



Algae to biodiesel: Turning a question into an answer

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<http://www.vcerc.org/>



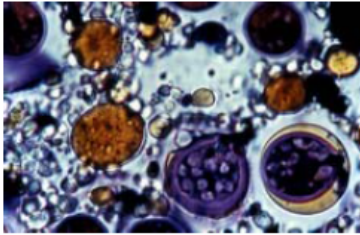


Biomass from Algae for the production of biodiesel

NREL/TP-580-24190

National Renewable Energy Laboratory

A Look Back at the
U.S. Department of Energy's
Aquatic Species Program:
Biodiesel from Algae



Close-Out Report

VCERC

Virginia Coastal Energy Research Consortium

Estimated cost: \$1.40 to \$4.40/gal

Or

\$60 to \$100 per barrel of oil equivalent

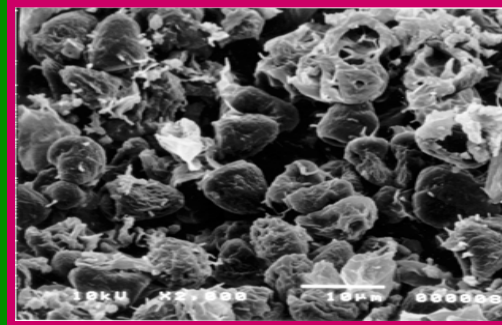
7.5 billion gallons of biodiesel per year requires 500,000 acres of water

At \$1/gal profit, the annual return would be \$7.5 billion

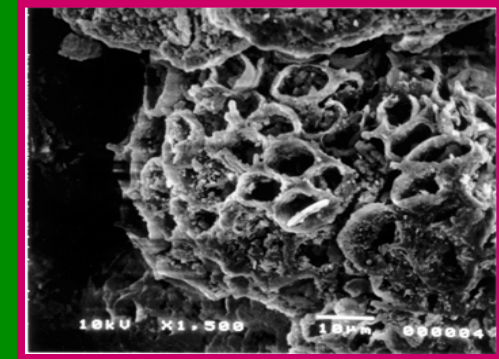
Why is it attractive ?

1. Algae are the original source of petroleum

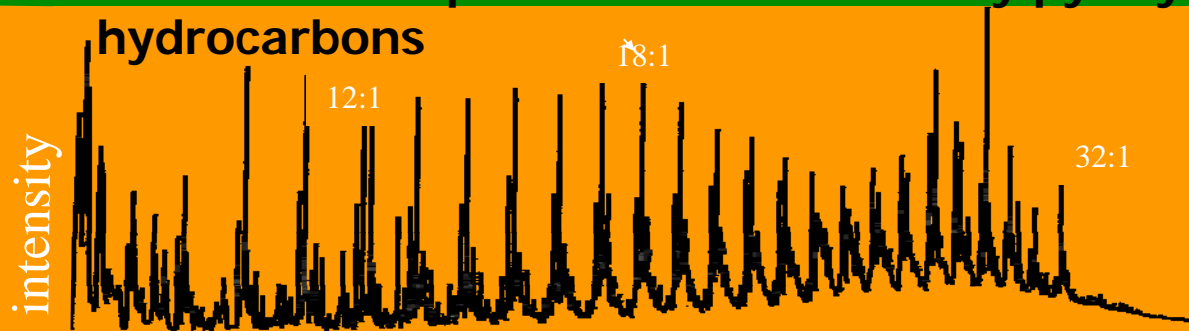
Cells during Growth



4-Million-Year-Old
Fossilized Cell
Walls



2. If we simulate petroleum formation by pyrolysis, we produce hydrocarbons



Pyrolysis/GC/MS
chromatogram of algae

3. that resemble petroleum

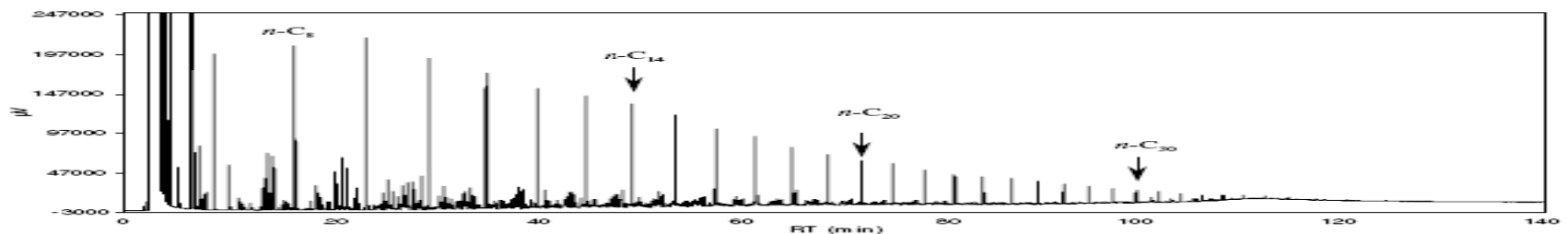


Fig. 1. GC trace of the total Safaniya oil.

Why Is It Attractive?



1. Algae outperforms all other plant-based sources of alternative fuels

Gallons of Oil per Acre per Year

Corn	15
Soybeans	48
Safflower	83
Sunflower	102
Jatropha	175
Rapeseed	127
Oil Palm	635
Microalgae*	1,850
Microalgae**	5,000 – 15,000

% of Agricultural Land Required to Fuel US Transportation

CORN	1,700 %
SOYBEANS	650 %
CANOLA	240 %
JATROPHA	154 %
COCONUT	108 %
OIL PALM	50 %
MICROALGAE	2 – 5 %

2. Does not require agricultural land, competing with farm crops

* Actual biomass yields ** Theoretical biomass yields

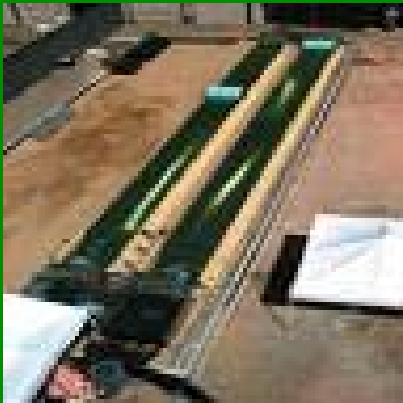
Oil Content of Some Microalgae

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

From : Chisti, Y. 2007. Biodiesel from microalgae. *Biotechnology Advances* **25** 294–306

Why is it attractive?

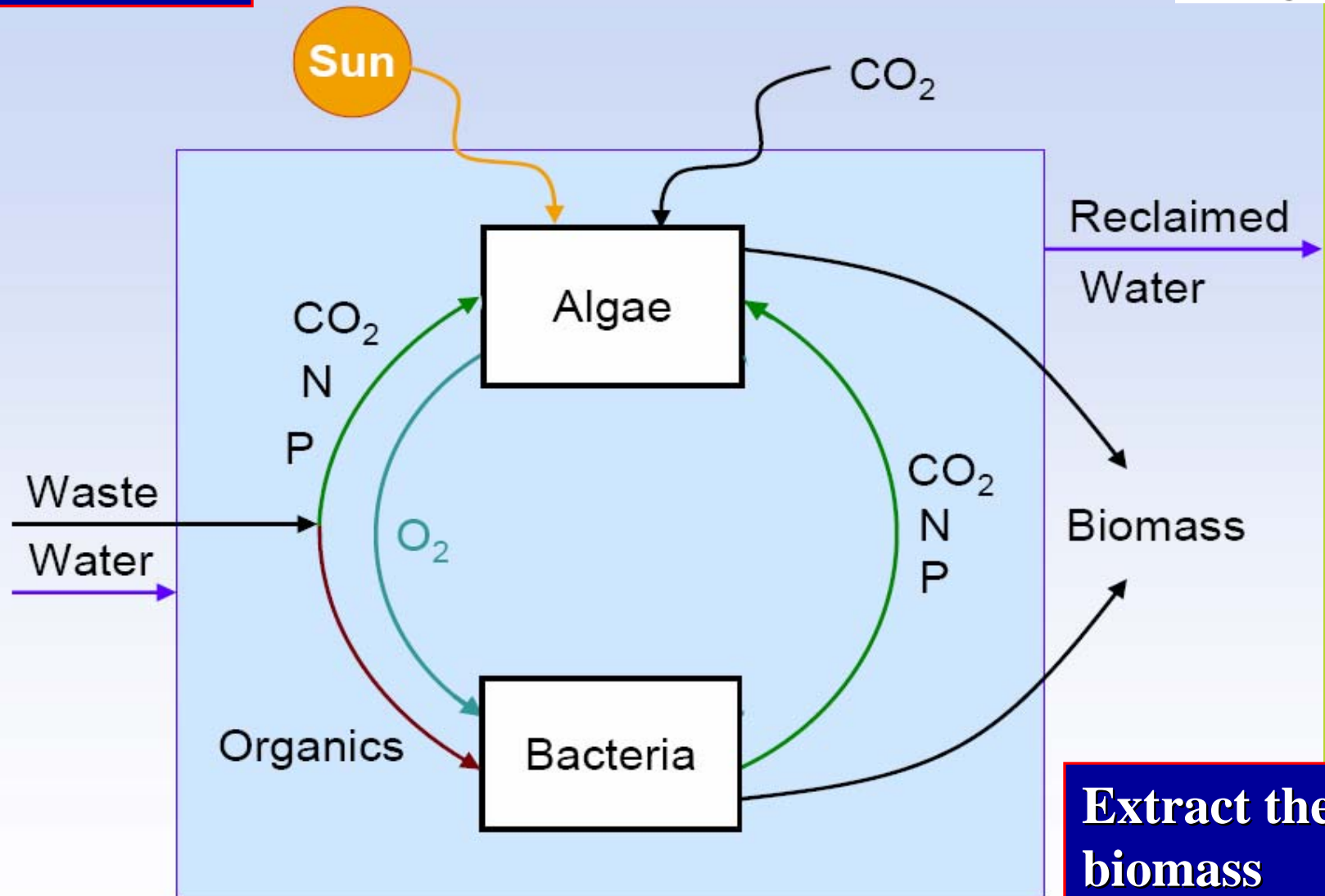
3. Algal production and ensuing biodiesel can be coupled with numerous industrial processes



- a. Electric power generation to reduce CO₂ emissions-carbon credits (algae need CO₂ as a carbon source to grow)
- b. Agricultural and municipal wastewater runoff to clean up nutrient-laden effluents (algae require the nutrients such as ammonia, phosphates, and nitrates for growth)
- c. Clean-up of algae from eutrofied waterways-can pump and filter algae for use as a feedstock for biodiesel

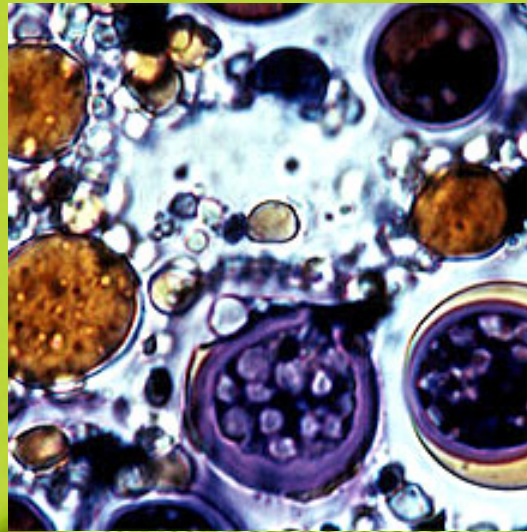
How It Works....

Grow the Algae



How It Works....

**Extract the
biomass**



**Extract the lipids =
“bio-crude” oil**

How It Works....

**Refine into bio-diesel and
other products**



What we (ODU, VCERC) are currently focusing on



Optimizing

Interfacing



Design Solutions

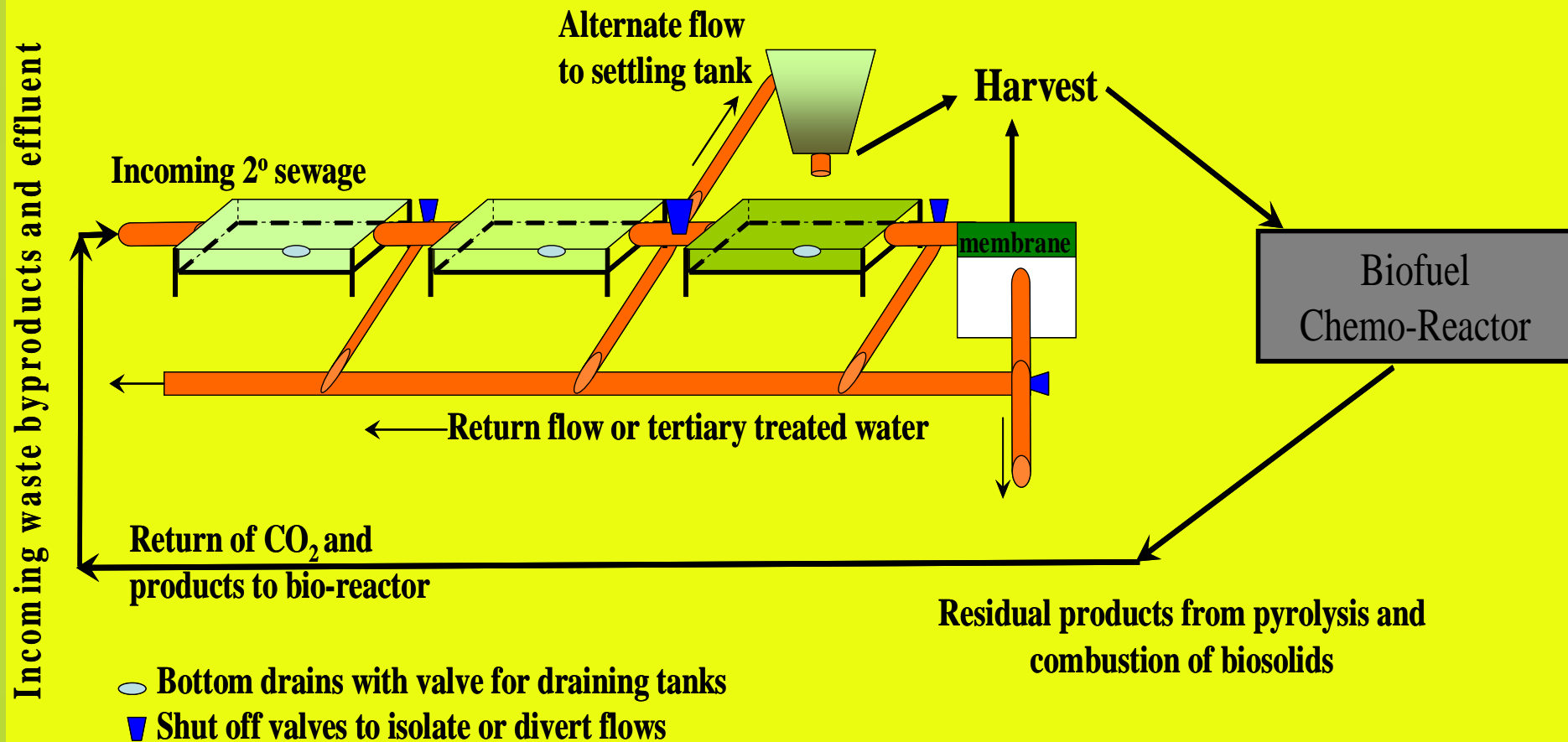


Scaling



The ODU strategy: production of algal biomass for conversion to biodiesel

Algae production coupled to wastewater





Test Facility:
**Virginia Initiative
Plant**
**Hampton Roads
Sanitation District**

Pilot-Scale Reactors at VIP

- Biomass production rate
- Nutrient uptake
- Balance gas transfer (CO_2 input O_2 stripping)
- Instrumentation and controls
- Separation/dewatering



Concurrent laboratory
culturing ongoing using
VIP effluent

Accomplishments:

- 1. Pilot-scale facility near Hopewell, VA- stand alone**
- 2. Build a similar facility at VIP plant- wastewater**



Stand-alone pilot-scale facility



Anticipated production:

3000 gallons biodiesel/yr/acre
9,000,000 kg biomass/yr/acre

\$ 980,000
\$3,200,000

Harvesting the algae

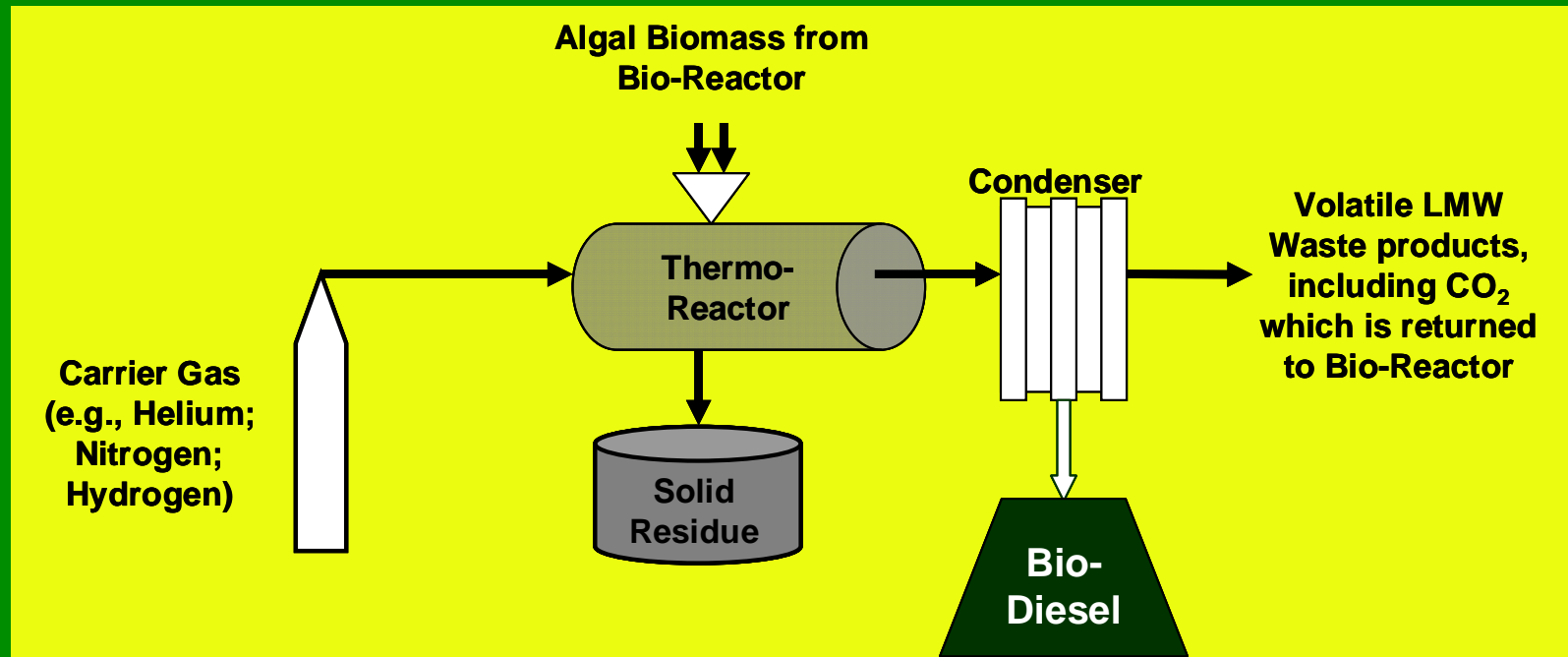


Continuous flow centrifuge
and other approaches

Algae paste



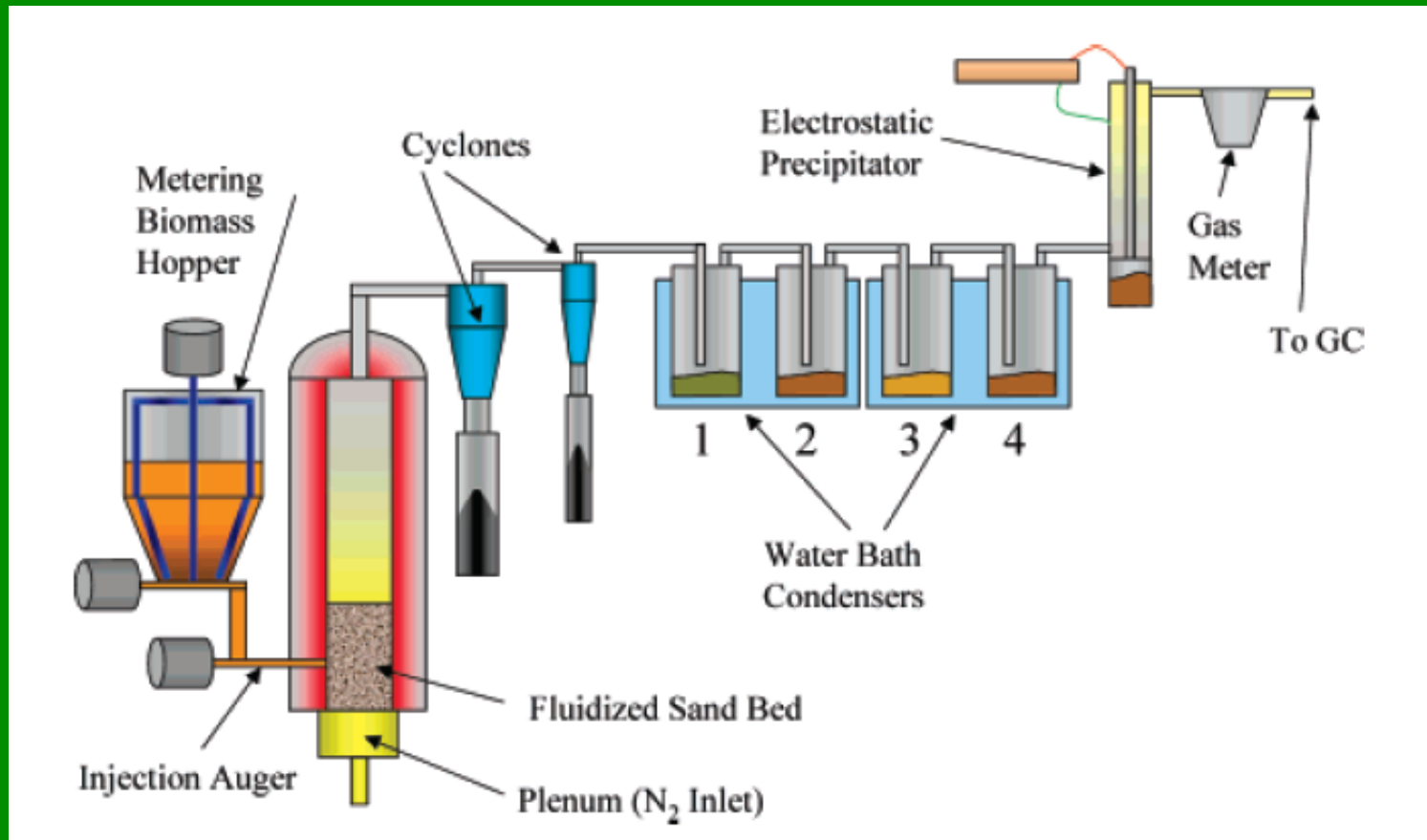
Batch-Mode Converter: for conversion of algal biomass to biodiesel-filed provisional patent



Seed funds from ODURF (\$50,000 in FY08) were used to develop “proof of concept” chemoreactor

Second generation flow-through converter

Fluidized bed converter being constructed from monies provided by ODURF and VCERC



Boteng et al., *Ind. Eng. Chem. Res.*, 2007

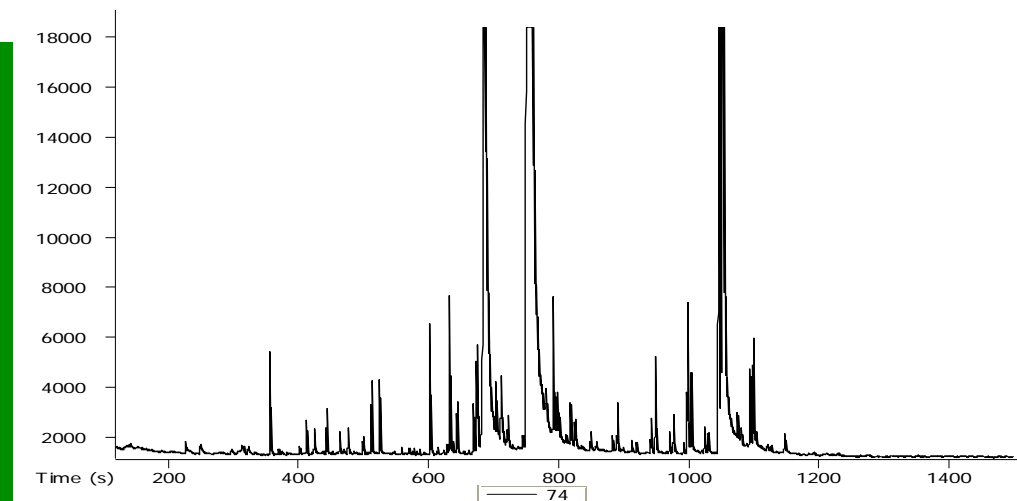
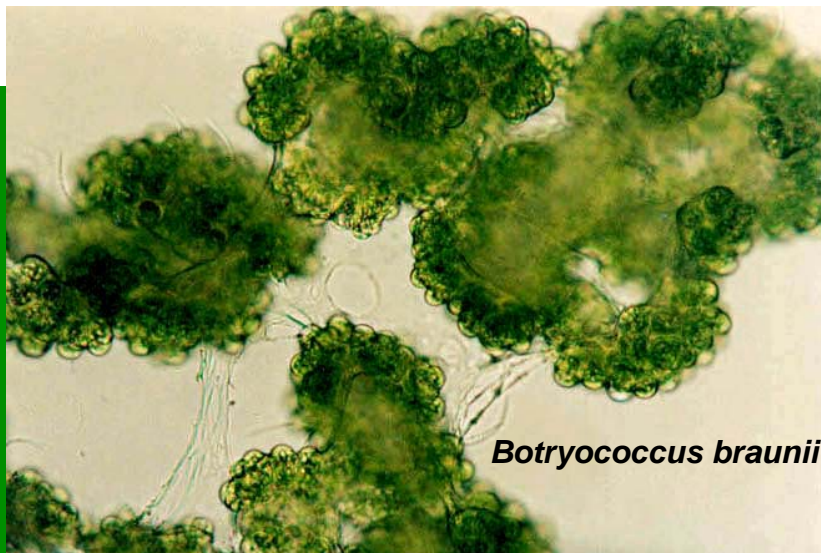
USDA, facility- being used for
switchgrass conversion to bio-oil

Biodiesel Production from Microalgae

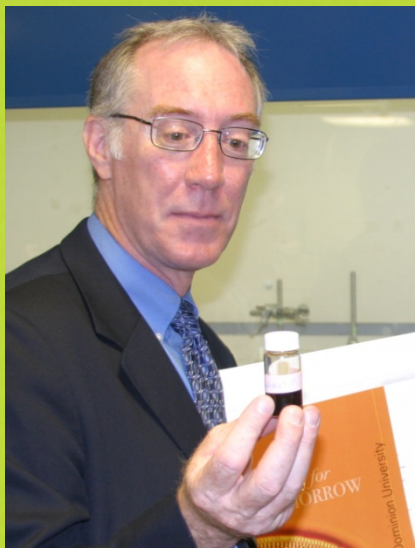
Table. Biodiesel production from different algae strains with a benchtop converter:

Type	Species	Oil-like yield
Protist (brown tide algae)	CCMP 1847	3%
Diatom	<i>Phaeodactylum tricornutum</i>	3%
Coccolithophorid	<i>Pleurochrysis carterae</i>	7%
Green algae	<i>Dunaliella</i> spp.	4%
Green algae	<i>Chlorella pyrenoidosa</i>	12%
Green algae	<i>Botryococcus braunii</i>	37%

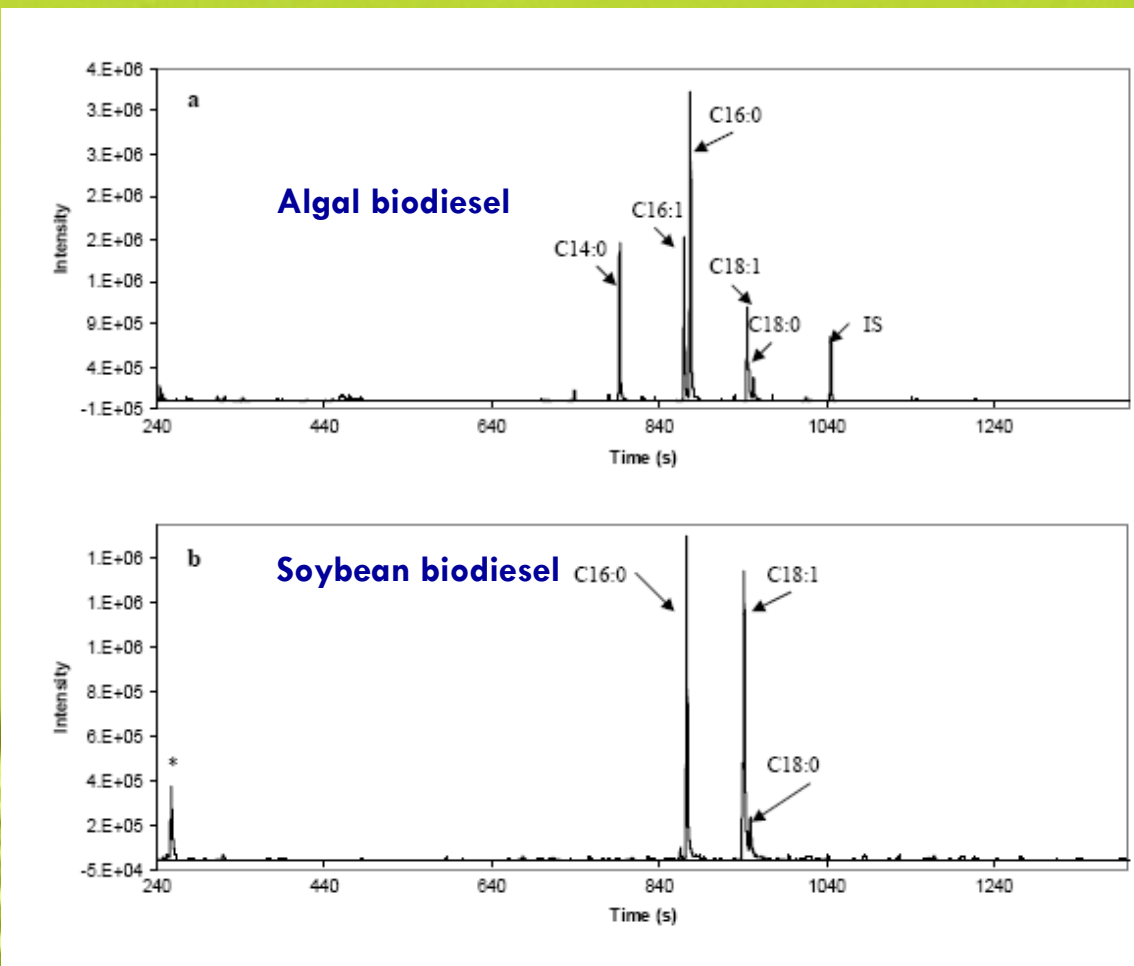
Our preliminary results demonstrate that *Botryococcus braunii*, a green algae strain from fresh water, produces the highest diesel yield using our converter.



- algae sample from Lake James, dominated by diatoms;
- soybean biodiesel is from a commercial biodiesel company;
- **Results: algae biodiesel is very similar chemically to commercial biodiesel**
- However, the procedure is tedious and time consuming. A better and faster method is needed.



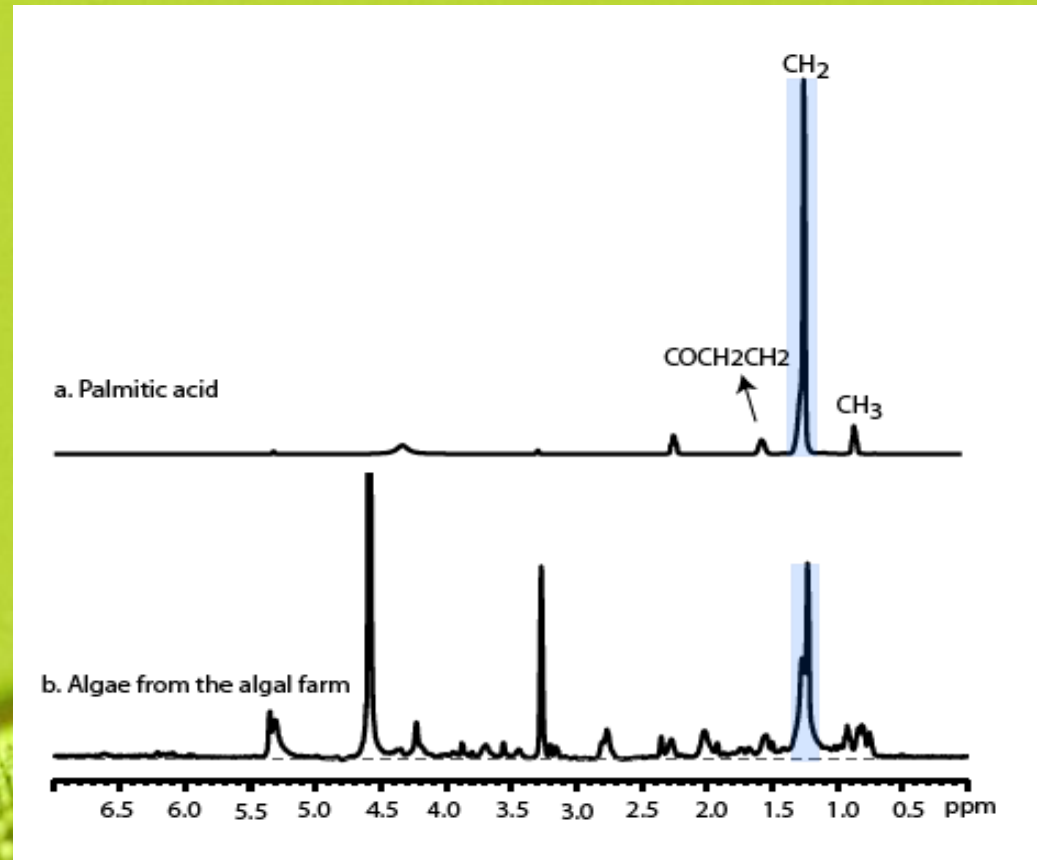
Quality of algae biodiesel



GC-TOF-MS analytical ion chromatograms

Use of Nuclear Magnetic Resonance (NMR) Spectroscopy

- This technique provides sharp signals, and only takes 30s to analyze a sample.

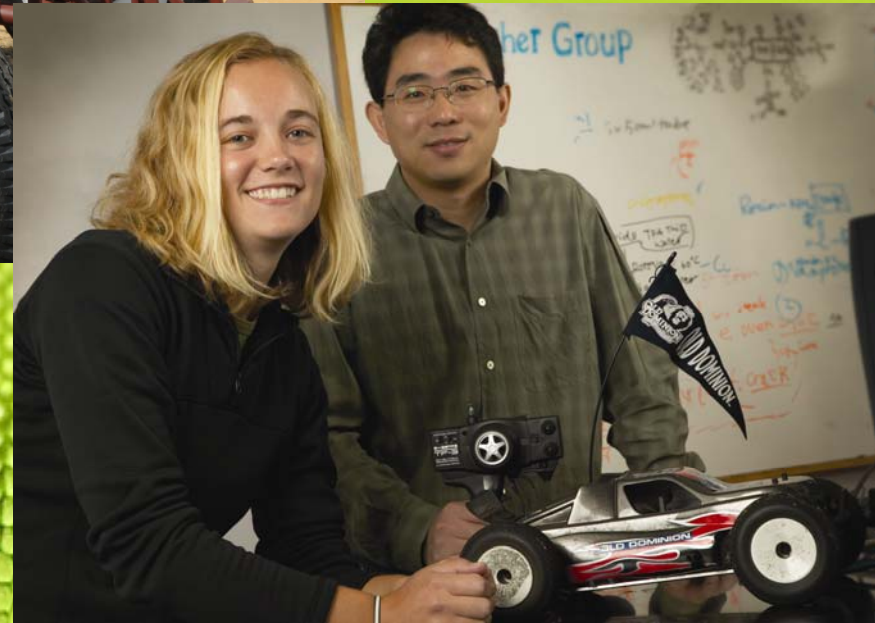


Proton NMR on a palmitic acid standard and an algal sample collected from the Hopewell algal farm.

Table 1. Oil contents (NMR) of algae collected from aquatic environment around Norfolk

Sample#	Location	Dominant Species	Oil content
6	Lake Smith	Cyanobacteria	22.4%
7	Lake Maury	Cyanobacteria	23.1%
9	Lake Whitehurst (west)	Cyanobacteria	23.9%
10	Lake Whitehurst (south)	Cyanobacteria	21.1%
11	Elizabeth River (ODU Sailing center)	Dinoflagellate diatom	42.1%
12	OAES pond	Cyanobacteria	13.3%
24	Lake Kempsville	Cyanobacteria	22.1%
27	Lake Christopher	Chlorophyte	20.0%
31	Elmwood Retention pond	Cyanobacteria	23.9%
VIP	ODU sewage treatment plant	Chlorophyte	31.2%
Big Blue	ODU Greenhouse	Chlorophyte	24.0%

Does the algal biodiesel work?



Current Activities

Constructing pilot-scale algal farms

1. Collaborative with HRSD VIP plant near campus- Tank farm
2. Collaborative with “algal” farmer in Hopewell, VA area



3. Collaborative with Hopewell, VA wastewater facility

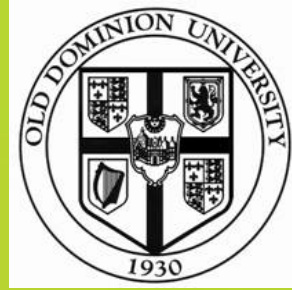
High throughput, second-generation chemoreactor under construction

Designing of harvesting technology (preparing IP disclosure)
Collaborating with Acent via SBIR

Possible Commercial Ventures

1. Algal biodiesel production for wastewater industry- \$40 million/yr profit
American Biofuels Corporation (ABC)- Donn Dresselhuys
2. Algal farming in stand-alone facilities- Algal Farms, Inc.- \$20 million/yr profit
3. Algal farming/large-scale for production of biofuels
 1. Use of Navy OLF site (20,000 acres)- \$50 million/yr profit
 2. In association with Danville/Southside wastewater facilities
4. Algal farming associated with Powerplants for CO₂ sequestration and fuels
BIOCO collaborative
5. Biodiesel production from algal/other feedstocks

Acknowledgements



ODU team

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