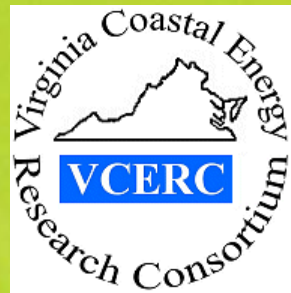


Algae: The next generation biofuel source

Patrick G. Hatcher, Executive Director VCERC

Batten Endowed Chair in Physical Sciences, Professor of Chemistry and Biochemistry, Old Dominion University

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





Virginia Coastal Energy Research Consortium



**Old Dominion University
Virginia Tech-ARI
University of Virginia
James Madison University
Virginia Commonwealth University
Norfolk State University
William & Mary (VIMS)
Hampton University
George Mason University**

Patrick G. Hatcher, Executive Director VCERC
Batten Endowed Chair in Physical Sciences, Professor of Chemistry and
Biochemistry, Old Dominion University

George Hagerman, Research Director VCERC
Senior Research Associate, Virginia Tech-ARI



Pilot Facility: in Spring Grove, Surry County, Virginia



ODU started operating a **1-acre pond** of parallel raceways in late September 2008

Pilot productivity will be **3,000 gallons** of biodiesel fuel per acre per year

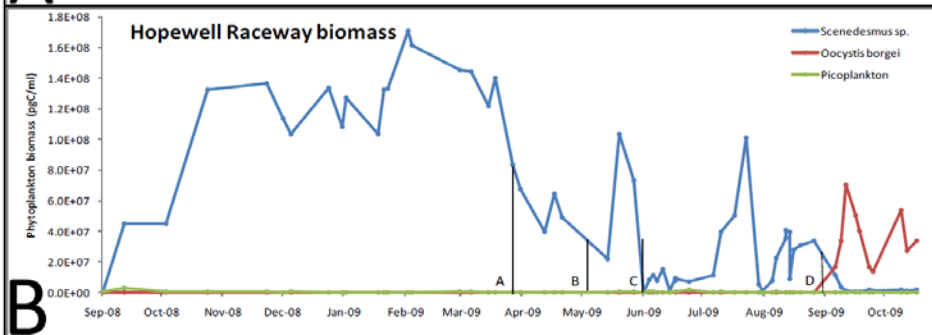
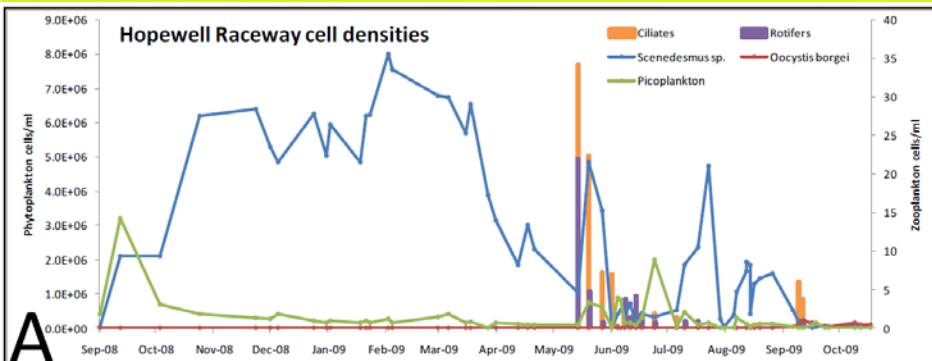
The next phase will expand pond area to **25 acres**, producing **75,000 gallons** per year by 2011

Periodic infusion of pure cultures from 500-gallon closed tanks along side of raceway will prevent take-over by invasive, oil-poor species



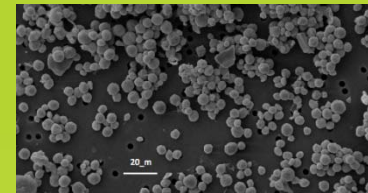


Growth Progression at Algal Farm 2008 - 2010



Two species of oil- and algaenan-producing algae:

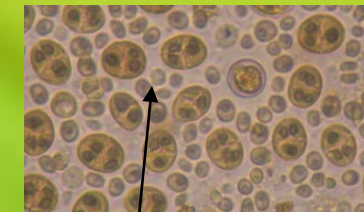
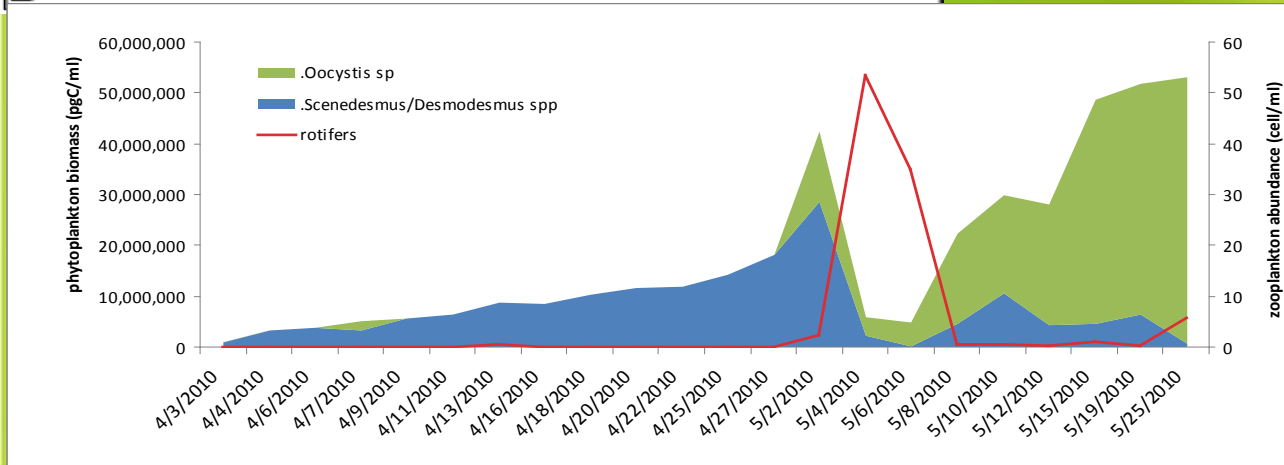
- *Scenedesmus spp.*
- *Desmodesmus spp.*



ODU greenhouse culture. *Desmodesmus* in 2 and 4 celled cenobia form with terminal spines



Desmodesmus in unicellular form without visible spines



Scenedesmus

Pilot-Scale Harvesting Process

1. Centrifugation



2. Coagulation, settling, and DAF

~10-20 g/L flocculated algae



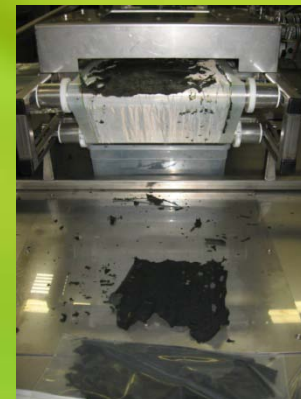
3. Drying – collaboration with AlgaeVentures Inc.



Micro-screen belt achieves complete dryness of the flocculated algae



Dried flake
(algae does not have to be 100% dry)

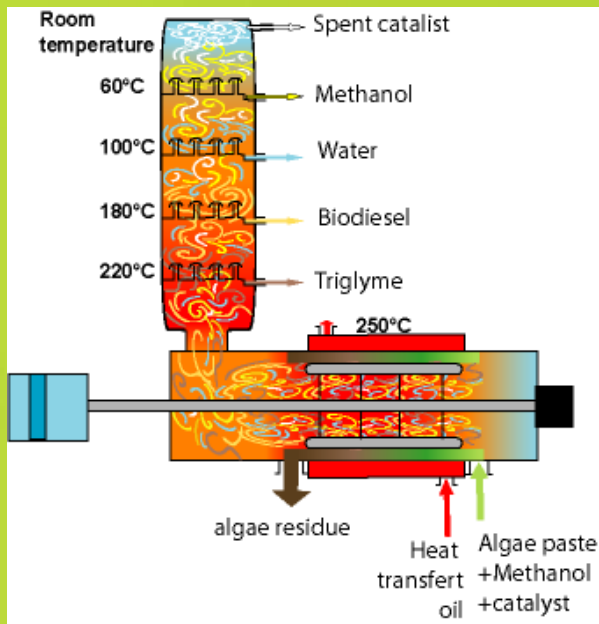


Conversion

Two pilot-scale conversion processes

1. Conversion to FAME biodiesel

Treat harvested algae directly in algaenator



FAME Biodiesel

By-product

Fertilizer

2. Conversion to Algae Crude for Jet Fuel

Treat to isolate algaenan

Pyrolysis

Liquid hydrocarbon-based Algae crude



Conventional refinery

Gasoline
 C_5-C_9

Kerosene
 $C_{10}-C_{15}$

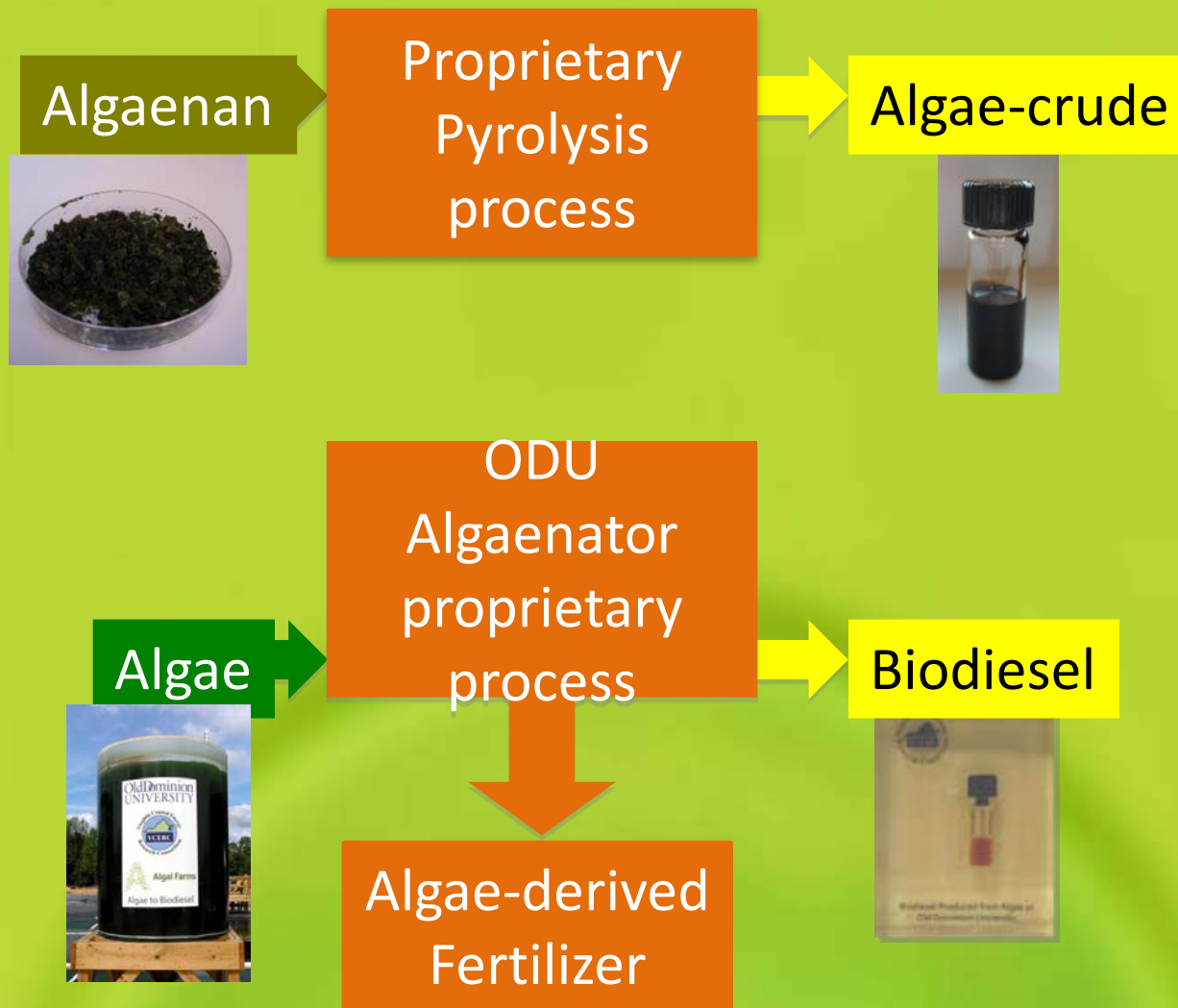
Diesel fuel
 $C_{16}-C_{18}$

Lubricating oil C_{19+}

Etc...



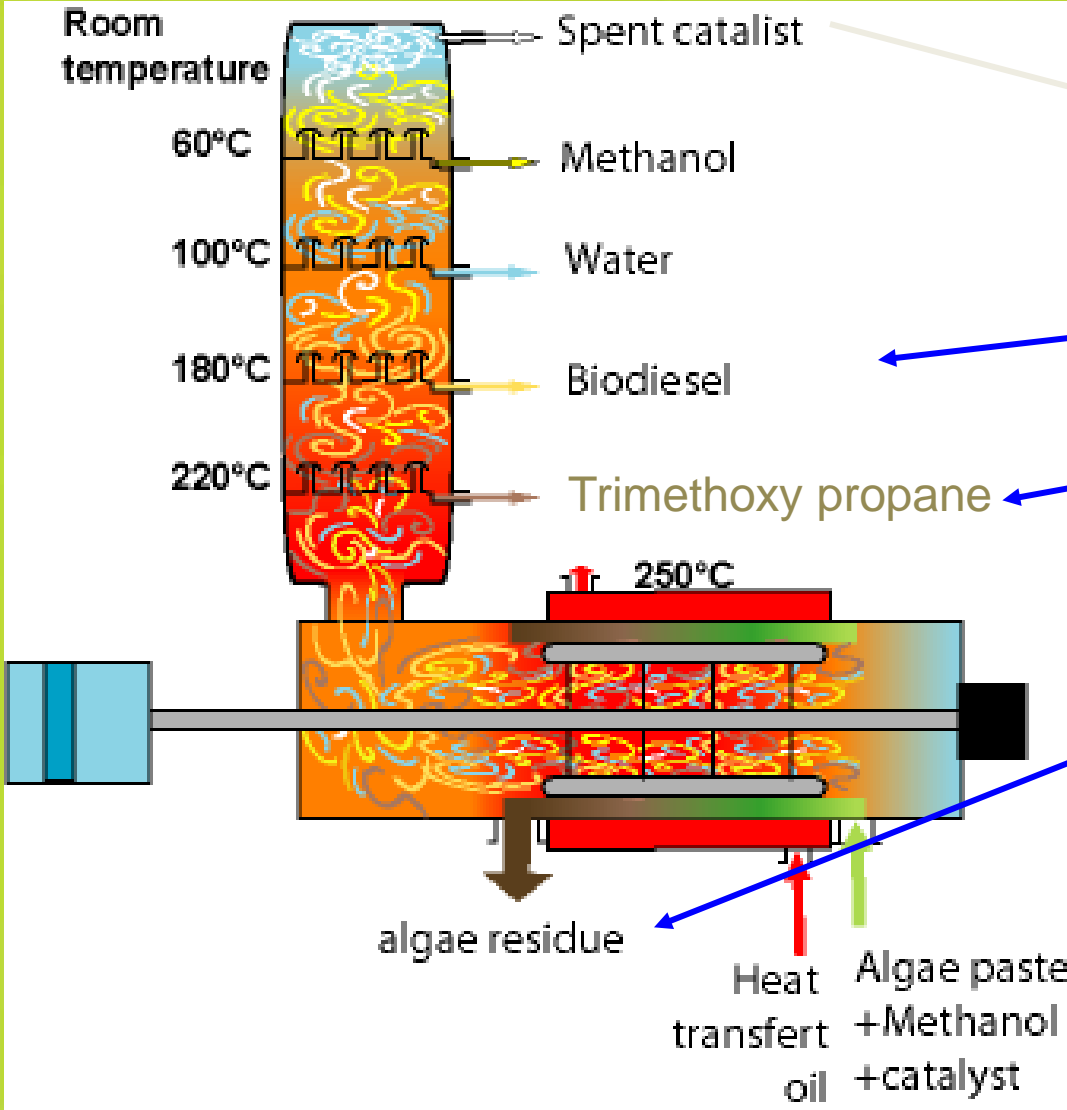
Two pilot-scale conversion processes





Strategy 1: Conversion to FAME biodiesel

New reactor being constructed, a wiped thin film reactor
DE-EE00000390



Regenerate catalyst

Fuel

Fuel additive

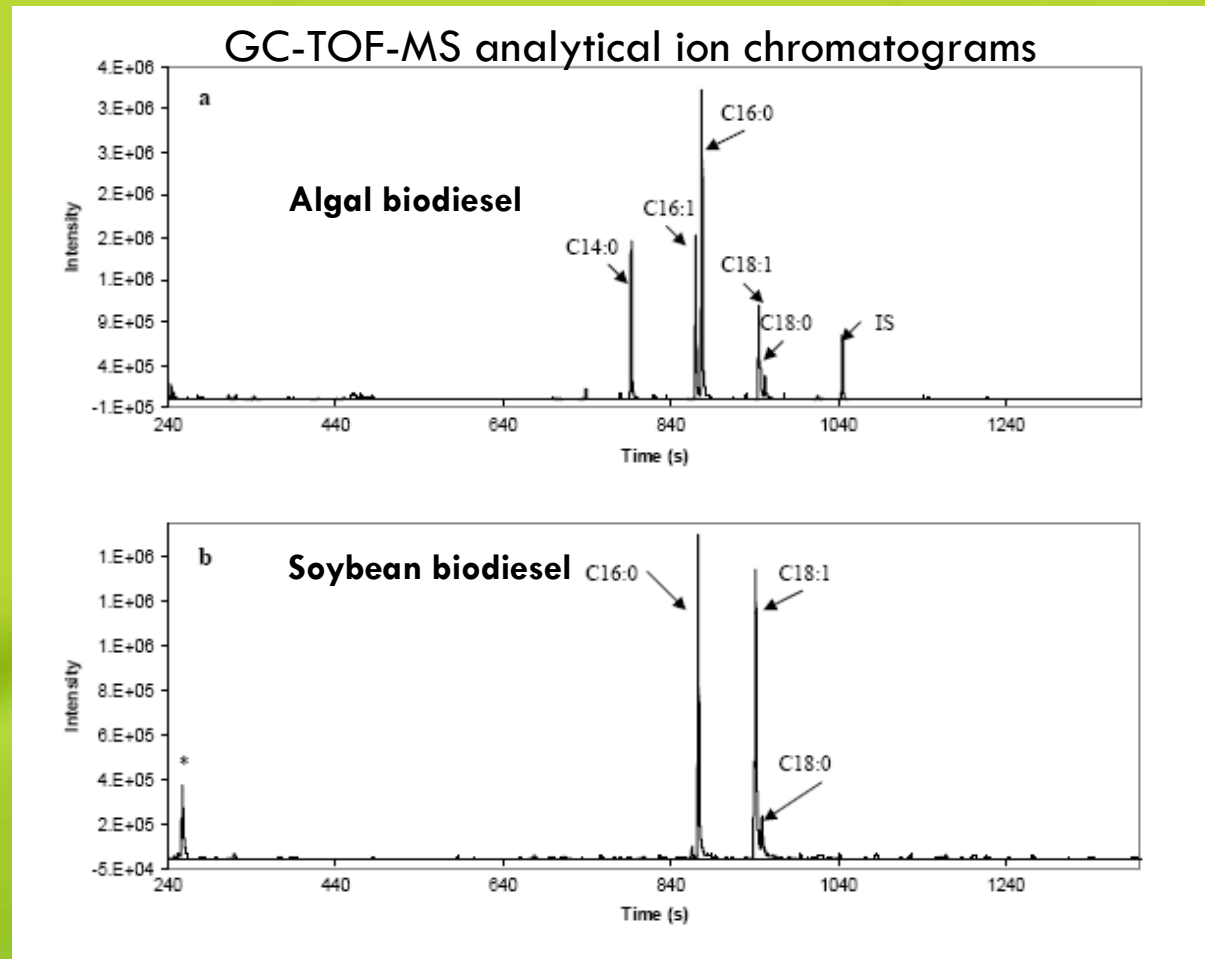
Fertilizer

Algaenator

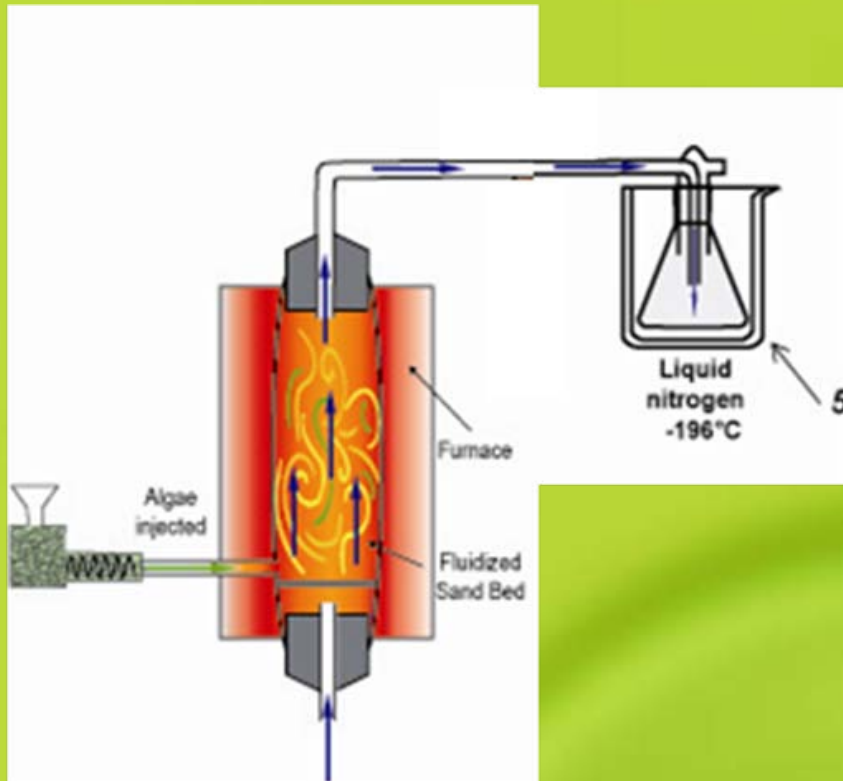


Quality of algae biodiesel

- 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**

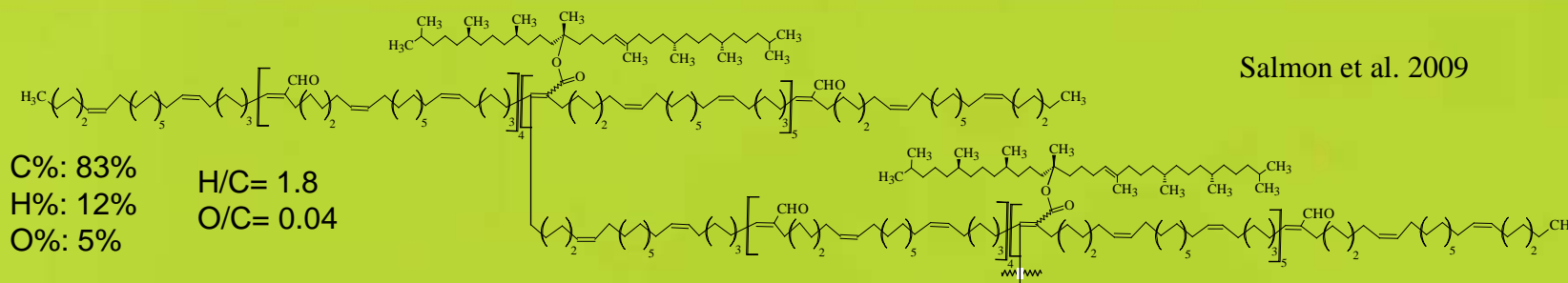


Fluidized bed Reactor



- Working progress: injection device and control of temperature
- Results are promising

What is algaenan?

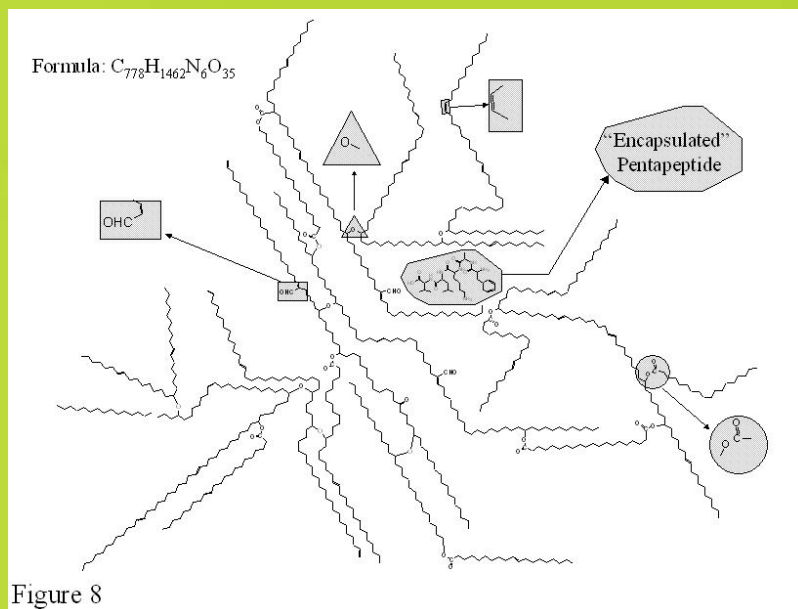


→ Aliphatic biopolymer containing ester and aldehyde functional groups

→ Resistant material :

Resistant to organic solvents, acid and basic treatments
Resistant to sedimentary processes like diagenesis

→ Fairly stable to temperature (< 300° C)
Precursor of petroleum



Zang 2001

C%: 76%
H%: 11%
O%: 10%

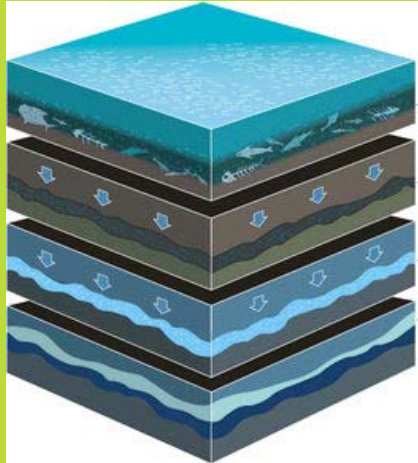
H/C= 1.7
O/C= 0.1



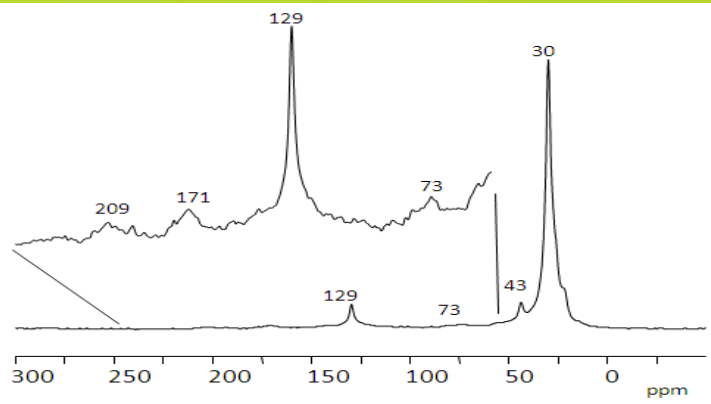
Algaenan is preserved in sediments and is the precursor of petroleum in reservoirs



Botryococcus Braunii



Solids NMR



Flash pyrolysis/GC/MS

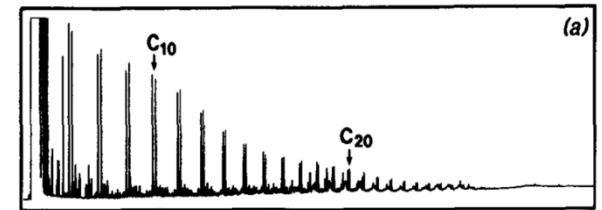
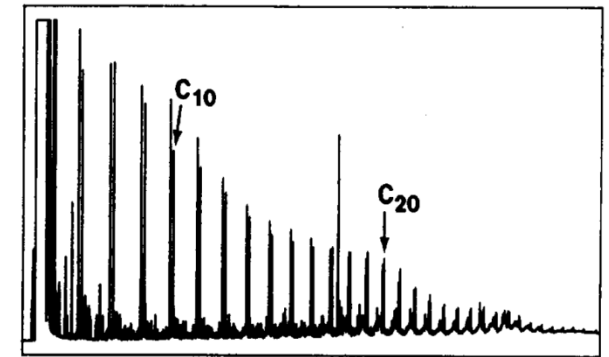
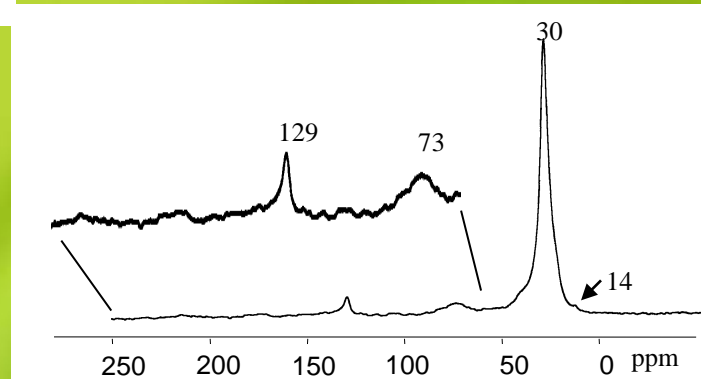
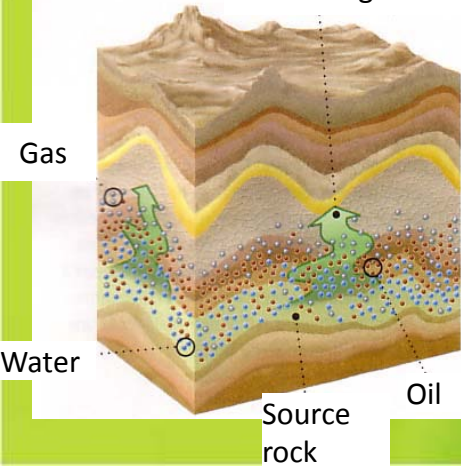


FIG. 1. GC traces of the C₇ hydrocarbon fraction of pyrolysates of PRB A (a), PRB B (b) and PRB L (c) isolated from extant *B. braunii* (II: *n*-alkanes/*n*-alk-1-ene doublets).

Derenne et al. 1994

Oil-prone Pula kerogen

Fluids migration



RETENTION TIME

FIG. 5. GC trace of the C₇ hydrocarbon fraction of the Tertiary Pula Torbanite pyrolysate.

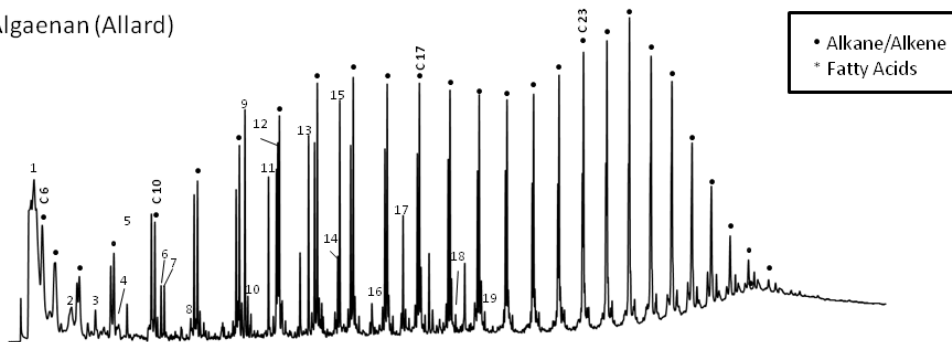
Derenne et al. 1994

Isolation of Algaenan

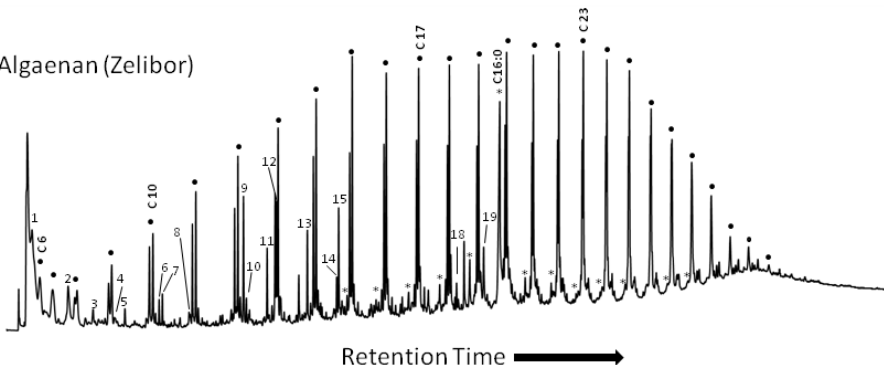
Lab testing from literature data

Flash pyrolysis/GC/MS

Algaenan (Allard)



Algaenan (Zelibor)



Peak Number	Corresponding Compound
1	1-Hexene
2	1-Heptene
3	2,6-Dimethyl-2-Heptene
4	3,7-Dimethyl-2-Heptene
5	3,6-Dimethyl Octane
6	4-Methyl-1-Decene
7	2,6-Dimethyl Nonane
8	Dodecadiene
9	2,6-Dimethyl Unidecane
10	2,5-Dimethyl-2-Unidecane
11	C14 Alkane Isoprene
12	C14 Alkene Isoprene
13	2,6,10-Trimethyl Dodecane
14	4,8,12-Trimethyl Trimethyl-1-ene
15	C16 Isoprene
16	4,11-Dimethyl Pentadecane
17	2,6,10-Trimethyl Pentadecane
18	5-Octadecene
19	1-Nonadecene

Resemble petroleum

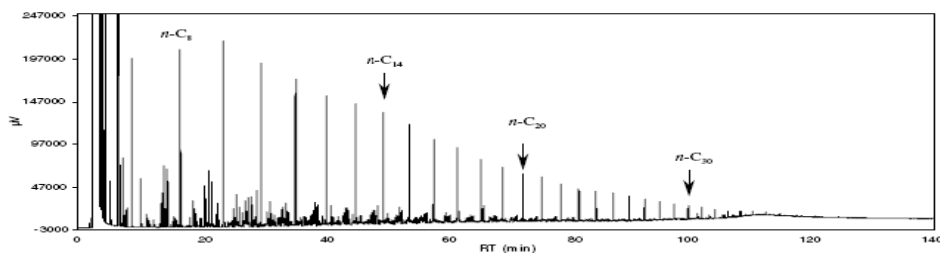


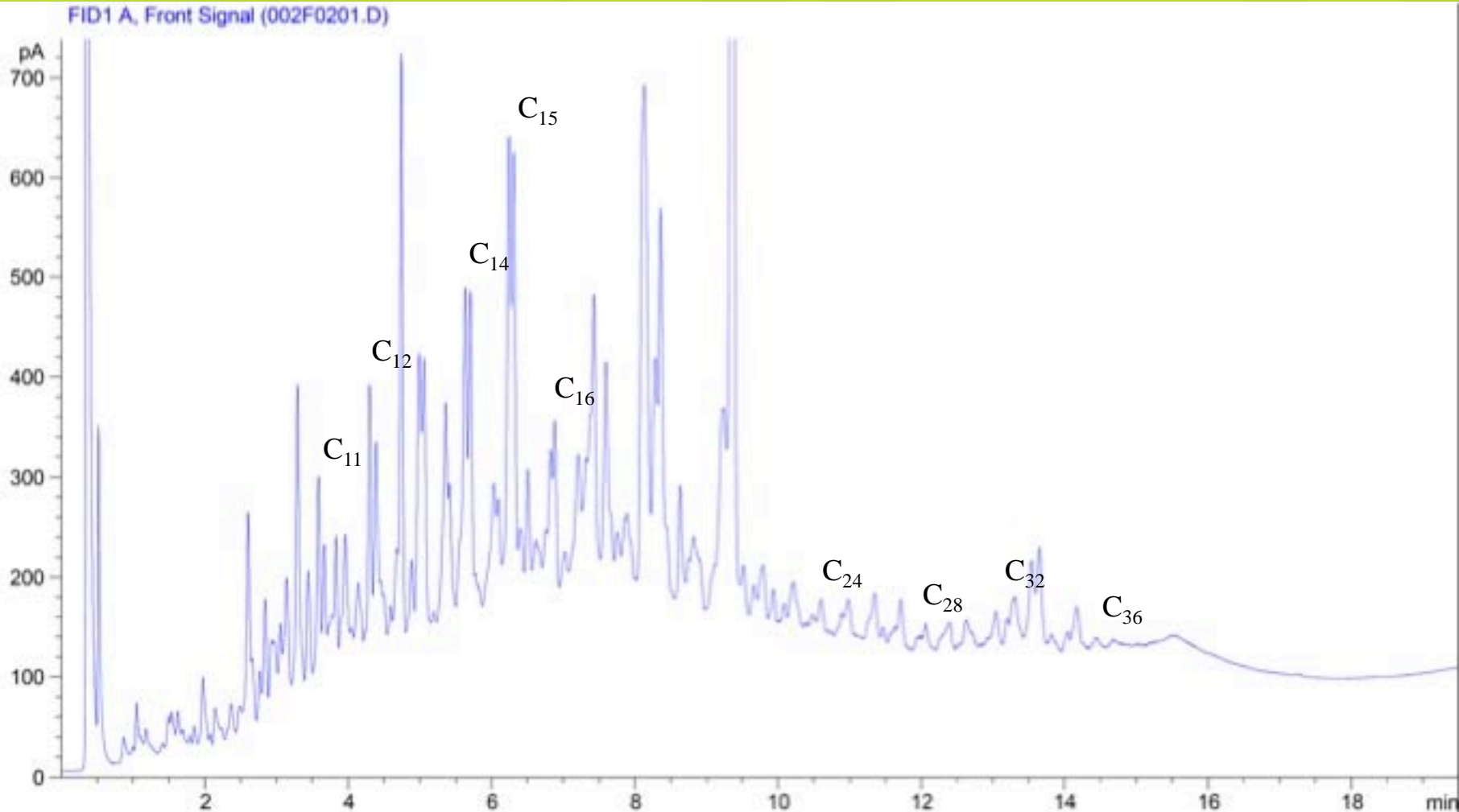
Fig. 1. GC trace of the total Safaniya oil.

=> Algaenan pyrolyzate contains essentially hydrocarbons



Concentrated Algaenan → oil potential

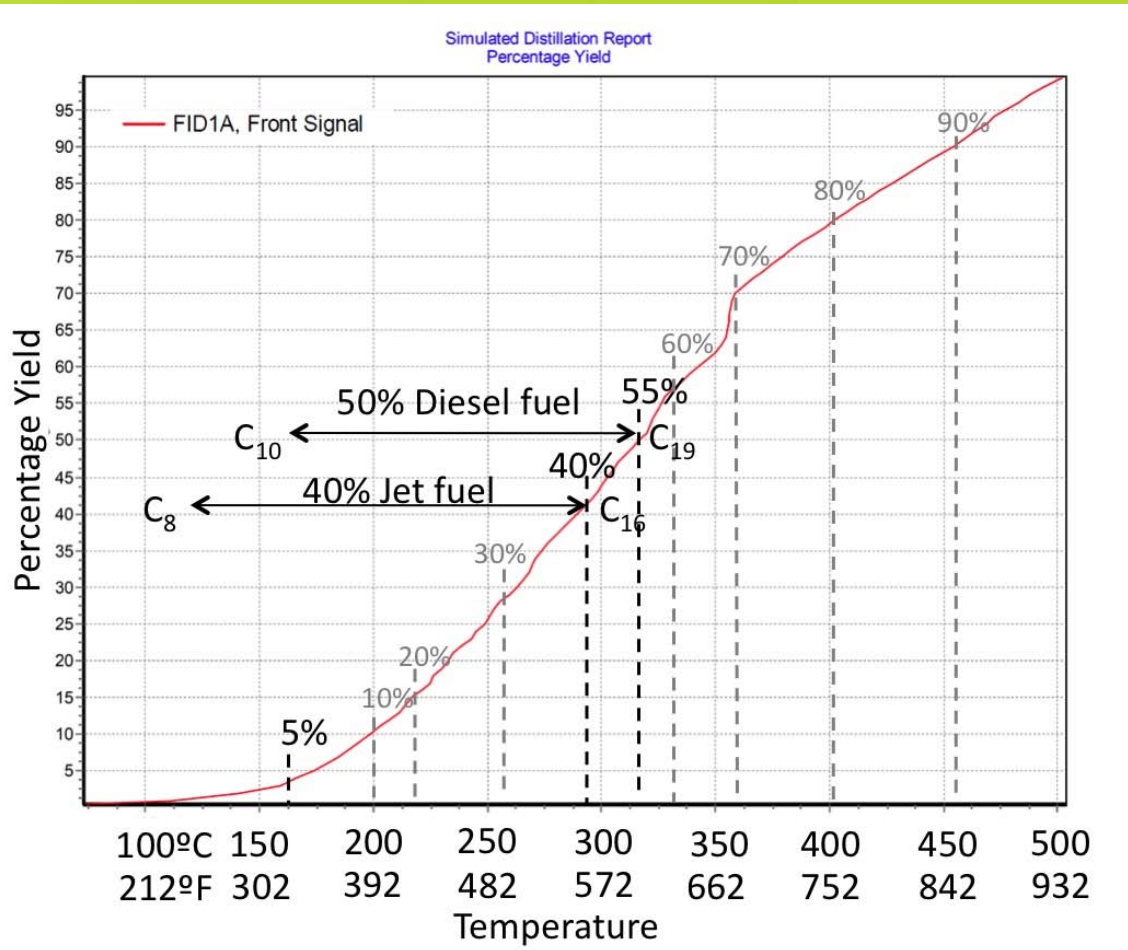
Simulated distillation of algae crude





Concentrated Algaenan → oil potential

Simulated distillation of algae crude



	Temp.	(Deg.C)	(Deg.F)
IBP:	0.50%	73	163
	5.00%	174	345
	10.00%	199	390
	15.00%	217	423
	20.00%	233	451
	25.00%	249	480
	30.00%	263	505
	35.00%	274	525
	40.00%	289	552
	45.00%	302	576
	50.00%	317	603
	55.00%	327	621
	60.00%	342	648
	65.00%	355	671
	70.00%	359	678
	75.00%	379	714
	80.00%	402	756
	85.00%	427	801
	90.00%	454	849
	95.00%	477	891
FBP:	99.50%	503	937



Concentrated Algaenan → oil potential

Simulated distillation of algae crude



Crude oil	Yield at temperature (°C)					% <720°C (<1328°F)	% >720°C (>1328°F)
	10%	20%	50%	70%	90%		
ODU Algae-Crude	199	233	317	359	454	100	0
Arabian Light	126	177	341	459	627	94	6
RAS Burden Medium	141	229	431	559	696	88	12
Sahara Blend Extra Light	95	135	258	359	530	100	0
Summatran light Waxy	158	234	401	494	663	94	6
Alba Heavy	253	307	449	550	688	93	7



Where do we go from here?



1. Need to build a pilot pyrolysis reactor to further develop our innovative drop-in fuels from algae research.
2. Expand to a 10+ acre production facility (Algae Research Center) where we can demonstrate commercial viability.
3. Develop a business partnership with companies willing to commercialize the activity.
 - Algae to FAME biofuels + fertilizer
 - Algae to biofuels + wastewater cleanup
 - Algae to drop-in biofuels (FAME and Algae Crude)



Acknowledgements

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Dr. Elodie Salmon, Postdoc, Chemistry & Biochemistry
Mr. Isaiah Ruhl, Research scientist
Richard Hubbard, Senior Technician
Adair Johnson, Technician, Chemistry & Biochemistry
Charles Denny, Chemical Engineer, retired, part-time

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JMU team

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UVA team

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HU team

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