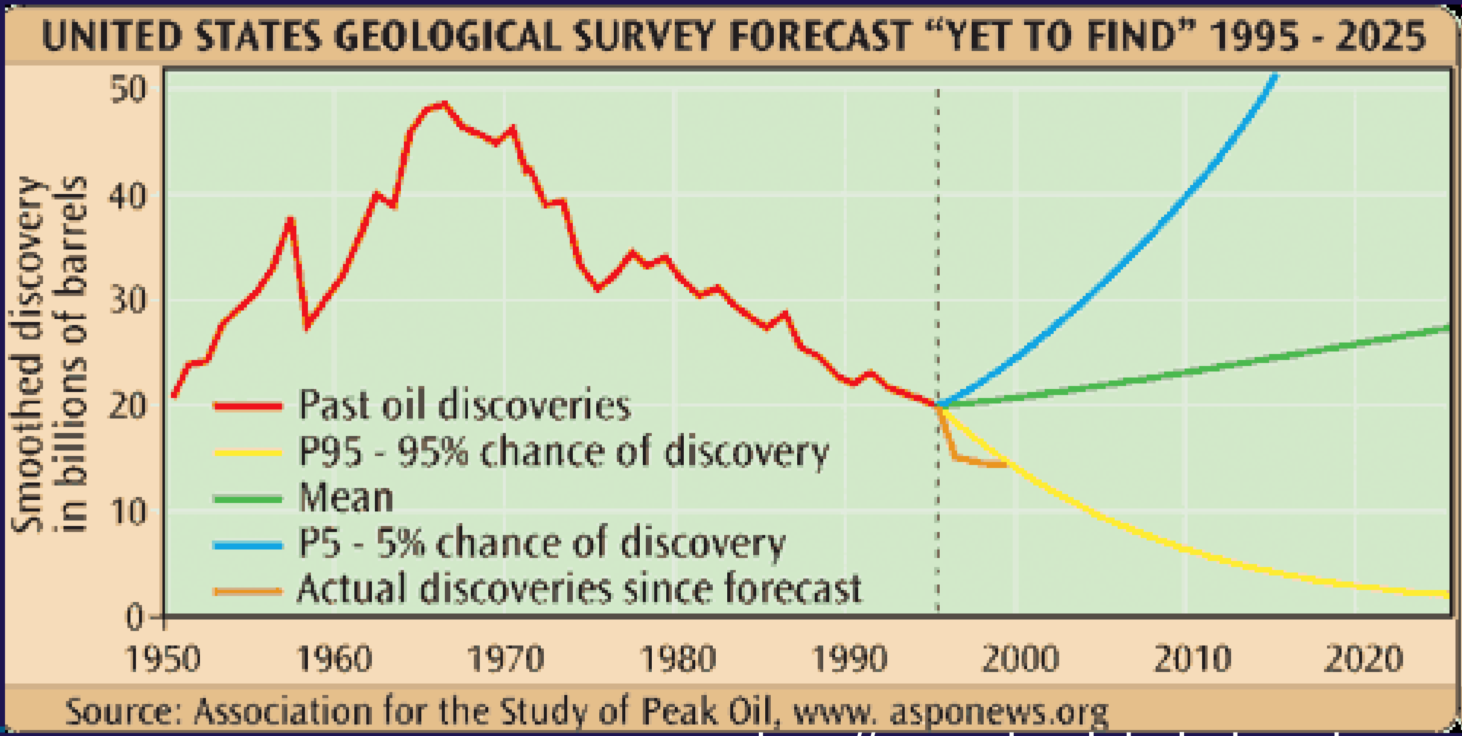
Oil Reserve Discover vs. Consumption

- Peak year for oil discover was in 1930
- By 1995 >80% of current oil reserves was discovered prior to 1973

"The rig count over the last 12 years has reached bottom. This is not because of low oil price. The oil companies are not going to keep rigs employed to drill dry holes" (Goldman Sachs – August 1999)

Oil Reserve Discovery vs. Consumption

Economic development and prosperity was built on cheap and abundance oil-based energy



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The Costs of Energy Consumption: Greenhouse Gas Emissions

- US has >400 coal-fired power plants
- Coal plants emit additional toxins: *vanadium, barium, zinc, lead, chromium, arsenic, nickel, hydrogen fluoride, hydrochloric acid, ammonia, selenium*
- ½ of all Americans live within 30 miles of a coal-burning plant

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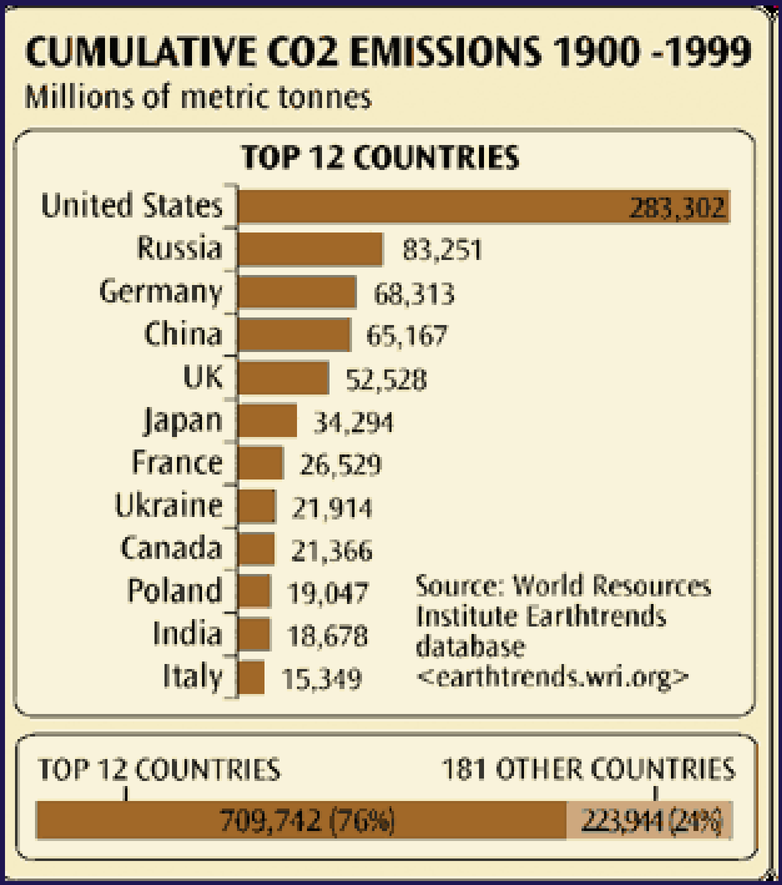

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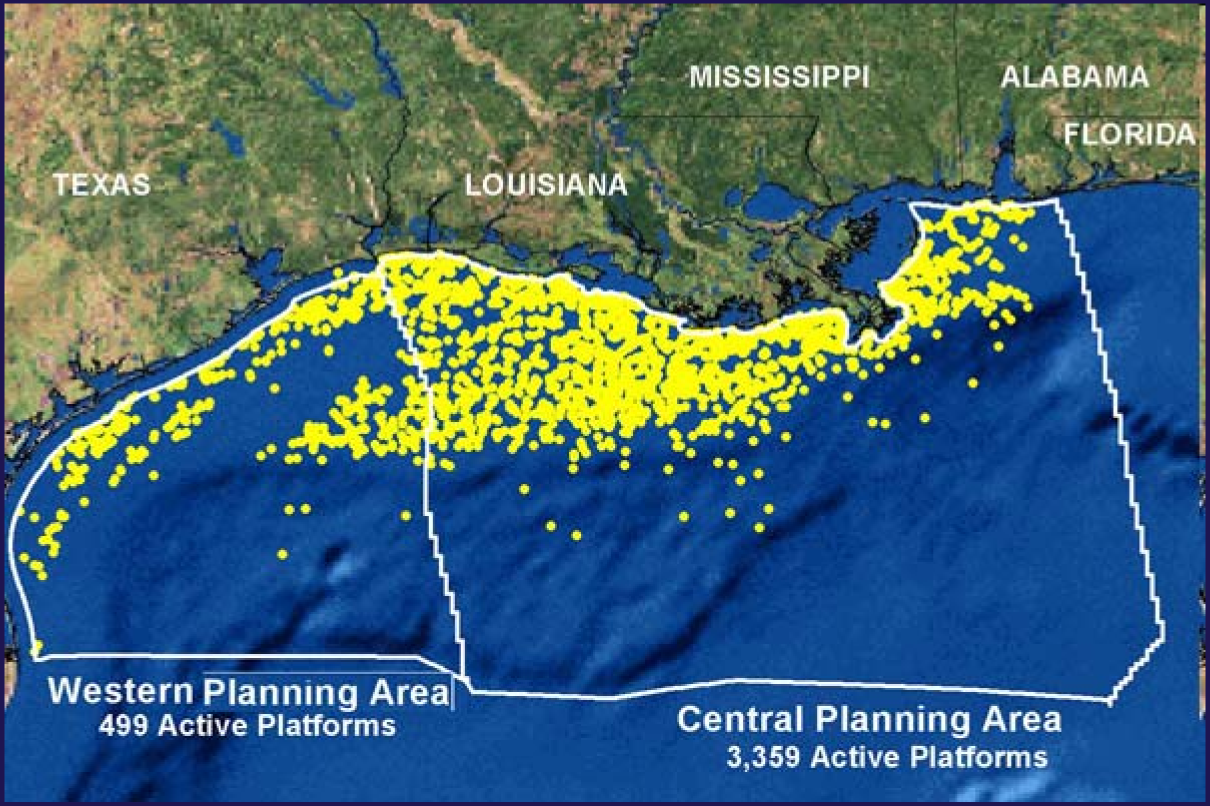
The Costs of Energy Consumption: Greenhouse Gas Emissions

- CO_2 threshold (450 ppm) is expected to be surpassed in the next decade
- CO_2 emission reduction targets are ~10-20% by 2020 will not be enough
- 50-85% reductions by 2050 are needed
- *Enormous Challenge!*

The Costs of Energy Consumption: Deepwater offshore oil drilling

- April 20, 2010
- Deepwater Horizon

The Costs of Energy Consumption: Deep Oil Well Drilling



The Costs of Energy Consumption:

www.treehugger.com

The Costs of Energy Consumption: Tar Sands (Canada, Venezuela)

- Bituminous sands – petroleum deposit in a mixture of sand, clay, water, bitumen

- High input of energy – 1 Gjoule per barrel
- Large deposits of toxic chemicals produced
- Tailing ponds – contaminated water produced (2 – 5 vol. unit per 1 vol. unit oil)
- Produces 2 – 4x more greenhouse gases per barrel of oil produced than conventional crude (40,000,000 tonnes CO_2 emitted/yr)

Alternative Biofuels

- Great concerns regarding supply and the environmental cost of traditional fossil fuels => large efforts in renewable biofuel research

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What criteria are essential for a viable alternative biofuel?

Alternative Biofuels

What criteria are essential for a viable alternative biofuel?

"Environmental Benefits"

What are the environmental effects (costs & benefits)?

"Economically Feasible"

What will a barrel of biofuel cost?

"Scalability"

Is production possible on a MASSIVE scale?

Alternative Biofuels
Living Biomass

- Current biofuel feedstocks:
  1. Terrestrial plant biomass
  2. Microalgae biomass
- Biofuel materials:
  - TAGs (triacylgylcerols) => biodiesel
  - Cellulosic compounds => ethanol, methanol

Alternative Biofuels
Plants vs. Algae

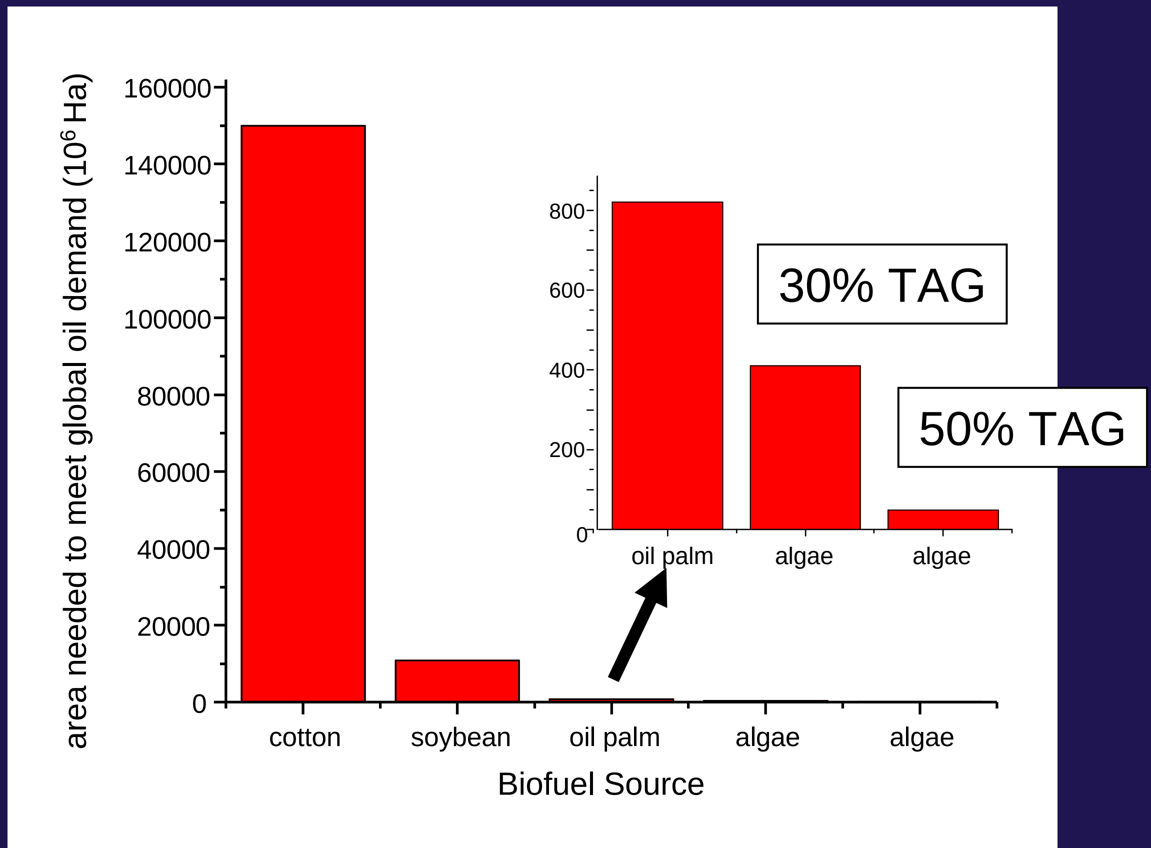
- How do plants and microalgae compare as biofuel feedstocks?

Source	Seed oil Content (% biomass)	Oil Yield (L oil/ha/yr)
Corn	44	172
Soybean	18	636
Algae	30-70	58,700-136,900

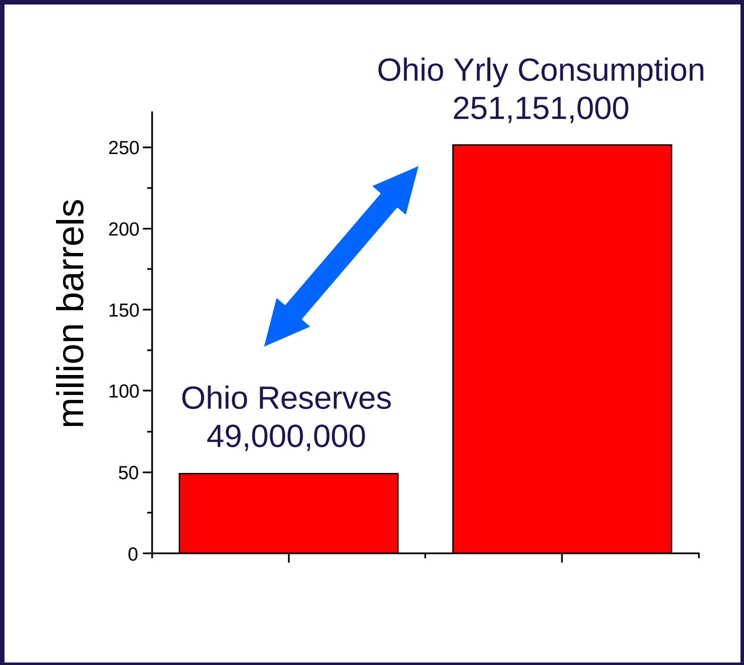
Alternative Biofuels
Plants vs. Algae

- How much **ARABLE** land is needed to meet current global petroleum needs?

Alternative Biofuels
Plants vs. Algae



Alternative Biofuels
Is Algae Fuel a Viable Solution?



What will Ohio need?

10.5×10^9 gallons of petroleum

"Energy consumption in Ohio's industrial sector ranks among the highest in the Nation"
U.S. Energy Information Administration

Alternative Biofuels
Is Algae Fuel a Viable Solution?

48 gallons of soybean fuel per acres

1.3×10^9 gallons of soybean fuel

~1 % yearly need

Alternative Biofuels
Is Algae Fuel a Viable Solution?

5.3 x 10^{10} gallons of algae fuel

Total need met on only 20% land use

1850 gallons of algae fuel per acre

Alternative Biofuels
Is Algae Fuel a Viable Solution?

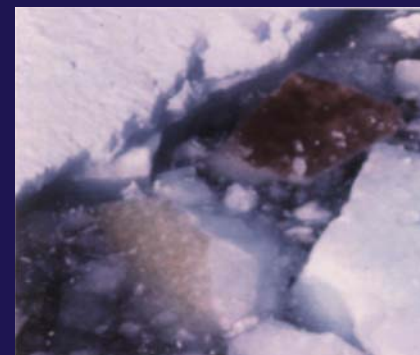
30,000,000 Acres

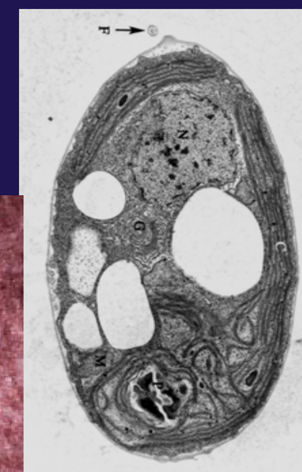
Total need met on only 9% land use

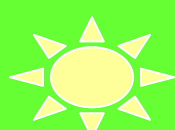
5000 gallons of algae fuel per acre

Algae Basics
The Advantages

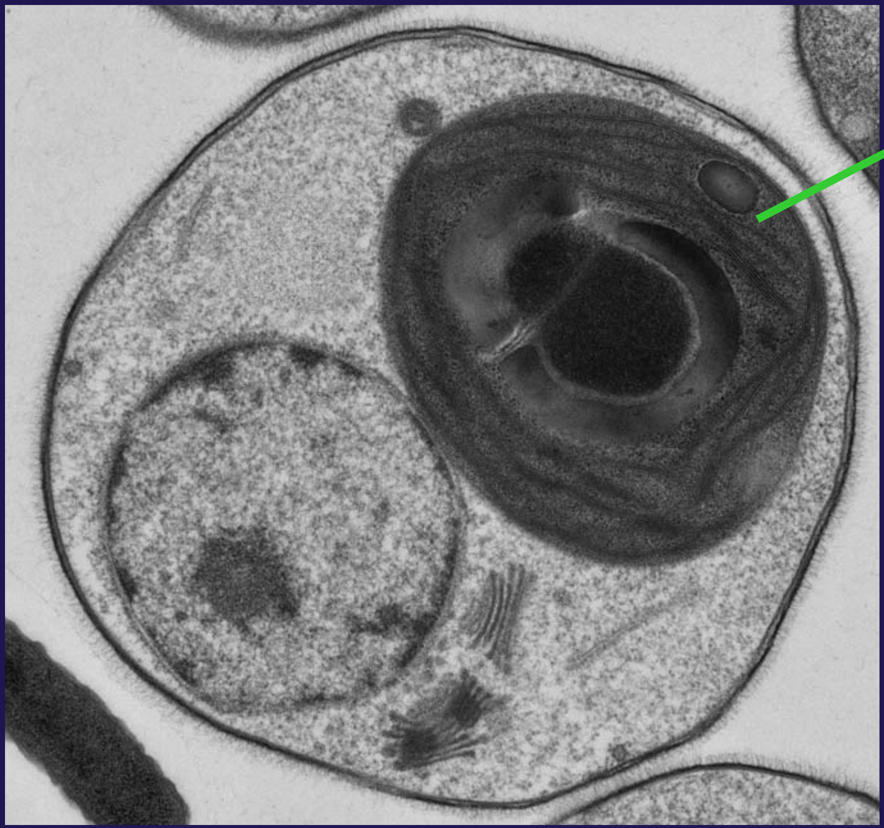
- ✓ Fast Growers
- ✓ Ubiquitous
- ✓ Metabolically versatile
- ✓ Grow in unfavorable water sources
- ✓ Genetically amenable
- ✓ Relatives of plants





 +  + CO_2 → biomass

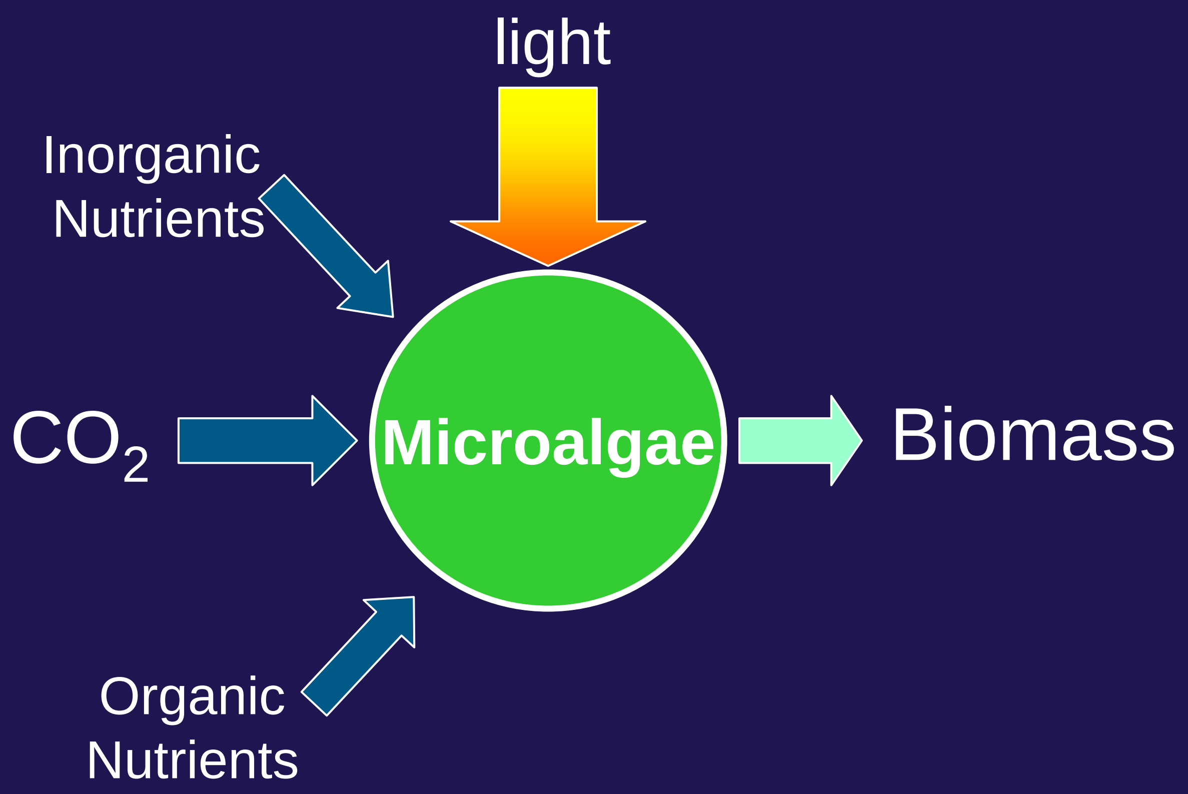
Algae Basics
The Algal Cell



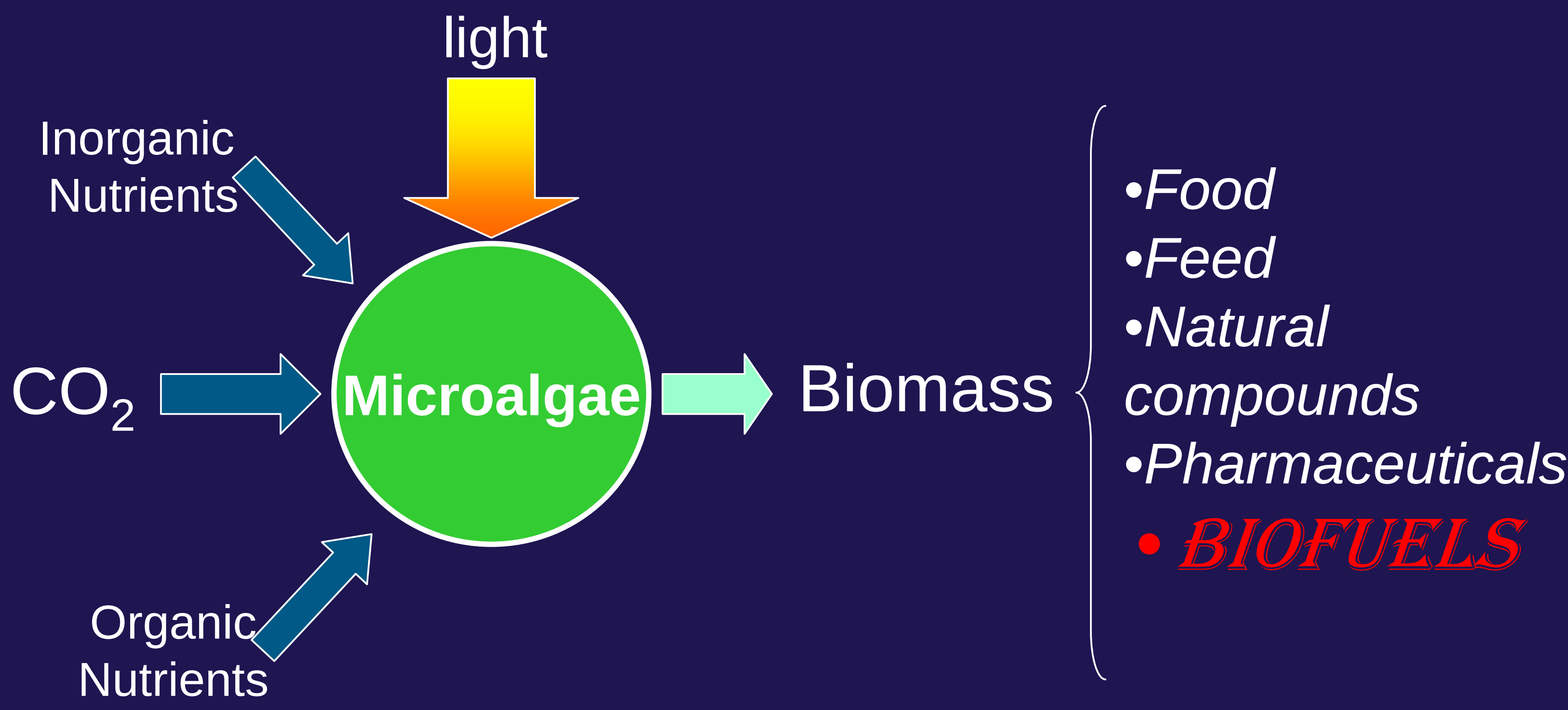
<u>The Chloroplast:</u>

- Light capture
- CO_2 fixation
- CCM
- Starch storage
- Fatty acid synthase
- Lipid biosynthesis
- N-assimilation

Algae Basics
What's required for biomass production?

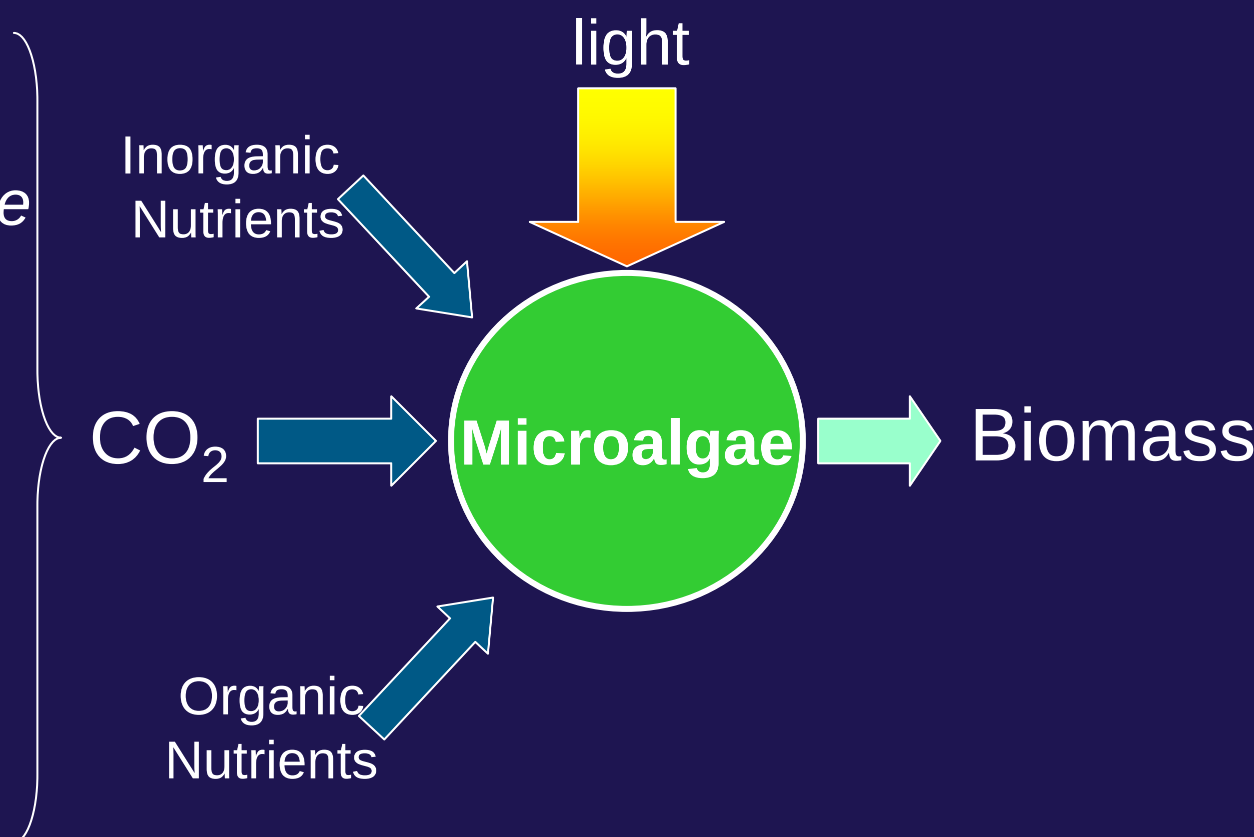


Algae Basics
Algae Products

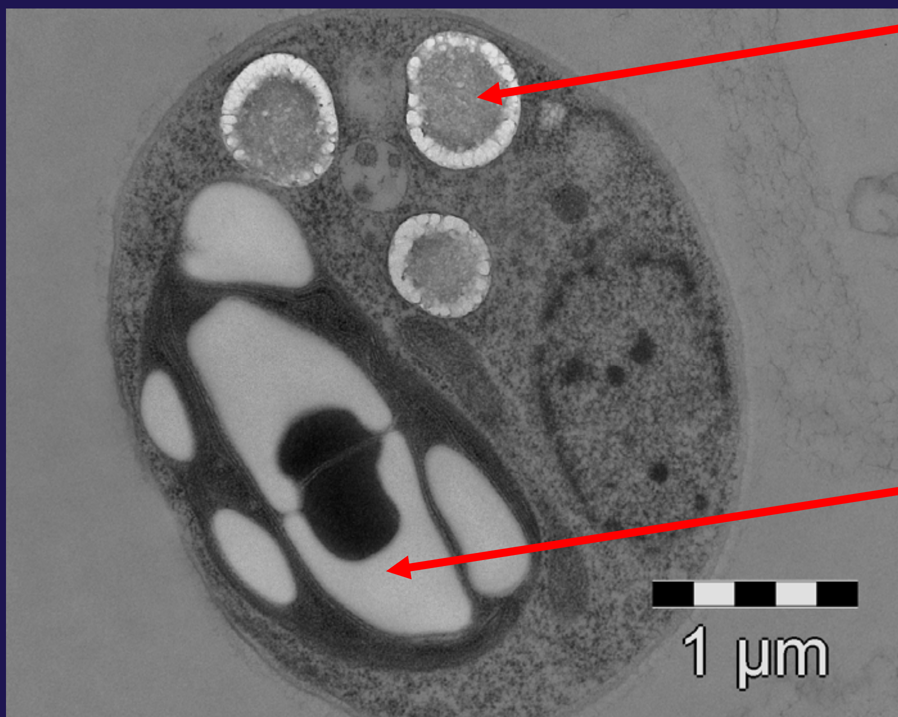


Algae Basics
Algae Products: Value Added

- *Industrial Waste Gas*
- *Sewage*
- *Agriculture Runoff*
- *Animal waste*



Algae Basics
Location of TAGS and Starch



Oil Bodies => *TAGs => Diesel*

carbon storage

Starch => =>=>Ethanol

More processing

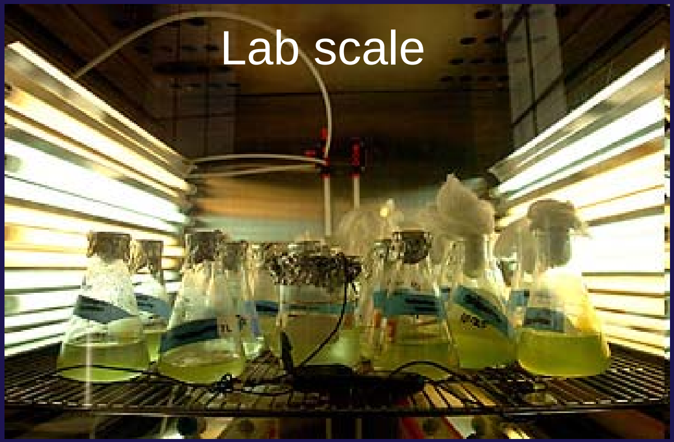
Algae Cultivation

- Considerations …………..

Light, photoperiod, temperature, nutrients, pH, aeration, mixing, sterile conditions

Algae Cultivation

- The scale-up problem…..



50 – 500 mL

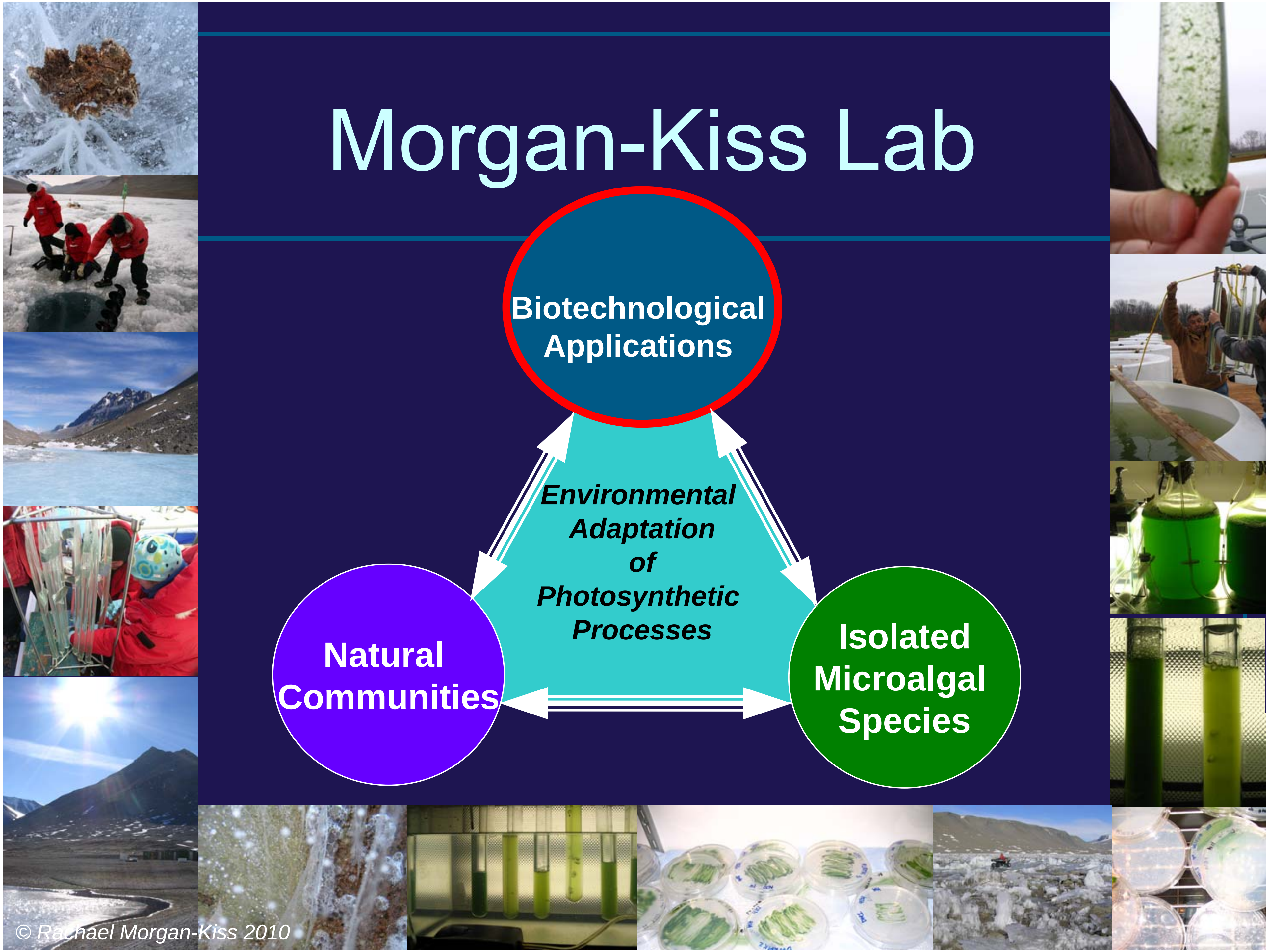
?

20,000 gallon tanks
(80, 000 L)

Algae Cultivation
Large Scale Reactors

Algae Harvesting & Extraction

The cost of a barrel of Algae biodiesel could be as high as $850 due to harvesting and extraction costs


Morgan-Kiss Lab
Biotechnological Applications
Environmental Adaptation of Photosynthetic Processes
Natural Communities
Isolated Microalgal Species
© Rachael Morgan-Kiss 2010

Are Algae a Viable Solution?

Native Ohio Algal Strains as Viable Biomass Alternatives.

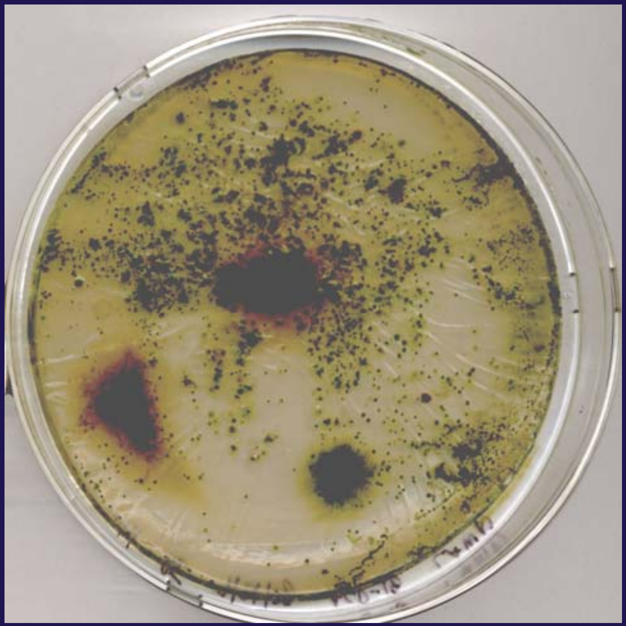
Phase I: Isolate native Ohio algae from watersheds varying in their land use.

Phase II: Characterize growth physiology under laboratory conditions and identify potential candidates.

Phase III: Monitor growth and lipid production of superior strains in small-scale reactors in a greenhouse.

Phase IV: Test strains in large-scale outdoor reactors.

Are Algae a Viable Solution? Phase I



Are Algae a Viable Solution? Phase I

Are Algae a Viable Solution? Phase I

Acton Lake	Deleware Lake	Pleasant Hill Lake	Piedmont Lake
ACD 2	DW 1	PH 1	PL-RMK 3
ACD 4	DW 2	PH 2	
ACD 18	DW-RMK 1	PH-RMK 4	
ACD-RMK 1	DW-RMK 2		
ACD-RMK 3	DW-RMK 3		

Are Algae a Viable Solution? Phase I

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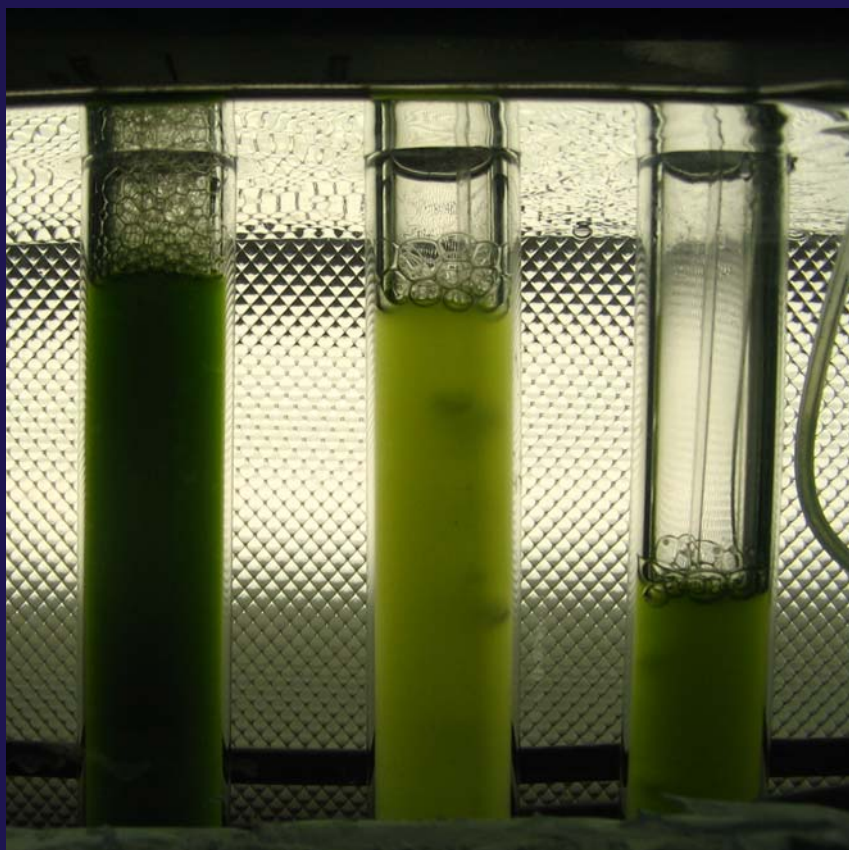
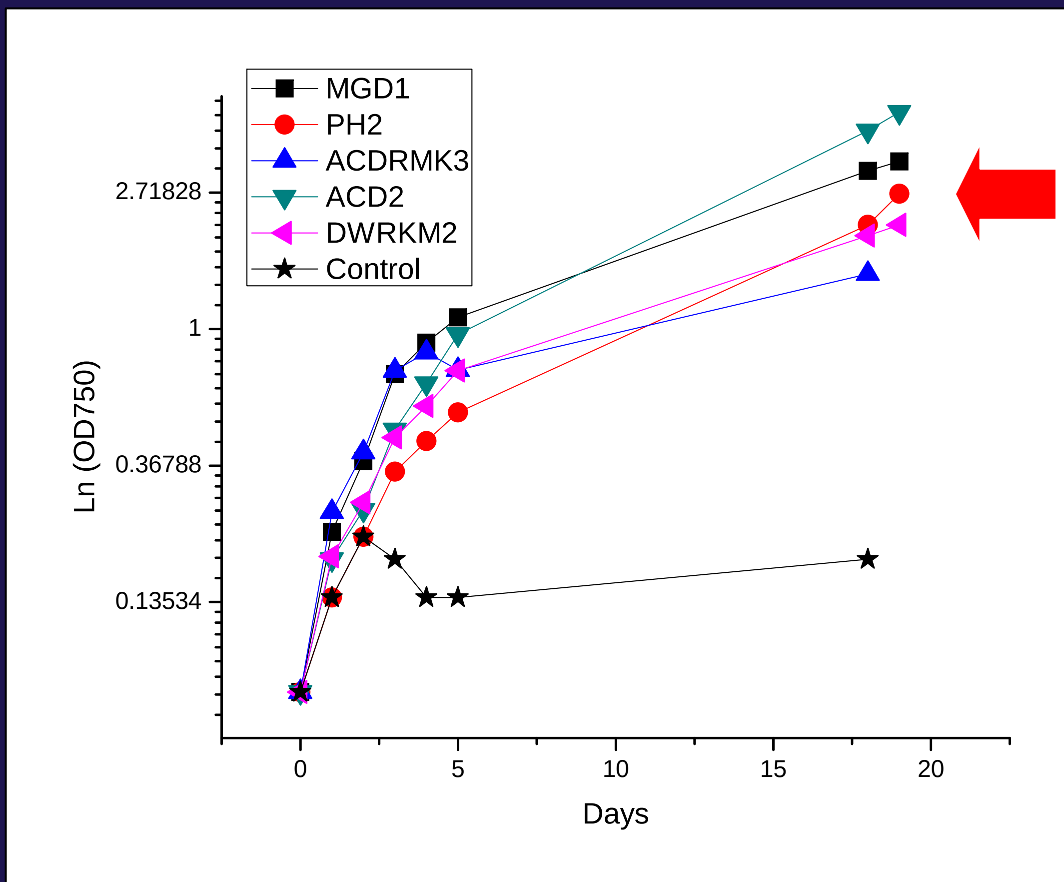


Preliminary assessment of candidate strains for Ohio Algal Farm at Miami University.				
Strain	Collection Site	Cold-response	Dry Mass (g/L)	Lipid Content (%/DW)
CTO-ACD2	Ohio	Tolerant	0.26	38
CTO-PHRMK3	Ohio	Tolerant	0.32	37
CTO-ACD4	Ohio	Tolerant	0.27	63
CTO-PHRMK1	Ohio	Tolerant	0.22	9
CTO-DW1	Ohio	Tolerant	0.17	35
CTO-PLRMK3	Ohio	Tolerant	0.32	28
CTO-PH2	Ohio	Tolerant	0.22	22
CTO-ACD78	Ohio	Tolerant	0.56	64
C. raudensis UWO241	Antarctica	Adapted	0.49	58
C. *raudensis* SAG49.72	Czechoslovakia	Temperate	0.39	28

Are Algae a Viable Solution?
Phase I – Waste water remediation

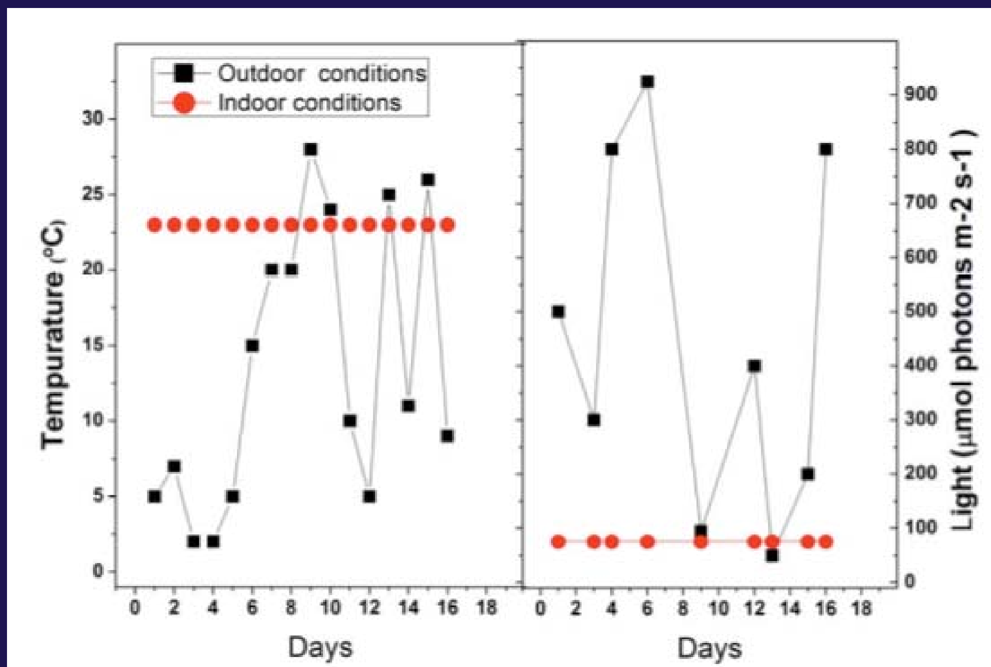


All CTO strains outperformed the “Lab Rat” Microalgal Strain in non-ammended waste water effluent

Are Algae a Viable Solution? Phase III

Small-Scale Algal Outdoor Runways for testing scale-up of CTO strains

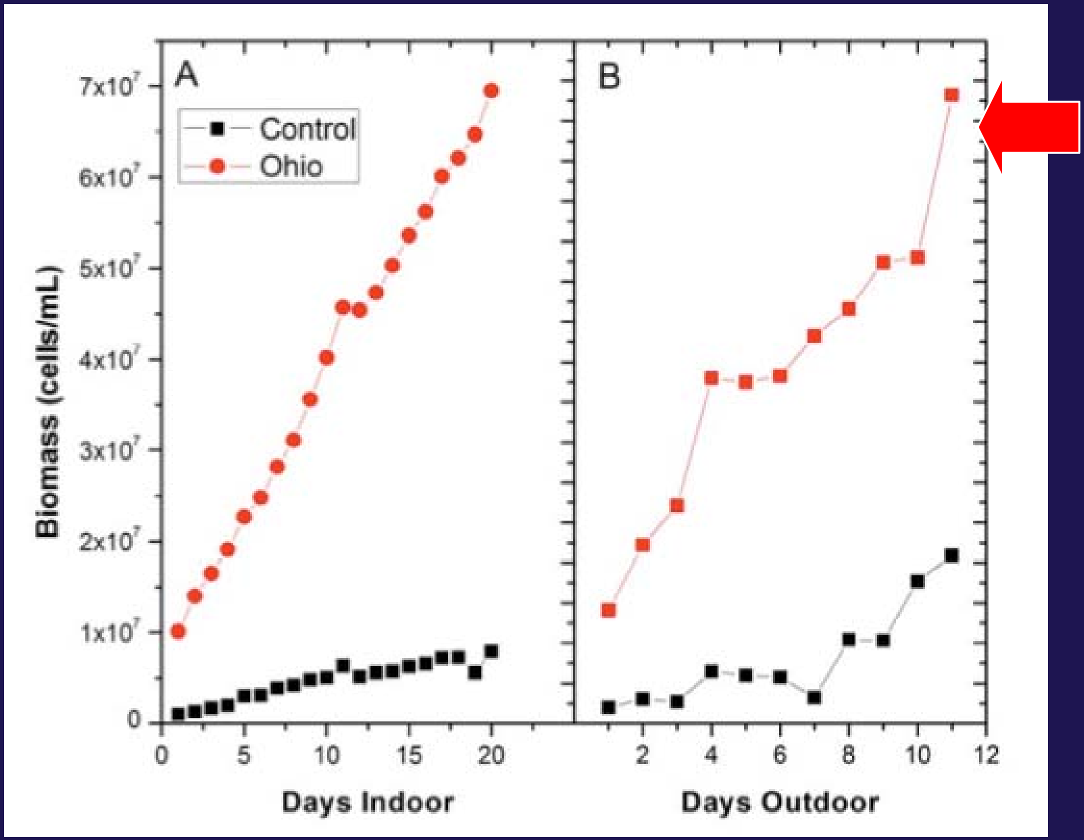
Are Algae a Viable Solution? Phase III



Light and temperature varied dramically in the algae farm greenhous between February and March, 2008

- Temperature & Light Monitoring

Are Algae a Viable Solution? Phase III



CTO strain outperformed the "Lab Rat" microalgal strain in OUTDOOR and INDOOR algal runways

- Biomass accumulation during growth

Are Algae a Viable Solution? Phase III

Organism	Growth Rate (cells/day)	Final Dry Wt (mg/L)	Oil Yield (mg/L)	% oil content (lipid/dw)
Control Algae				
-Indoors	1.08×10^6	155±15	60.0	40±7
-Outdoors	3.93×10^6	160±30	64.0	-----
MGD1				
-Indoors	2.75×10^6	265±79	165.0	62±26
-Outdoors	1.83×10^7	265±60	154.3	----

- Final biomass and Oil Yields

Are Algae a Viable Solution? Phase III

- New Algal Greenhouse at Miami's Ecological Research Center in Fall 2009 for outdoor testing of CTO strains.

miamigreendiesel
Powered by Undergraduates

Are Algae a Viable Solution? What's the Future of Miami Green Deisel?

1. Ongoing recruitment of new undergraduate researchers.
2. Develop high through-put lipid fluorescence screening protocol.
3. Improve lipid production in superior CTO strains such as MDG1 using genetic engineering.
4. Continue with "value added" experiments, including waste water remediation.
5. Build prototype large-scale algal runway at Miami's ERC.