Biofuels & Bioenergy: A Changing Climate

IEA Bioenergy, U. British Columbia, August 24, 2009

MICROALGAE BIOFUEL ECONOMICS

John R. Benemann,
Tryg Lundquist and Ian Woertz
Benemann Associates, MicroBio Engineering, Inc. and Cal Poly (Walnut Creek and San Luis Obispo, CA)
jbenemann@aol.com

Biofuels and Bioenergy: Challenges and Opportunities
IEA Bioenergy, UBC, Vancouver, Canada, August 28, 2006

ETHANOL FROM LIGNOCELLULOSIC BIOMASS – A TECHNO-ECONOMIC ASSESSMENT

John R. Benemann*, Don C. Augenstein,
Institute for Environmental Management, Inc.
Palo Alto, CA 94306 *Presenter jbenemann @aol.com
and
Don J. Wilhelm and Dale R. Simbeck
SFA Pacific, Inc, Mountain View, CA 94041

Conclusions: lignocellulosic ethanol was not ready to go commercial, still needed long-term R&D.

Ethanol producers warily eye algae's bloom
E&E News 8/21/2009 Katie Howell

It's been the summer of algae-based fuels: investments [BP, Dow, ExxonMobil.] technical advances, tax incentive [Continental flight]

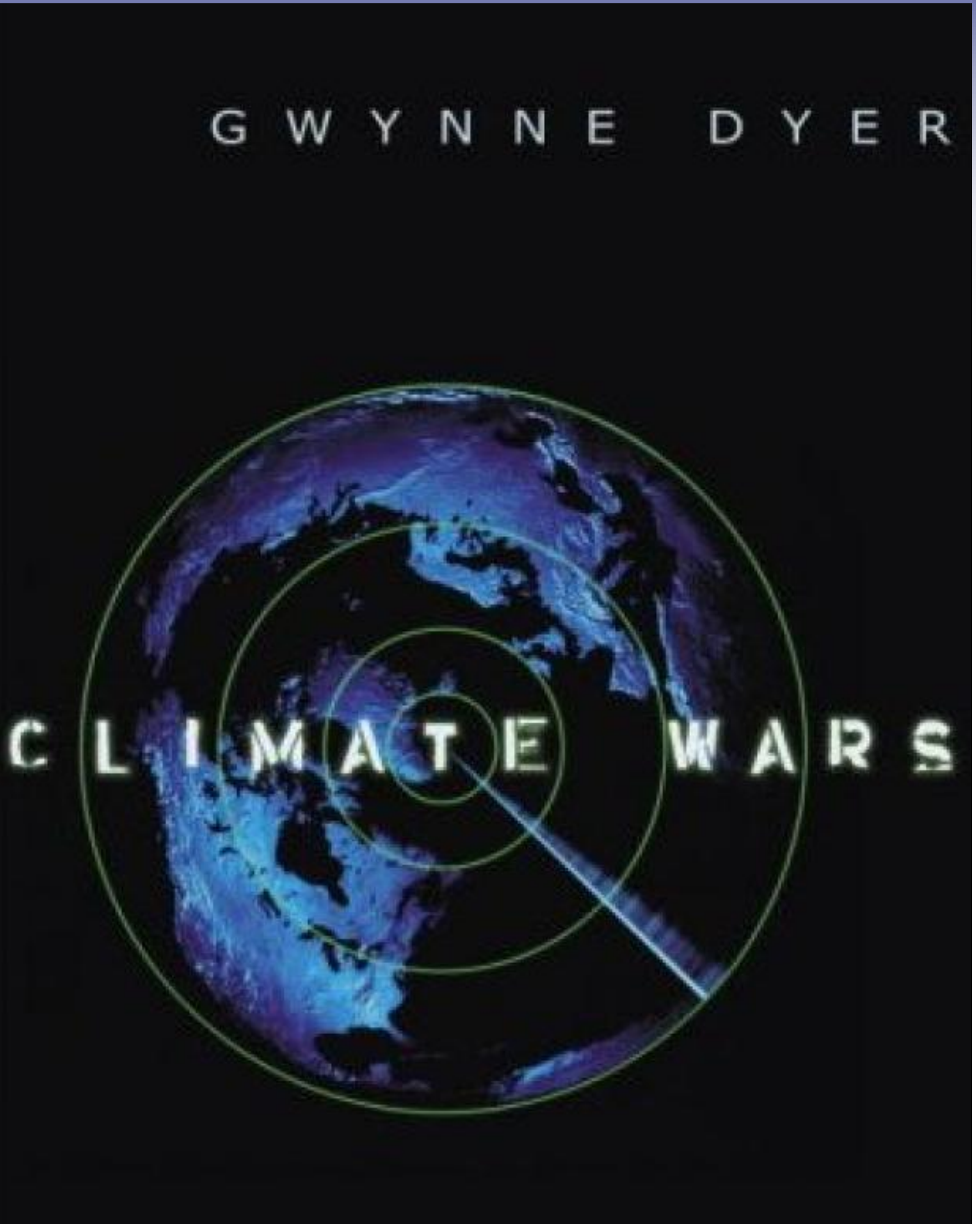
can't blame ethanol producers for being a little defensive. "*ethanol is here today, it's a proven fuel"* said Mark Stowers, VP R&D, Poet LLC, the largest ethanol producer, developing cellulosic ethanol

But last week in *Science* J. Regalbuto (NSF) writes that cellulosic ethanol has serious drawbacks while biomass-derived gasoline-like hydrocarbons from forest wastes, cornstalks, algae, might not *"If recent technological innovations result in competitive costs*

And O'Hanlon, of the American Biofuels Council, recently said that algae-based biofuels show the most promise... "*It's algae – period. There's so much upside to algae. I've yet to find a downside*".

But Stowers from Poet LLC says: "*They're not making gasoline from algae today... it is still R&D... We're going to need it all*"

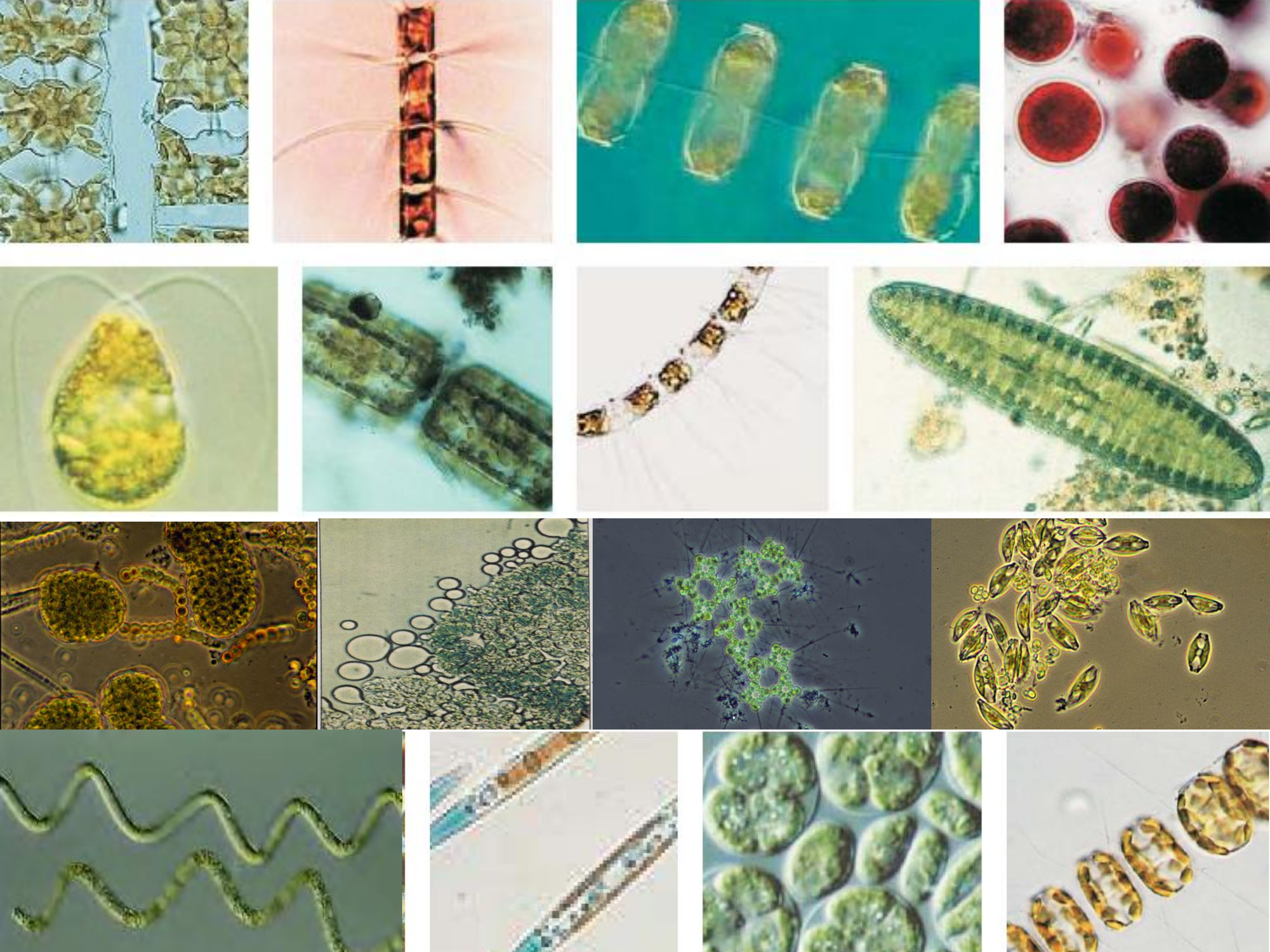
Why we need all biofuels: Global Warming!



(from the book jacket):

"...the geopolitical conflicts that may unfold over the next few decades [are] almost too fearsome to absorb...

[among] the scientists themselves, there is a palpable sense of panic, something confirmed by Dyer in his interviews conducted around the world."



Abstract: Background and Introduction

Microalgae are very small, dilute, low standing biomass, daily harvesting. Microalgae biomass could be used to produce methane, ethanol, biodiesel, hydrocarbons, H2, etc. No practical process has yet been developed.

Microalgae cultivation requires an enriched source of CO2, such as power plants flue gases, from biogas, ethanol plants, etc. GHG abatement derives from the biofuels, not from CO2 capture. Co-products, such as wastewater treatment, can improve the economics and reduce GHG of such systems above biofuel contribution.

Microalgae are cultivated commercially mainly in shallow raceway -type, paddle wheel mixed, open ponds for high value nutritional supplements, ~10,000 mt/yr produced

Absract: Microalgae Biofuel Economics

Engineering cost studies suggest that such ponds, scaled to hundreds of hectares, could produce biofuels economically, IF the algae can be stably cultivated, at high productivities and simple low-cost harvesting (“bioflocculation”).

Closed photobioreactors not feasible (engineering limits).
(NOTE: I do not discuss algae fermentations using sugars!).

Achieving the goals of high culture productivity, stability and harvestability still requires long-term applied & fundamental R&D in algal physiology, genetics, photosynthesis, mass cultivation, control of grazers and 'weed' algae, harvesting and processing. We need better algae strains! (GMOs!!)
.
The microalgae biofuels potential is limited by the need for simultaneous availability of water, flat land, CO2, good climate. It will not be a panacea, cannot replace fossil fuels.

OUTLINE OF TALK

1. Historical development of microalgae biofuels
2. Closed photobioreactors vs. Open Ponds
3. Current commercial microalgae production
4. Wastewater Treatment with microalgae
5. Prior microalgae biofuels engineering-cost analyses
6. Recent microalgae biofuel cost studies, LCAs
7. CONCLUSIONS: Not Shovel Ready. Caveat emptor!

Going Green: An In-Depth Look at the Emerging Algae Industry

cover page of Multiclient report by

greener dawn™
research

This is for PetroAlgae in Florida NOT algae; duckweed! (Caveat emptor!!)

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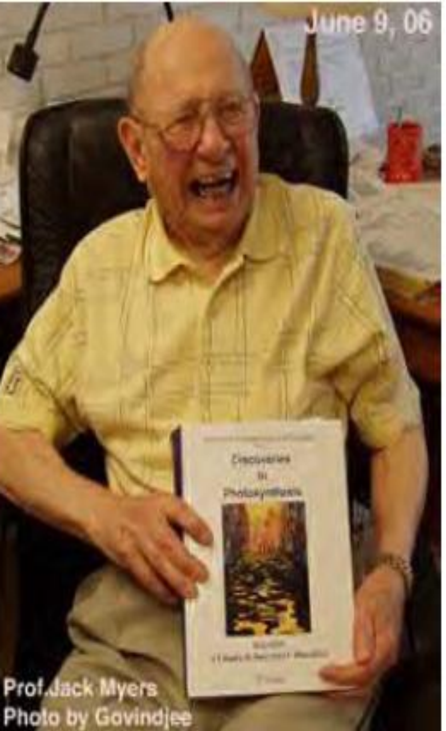


ALGAL CULTURE

FROM LABORATORY TO PILOT PLANT

Edited by

JOHN S. BURLEW

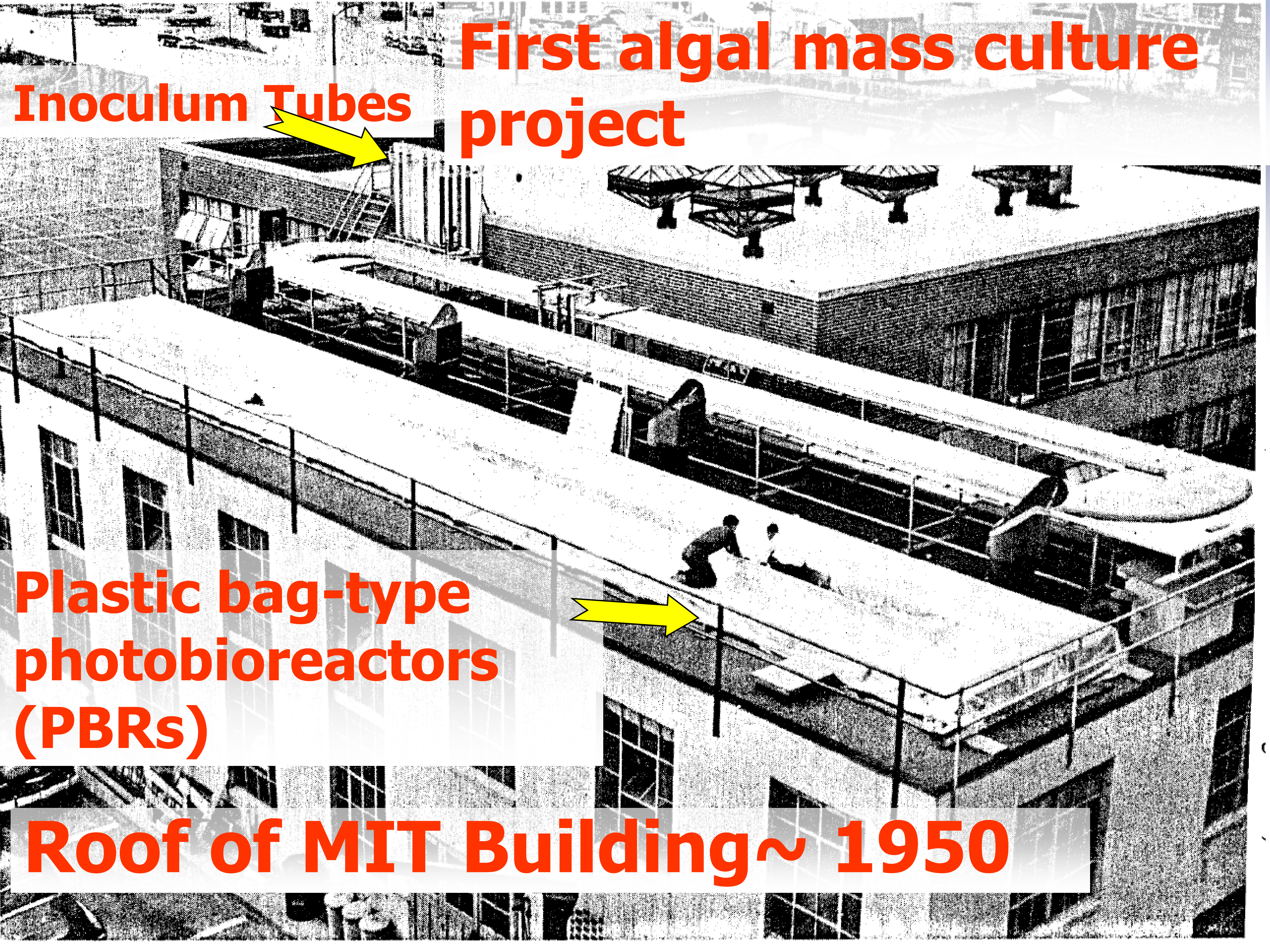
Jack Myers
2006, Austin, TX

CARNEGIE INSTITUTION OF WASHINGTON PUBLICATION 6

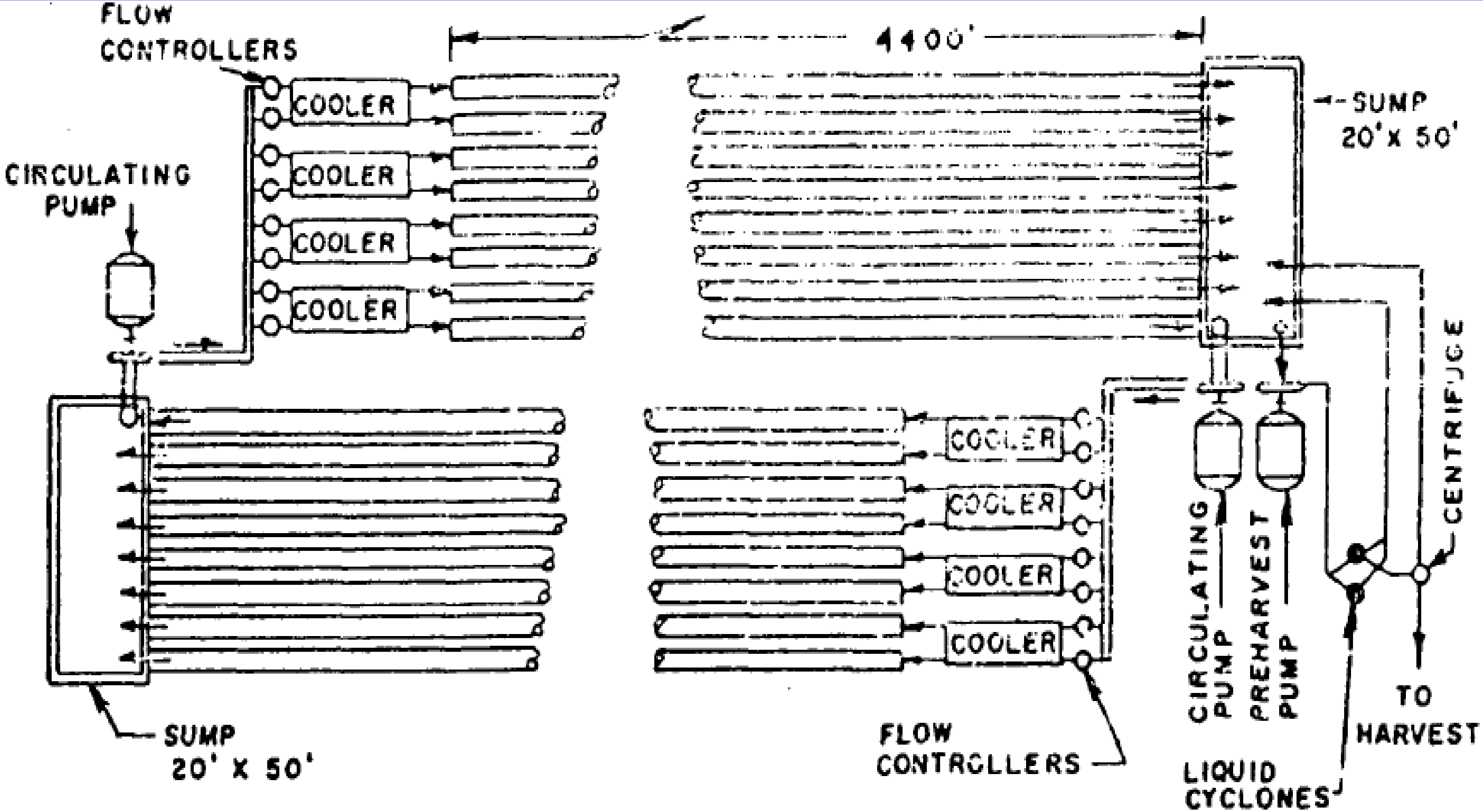
WASHINGTON, D. C.

1953

Bessel Kok
1956, Stanford


First algal mass culture project
Inoculum Tubes
Plastic bag-type photobioreactors (PBRs)
Roof of MIT Building~ 1950

40 hectare design based on MIT Rooftop pilot plant



Fisher (1956), A.D. Little Co.: engineering design-cost estimate for 40 ha PBR system: 2009**$>2,000,000/ha** (plastic tubes ~5% of total) A rather detailed study!

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History repeating itself: GreenFuel Technologies

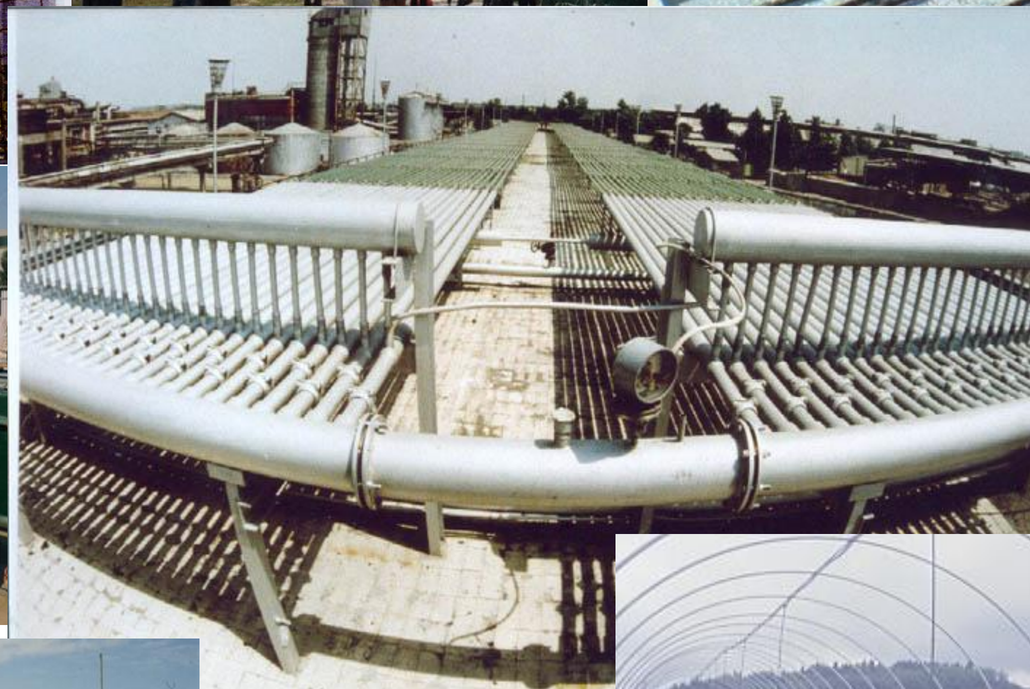
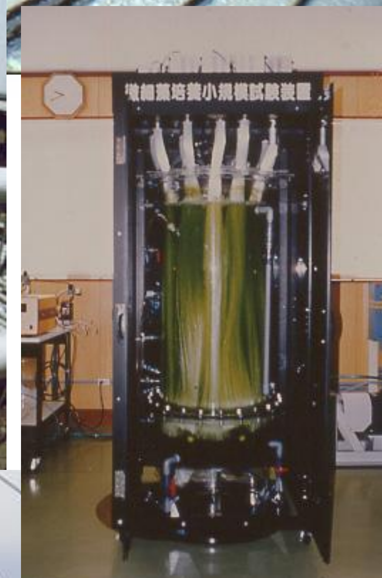
Roof of MIT at Campus power plant. Claimed that their PBRs captured 85% NOx & 50% CO_2, and produced biodiesel at >250,000 l/ha-yr (absurd!). Then tested at Arizona Public Services power plant (photoshop!), tests failed… Went broke May 2009, wasting \$70 million - 1st funded, 1st to go broke!

Latest Technology: Photoshop [Solix Biofuels]

First, grow colonies of *Botryococcus braunii* algae (a species especially prone to storing fat) [1] in long, thin, transparent plastic bags in the desert [above]. As the







PBRs Studied for over 50 years: DO NOT SCALE!

Biotechnology and Bioengineering, Vol. 31, Pp. 336–344 (1988)

Photobioreactor Design: Mixing, Carbon Utilization, and Oxygen Accumulation

Joseph C. Weissman* and Raymond P. Goebel
Microbial Products, Inc. 408A Union Ave., Fairfield, California 94533

John R. Benemann
Department of Applied Biology, Georgia Institute of Technology, Atlanta,

Photobioreactor design and operation are discussed in terms of mixing, carbon utilization, and the accumulation of photosynthetically produced oxygen. The open raceway pond is the primary type of reactor considered; however small diameter (1–5 cm) horizontal glass tubular reactors are compared to ponds in several respects.

Paper in response to many claims that PBRs superior to open ponds. Points out problems of both open ponds and closed PBRs. One main issue for PBRs scalability: maximum unit size <1000 m^2. Also PBRs too expensive for biofuels, can produce inoculum (~1% of need)

EXAMPLE OF A COMMERCIAL PBR (only a few): Photobioreactors in Israel (>300 km tubes!) for a very high value product (astaxanthin >$10K/kg biomass, *Haematococcus pluvialis*). ... failed, closed, reopened, now going to ponds!

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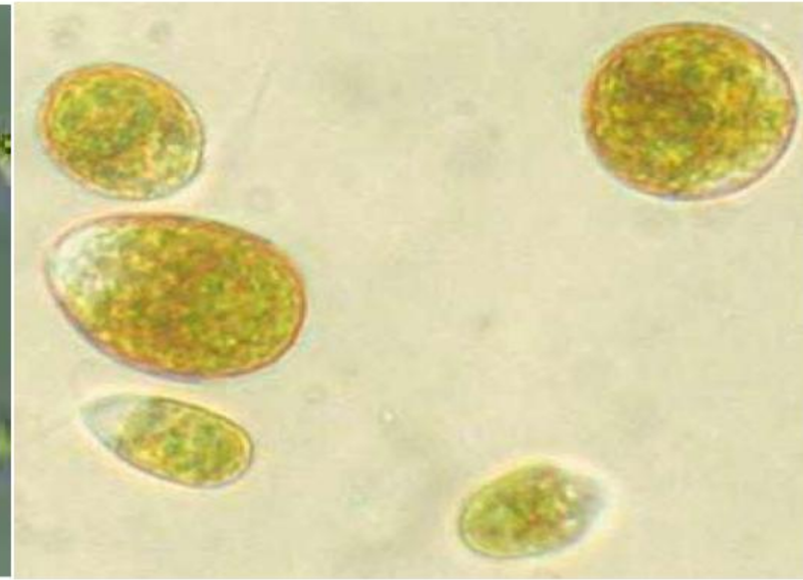
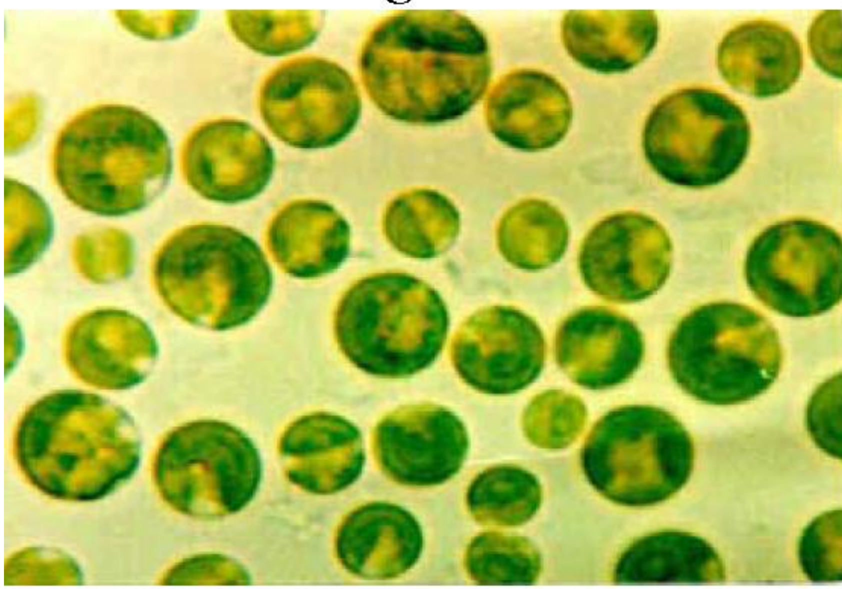
Microalgae produced commercially today

Spirulina (Arthrospira platensis)

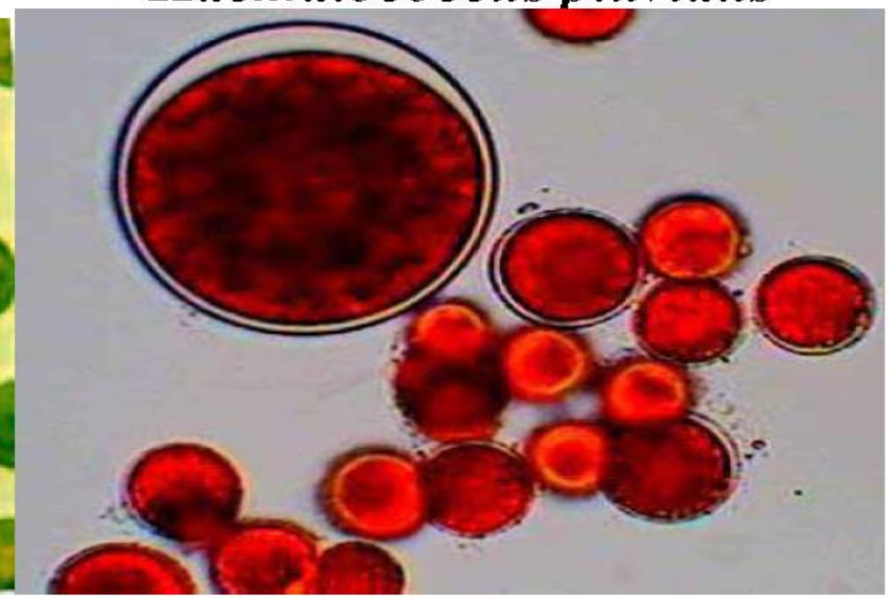
Dunaliella salina



Chlorella vulgaris



Haematococcus pluvialis



1st Commercial Algae Production 1960s: Chlorella In Japan, using circular ponds (these do not scale)

Perspective of microalgae production Earthrise Nutritionals, LLC, S. California

Microalgae Products: >95% "nutraceuticals", total world production ~10,000 tons (~1% PBRs)

Cyanotech Co.
Open, raceway ponds, algae plant in Hawaii.
Red ponds for *Haematococcus pluvialis* for astaxanthin.
others Spirulina
NOTE red ponds source of oil used in flight by Continental

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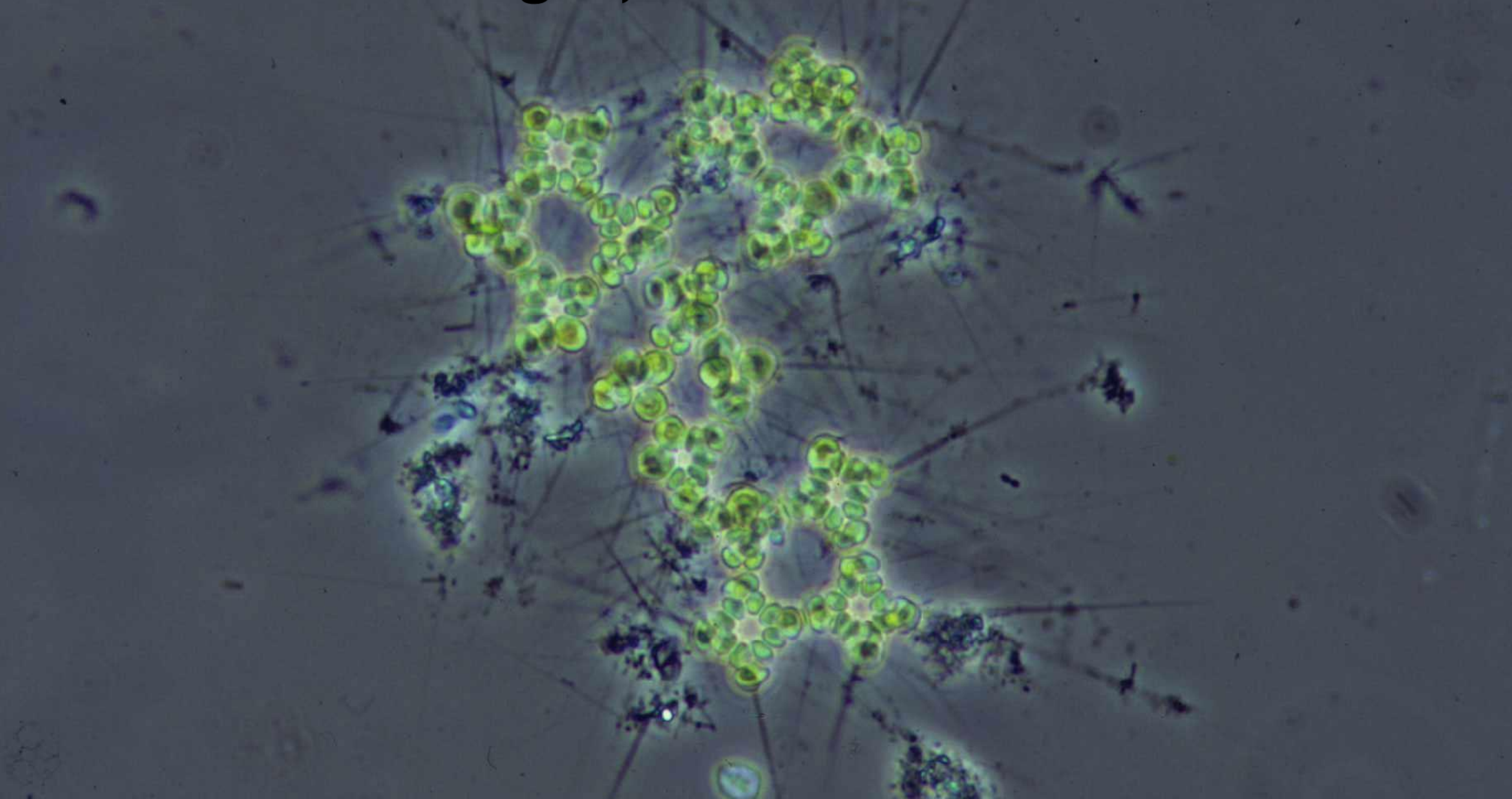
MICROALGAE FOR WASTEWATER TREATEMENT
Napa, CA, Wastewater Treatment Ponds ~ 100 hectare

In 1974 I started an R&D project on low-cost algae harvesting by bioflocculation….


U.C. Berkeley, Richmond Field Station,
Sanitary Engineering Research Laboratory.
1st paddle-wheels used for mixing large ponds

BIOFLOCCULATION OF MICROACTINIUM

these spontaneously forming flocs settle rapidly for low-cost harvesting - a key requirement in mass culture of microalgae, for biofuels or waste treatment



Algae Biomass
G. Shelef and C.J. Soeder, Editors

DEVELOPMENT OF MICROALGAE HARVESTING AND HIGH-RATE POND TECHNOLOGIES IN CALIFORNIA

JOHN BENEMANN, BEN KOOPMAN, JOSEPH WEISSMAN, DON EISENBERG AND RAY GOEBEL

Sanitary Engineering Research Laboratory, University of California, Berkeley

It is reported on techniques for high-rate pond operations which could control algal population characteristics such that low-cost microstraining and bioflocculation processes can be used for algae removal. The primary parameters tested were: detention time, mixing, inoculations, and biomass recycle. Results were encouraging; however, further work is required to develop the reliability of these processes and to demonstrate them in practice. Effluents from high-rate oxidation ponds from which microalgae had been harvested were used in preliminary experiments for regrowth of green algae followed by cultivation of blue-green algae, as methods for nutrient (N, P) removal in a tertiary treat-

Algae-powered cars: Science fiction or science?

Say algae, and most people think of those unpleasant green organisms found in swimming pools and fish tanks. But to the scientists and engineers of ExxonMobil, algae conjure something far more appealing: Opportunity. Why? Because algae can create renewable energy while absorbing CO_2

The energy from algae might someday produce biofuels that are compatible with those made from conventional crude oil. That's why ExxonMobil is committed to a major long-term research and development program aimed at developing algae as a viable fuel source. Unlike other biofuel sources such as corn and sugar cane, algae do not compete with our food supply. And because they consume CO_2, algae could help reduce greenhouse gases.

ExxonMobil is partnering with Synthetic Genomics Inc., pioneers in biotechnology, on this groundbreaking research effort. Our goal is to produce biofuels from algae in the future to supplement the fuels we use in our vehicles today, while reducing greenhouse gas emissions. Algae have never looked so inviting.

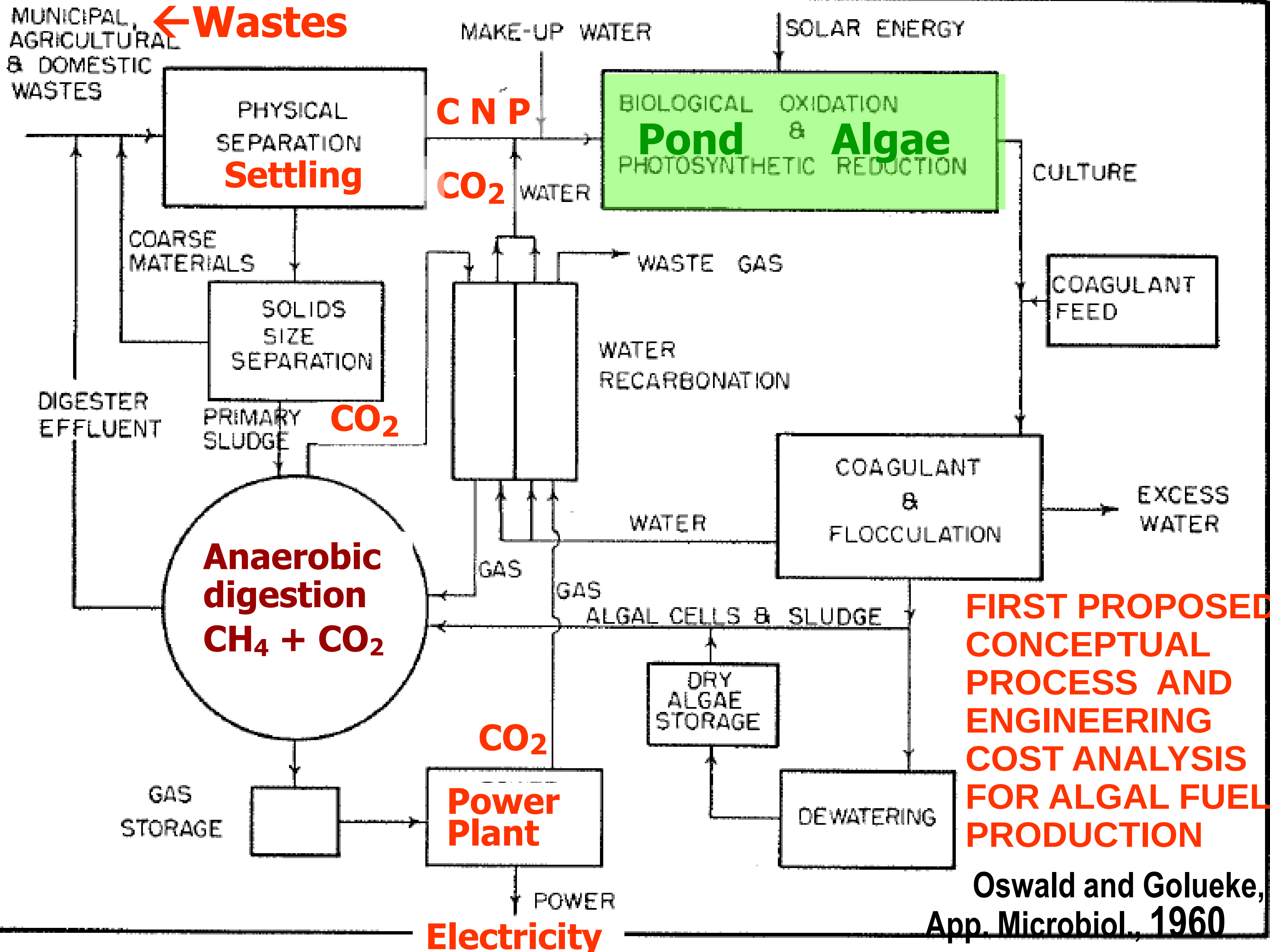
Joe Weissman

Scientist

ExxonMobil

Scientist


Prof. W.J. Oswald at high-rate paddle wheel mixed pilot-scale wastewater treatment ponds at UC Berkeley Engineering Lab 1977



FIRST PROPOSED CONCEPTUAL PROCESS AND ENGINEERING COST ANALYSIS FOR ALGAL FUEL PRODUCTION

Oswald and Golueke, App. Microbiol., 1960

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Prior techno-economic analyses for open pond microalgae biofuel production http://www.osti.gov/bridge/)

Benemann, J.R. P. Pursoff, & W.J. Oswald, **1978. Engineering Design and Cost Analysis of a Large-Scale Microalgae Biomass System**, Final Report US DOE. NTIS #H CP/T1605-01 UC-61.

Benemann, J.R., R.P. Goebel, J.C. Weissman, & D.C. Augenstein **1982. Microalgae as a source of liquid fuels**. Final Report U.S.DOE BER

Weissman, J.C., & R.P. Goebel, **1987**. **Design and analysis of microalgal open pond systems for the purpose of producing fuels** Report to US DOE- SERI (for the Aquatic Species Program)

Benemann, J.R. & W.J., Oswald **1996**, **Systems and economic analysis of microalgae ponds for conversion of CO2 to biomass.** Report to US DOE-NETL (National Technology Energy Laboratory)

Caution: These reports lack in design and cost details – and made many very favorable assumptions about process.

Conclusion: it may not be impossible to produce algae biofuels

Aquatic Species Program Report 1998 .

Executive Summary
J. Sheehan (NREL) et al.

Part 1. Algal Cultures and Genetics (P. Roessler and T. Dunahay, consultants)

Part 2. Algal Mass Cultures and Production Technology (J. Benemann, Principal Investigator, and J. Weissman, consultant).

<u>Report only summarizes extensive work by the ASP</u>

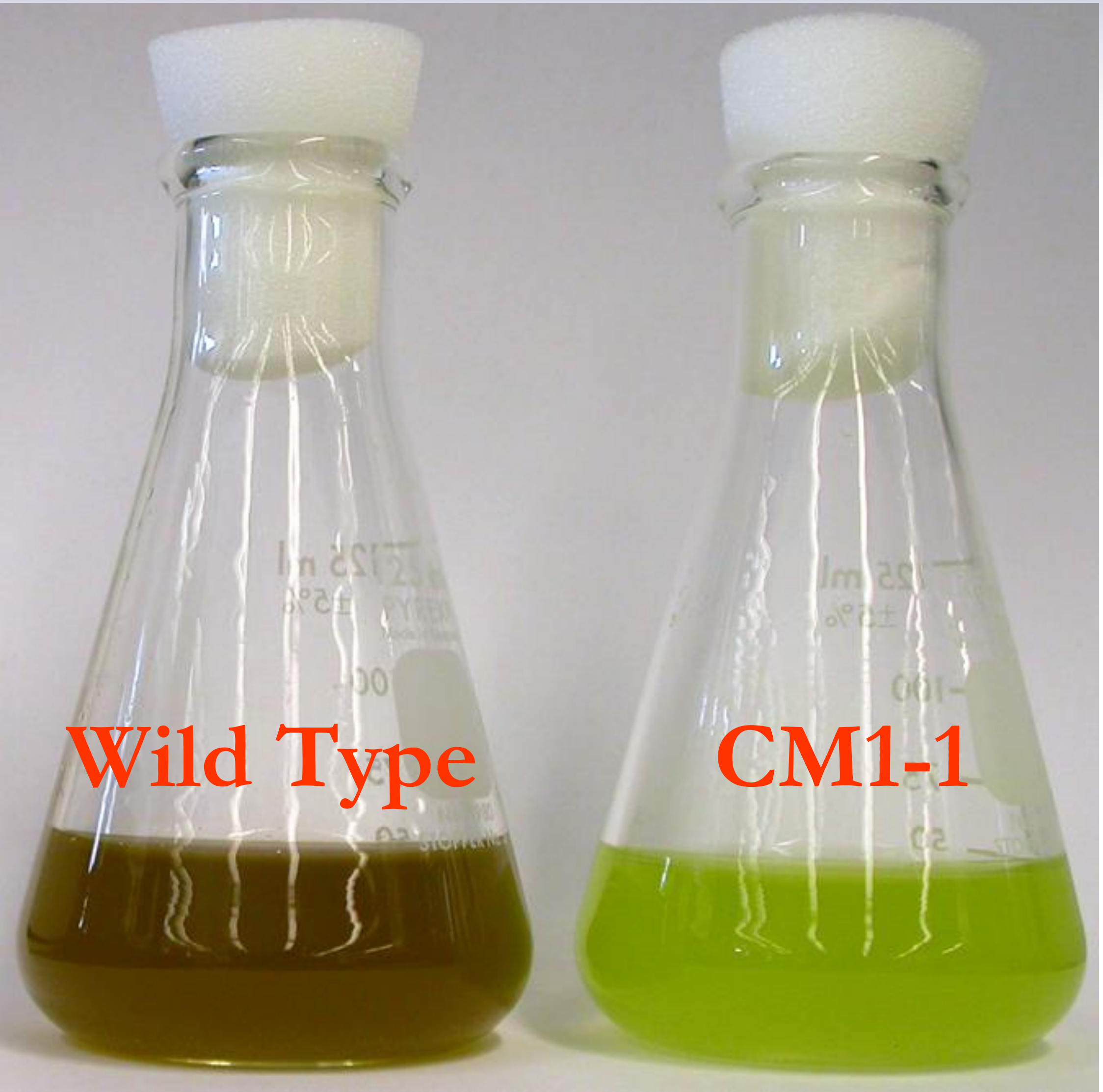
ASP Isolated many algal strains, tested for mass cultures
Each species, even each strain has its own story
11 Division, 29 classes (vs. 2/12 vascular plants)
30 000 described species (< 10% of estimated)

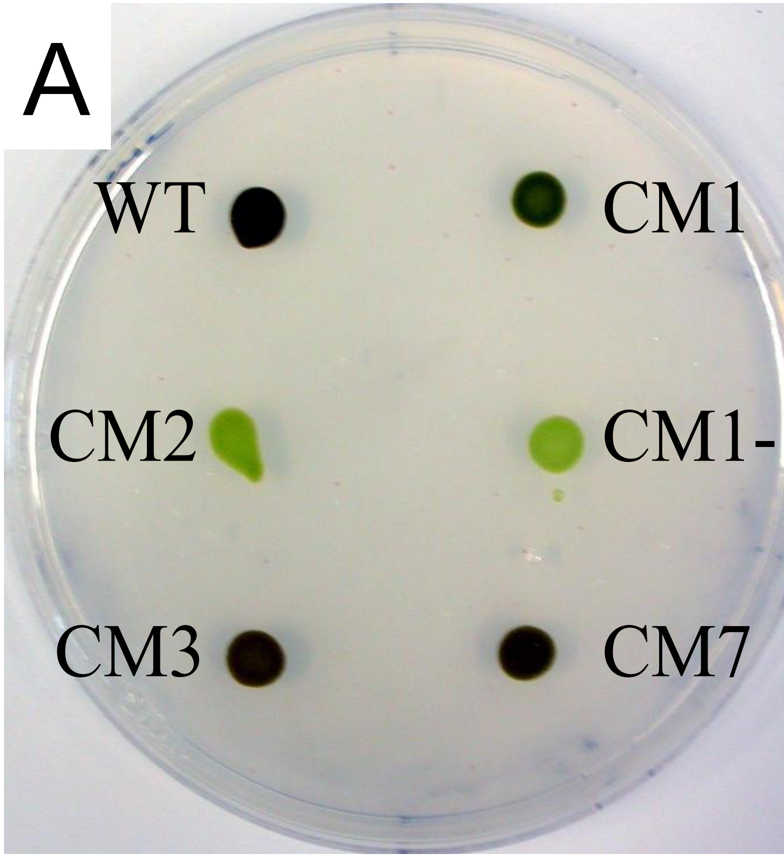

ASP MICROALGAE R&D PONDS ROSWELL, NEW MEXICO
J. Weissman, Microbial Products, Inc., P.I.
two 0.25 acre ponds, one lined and one unlined
Demonstrated key engineering and biological parameters in algal mass cultures, such as gas transfer, mixing, effect of liners, productivity, culture stability, strain selection, etc.

ROTIFERS [JUST ONE TYPE OF ALGAE GRAZER]

Must manage ponds for algal species & culture stability

Genetics needed to increase algal productivity
Example: Mutant of Cyclotella with reduced antenna
(Huesemann, Weissman, Benemann et al., 2009)





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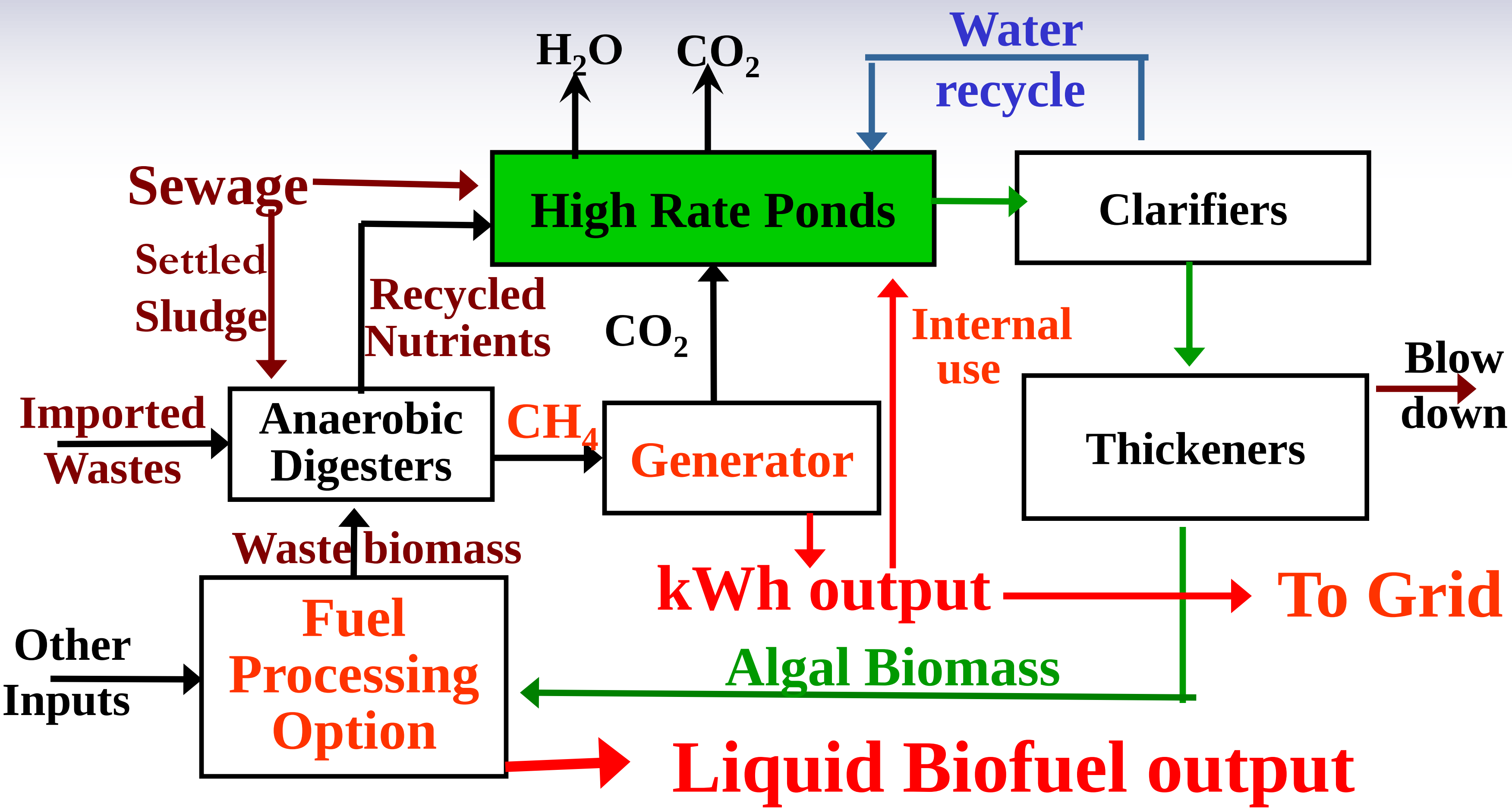
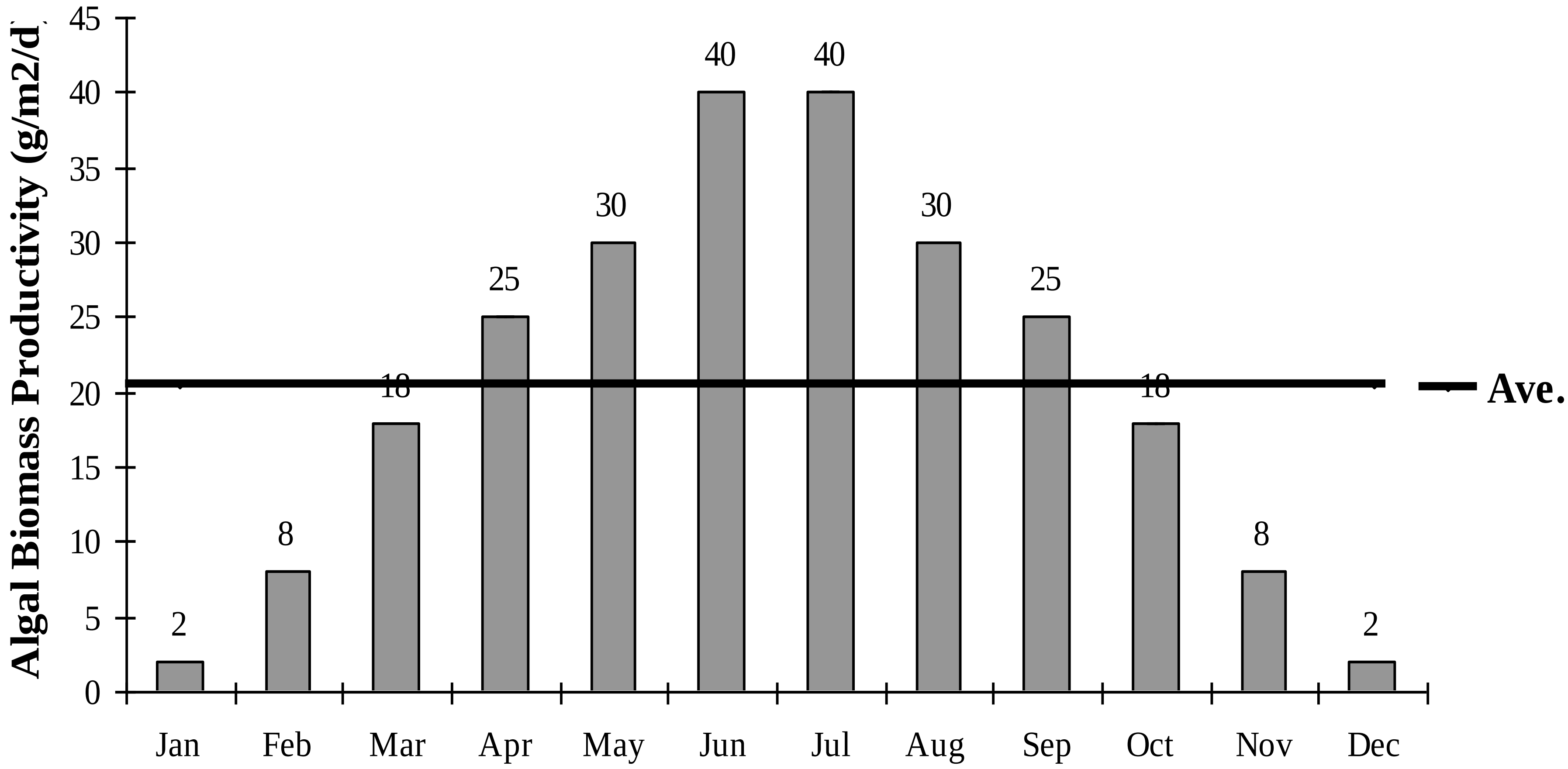
Updated Engineering Design Cost Analysis Project 2009 (Energy Biosciences Institute, UC Berkeley/LBL) Lundquist, Woertz (Cal Poly), Benemann, Quinn (LBL)



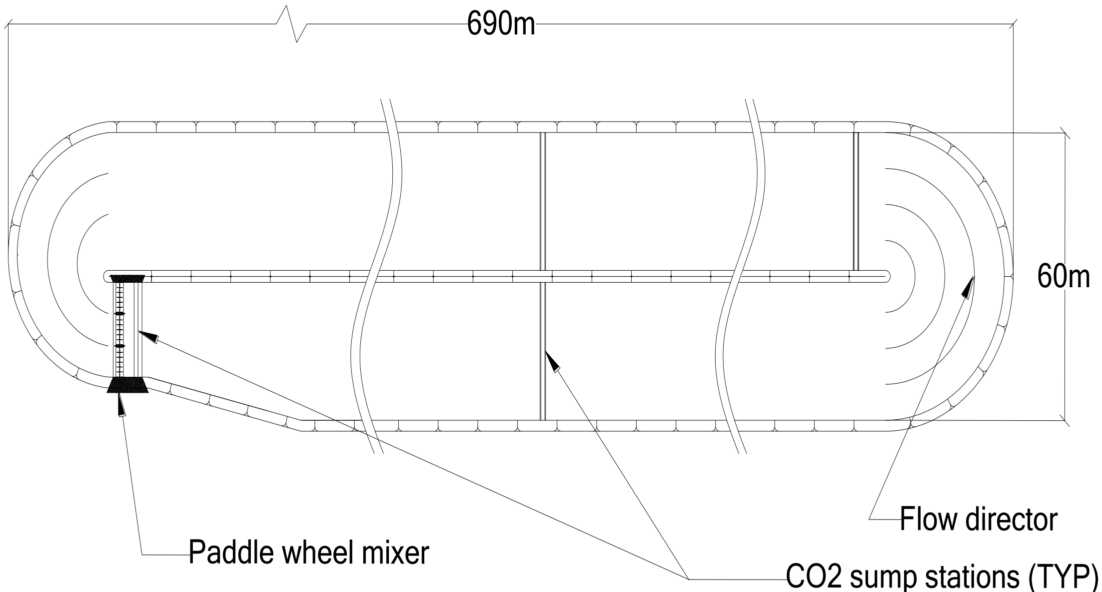
Oil + Biogas Production - water +nutrients recycled

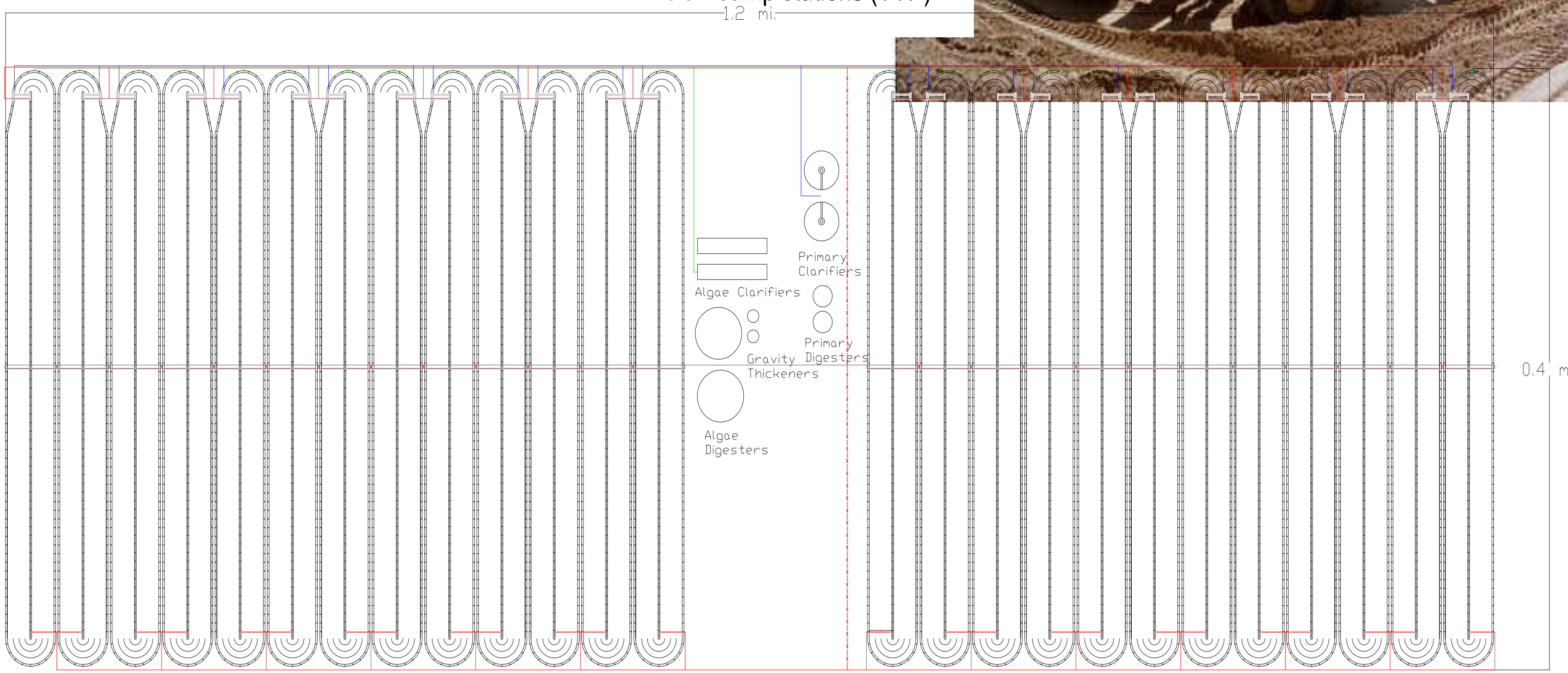
Southern California climate and optimistic productivities assumed

- Annual daily average projected at = 20 g/m2/d
- Max = 4 g/m2/hr for designs of ducts, pipes, pumps, etc.



Pond Design Layout and Construction (Ag. engineering!)





Recycle wastewater case

Set Price for Land (50% increase for >100ha)	15,000	$/ha	
Set Price for Barrel of Oil	180	$/barrel	Soy bean oil cost as of 2007
Set Price for Carbon Credit	1.85	$/mt	As of 10-08-08
Gas Turbine Cost ($/kW)	$ 475	/kW	REF Boyce 2002
Additional area req. `based on drawing	39%		

Operation	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Average algae productivity (g/m2/d)	2	8	18	25	30	40	40	30	25	18	8	2
Evaporation of total flow (%)	2.5%	3.4%	5.5%	7.3%	9.2%	9.6%	9.7%	9.1%	7.4%	5.5%	3.3%	2.4%
Volatilazation N (%)	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Blow down (%)	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Anaerobic digestion loss (%)						10%						
Operation Results	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Influent (m3/d)	311,400	311,400	311,400	311,400	311,400	311,400	311,400	311,400	311,400	311,400	311,400	311,400
Total Flow Q (m3/d)	80,607	81,353	82,626	83,541	84,207	85,569	85,569	84,207	83,541	82,626	81,353	80,607
Total area req. (ha)	100	101	103	104	105	107	107	105	104	103	101	100
# of Ponds	25	25	26	26	26	27	27	26	26	26	25	25
Evaporation (m3/d)	2,018	2,773	4,555	6,030	7,713	8,179	8,253	7,649	6,129	4,475	2,642	1,887
Blow down Q (m3/d)	77,718	76,610	74,226	72,318	70,319	69,205	69,132	70,383	72,219	74,306	76,742	77,849
Blow down N (mg/L)	28	24	19	15	12	5	5	12	15	19	24	26
Total Biomass Available (kg/d)	1,620	6,539	14,942	20,983	25,380	34,388	34,388	25,380	20,983	14,942	6,539	1,620
Total Biomass per month (kg/month)	48591	196161	448272	629493	761410	1031645	1031645	761410	629493	448272	196161	48591
Labor Requirements												
$/ha/yr	$ 3,349	$ 3,343	$ 3,333	$ 3,325	$ 3,320	$ 3,309	$ 3,309	$ 3,320	$ 3,325	$ 3,333	$ 3,343	$ 3,349
$/yr	$ 378,194	$ 380,243	$ 383,755	$ 386,290	$ 388,141	$ 391,946	$ 391,946	$ 388,141	$ 386,290	$ 383,755	$ 380,243	$ 378,194
Carbon Dioxide	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Peak hourly												
Peak Algae Productivity (g/m2/hr)	0.5	0.5	0.5	2	4	4	4	4	3	2	0.5	0.5
Max Biomass (kg/hr)	536	536	536	2143	4286	4286	4286	4286	3214	2143	536	536
C needed (kg/hr)	268	268	268	1,071	2,143	2,143	2,143	2,143	1,607	1,071	268	268
CO2 Required with uptake eff. (kg/hr)	1,323	1,323	1,323	5,291	10,582	10,582	10,582	10,582	7,936	5,291	1,323	1,323
CO2 Req. (m3/hr)	962	962	962	3,850	7,700	7,700	7,700	7,700	5,775	3,850	962	962
Flue Gas Req. (m3/hr)	9,625	9,625	9,625	38,498	76,997	76,997	76,997	76,997	57,747	38,498	9,625	9,625
Flue Gas Req. (ft3/min)	5,665	5,665	5,665	22,659	45,318	45,318	45,318	45,318	33,989	22,659	5,665	5,665
Daily												
Biomass produced (kg/d)	2,000	8,072	18,447	25,905	31,334	42,455	42,455	31,334	25,905	18,447	8,072	2,000
C needed minus recycled C and WW C (kg/day)	0	417	4,925	8,133	10,469	15,307	15,246	10,379	8,063	4,829	343	0
CO2 Required with uptake eff. (kg/d)	0	2,060	24,321	40,163	51,698	75,589	75,291	51,254	39,820	23,847	1,692	0
CO2 Req. (m3/hr)	0	107	1,264	2,087	2,687	3,929	3,913	2,664	2,070	1,239	88	0
Flue Gas Req. (m3/hr)	0	1,071	12,641	20,875	26,870	39,287	39,132	26,639	20,696	12,394	879	0
Flue Gas Req. (ft3/min)	0	630	7,440	12,286	15,815	23,123	23,032	15,679	12,181	7,295	517	0
Parasitic Energy												
Water pumping (filling HRP) (kWh/d)	1,560	1,574	1,599	1,617	1,630	1,656	1,656	1,630	1,617	1,599	1,574	1,560
HRP mixing (kWh/d)	10,196	10,196	10,196	10,196	10,196	10,196	10,196	10,196	10,196	10,196	10,196	10,196
Solvent Extraction (kWh/d)	1,065	1,300	1,703	1,992	2,202	2,634	2,634	2,202	1,992	1,703	1,300	1,065
Primary Sludge pumping (kWh/d)	984	984	984	984	984	984	984	984	984	984	984	984
Blowers for Flue gas (kWh/d)	0	138	1,629	2,690	3,462	5,062	5,042	3,432	2,667	1,597	113	0
Setted algae pumping (2 times) (kWh/d)	44	178	406	570	690	935	935	690	570	406	178	44
Total Energy Consumption (kWh/d)	13,849	14,371	16,517	18,049	19,164	21,466	21,446	19,134	18,026	16,485	14,346	13,849
Total Energy Consumption (kWh/month)	415,474	431,121	495,503	541,461	574,921	643,990	643,391	574,030	540,771	494,550	430,380	415,474
Value ($/day)	$ 1,385	$ 1,437	$ 1,652	$ 1,805	$ 1,916	$ 2,147	$ 2,145	$ 1,913	$ 1,803	$ 1,649	$ 1,435	$ 1,385
Value ($/month)	$ 41,547	$ 43,112	$ 49,550	$ 54,146	$ 57,492	$ 64,399	$ 64,339	$ 57,403	$ 54,077	$ 49,455	$ 43,038	$ 41,547
Total Energy Produced (kWh/month)	509,697	707,811	1,046,269	1,289,558	1,466,658	1,829,447	1,829,447	1,466,658	1,289,558	1,046,269	707,811	509,697
Value of Total Energy Produced ($/month)	$ 50,970	$ 70,781	$ 104,627	$ 128,956	$ 146,666	$ 182,945	$ 182,945	$ 146,666	$ 128,956	$ 104,627	$ 70,781	$ 50,970
Net Energy Produced (kWh/month)	94,223	276,690	550,766	748,097	891,737	1,185,457	1,186,057	892,628	748,788	551,719	277,431	94,223

Recycle wastewater case

Set Price for Land (50% increase for >100ha)		15,000	$/ha
Set Price for Barrel of Oil		180	$/barrel
Set Price for Carbon Credit		1.85	$/mt
Gas Turbine Cost ($/kW)	$	475	/kW
Additional area req. `based on drawing		39%	

Soy bean oil cost a
As of 10-08-08
REF Boyce 2002

Operation	Jan	Feb	Mar	Apr
Average algae productivity (g/m2/d)	2	8	18	25
Evaporation of total flow (%)	2.5%	3.4%	5.5%	7.3%
Volatilazation N (%)	10%	10%	10%	10%
Blow down (%)	100.00%	100.00%	100.00%	100.00%
Anaerobic digestion loss (%)				

Operation Results	Jan	Feb	Mar	Apr
Influent (m3/d)	311,400	311,400	311,400	311,400
Total Flow Q (m3/d)	80,607	81,353	82,626	83,541
Total area req. (ha)	100	101	103	104
# of Ponds	25	25	26	26
Evaporation (m3/d)	2,018	2,773	4,555	6,030
Blow down Q (m3/d)	77,718	76,610	74,226	72,318
Blow down N (mg/L)	28	24	19	15
Total Biomass Available (kg/d)	1,620	6,539	14,942	20,983
Total Biomass per month (kg/month)	48591	196161	448272	629493

		Jan	Feb	Mar
36	**Carbon Dioxide**			
37	**Peak hourly**			
38	Peak Algae Productivity (g/m2/hr)	0.5	0.5	0.5
39	Max Biomass (kg/hr)	536	536	536
40	C needed (kg/hr)	268	268	268
41	CO2 Required with uptake eff. (kg/hr)	1,323	1,323	1,323
42	CO2 Req. (m3/hr)	962	962	962
43	Flue Gas Req. (m3/hr)	9,625	9,625	9,625
44	Flue Gas Req. (ft3/min)	5,665	5,665	5,665
45				
46	**Daily**			
47	Biomass produced (kg/d)	2,000	8,072	18,447
48	C needed minus recycled C and WW C (kg/day)	0	417	4,925
49	CO2 Required with uptake eff. (kg/d)	0	2,060	24,321
50	CO2 Req. (m3/hr)	0	107	1,264
51	Flue Gas Req. (m3/hr)	0	1,071	12,641
52	Flue Gas Req. (ft3/min)	0	630	7,440
53				
54	**Parasitic Energy**			
55	Water pumping (filling HRP) (kWh/d)	1,560	1,574	1,599
56	HRP mixing (kWh/d)	10,196	10,196	10,196
57	Solvent Extraction (kWh/d)	1,065	1,300	1,703
58	Primary Sludge pumping (kWh/d)	984	984	984
59	Blowers for Flue gas (kWh/d)	0	138	1,629
60	Setted algae pumping (2 times) (kWh/d)	44	178	406
61	Total Energy Consumption (kWh/d)	13,849	14,371	16,517
62	Total Energy Consumption (kWh/month)	415,474	431,121	495,503
63	Value ($/day)	$ 1,385	$ 1,437	$ 1,652
64	Value ($/month)	$ 41,547	$ 43,112	$ 49,550
65				
66	**Total Energy Produced (kWh/month)**	509,697	707,811	1,046,269

100 ha Oil+Biogas, preliminary cost estimate

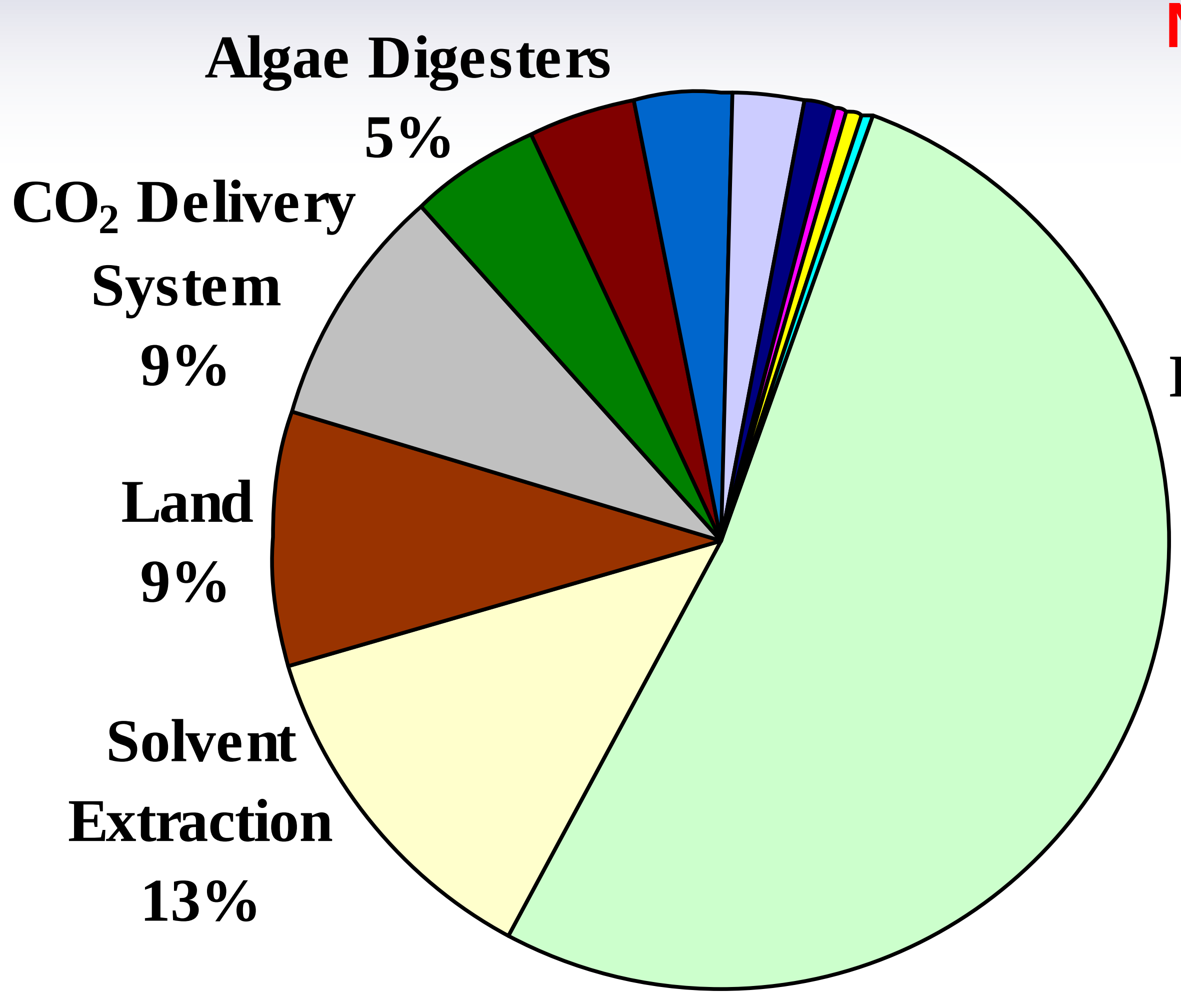
Total capital cost = $23 Million

Financial summary	
Total revenue from electricity ($/yr)	$800,000
Total operating expenses ($/yr)	($2,100,000)
Bond repayment ($/yr)	($2,000,000)
Total cash outlay requirements ($/yr)	**($3,300,000)**
Total oil produced (bbl/yr)	10,100
Total cash outlay per barrel ($/bbl)	**($327)**

Not Included: income, property taxes, wastewater treatment revenues, depreciation, corporate overheads, license fees ...

Capital costs dominated by pond (clay lined)

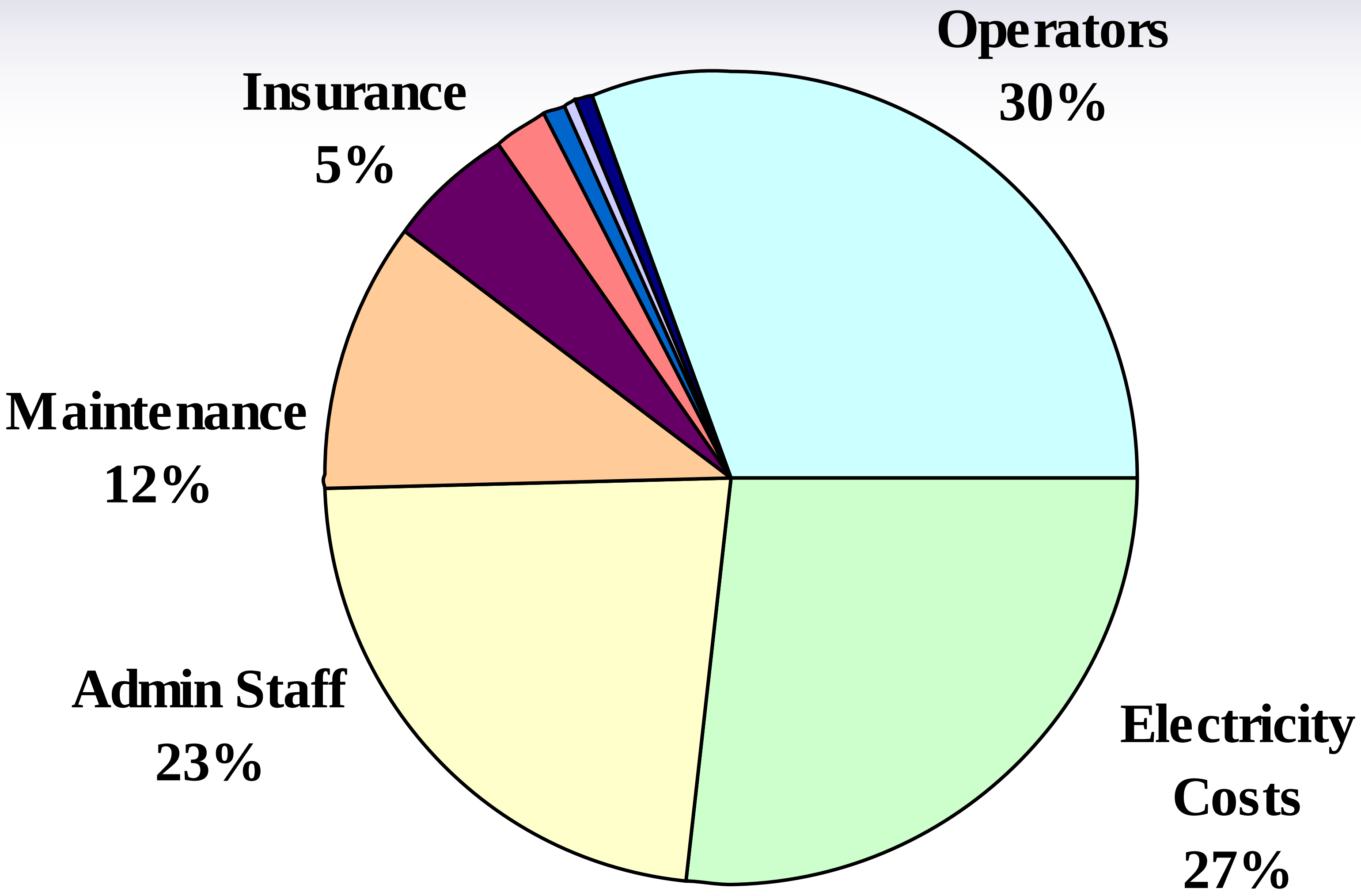
100 ha, Oil+Biogas: Total capital cost = $23 Million



Note: Municipal engineering construction costs ~ X6!

Operating costs were dominated by staffing
(because at this scale mainly a WWT function)

100 ha, Oil+Biogas: Total O&M = $2.1 Million



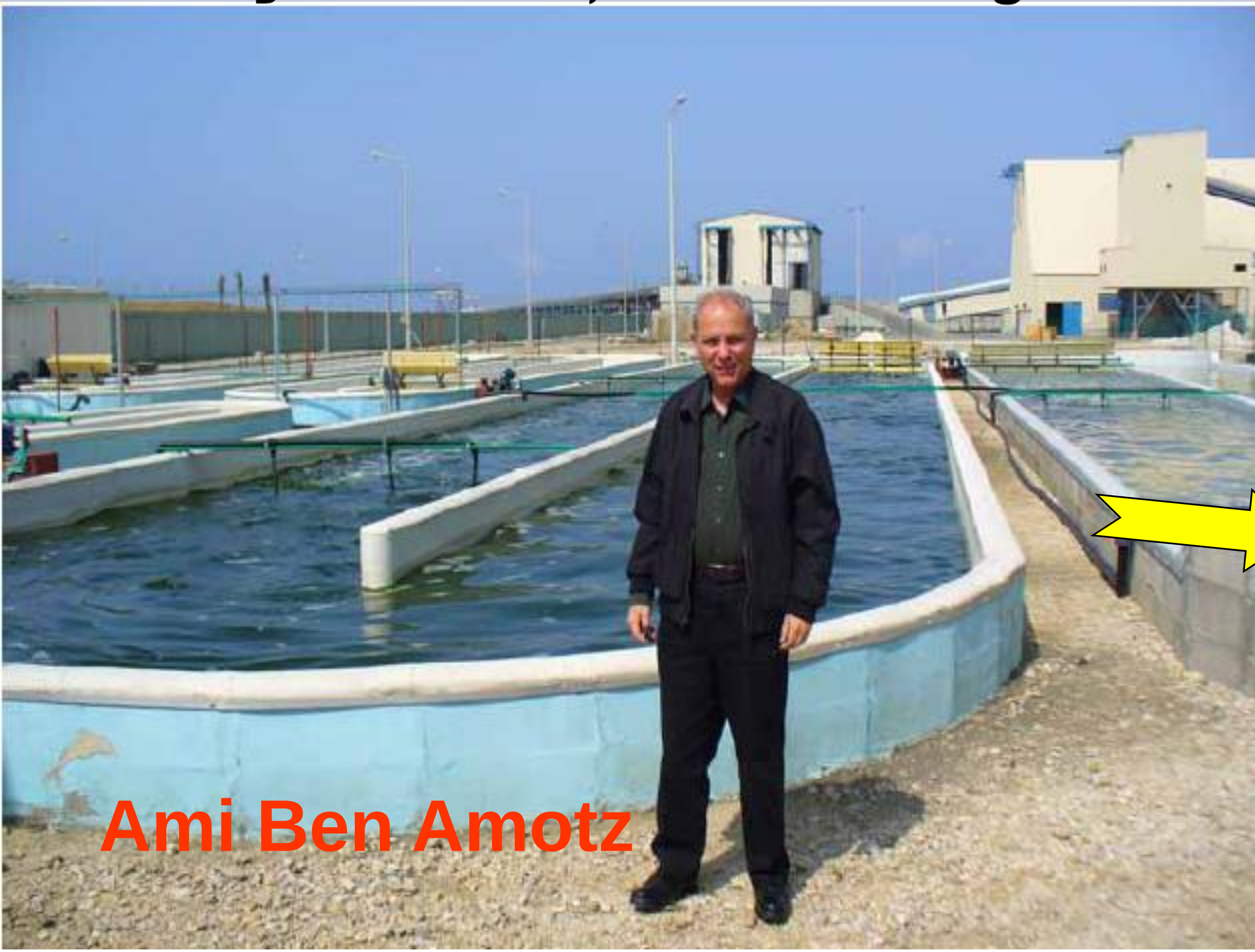
LCA GREENHOUSE GAS EMISSIONS & COSTS OF ALGAE BIODIESEL

Diesel trucks: algae vs. canola biodiesel/fossil diesel
Summary LCA Study by Campbell et al., 2009 basis
Benemann & Oswald,1996, for "conservative" case:
productivity of 55 mt/ha-yr, 40% oil, ~20,000 l/ha-yr

Emissions & Costs for moving 1 mt 1 km by diesel truck	Algae 100%CO2	Algae Flue Gas	Canola biodiesel	Diesel Fossil
GHG CO_2e emissions g/t-mi	-22.7	-15.2	95.3	108.8
Cost, feedstock or algae ops	0.015	0.013	0.035	0.026
Cost, conversion & dist	0.006	0.007	0.007	0.003
Cost, capital	0.014	0.019	0.001	0.000
TOTAL COST $/mt-km	0.044	0.039	0.042	0.038

CO_2e: total greenhouse gases, includes CH_4 and N_2O. Costs do not include taxes. (Costs are relative: not adjusted from AUS$, cost of oil, etc.) Algae 100% CO_2 purchased CO2.

The Israeli Seambiotics Co. produces algae biomass with ~30% oil content using CO2 from coal power plant flue gas. Inventure Co., in Seattle, converts it to biodiesel and ethanol. (used by GreenFuels, others claiming their own production)

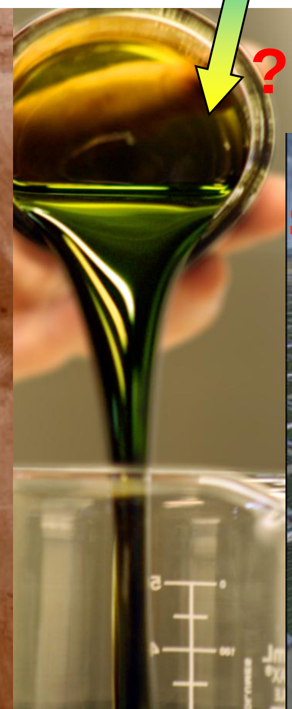


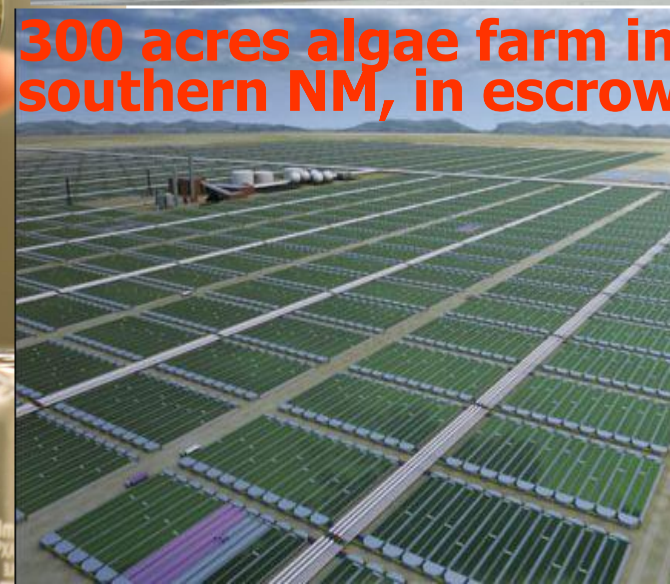
RECENT DEVELOPMENTS: Hydrocarbons from Algae

April'09 Sapphire Energy: Algae commercializaton accelerating!
Expects to double commercial output to 1 million gallon /year of jet fuel and green diesel by 2011, 100 MGY, by 2018, 1000 MGY...
Currently constructing first production plant in New Mexico

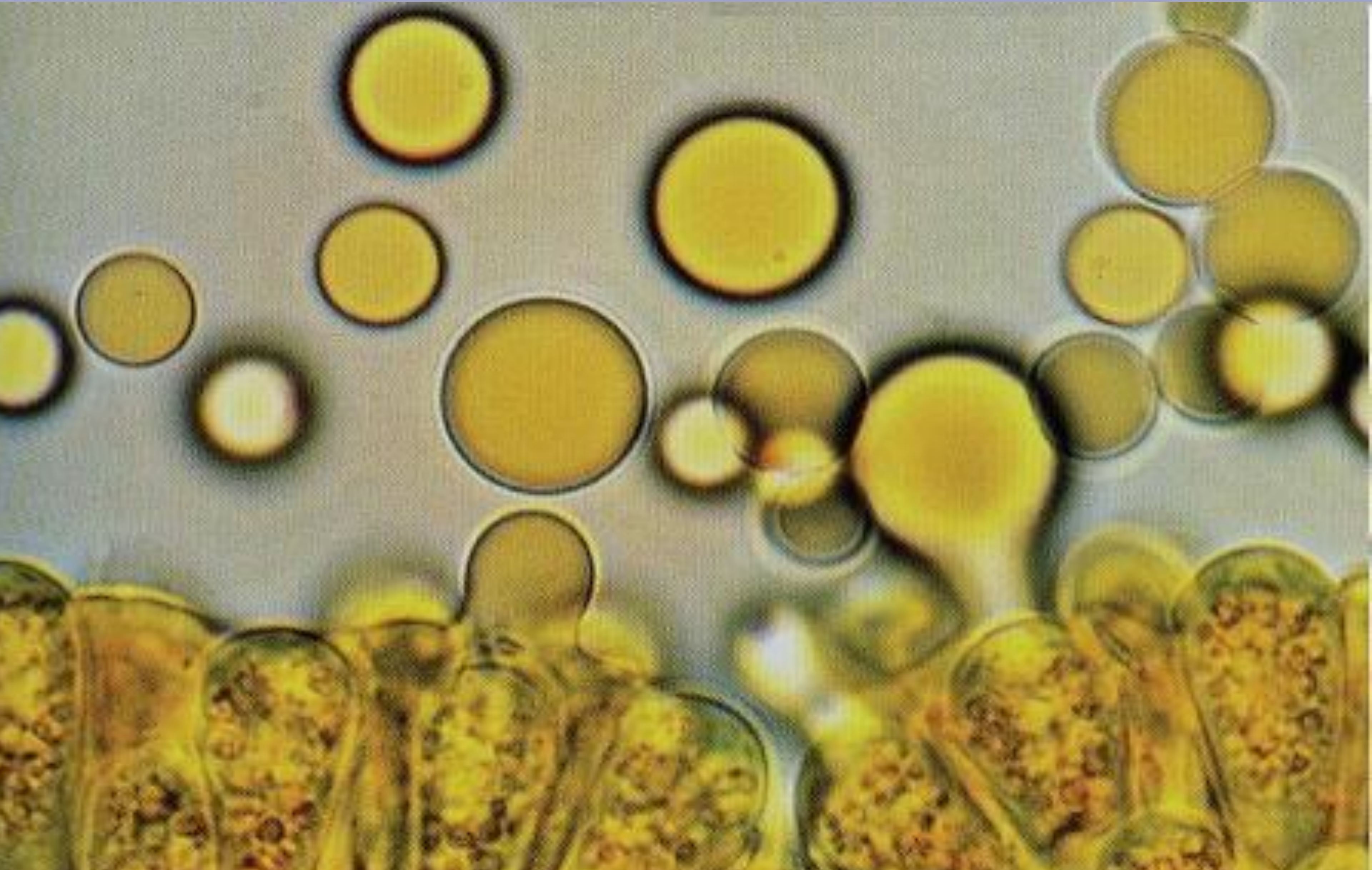
Continental flight Jan '09 used 2.5% algae biojet fuel Sapphire "supplied"→

Are we ready for GMO algae?





Nature already provides what some want to make algae do: oil globs from *Botryococcus braunii*




ANY QUESTIONS?

Public Service Announcement:

ALGAL BIOMASS ORGANIZATION

1st Summit San Francisco Nov. 2007

2nd Summit Seattle, Oct. 2008

3rd Algae Biomass Summit:

October 7-9, San Diego

www.algalbiomass.org