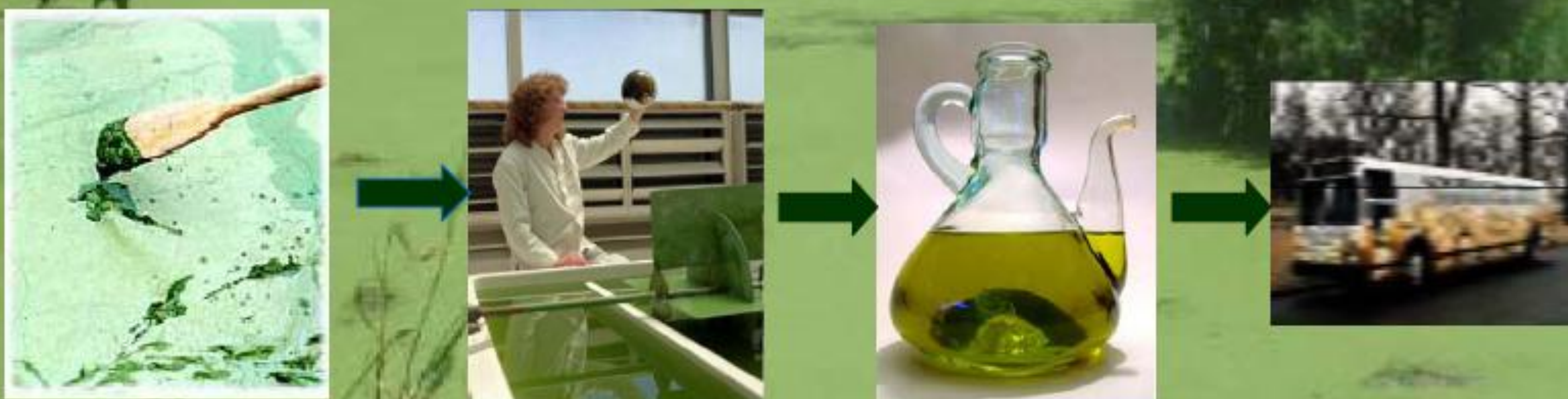
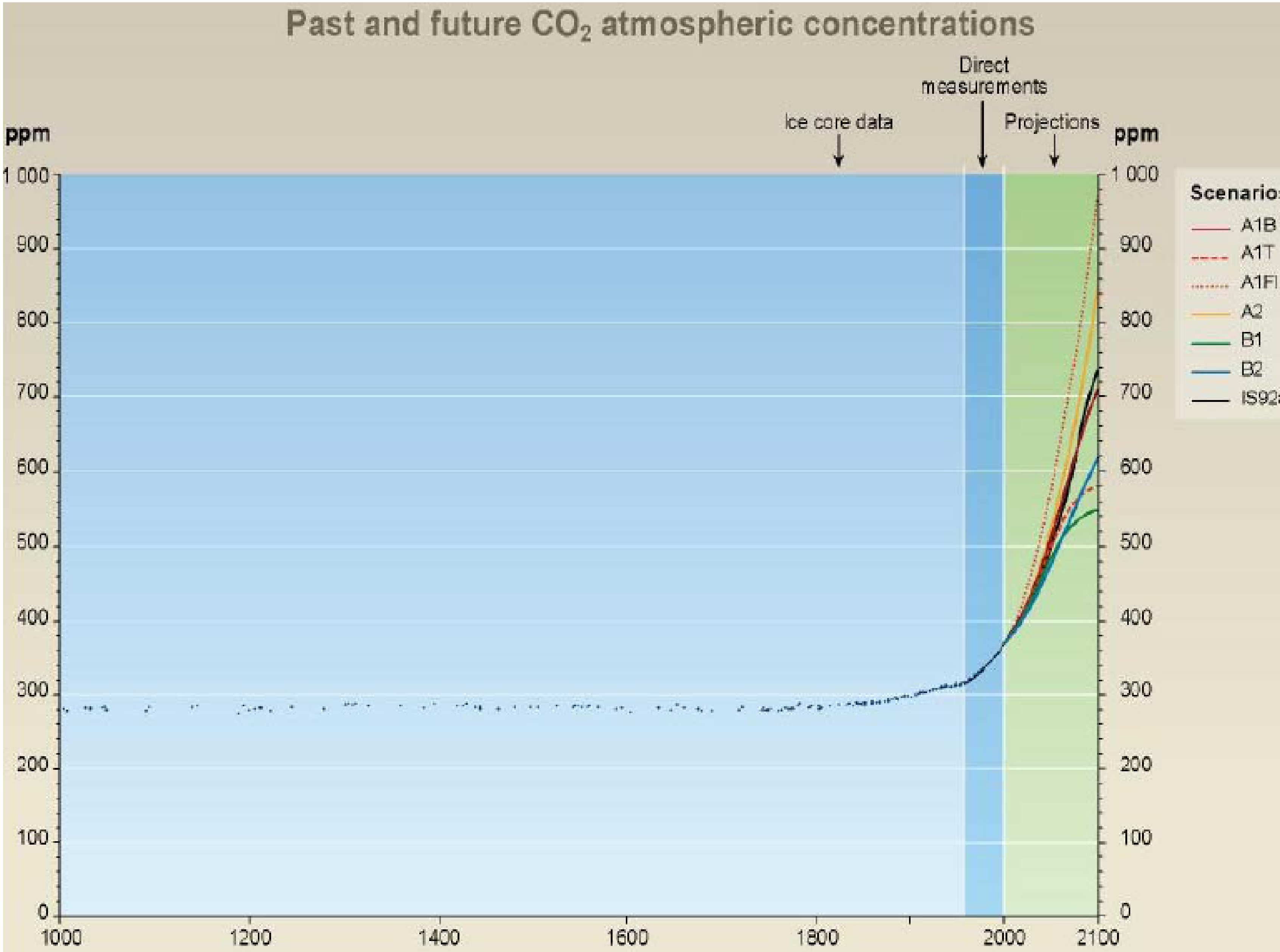
Biodiesel from Algae:

Challanges, oppurtunuties and the way forward





Past and future CO_2 atmospheric concentrations
Direct measurements
Ice core data
Projections
ppm
ppm
1 000
900
800
700
600
500
400
300
200
100
0
1000
1200
1400
1600
1800
2000
2100
Scenarios
A1B
A1T
A1FI
A2
B1
B2
IS92a


aninconvenienttruth
A GLOBAL WARNING
by far the most terrifying film
you will ever see.
An Inconvenient Truth on DVD
November 21

Types of Alternative Fuels

- Methanol
- Ethanol
- Biodiesel
- Electricity
- Hydrogen
- Compressed Natural Gas
- Liquefied Natural Gas

Definition of Biofuels

- "**Biofuel** is derived from biomass — recently living organisms or their metabolic byproducts, such as manure from cows. It is a renewable energy source, unlike other natural resources such as ***petroleum***, coal, and nuclear fuels." -www.biofpr.com

Biofuels

- Effective
- Less harmful
- Renewable
- Can be used in many cars today

Biofuel History

- 1898 Rudolph Diesel created a diesel engine that ran on peanut oil in Paris
- 1908 Model T engine to run on ethanol
- Biofuels were nearly 25% of the oil sales in the 1920's
- Disappear in 1940's due to lowered petroleum gas prices

www.oilandwaterproject.org

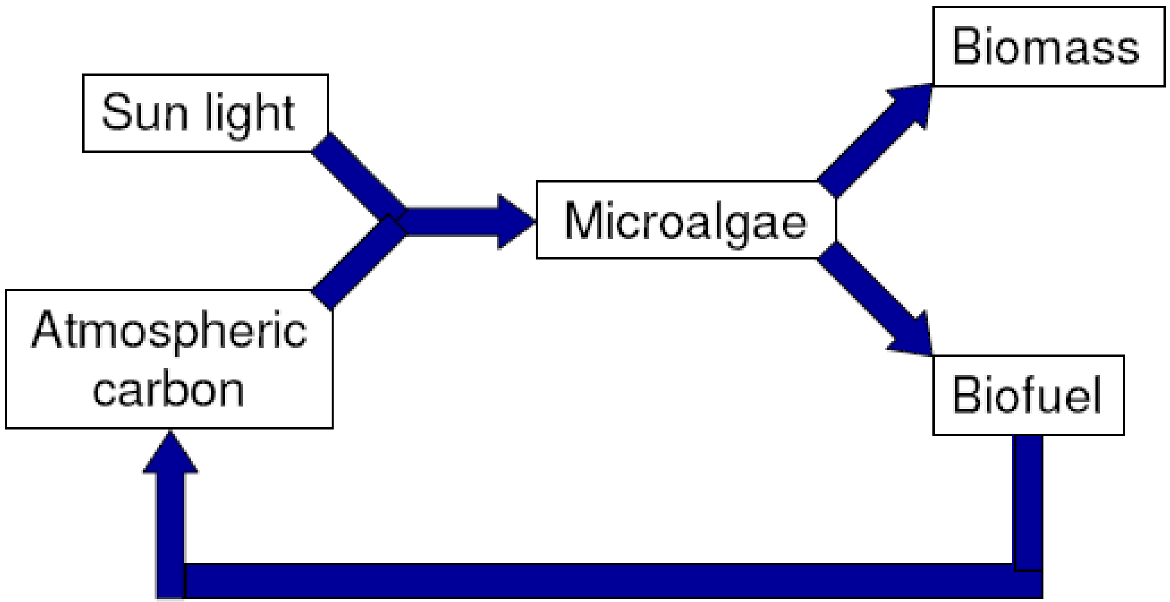
Biodiesel

- Fatty acid and methyl esters originating from vegetable oils and animal fats are generally known as biodiesel.
- Biodiesel derived from oil crops is a potential renewable and carbon neutral alternative to petroleum fuels.
- Biodiesel has been in commercial use as an alternative fuel since 1988 in many European countries.
- Biodiesel usually costs over US$0.5/L, compared to US$0.35/L for normal diesel.
- Exploring ways to reduce the high cost of biodiesel is of much interest in recent biodiesel research

Bio-diesel Fuel

- The bio-diesel engine can be used in usual engines of internal combustion as it is independent, and in a mix with usual diesel fuel, without modification in a design of the engine.
- Possessing approximately identical energy potential with mineral diesel fuel, the bio-diesel engine has a number of essential advantages:
  - It is not toxic, practically does not contain some sulfur and carcinogenic benzene;
  - Decays in natural conditions (approximately the same as sugar);
  - Provides significant reduction in harmful emissions in an atmosphere at burning, both in engines of internal combustion, and in technological units; (biodiesel is carbon neutral- no net accumulation of CO’ in the atmosphere)
  - Increases cetane number of fuel and its greasing ability, that essentially increases a resource of the engine;
  - Has high temperature of ignition (more than 100 °C),
  - Its source are renewed resources;

Relatively Carbon Neutral Process



Sustainability Issues

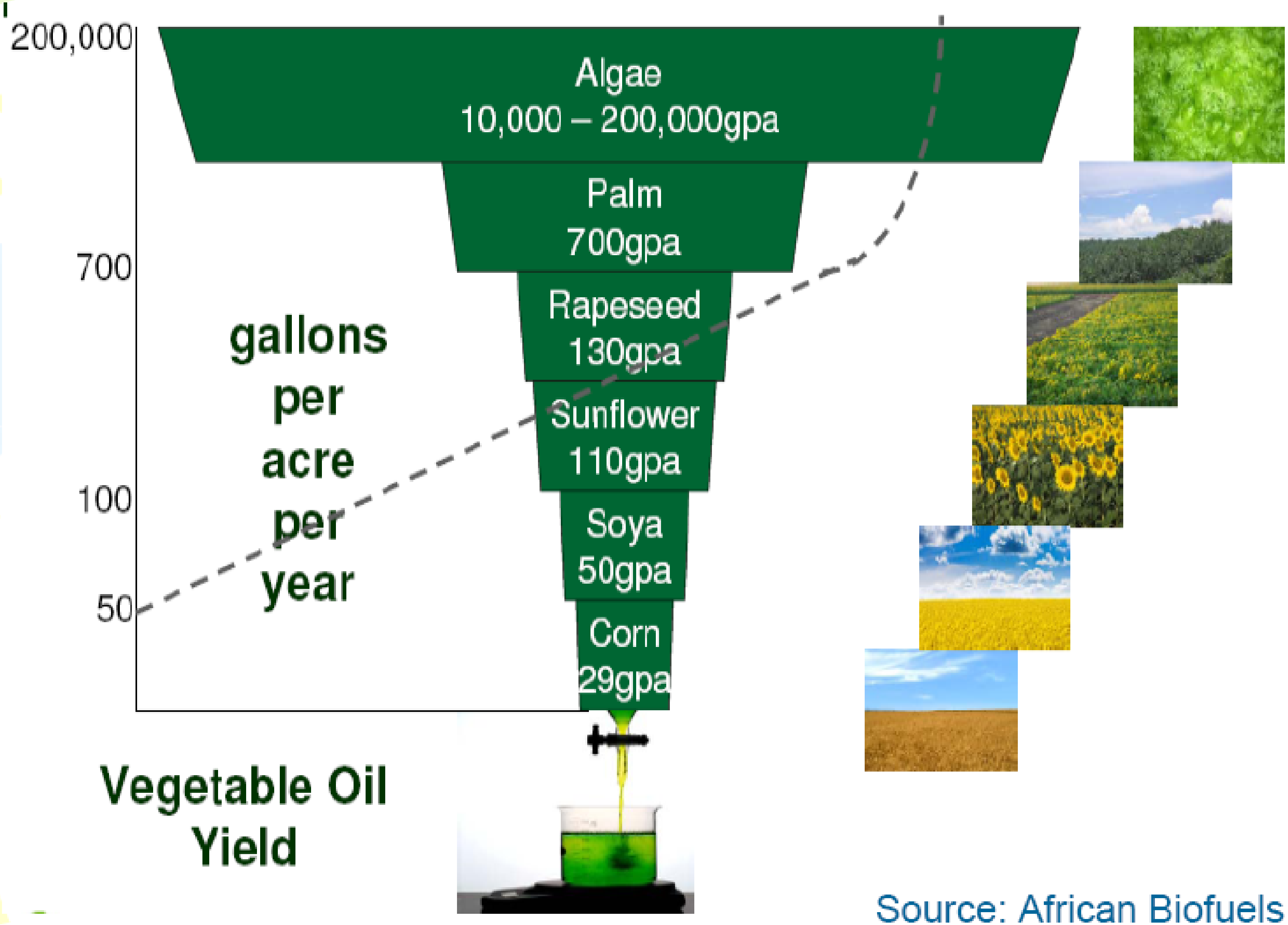
Criteria for future energy crops:-

- High Yields
- Low Agricultural Land requirement
- Low Freshwater usage
- Economical

THE ALLURE OF MICROALGAE BIODIESEL

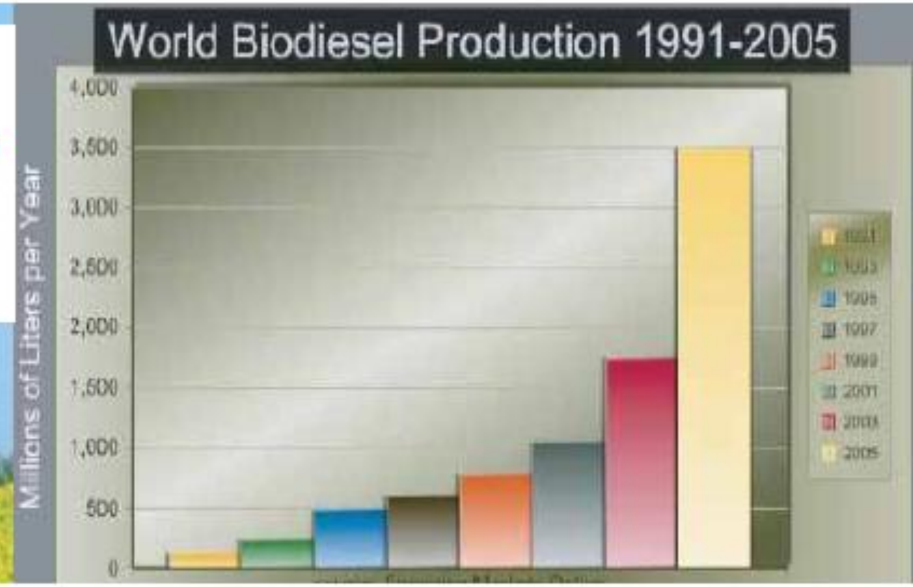
Oil yields	liters/ha-yr	barrels/ha-yr
Soybeans	400	2.5
Sunflower	800	5
Canola	1,600	10
Jathropha	2,000	12
Palm Oil	6,000	36
Microalgae	60,000-240,000*	360 -1500*

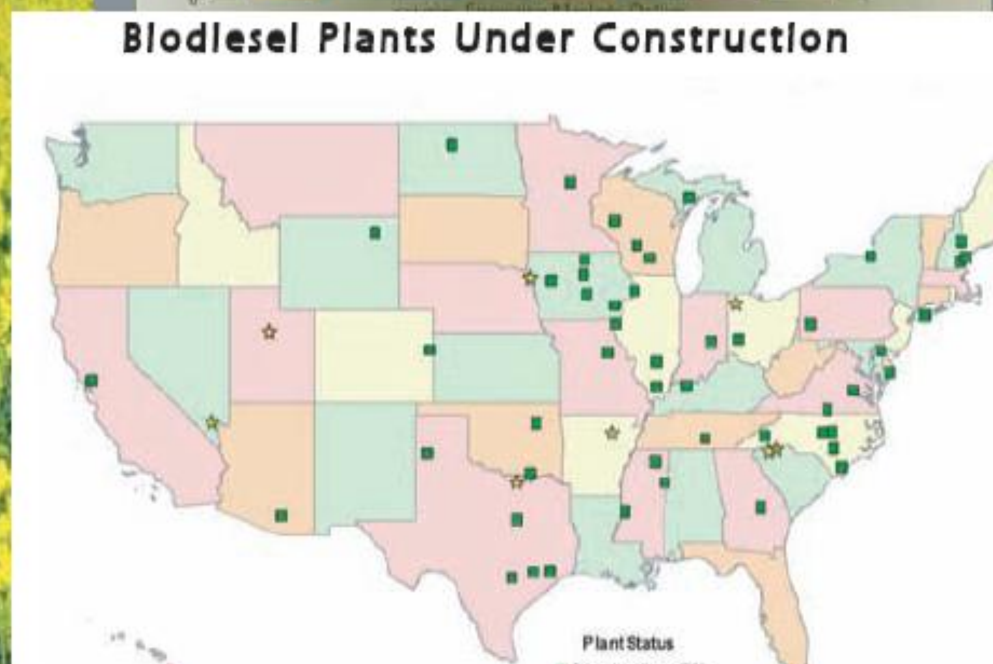
Biodiesel Feedstock Tree



Source: African Biofuels 2007

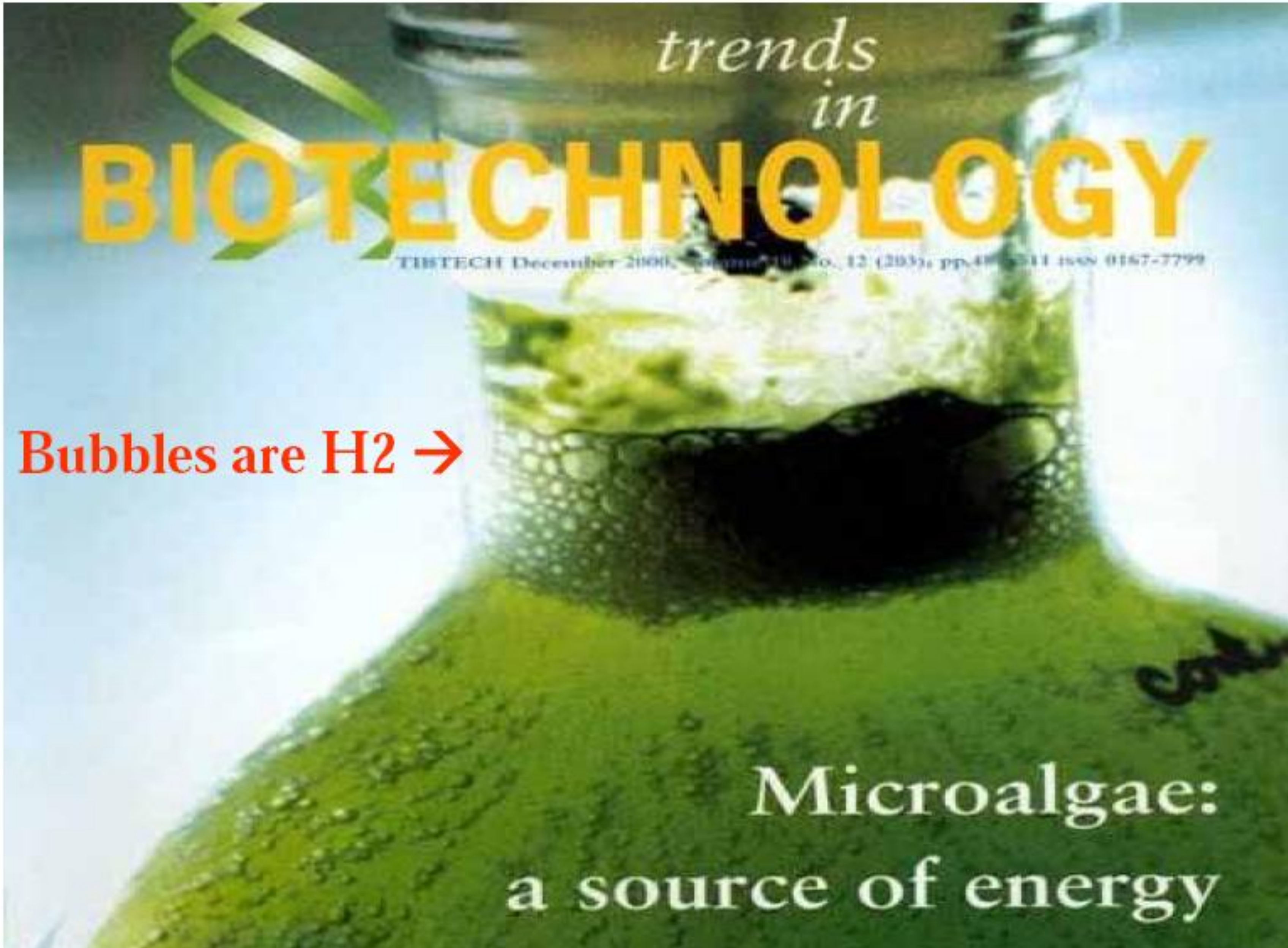
Not enough vegetable oil available. Biodiesel plants now at ~25% capacity, → need new sources

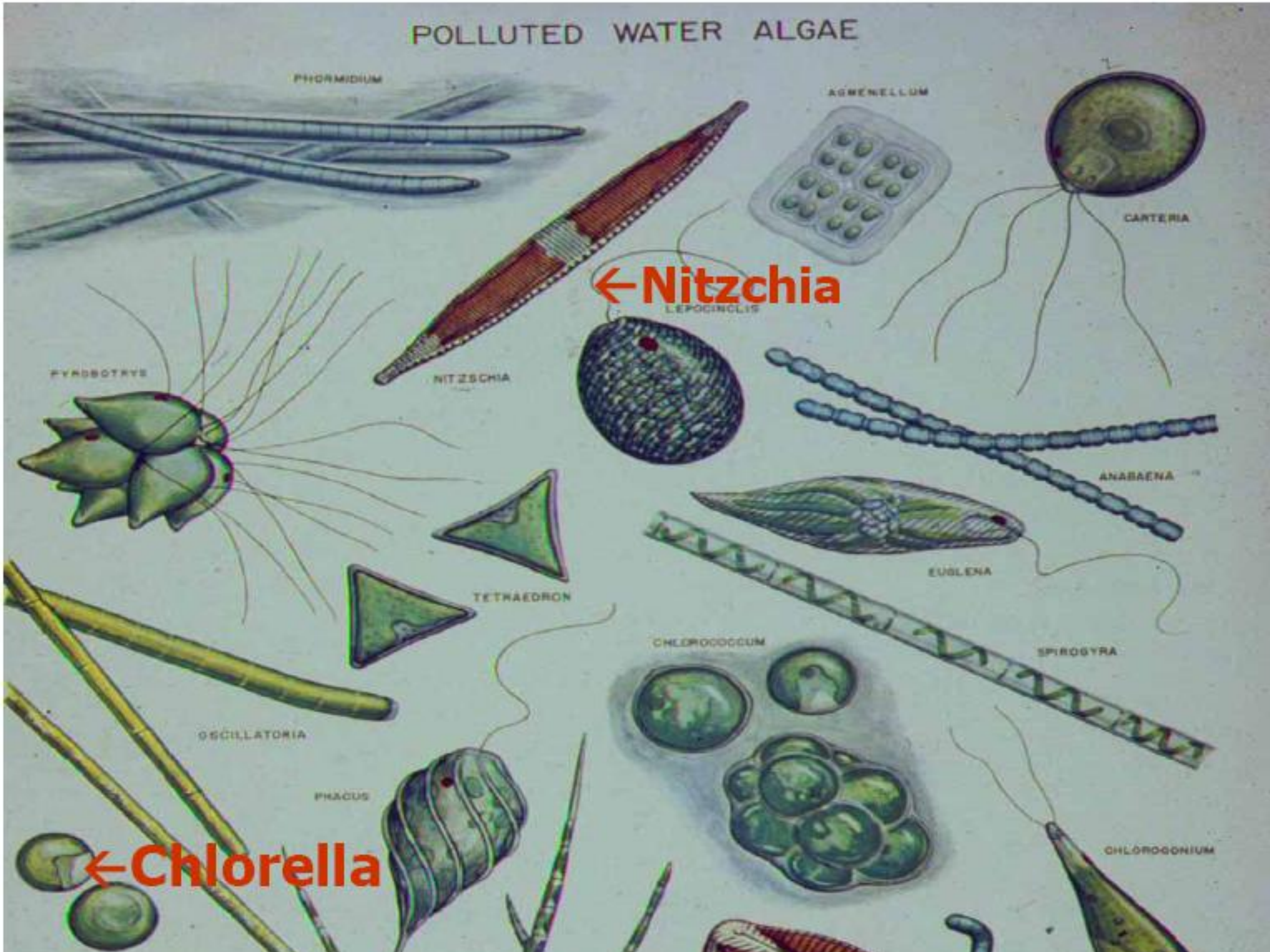




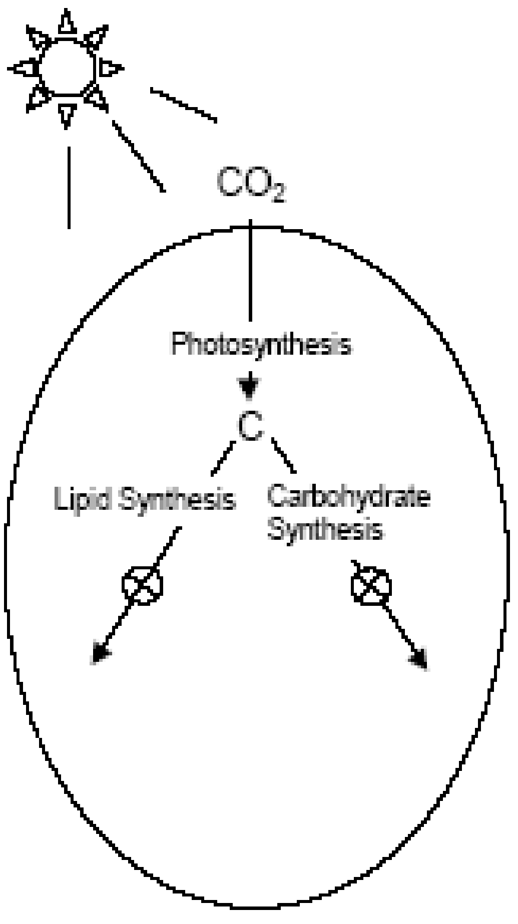
Algae biomass

Algae oil


trends in
BIOTECHNOLOGY
Bubbles are H2 →
Microalgae:
a source of energy

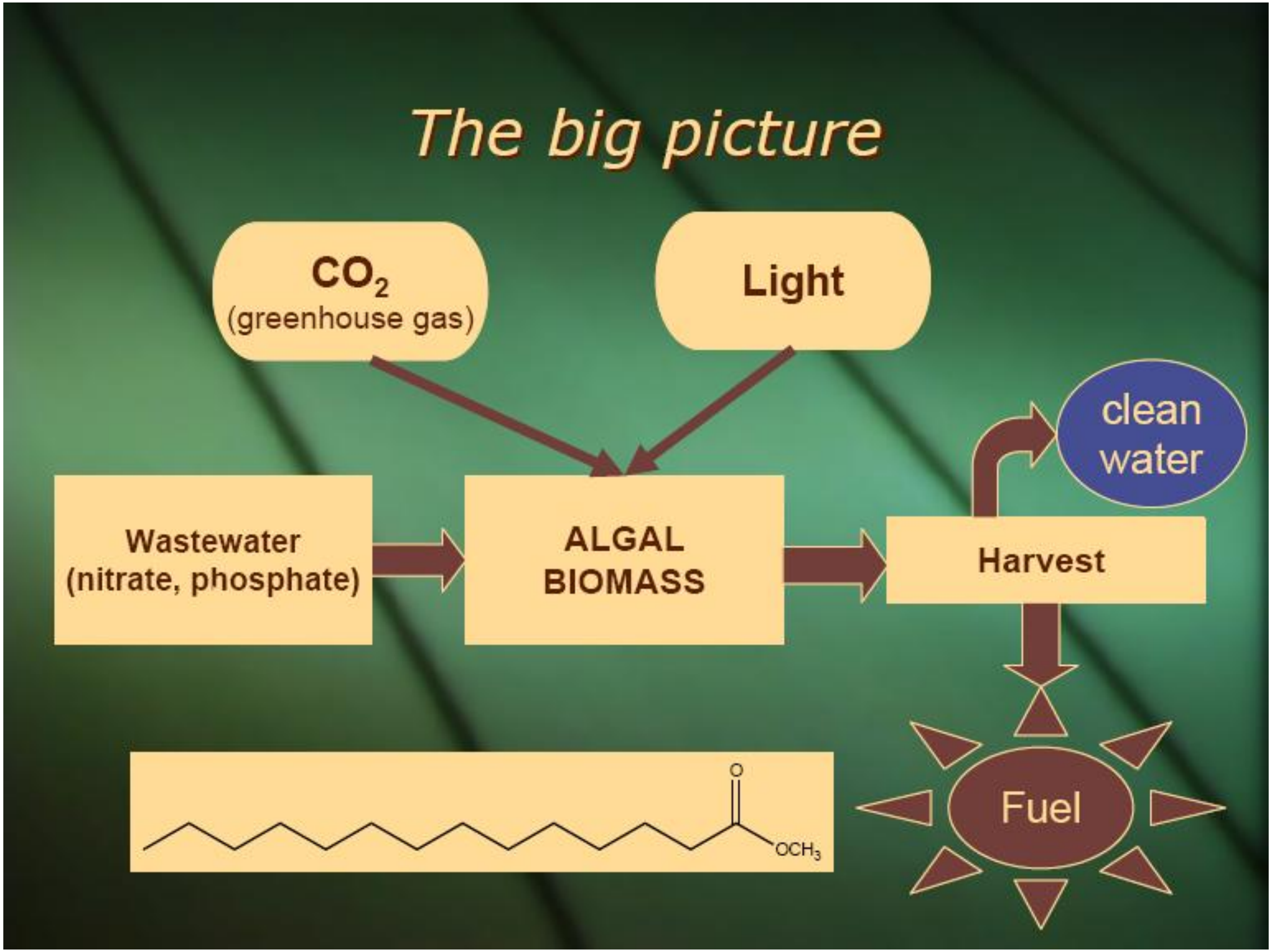

POLLUTED WATER ALGAE
PHORMIDIUM
AGMENELLUM
CARTERIA
←Nitzchia
LEPOCINCLIS
NITZSCHIA
PYROBOTRYS
ANABAENA
EUGLENA
TETRAEDRON
CHLOROCOCCUM
SPIROGYRA
OSCILLATORIA
PHACUS
CHLOROGONIUM
←Chlorella

Storing the Sun's Energy (Photosynthesis)

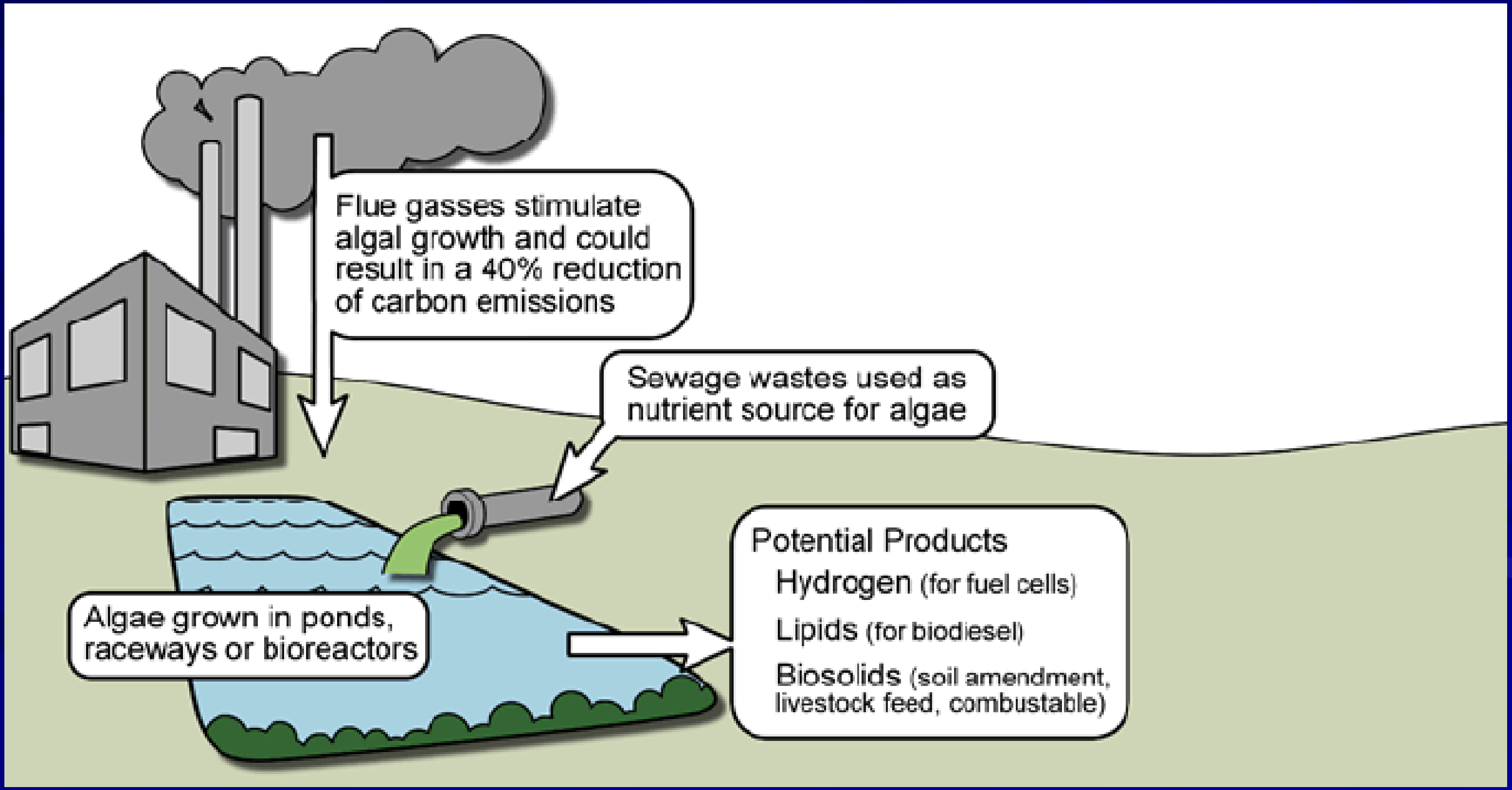


- What is needed
  - Sunlight
  - CO_2
  - Nutrients
- Storage of Energy
  - Lipids and oils
  - Carbohydrates

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

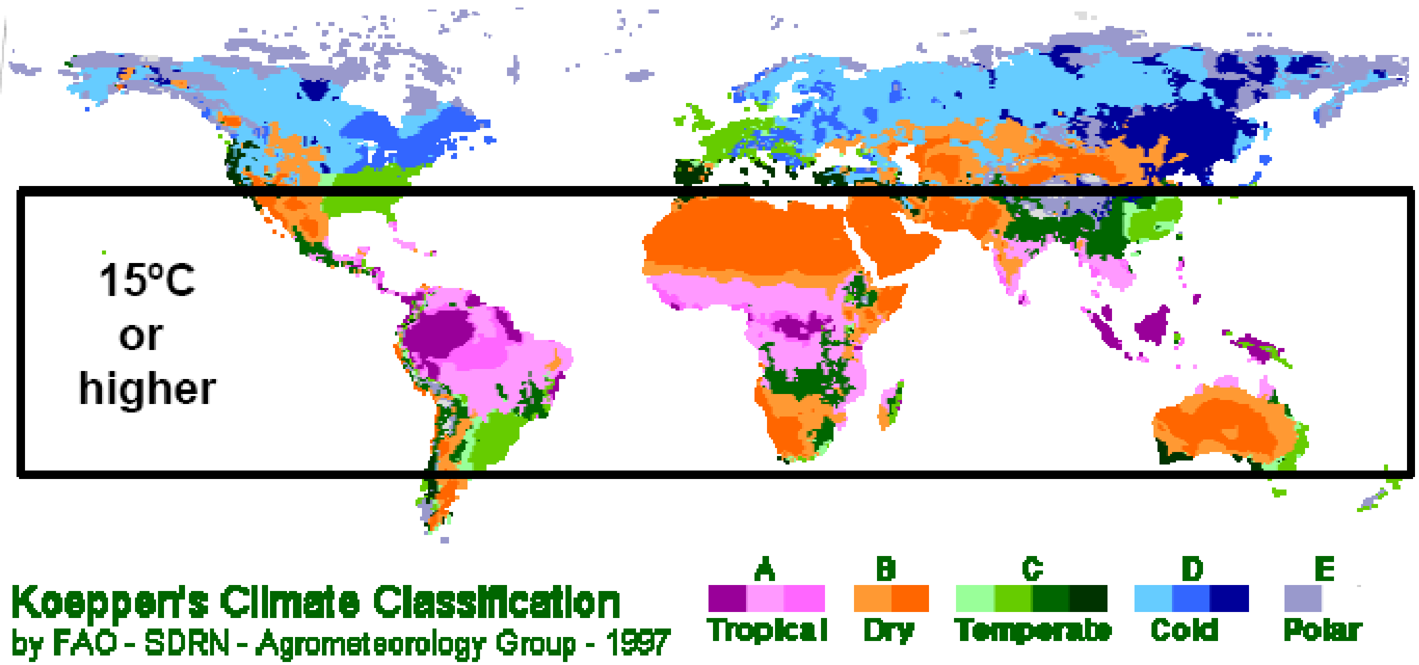

The big picture
CO2
(greenhouse gas)
Light
Wastewater
(nitrate, phosphate)
ALGAL
BIOMASS
Harvest
clean
water
Fuel
O
OCH3

During photosynthesis algae capture CO_2 and release oxygen into the atmosphere. CO_2 produced during the combustion of fossil fuels can therefore supply raw material for algae production.



- Micro-algae grows within all year and has short life cycle;
- Micro-algae the most fast-growing plant on Earth - grows in 100 times faster, than trees. Usually the weight of micro-algae for a day is doubled;
- For micro-algae the readily available raw material is required: sunlight, water, carbon dioxide and nutrients (P and N);
- From micro-algae it is possible to receive natural products: pigments, fibers, enzymes, sugar, fats, amino acids, vitamins.
- Depending on kinds of algae (exists more than 30.000 kinds) and conditions of its cultivation, the chosen algae makes about 40-60 % of oil.
- Micro-algae grows in all environments. Even if the temperature of water makes - 2°C.

Suitable Climatic Areas



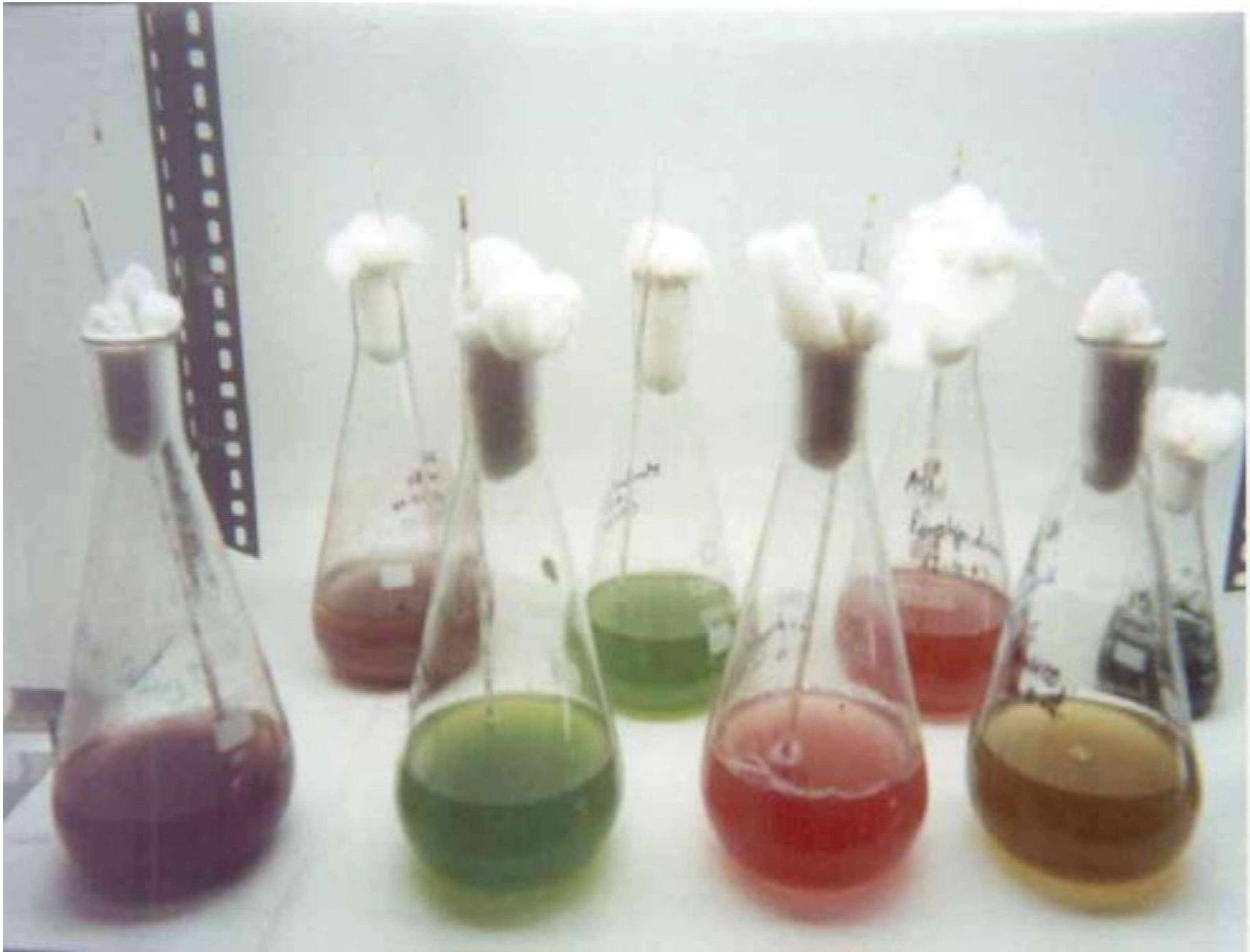
CSIRO Biodiesel from Algae

Potential species

- There are many marine and freshwater species
- High Lipid productivity
- High growth rate (45-180 times canola)

MICROALGAE DIVERSITY

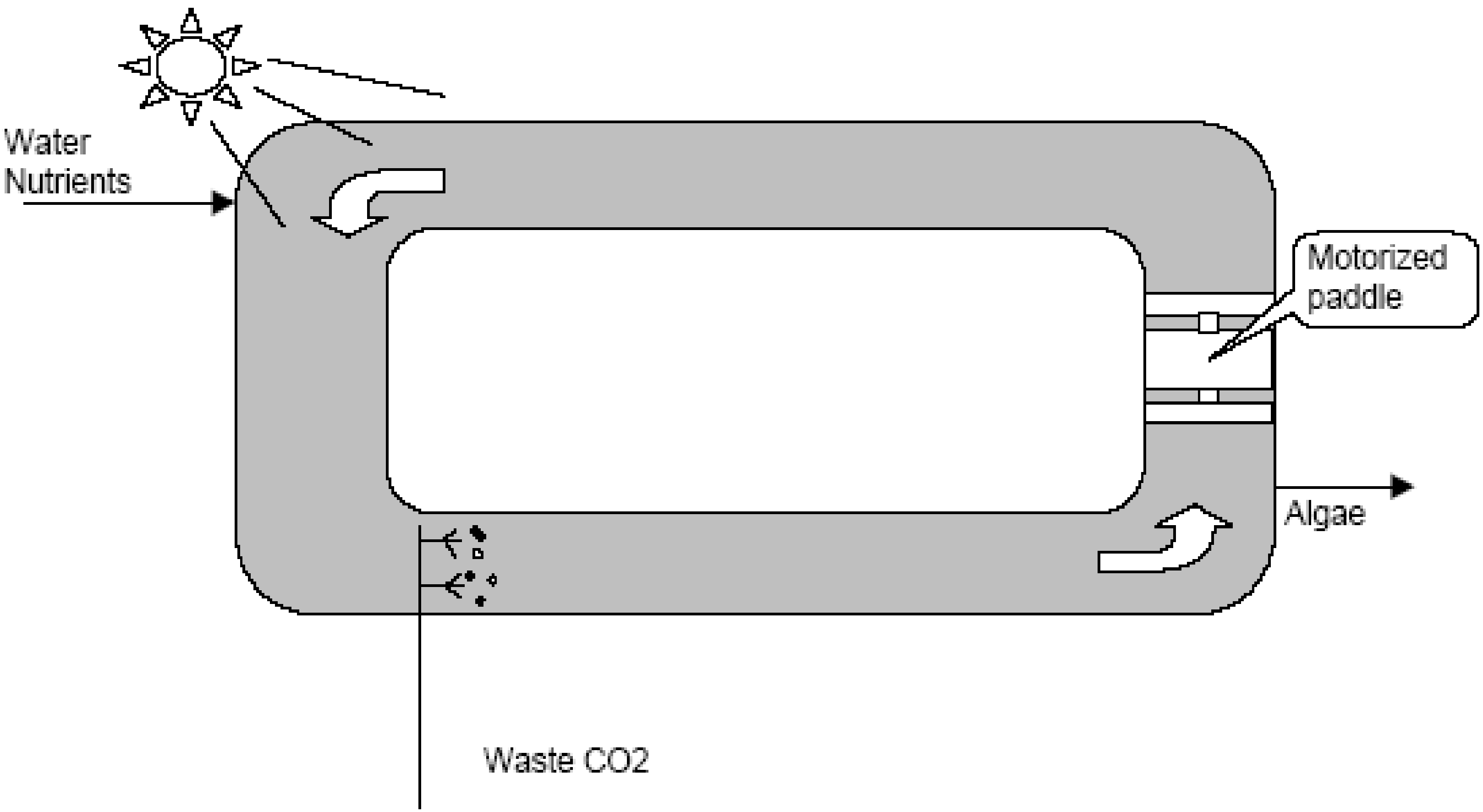
- **30 000 described species (< 10% of estimated)**



What affects oil production?

- Climate
  - Cold weather reduces algae oil production
  - Overcast days reduce sunlight and lower oil production
- Nutrients
  - Depletion of Nitrogen and Silicate
- Biotic factors including pathogens, predation and competition by other algae
- Operational factors such as: shear produced by mixing, dilution rate, depth and harvest frequency

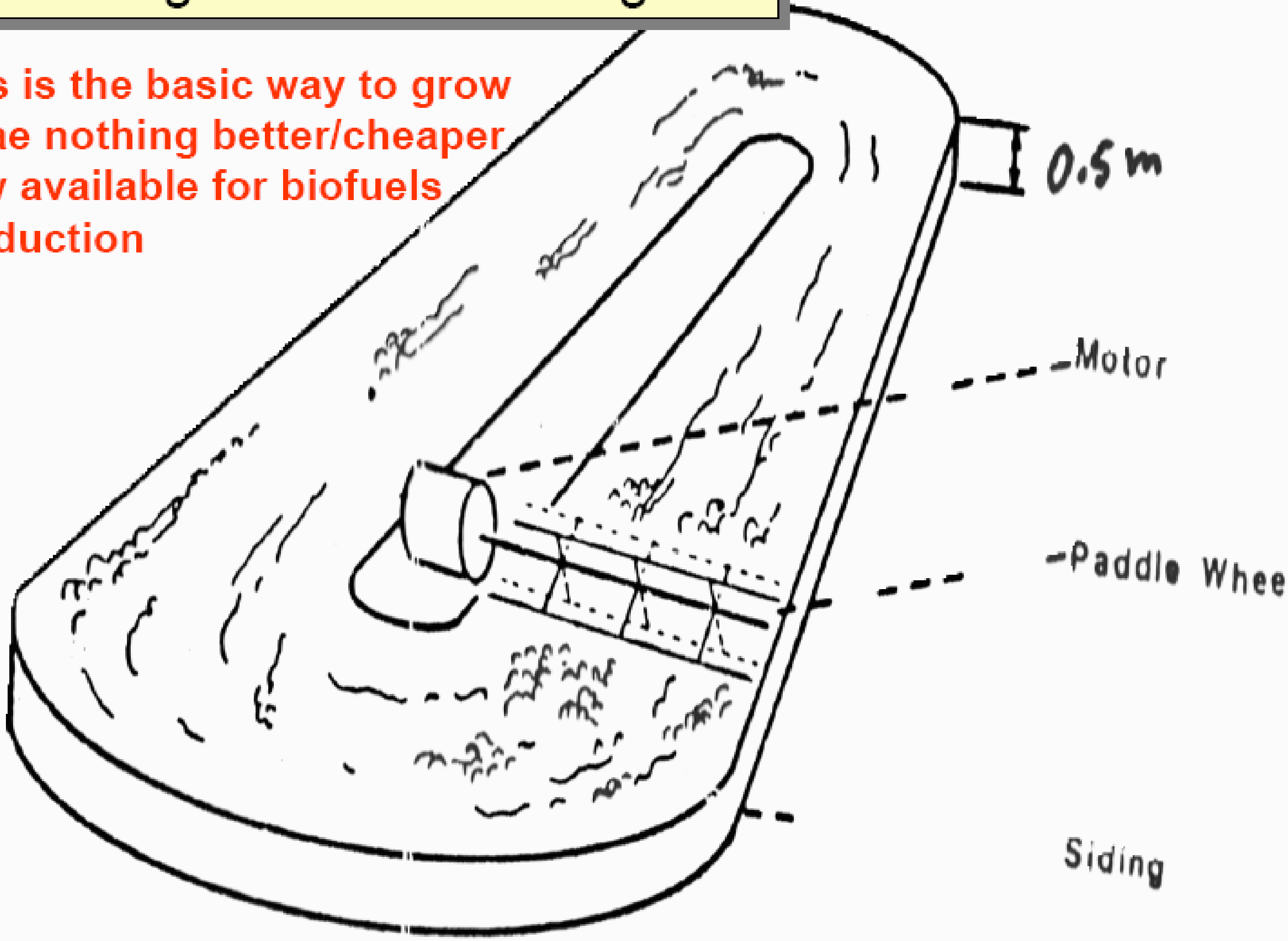
The Algae Pond



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

Typical High Rate Pond Design

This is the basic way to grow algae nothing better/cheaper now available for biofuels production



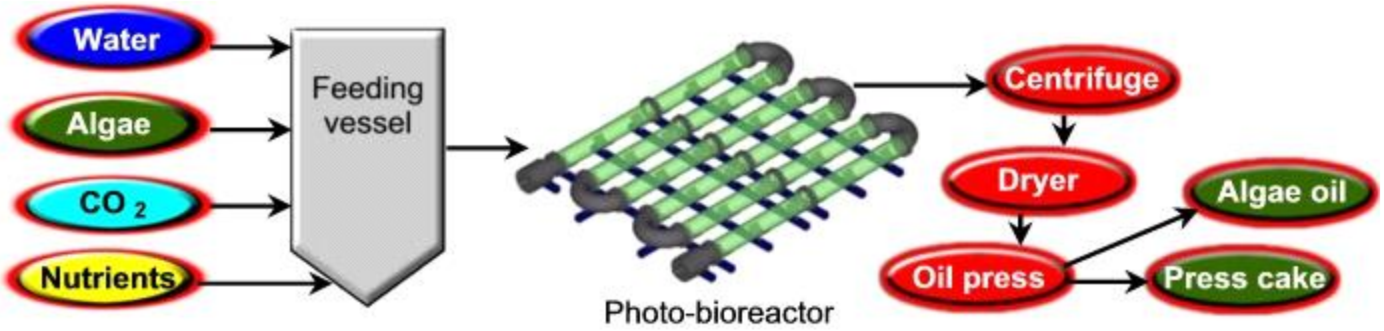
CO2 Mass Transfer Coefficients in Roswell Ponds (from Weissman et al., 1990)

Depth cm	Velocity cm/sec	k_L cm/sec	Surface Renewal, sec
10	10	3.9×10^{-4}	150
10	30	1.4×10^{-3}	12
30	10	2.2×10^{-4}	480
30	30	0.8×10^{-3}	37

Efficient CO2 use at <30 cm depth, <30 cm/sec velocity

Greenhouse 	The use of CO_2 for growing algae 
Horizontal mode 	Vertical mode 

The technological circuit of installation of a bioreactor



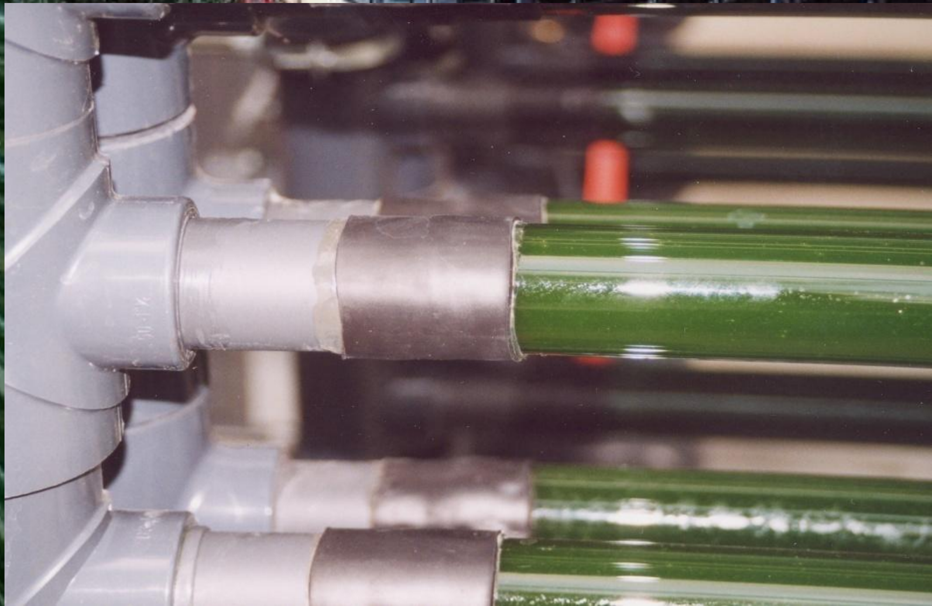
Example: High Rate Ponds in Florida

Spirulina Production in India (Parry Nutraceuticals Ltd.)

Greenfuel Bioreactors on Rooftop

Commercial Photobioreactor in Germany

For Chlorella production.
Over $10million/hectare!
Went broke in short order



Choosing an Algae

- Important characteristics of Algae
  - High % of total biomass is oil
  - Maintains a high % of oil even under stress

www.kluyvercentre.nl/content/ documents/Verslag2biodieselBaarnschLyceum.pdf -

What Type of Algae

- Botryococcus braunii
  - Converts 61% of its biomass into oil
  - Drops to only 31% oil under stress
  - Grows best between 22-25^{o}C (71-77^{o}F)

www.kluyvercentre.nl/content/ documents/Verslag2biodieselBaarnschLyceum.pdf -

Table 2. Oil content of some microalgae

Microalga	Oil content (% dry wt)
Botryococcus braunii	25–75
Chlorella sp.	28–32
Crypthecodinium cohnii	20
Cylindrotheca sp. (diatom)	16–37
Dunaliella primolecta	23
Isochrysis sp.	25–33
Monallanthus salina	>20
Nannochloris sp.	20–35
Nannochloropsis sp.	31–68
Neochloris oleoabundans	35–54
Nitzschia sp. (diatom)	45–47
Phaeodactylum tricornutum	20–30
Schizochytrium sp.	50–77
Tetraselmis sueica	15-23

Arthrospira platensis (Spirulina)

Spirulina is easy to culture (high alkalinity medium and easy to harvest by screens

Current products from microalgae: nutraceuticals

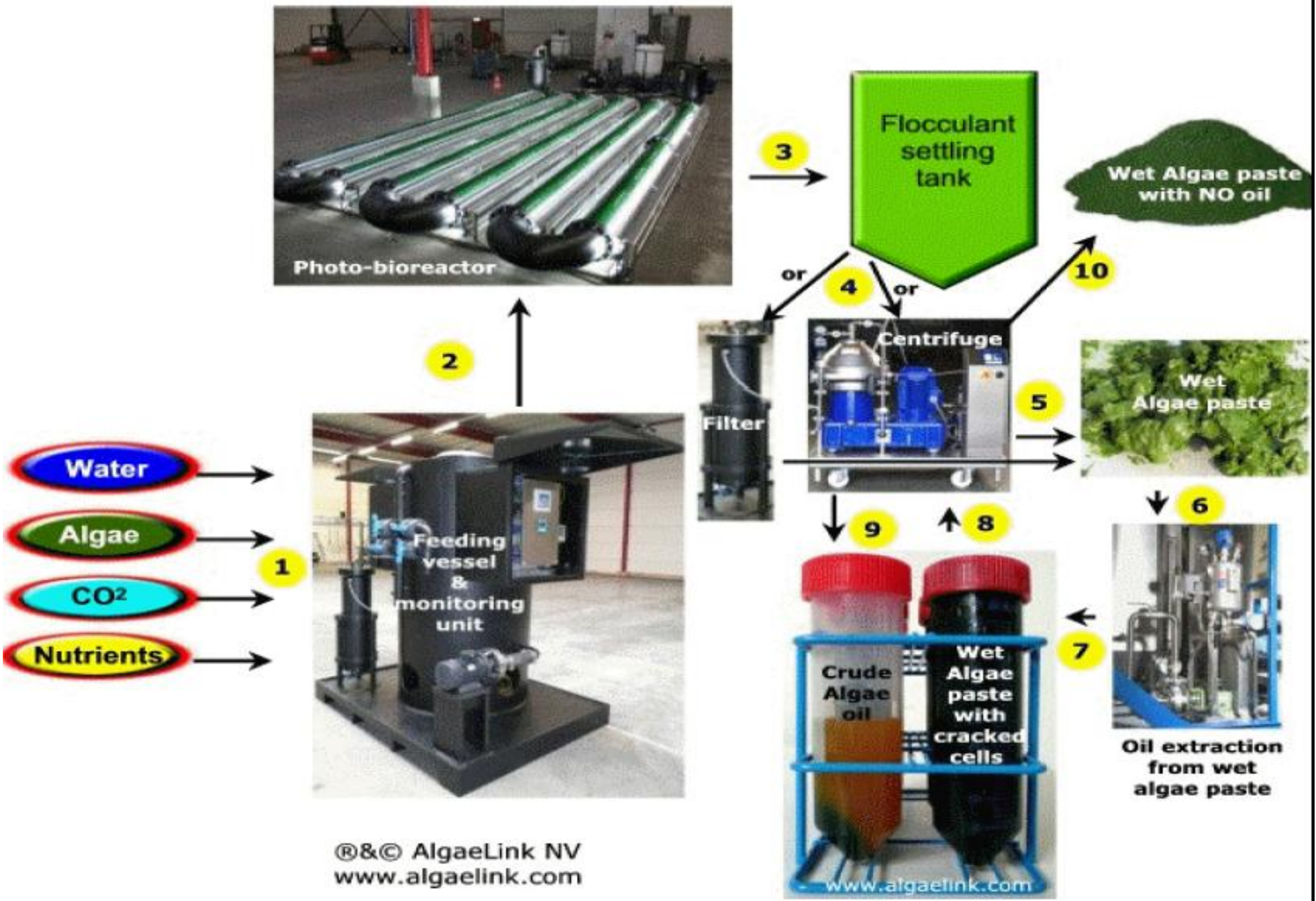
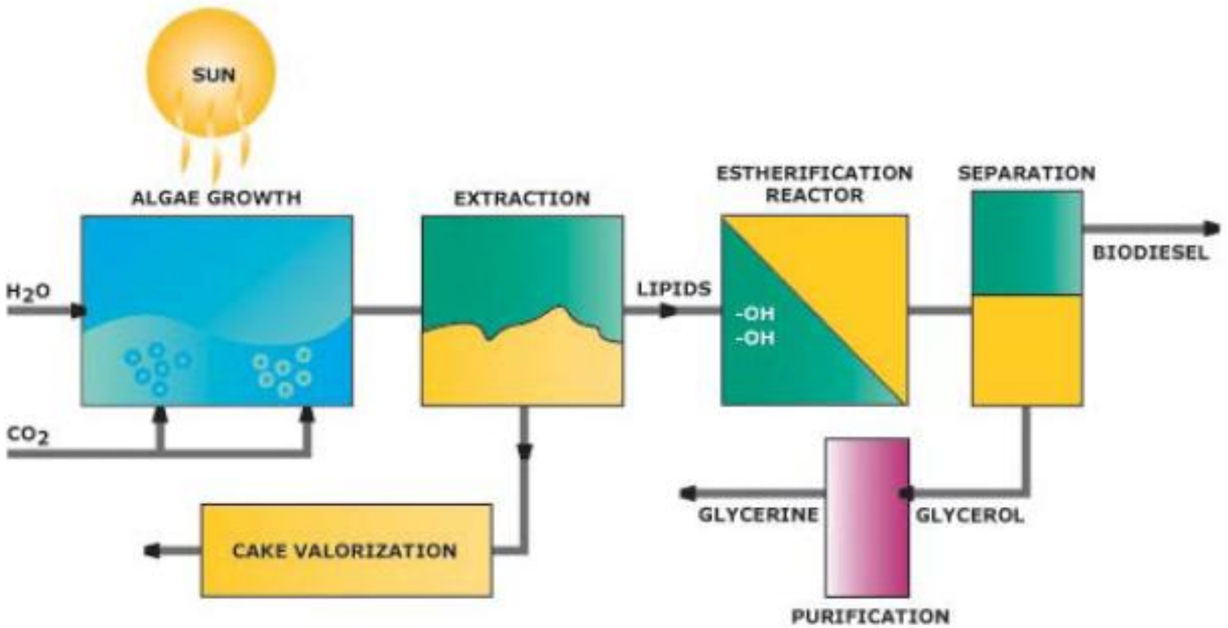


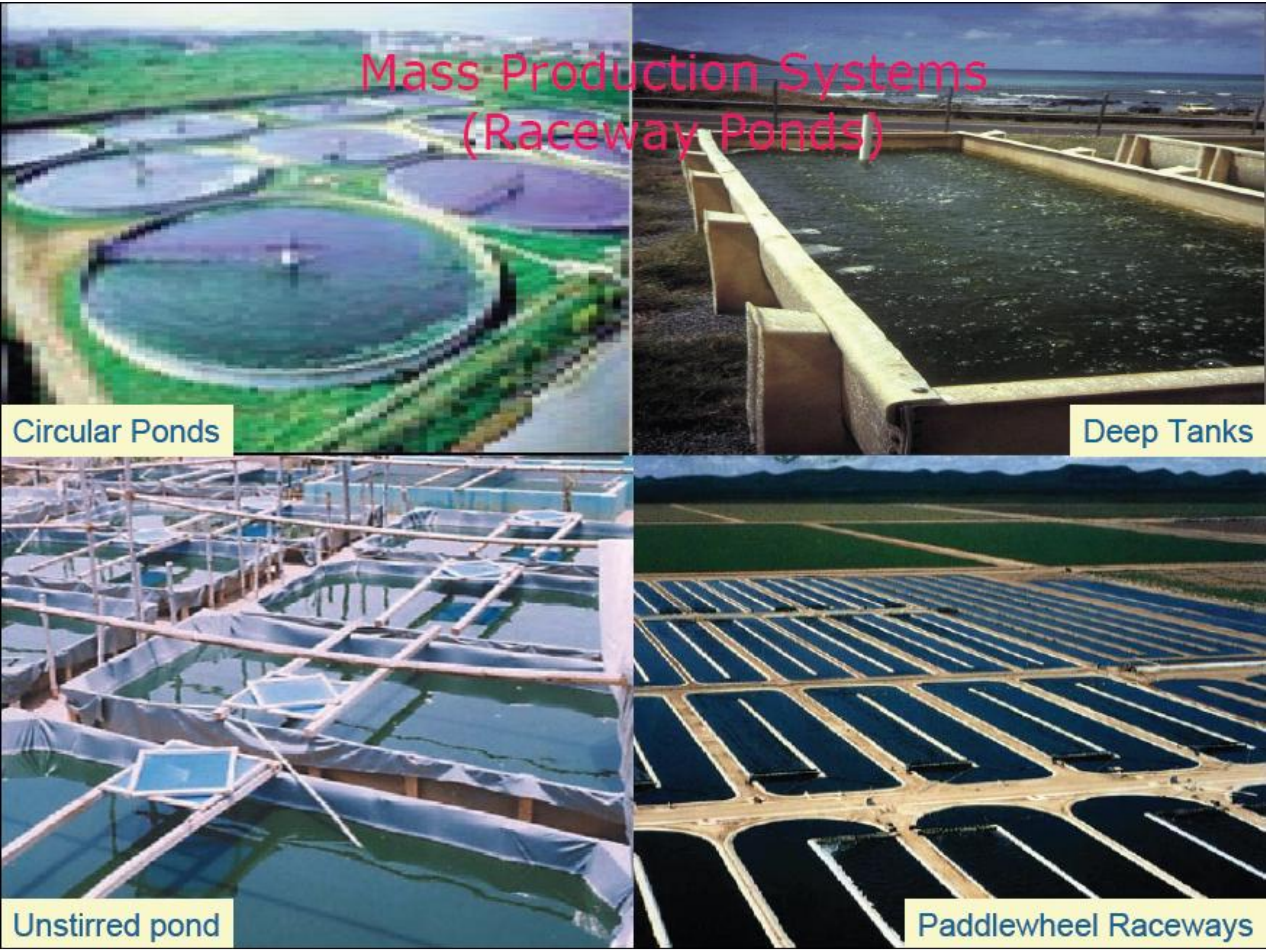
Photo-bioreactor
Flocculant settling tank
Wet Algae paste with NO oil
or
or
Centrifuge
Filter
Wet Algae paste
Water
Algae
CO2
Nutrients
Feeding vessel & monitoring unit
Crude Algae oil
Wet Algae paste with cracked cells
Oil extraction from wet algae paste
1
2
3
4
5
6
7
8
9
10
www.algaelink.com
®&© AlgaeLink NV
www.algaelink.com

Production of Biodiesel from micro-algae



AirScience BIOFUELS

Mass Production Systems (Raceway Ponds)



PHOTOBIOREACTORS

Stirred Tank Reactor

Bag Culture

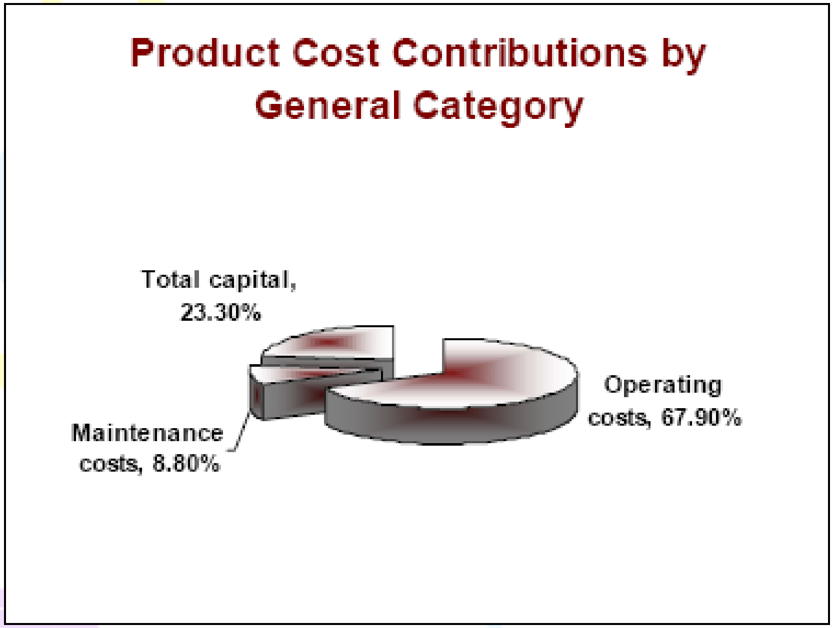
Airlift Bioreactor

Tubular Reactor

Raceway Ponds vs. Photobioreactors

- 13-fold high biomass productivity and higher oil yield per hectare in photobioreactors.
- Recovery of biomass is also an important issue.
- Total area need for photobioreactor is smaller.

Economic Analysis of Microalgae Production



- Economic potential can be judged by assessing individual cost centers.
- General cost distribution for total product cost:
  - Operating costs: 68%
  - Capital costs (depreciable and non-depreciable): 23%
  - Maintenance costs: 9%

How to reduce the cost for algal biofuels?

To find microalgae that

- Contain high lipid content
- Grow fast
- Utilize flue gas (CO_2 from power plant)
- Utilize waste water (nutrients)

Bottlenecks

- Energy for mixing
- Productivity/photosynthetic efficiency
- Lipid productivity
- CO_2 fixation
- O_2 production → **Produced oxygen is toxic**
- Making use of waste nutrients
- Biorefinery: fractionation of proteins
- Harvesting
- Extraction
- Production scenarios

High CO2 influx can decrease the pH

AGROTECHNOLOGY & FOOD SCIENCES GROUP

WAGENINGEN UR

Algal slurry ready for harvest

Dec 2005: 1st Car in world to run Algae Biodiesel
~10/90 algae biodiesel/soy biodiesel >1500 km

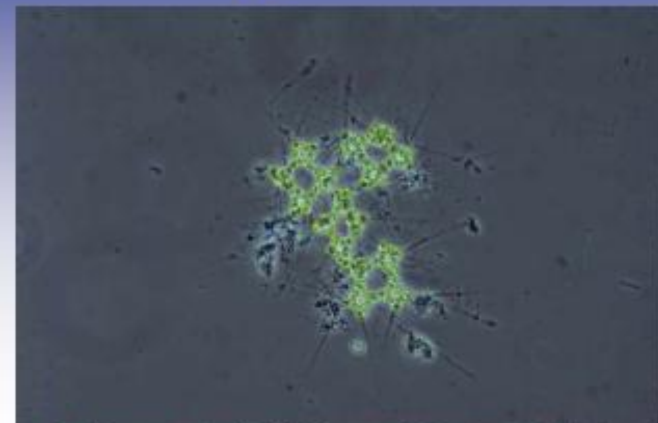
Microalgae harvesting

Traditional bulldozer approach:

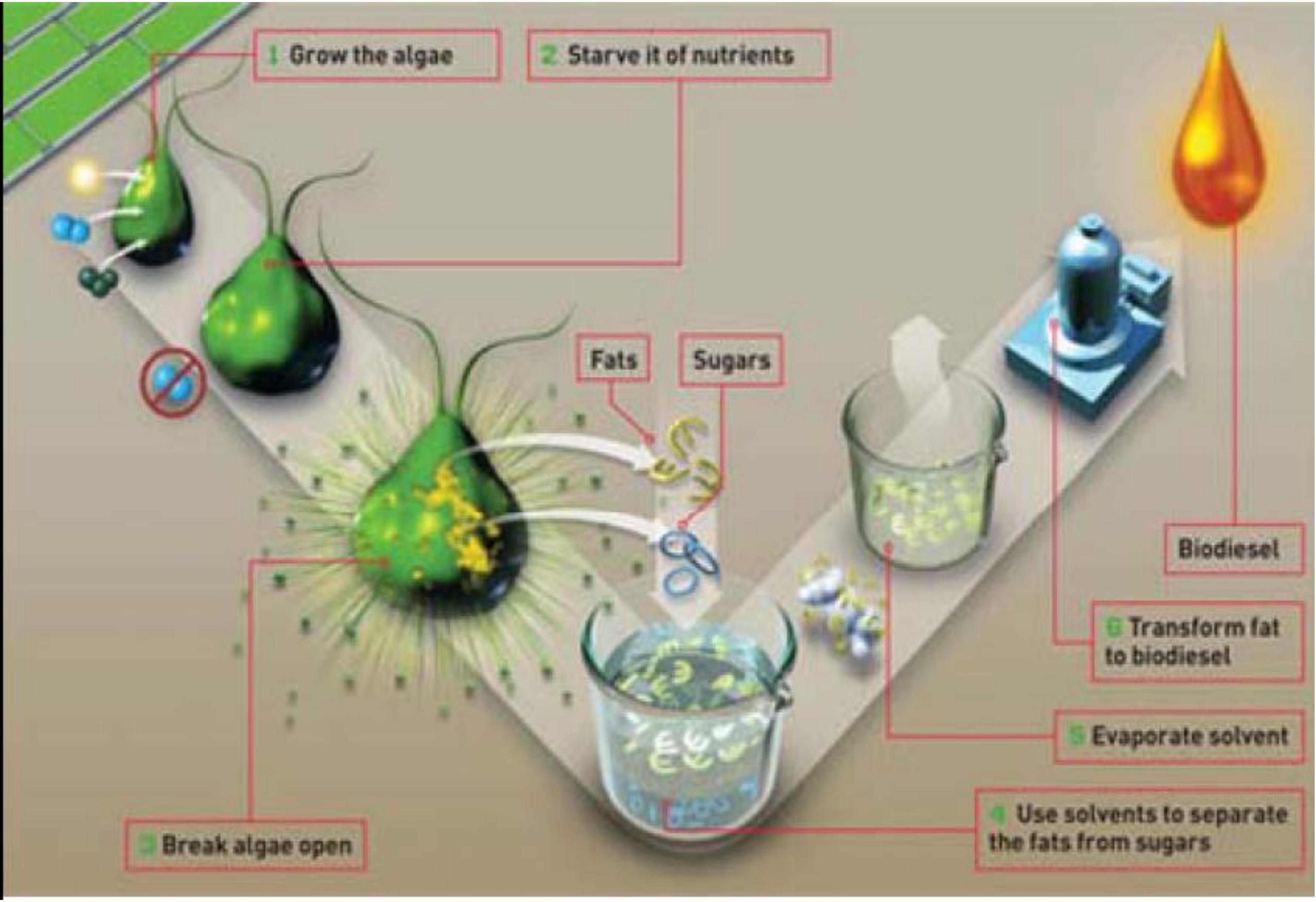
- » Chemical flocculation
- » Centrifugation
- » Filtration
- » Dissolved air floatation

Future approach:

- » Biofloculation
- » Micro-filtration
- » Activated algae



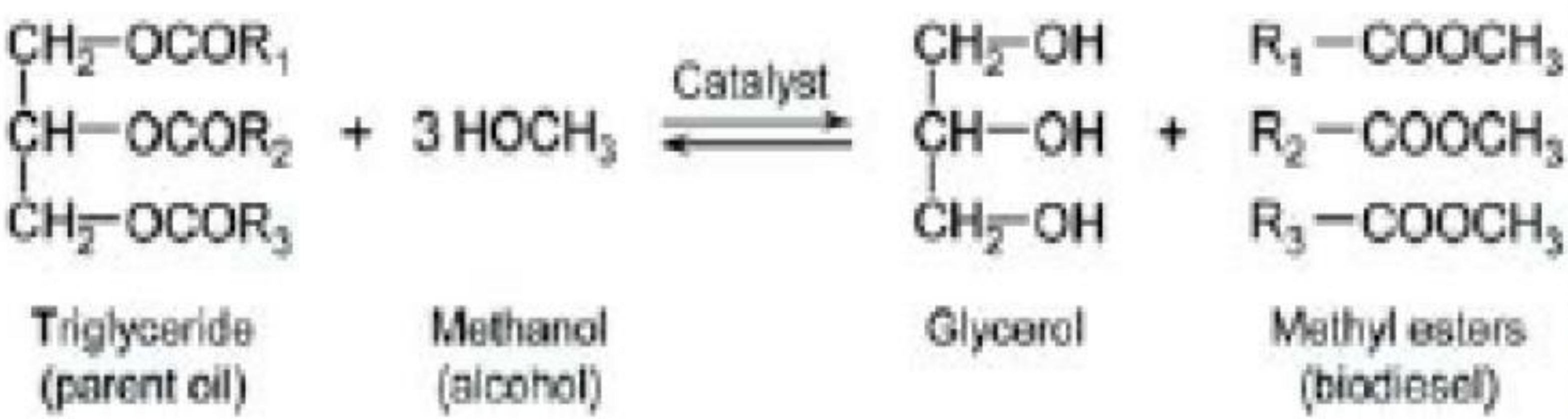
Oil Collection and Refining



1 Grow the algae
2 Starve it of nutrients
Fats
Sugars
Biodiesel
6 Transform fat to biodiesel
5 Evaporate solvent
4 Use solvents to separate the fats from sugars
3 Break algae open

Biodiesel Production

- Transesterification of oil to biodiesel. R_{1-3} are hydrocarbon groups.
- Catalysts: acids, alkalis, lipase enzymes



Pressing oil from the algae

- Dry the algae and press the oil from it.
- Can retrieve up to 70% of the oil.
- While drying must prevent the algae from becoming contaminated.
- Cheapest and simplest method

Chemical Oil Extraction

- Use hexane solvents to remove the oil.
- Hexane is a neurotoxin.
- Must be careful when using.
- Removes oil out of almost all things.

http://forums.biodieselnow.com/topic.asp?TOPIC_ID=3414

Super Critical Oil Extraction

- Most efficient method.
- Uses carbon dioxide at critical pressure and temperature (CO_2 is almost a liquid).
- Carbon dioxide.
- Rapid diffusion of the oil.
- Very expensive process.

http://www.organix.net/organix/supercritical.htm

Conclusion

- Algae is a very efficient means of producing biodiesel
- The oil production from algae farms is feasible and scalable
- Further research necessary to unlock full potential of algae
- Contribute morethan 4% of fuel consumption in USA by 2010