Algae Applications for Power Generation and CO_2 Recycling

Ami Ben-Amotz
Seambiotic Ltd., Israel
The National Institute of Oceanography
ami@benamotz.com
ISES Annual Meeting
Tel-Aviv October 5th 2011

Seambiotic

Commercial Microalgae Facilities

Open Ponds since 1950 Taiwan & Japan

round & oblong open ponds
mostly mixotrophic cultivation

Commercial Microalgal Products

High value high price health food products, cosmetics and mariculture

Photosynthesis & Algal Productivity
Autotrophy

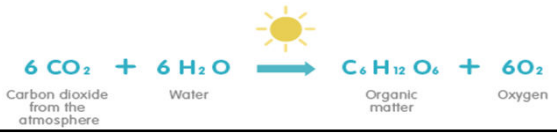
3% Photosynthetic Efficiency (PE)

Mean average daily solar intensity: 4,000 kcal/m^2/day

PE 3% = 120 kcal/m^2/day

Algal caloric value, 5 kcal/g

<u>Expected algal biomass productivity 25g/m^2/day</u>



Dunaliella

β-carotene Intensive Plant, NBT Ltd., Eilat, Israel, 100,000 m^2

Japan & Far East Market Price
β-Carotene Health Food
Total sale ~US$ 100 million/year

Final Product Japan

***Dunaliella* Powder Israel**

Annual Microalgae Production Cost (OPEX)
NBT *Dunaliella* Plant versus Alternative Bio-Fuel Algae Plant
(10 Hectares Plant Open Ponds)

	NBT Ltd. Eilat, 2010	Alternative Algal Plant (?)
	Cost in US$/year	
Manpower	500,000 (20 workers)	?
Electricity ($0.125/KW)	180,000	?
CO_2 ($500/ton)	250,000	?
Sea Water ($0.25/m3)	200,000	?
Fresh Water	20,000	?
Other supplies and Miscellaneous	30,000	?
Total	<u>1,166,000</u>	?
Yearly production of dry algae biomass	70 tons (2g/m2/day)	?
Cost of 1Kg dry microalgae	<u>$18.00/kg</u>	<u>???</u>

Major Production Costs

NBT Ltd., Eilat, Israel

Manpower

Production Cost
Manpower (20), US$500,000/y
Electricity ($0.125/KW)
Fertilizers (N,P,K, Fe) and other chemicals
Domestic Land City Taxes, US$50,000/y
CO_2 ($500/ton)
Sea Water ($0.25/m3)
Fresh Water
Other supplies and Miscellaneous
Total
Yearly production of dry algae biomass
Cost of 1Kg dry microalgae

Major Production Costs

NBT Ltd., Eilat, Israel

CO_2 Liquid Gas, $500/ton, 2011

Theoretical CO_2 consumption: 2g/g algae

Actual CO_2 consumption, 5-30 ton/month

Production Cost
Manpower
Electricity ($0.125/KW)
Fertilizers (N,P,K, Fe) and other chemicals
Domestic Land City Taxes
CO_2 ($500/ton), US$250,000/y
Sea Water ($0.25/m3)
Fresh Water
Other supplies and Miscellaneous
Total
Yearly production of dry algae biomass
Cost of 1Kg dry microalgae

CO_2 Input & Loss

Summer (>30°C) CO_2 consumption: >10g/g

Actual summer consumption: 30 ton/month

Major Production Costs

NBT Ltd. Eilat, Israel

Seawater, $0.25/m^3

Additional Costs: Filtration & Chlorination

Production Cost
Manpower
Electricity ($0.125/KW)
Fertilizers (N,P,K, Fe) and other chemicals
Domestic Land City Taxes
CO_2 ($500/ton)
Sea Water ($0.25/m3), US$200,000/y
Fresh Water
Other supplies and Miscellaneous
Total
Yearly production of dry algae biomass
Cost of 1Kg dry microalgae

Major Production Costs

NBT Ltd. Eilat

Super Centrifuge ~ $750,000

(Westphalia, Germany)

High Electric Running Cost (24 hrs/day)

Production Cost
Manpower
Electricity ($0.125/KW), US$ 200,000/y
Fertilizers (N,P,K, Fe) and other chemicals
Domestic Land City Taxes
CO_2 ($500/ton)
Sea Water ($0.25/m3)
Fresh Water
Other supplies and Miscellaneous
Total
Yearly production of dry algae biomass
Cost of 1Kg dry microalgae

Major Production Costs
NBT Ltd. Eilat
Fertilizers

KNO_3, NH_4NO_3
KH_2PO_4, H_3PO_4
(~$1.0/kg)

Production Cost
Manpower
Electricity ($0.125/KW)
Fertilizers (N, P, K, Fe) and other chemicals US$ 36,000/y
Domestic Land City Taxes
CO_2 ($500/ton)
Sea Water ($0.25/m3)
Fresh Water
Other supplies and Miscellaneous
Total
Yearly production of dry algae biomass
Cost of 1Kg dry microalgae

Annual Microalgae Production Costs
NBT *Dunaliella* Plant
(10 Hectares Plant Open Ponds)

	Dunaliella NBT Ltd., Eilat, 2010
	Cost in US$/year
Manpower	500,000 (20 workers)
Electricity ($0.125/KW)	180,000
Fertilizers (N,P,K, Fe) and other chemicals	36,000
Domestic Land City Taxes	50,000
CO_2 ($500/ton)	250,000
Sea Water ($0.25/m3)	200,000
Fresh Water	20,000
Other supplies and Miscellaneous	30,000
Total	1,166,000
Yearly production of dry algae biomass	70 tons (2g/m2/day)
Cost of 1Kg dry microalgae	$18.00/kg

Use of Power Plants Wastes

Electric Power Stations

Burn: oil, gas, coal and mix

Use: sea water for cooling

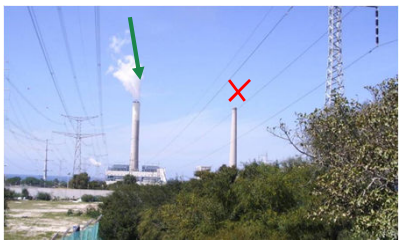
Average mid-large station emits ~ 4,000 ton CO_2 per hr

CO_2 emission, 4-14%, plus NOx, plus minerals, plus?

"Algal Culture, From Laboratory to Pilot Plant"
John S. Burlew (Ed.), 1953:
"Flue Gas is Toxic to Algae" SO_2 & H_2S toxicity

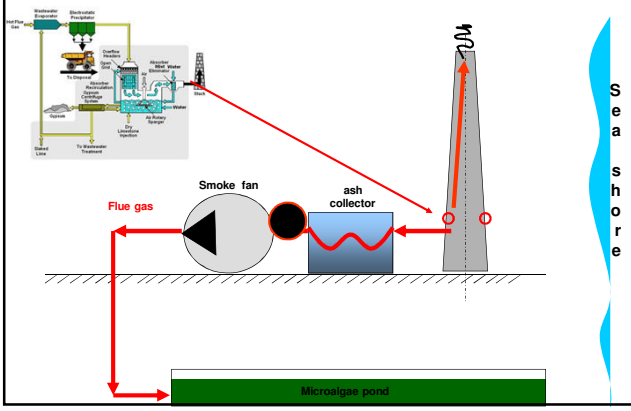
It was found that the carbon dioxide (from cylinders filled here), if unwashed, was extremely toxic to the algae because of the presence of sulfur dioxide and hydrogen sulfide, which resulted in the death of the cultures in 1 to 1½ days. The gas had to be washed by passing through alkaline per-

FGD Chimney versus Polluted Chimney

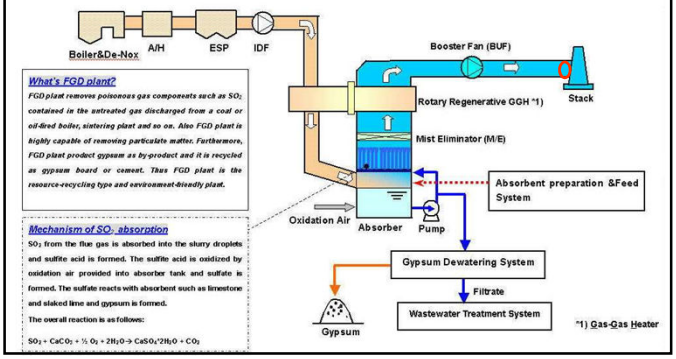


IEC CO_2- Generation Basic Scheme

Flue Gas Desulfurization (FGD) 700 to ~60 ppm SO_2



Flue Gas Desulphurization (FGD, SO_2 Scrubbing)



Flue Gas Desulphurization (FGD SO_2 chemistry)
Scrubbing with a basic solid or solution

SO_2 is an acid gas and thus the typical sorbent slurries or other materials used to remove the SO_2 from the flue gases are alkaline.

The reaction is taking place in **wet scrubbing** using limestone, $CaCO_3$ to calcium sulphite, $CaSO_3$ that can be expressed as:

$CaCO_3$ (solid) + SO_2 (gas) → $CaSO_3$ (solid) + CO_2 (gas)

When wet scrubbing with a $Ca(OH)_2$ (lime slurry), the reaction also produces $CaSO_3$ (calcium sulphite) and can be expressed as:

$Ca(OH)_2$ (solid) + SO_2 (gas) → $CaSO_3$ (solid) + H_2O (liquid)

When wet scrubbing with a $Mg(OH)_2$ (magnesium hydroxide slurry), the reaction produces $MgSO_3$ (magnesium sulphite) and can be expressed as:

$MgOH_2$ (solid) + SO_2 (gas) → $MgSO_3$ (solid) + H_2O (liquid)

Some FGD systems go a step further and oxidize $CaSO_3$ (calcium sulphite) to produce marketable $CaSO_4.2H_2O$ **(gypsum):**

$CaSO_3$ (solid) + 1/2 O_2 (gas) + 2H_2O (liquid) → $CaSO_4.2H_2O$ (solid)

israel electric Engineering Division

Table 2. Average composition of flue gases at Rutenberg Power Station.

CO_2, %,Volumetric (wet)	13
N_2 %,Volumetric (wet)	69
O_2 %,Volumetric (wet)	5
H_2O %,Volumetric	13
CO, mg/dNm^3	40
NO_x, mg/dNm^3	450
SO_2, mg/dNm^3	120
Solid particles, mg/dNm^3	20 - 40

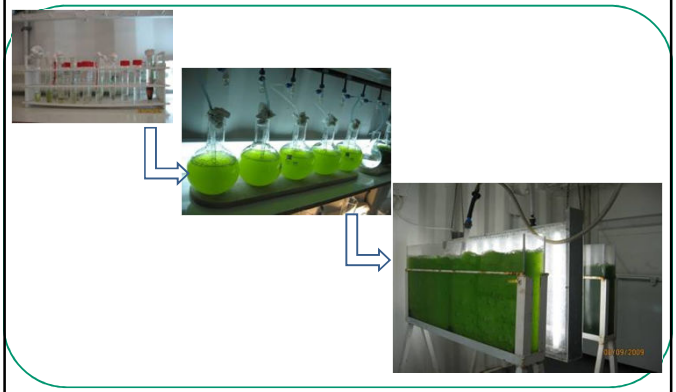
FGD Power Station, Ashkelon, Israel, 1,000MW
431 ton CO_2 /hr, 10,344 ton CO_2/day

Israel Electric Corporation
The connections to the chimney
(FGD 2 units)

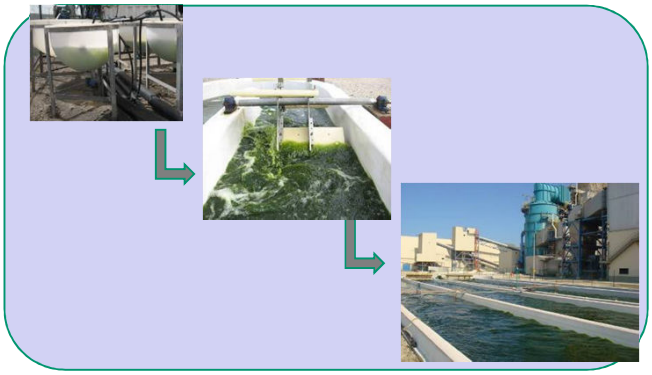
FGD Gas
From the Chimney to the Algae Ponds

Nannochloropsis sp
Eustigmatophyceae
Bio-Fuel or High W3 FA

Indoor Cultivation



Scale-Up Cultivation

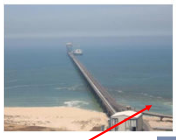


Seawater Supply

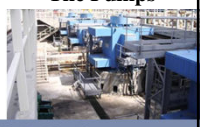
~ 450,000 m^3/hr

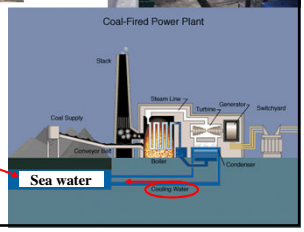
(Filtered & Chlorinated)

Production Cost
Manpower
Electricity ($0.125/KW)
Fertilizers (N,P,K, Fe) and other chemicals
Domestic Land City Taxes
CO_2 ($500/ton)
Free Sea Water
Fresh Water
Other supplies and Miscellaneous
Total
Yearly production of dry algae biomass
Cost of 1Kg dry microalgae ?



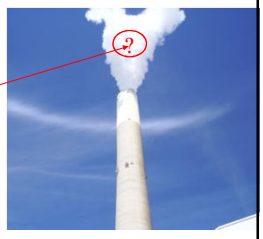
The Pumps





Flue gases
NO_X (N fertilizer?)

Production Cost
Manpower
Electricity ($0.125/KW)
Fertilizers (N,P,K, Fe) and other chemicals
Domestic Land City Taxes
CO_2 ($500/ton)
Free Sea Water
Fresh Water
Other supplies and Miscellaneous
Total
Yearly production of dry algae biomass
Cost of 1Kg dry microalgae ?

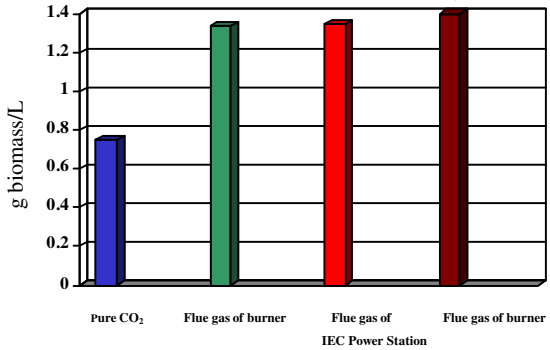


Coal Burning FGD Flue Gas
Superior Algal Growth!
Algal density at depth of 20 cm ~ 1g algae/L

Production Cost
Manpower
Electricity ($0.125/KW)
Fertilizers (N,P,K, Fe) and other chemicals
Domestic Land City Taxes
Free FGD CO_2
Sea Water ($0.25/m3)
Fresh Water
Other supplies and Miscellaneous
Total
Yearly production of dry algae biomass
Cost of 1Kg dry microalgae ?

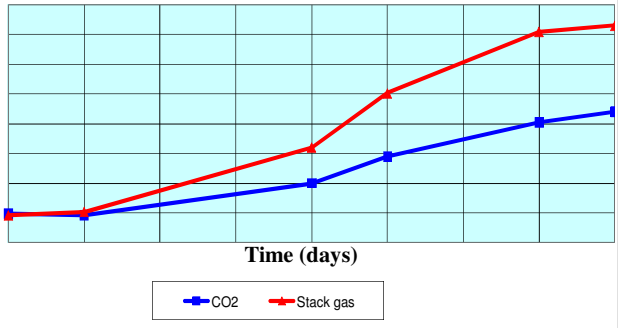
Nannochloropsis sp grows better on coal FGD flue gas than on pure CO_2

1. Pure CO_2
2. Flue gas
3. Flue gas from the Power Plant
4. Flue gas

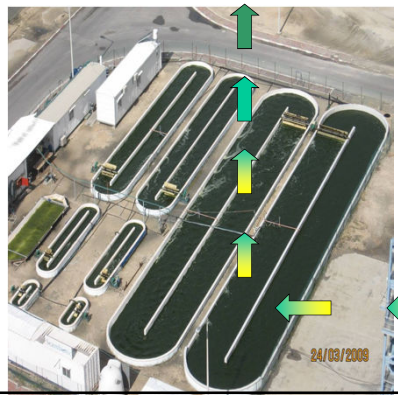


Flue Gas versus Pure CO_2

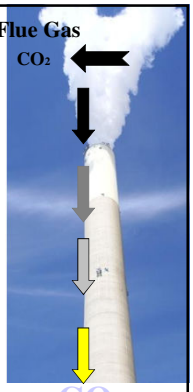
Algal Biomass (g/L)



Algae

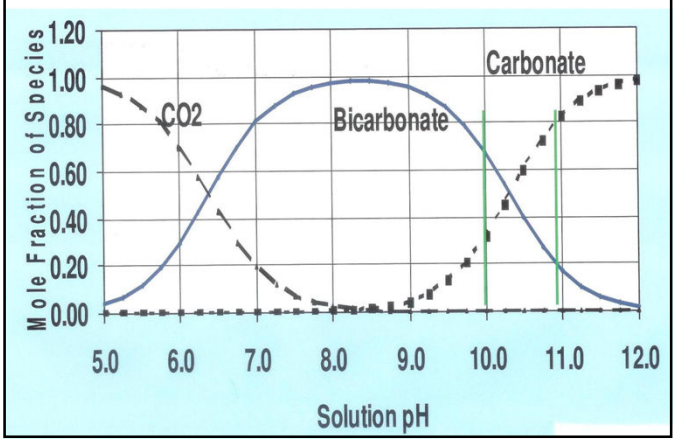


Flue Gas
CO_2



CO_2

CO_2 (Carbonic Acid)/Bicarbonate/Carbonate Equilibrium



Analysis of the FGD Flue Gas Mist Minerals at Low pH Water (variety of coals)

תוצאה	יחידות מידה	הבדיקה
		ICP- סריקת מתכות סלאה ב
<0.05	mg/L	Ag- כסף
3	mg/L	Al- אלומיניום
<0.1	mg/L	As- ארסן
<0.1	mg/L	B- בורון
0.07	mg/L	Ba- בריום
<0.05	mg/L	Be- בריליום
5	mg/L	Ca- סידן
<0.05	mg/L	Cd- קדמיום
<0.05	mg/L	Co- קובלט
0.06	mg/L	Cr- כרום
31	mg/L	Cu- נחושת
23	mg/L	Fe- ברזל
<0.05	mg/L	Hg- כספית
0.6	mg/L	K- אשלגן
<0.05	mg/L	Li- ליתיום
1	mg/L	Mg- מגנזיום
0.2	mg/L	Mn- מנגן
<0.05	mg/L	Mo- מוליבדן
<0.5	mg/L	Na- נתרן
1	mg/L	Ni- ניקל
1	mg/L	P- זרחן
2	mg/L	Pb- עופרת
6347	mg/L	S- גופרית
<0.05	mg/L	Se- סלן
0.1	mg/L	Sr- סטרונציום
0.2	mg/L	Ti- טיטניום
<0.05	mg/L	V- ונדיום
72	mg/L	Zn- אבץ

Mist (acid H_2O)
Flue Gas
13% CO_2
NOx
Minerals
Low pH

Average Yearly Productivity
of
unicellular marine algae
on
FGD flue gas
in
open ponds
~20 g / m^2 / day

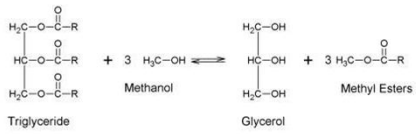
Annual Microalgae Production Cost *Dunaliella* Plant versus Seambiotic/ FGD Plant (10 Hectares Plant)		
	Dunaliella (2011)	Seambiotic/Power Plant (estimated, 2011)
	Cost in US$/year	
Manpower	500,000 (20 workers)	120,000 (8 workers)
Electricity ($0.125/KW) & residual energy	180,000	30,000
Fertilizers (N,P,K, Fe) and other chemicals	36,000	36,000
Domestic Land Taxes	50,000	10,000
CO_2	250,000	5,000
Sea Water	200,000	5,000
Fresh Water	20,000	10,000
Other supplies and Miscellaneous	30,000	20,000
Total	1,266,000	236,000
Yearly production of dry algae biomass	70 tons (2g/m2/day)	700 tons (20g/m2/day)
Cost per 1Kg dry microalgae	$18.00	$0.34
Market Price	$200	For Bio-Fuel cost should be below $0.5/kg algal dw

From the Algae to Bio-Fuel

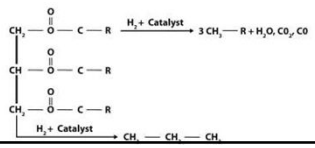
Algae Paste

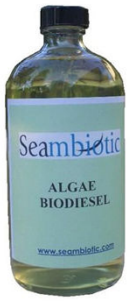
From Algae to Bio-Diesel

Extraction and Transesterification

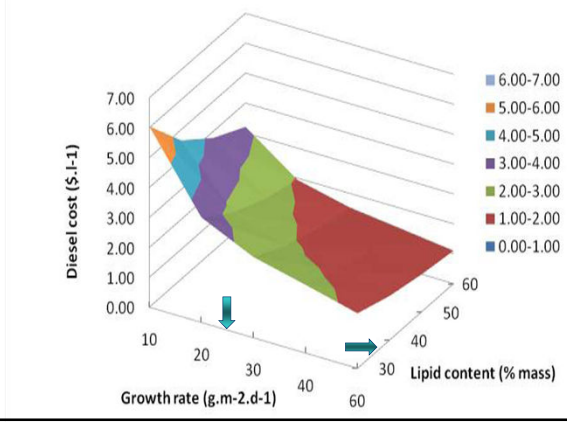


Catalyzed Hydro reaction





Effect of Growth Rate and Lipid Content of Algae in Open Ponds on Bio-Diesel Production Cost (Darzin, NREL 2010)



Seambiotic New Algae Sites (★)
Coal Flue Gas & Sea Water
Japan, (Sendai), China (Yantai), Israel (Ashkelon), 2011
Power Plants Coal Flue Gas and Seawater

Commercial Production of *Nannochloropsis*

Seambiotic Ltd. Israel

&

Hairong Electric Company, China

JV

Microalgae Plants on Coal Burning Flue Gas in China

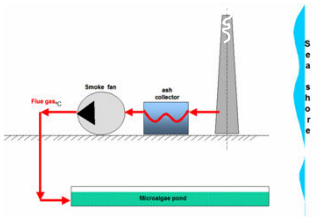
1st Plant Penglai, China

October 2011

The Vision

Utilization of electric power plant resources for growing selected marine microalgae at energy cost for valuable products and bio-fuels while considering the issue of CO_2 sink to reduce global warming

- **Low cost flue gas (CO_2)**
- **Low cost seawater**
- **Residual energy**
- **Arid land**
- **All year algae production**
- **Improved hydrodynamic**



Seambiotic

Thank You