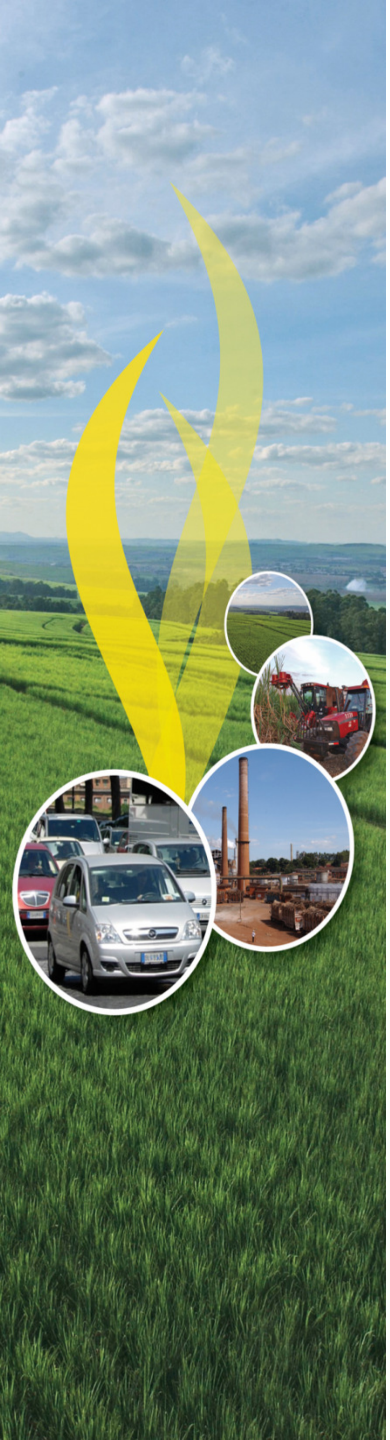


Algae-based Biofuels

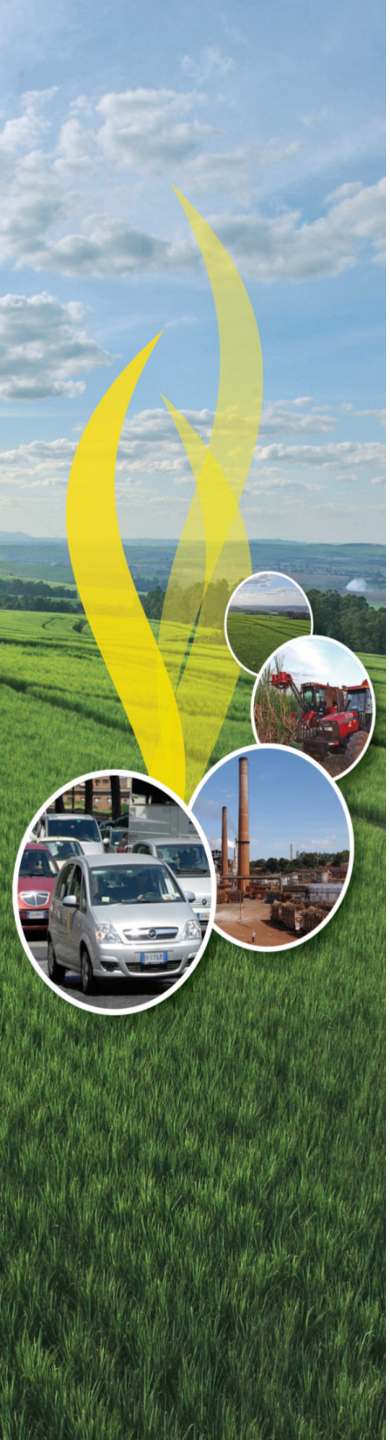
Perspectives for developed and developing countries

Workshop "Algen - eine Energiequelle für Österreich? "

16 March 2011

Hotel Mercure Graz Messe

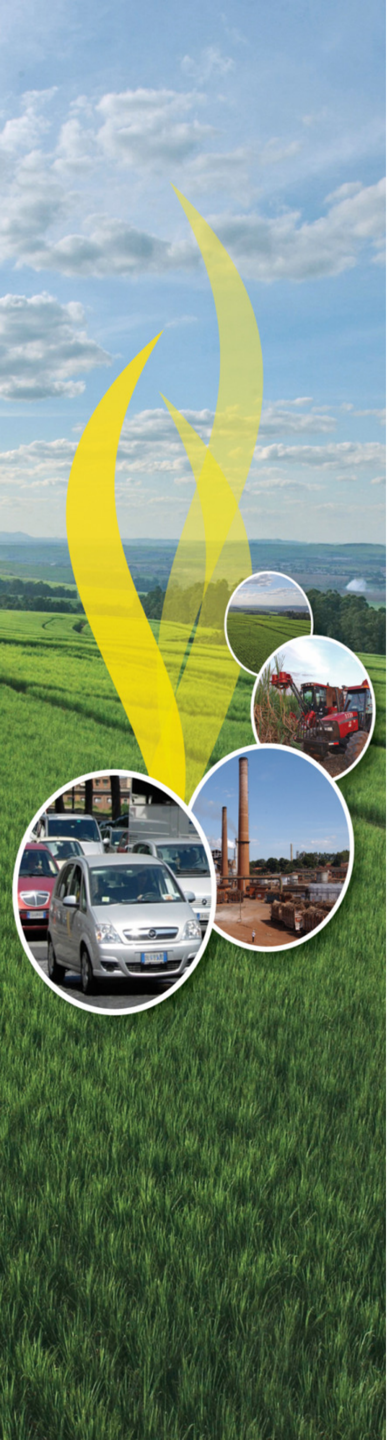
Alessandro Flammini
Food and Agriculture Organization of the UN (FAO)



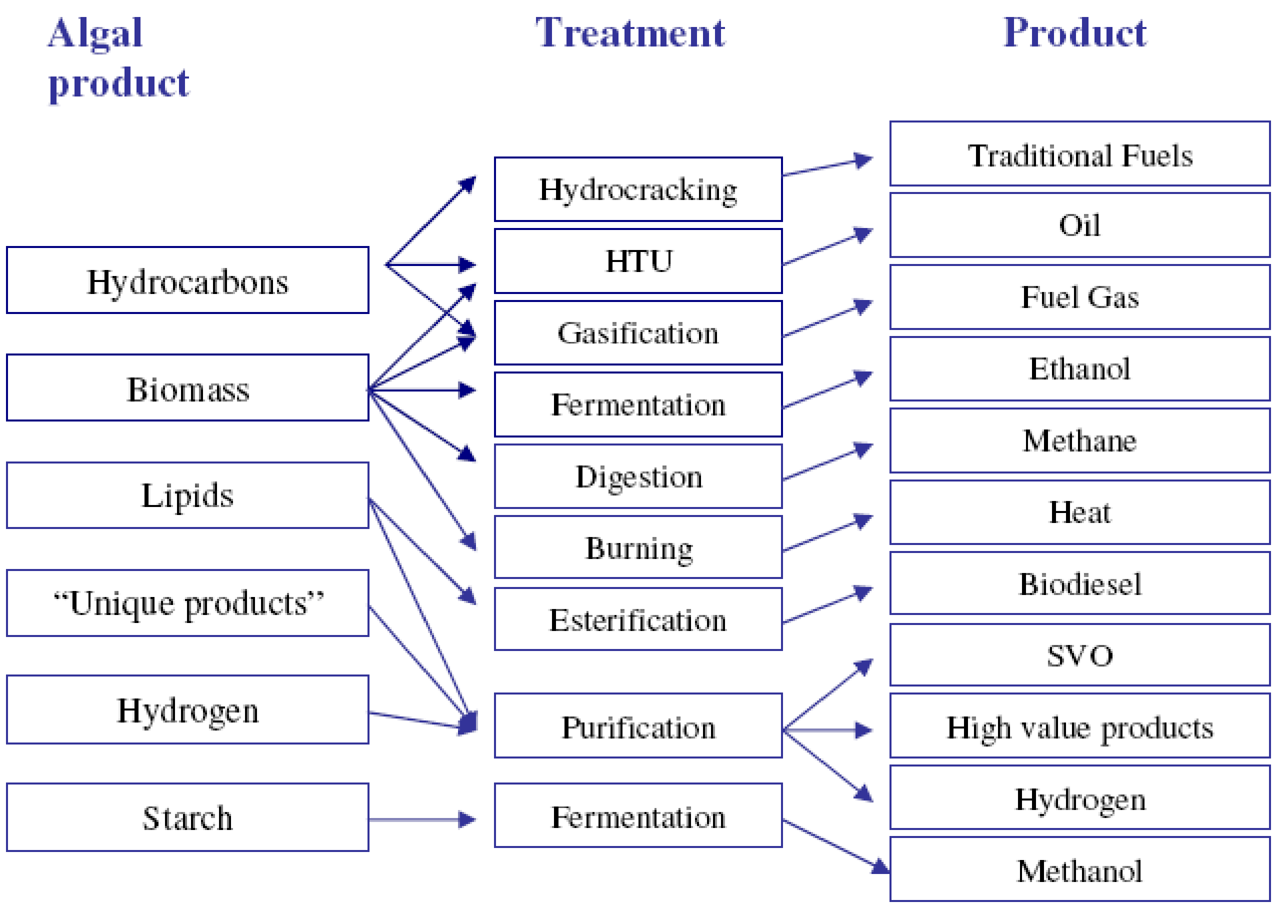
Advantages/Limitations

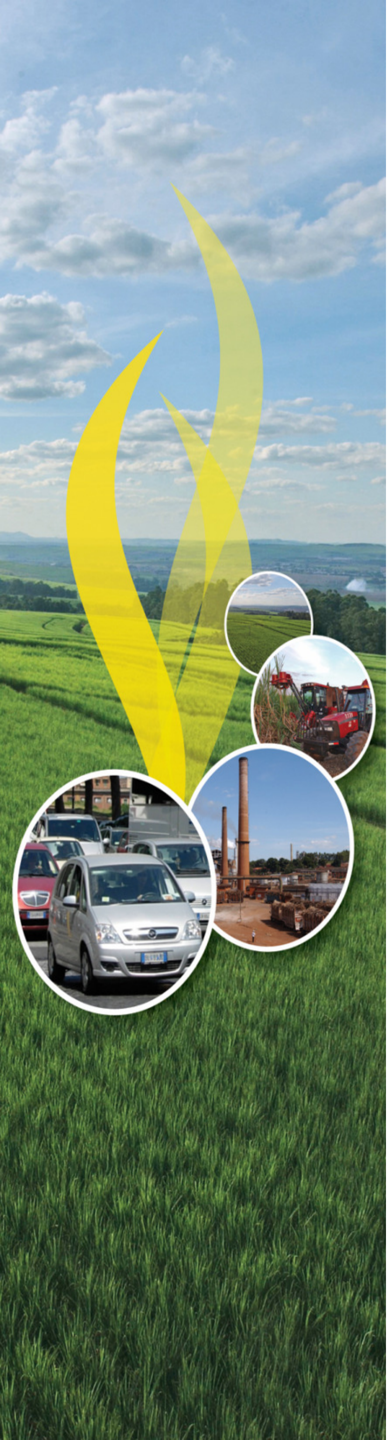
- no need for agricultural land
- high productivity
- high fertilizer use efficiency
- utilization of combustion gas
- can use wastewater (treatment)
- year-round production
- metabolic flexibility (biochemical content can be influenced)
- can use current fossil fuel infrastructure
- can count on political and consumer support

- high cost
- non-integrated systems have usually a negative energy balance (harvesting tech and drying needs?)



Bioenergy options

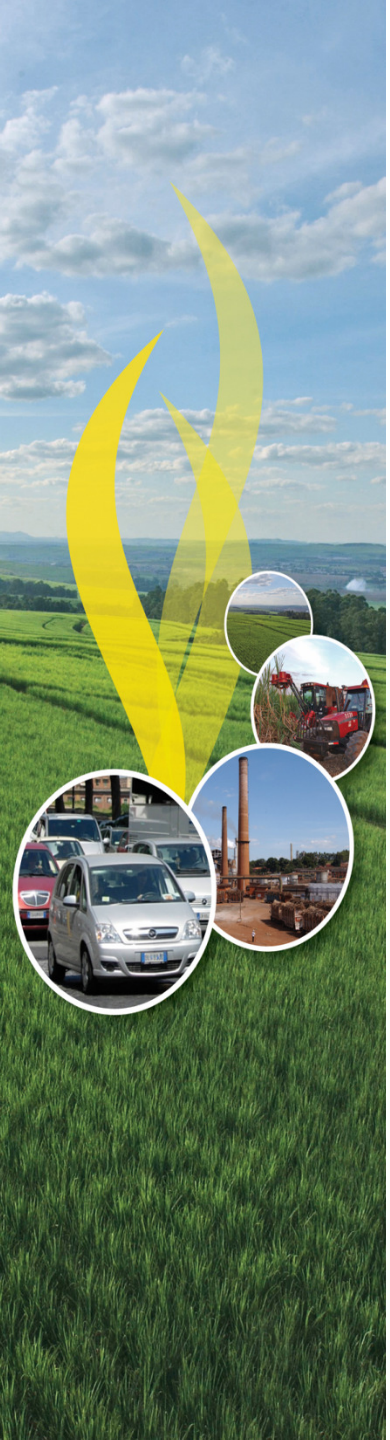




General composition of different algae (% DW)

Alga	Protein	Carbohydrates	Lipids
Anabaena cylindrical	43-56	25-30	4-7
Aphanizomenon flos-aquae	62	23	3
Chlamydomonas rheinhardii	48	17	21
Chlorella pyrenoidosa	57	26	2
Chlorella vulgaris	51-58	12-17	14-22
Dunaliella salina	57	32	6
Euglena gracilis	39-61	14-18	14-20
Porphyridium cruentum	28-39	40-57	9-14
Scenedesmus obliquus	50-56	10-17	12-14
Spirogyra sp.	6-20	33-64	11-21
Arthrospira maxima	60-71	13-16	6-7
Spirulina platensis	46-63	8-14	4-9
Synechococcus sp.	63	15	11

(Becker 2007)



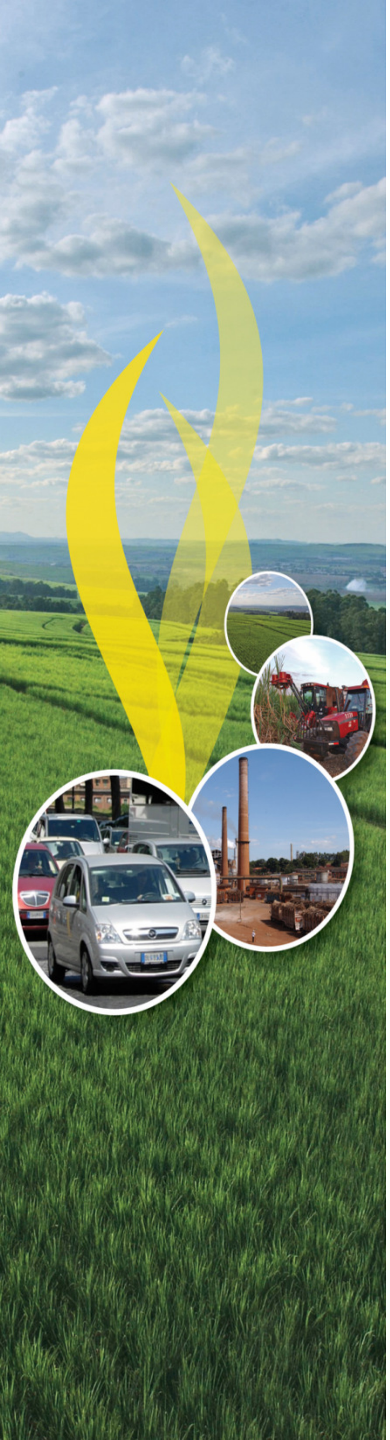
Food options

Food item	Protein content per 100 g (g)	Cost per 100 g of protein (Rs)	Comparative ratio of cost of protein with Spirulina	Comparative ratio of cost of lysine with Spirulina	Comparative ratio cost of cystine with Spirulina	Comparative ratio cost of tryptophan with Spirulina
Spirulina	66	1.38	1	1	1	1
Egg	13.2	11.20	8.23	5.10	5.11	3.82
Milk (100 ml)	3.3	15.15	10.97	6.19	11.98	6.62
Cluster beans	3.2	31.25	22.64	14.67	26.13	15.09
Eggplant	1.4	57.14	41.41	44.45	78.52	19.48
Carrot	0.9	88.88	64.41	10.10	28.90	14.13
Potato	1.6	62.50	45.28	26.56	95.97	7.55
Onion	1.20	66.66	48.30	46.30	96.66	13.88
Mutton	18.50	16.21	11.75	6.31	26.45	1.68
Notes:	Only the cost of protein from consumed foods other than staple food is compared here. The costs per unit of vitamin A, nicotinic acid, riboflawin, thiamin, vitamin B12 and iron are cheaper in Spirulina than from other sources. The protein content of Spirulina is based on a dry weight whereas the protein content of other food sources is reported on a wet weight basis.					

Spirulina protein content compared with other staple foods in (vegetarian) South India, 1991 (Babu and Rajasekaran 1991)

Staple food | Pigments | PUFAs | Polysaccharides

Livestock consumption | Fish and shellfish consumption



Other options

Chemical industry

- in the process to produce ethanol/butanol
- bio-plastics / paints
- will initially focus on cheaper feedstock

Cosmetics

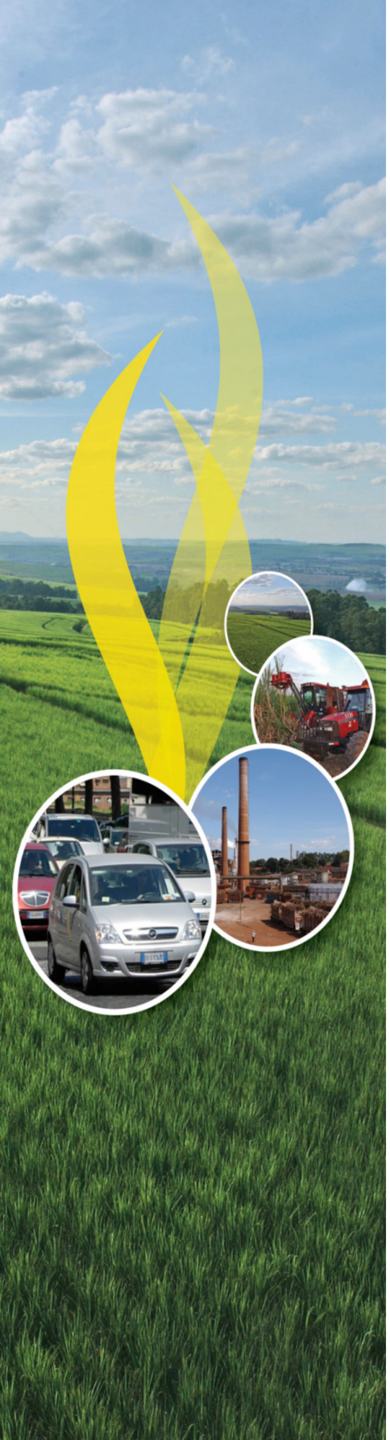
- used in the skin care market (*Arthrospira* and *Chlorella*)
- gaining commercial importance in lipid-based cosmetics (lotions)

Fertilizers

- seaweed used worldwide in coastal regions (N fixing species)
- nutrients still present after extraction of oil or carbohydrates
- nutrients released slowly

Fibres for paper

- process/quality improvement (mech strength, cooking times,…)
- lower material cost
- applicable to wastewater



Commercially produced algae

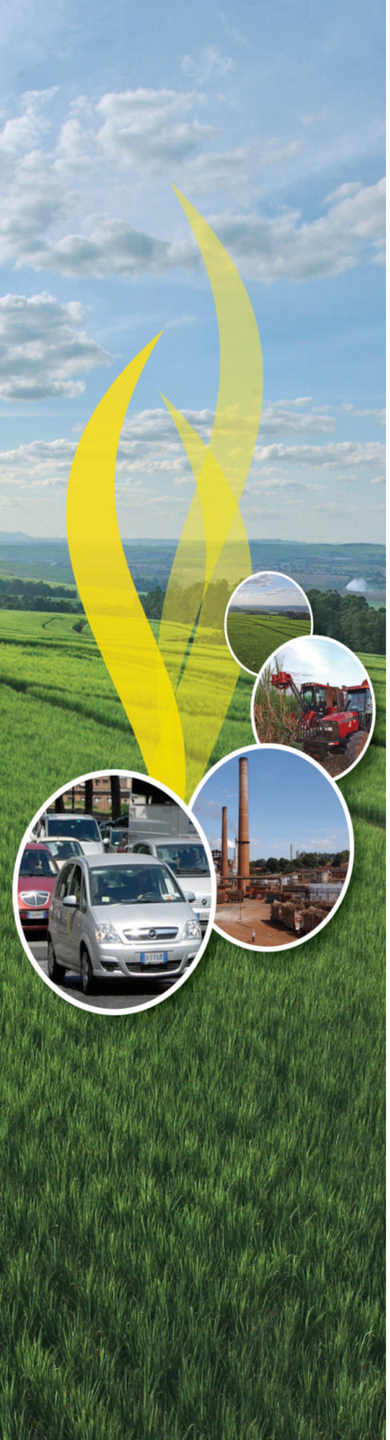
Microalga	Annual production	Producer country	Application and product	Price
Spirulina	3000 tons dry weight	China, India, USA, Myianmar, Japan	Human nutrition Animal nutrition Cosmetics Phycobiliproteins	36 €/kg 11 €/mg
Chlorella	2000 tons dry weight	Taiwan, Germany, Japan	Human nutrition Cosmetics Aquaculture	36 €/kg 50 €/L
Dunaliella salina	1200 tons dry weight	Australia, Israel, USA, Japan	Human nutrition Cosmetics β-carotene	215-2150 €/kg
Aphanizomenon flos-aquae	500 tons dry weight	USA	Human nutrition	
Haematococcus pluvialis	300 tons dry weight	USA, India, Israel	Aquaculture Astaxanthin	50 €/L 7150 €/kg
Crypthecodinium cohnii	240 tons DHA oil	USA	DHA oil	43 €/g
Shizochytrium	10 tons DHA oil	USA	DHA oil	43 €/g

(Brennan and Owende 2010)

Average market price of algae biomass: €250/kg (1000x too high)

Estimated cost range for ABB: €0.5 - €6 /kg

Production cost for ABB can only be determined by running a commercial scale production facility. Extrapolation from test scale is inaccurate and risky

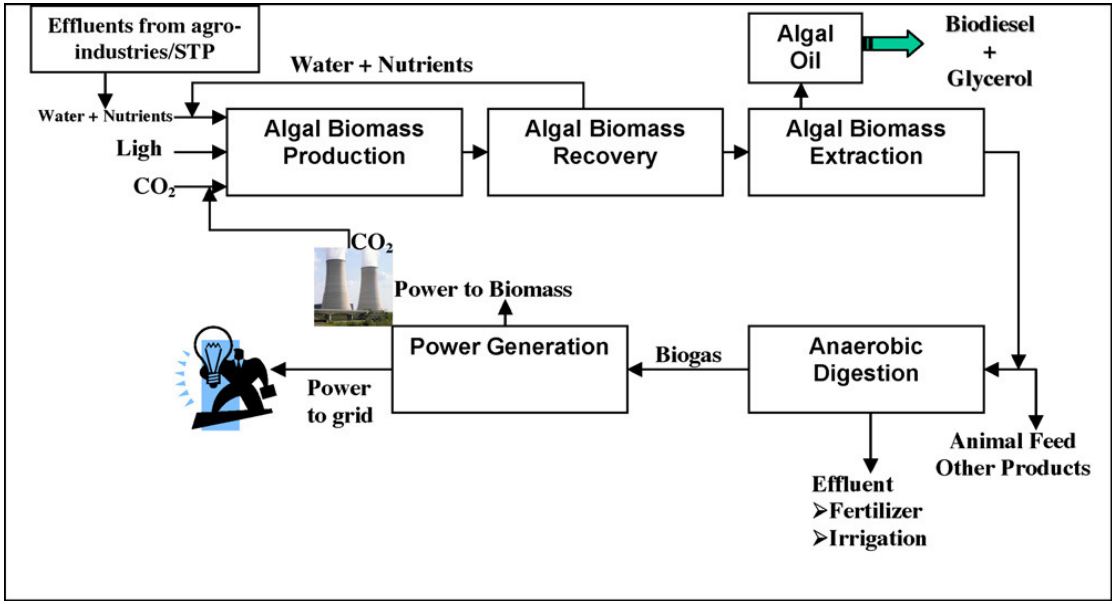


Integrated concepts

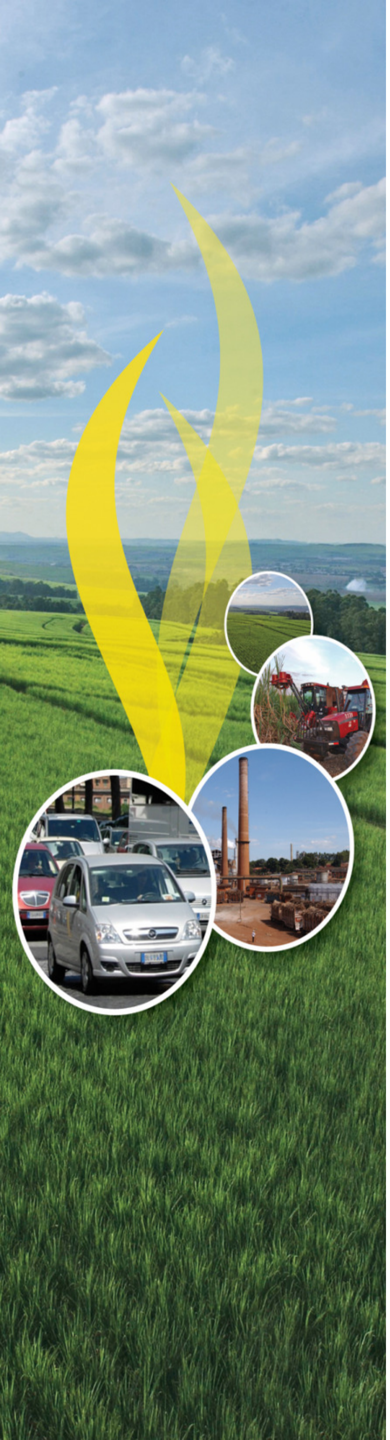
- Multiple resource use through the <u>diversification</u> of land use and production

(e.g. systems that co-produce algae, seaweed, fish, shellfish, bioenergy, but mild conditions are slower and more expensive)

- Multiple resource use through the <u>full utilization</u> of products and by-products/residues



Integrated algal production concept with various co-products (Khan, Rashmi et al. 2009)



Integrated concepts /markets

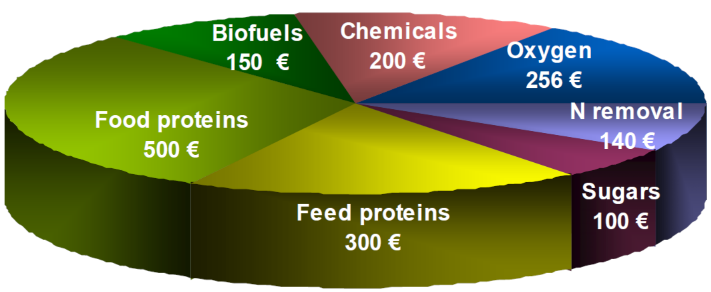
Applications	Price / Kg biomass	Market volume
Nutraceuticals (human consumption)	€ 100	€ 60 million
Nutraceuticals (animal and fish feed)	€ 5-20	€ 3-4 billion
Bulk chemicals	€ 1-5	> € 50 billion
Biofuels	< € 0.40	> € 1 trillion

(Wijffels 2008)

Potential markets

Wijffels, Barbosa et al. (2010) have chosen a random combination of microalgal products with bulk-scale market. Assuming 40% lipids, 50% proteins and 10% carbohydrates, a quarter of the lipids is sold to the food and chemical industry for €2/kg, the rest for biodiesel at €0.50/kg, soluble proteins (20%) for food at €5/kgm the rest (80%) for feed at €0.75/kg.

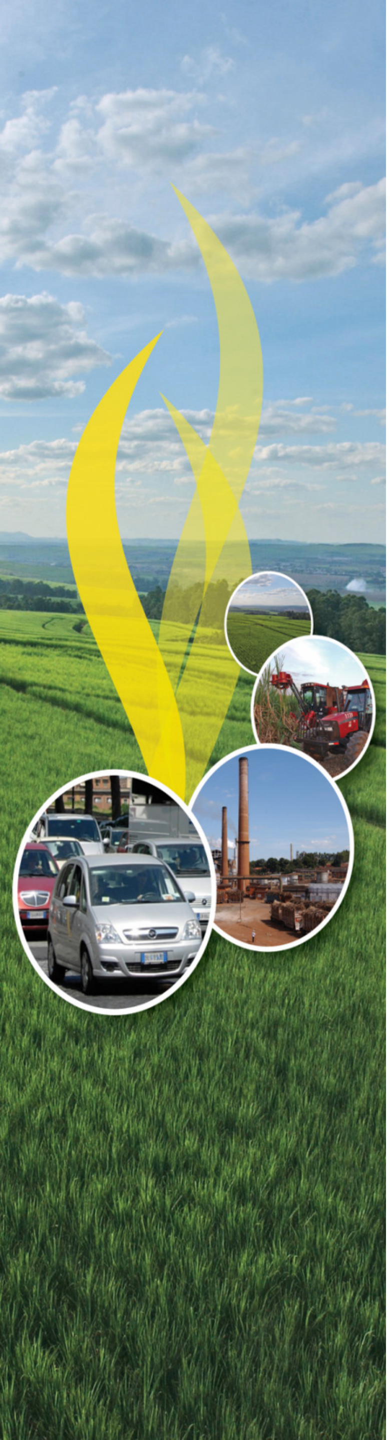
Biorefinery yields €1.65 /kg algal biomass, relying solely on products with a low market value and large market size.



Market value distribution of 1000 kg algae after biorefinery

(Wijffels, Barbosa et al. 2010)

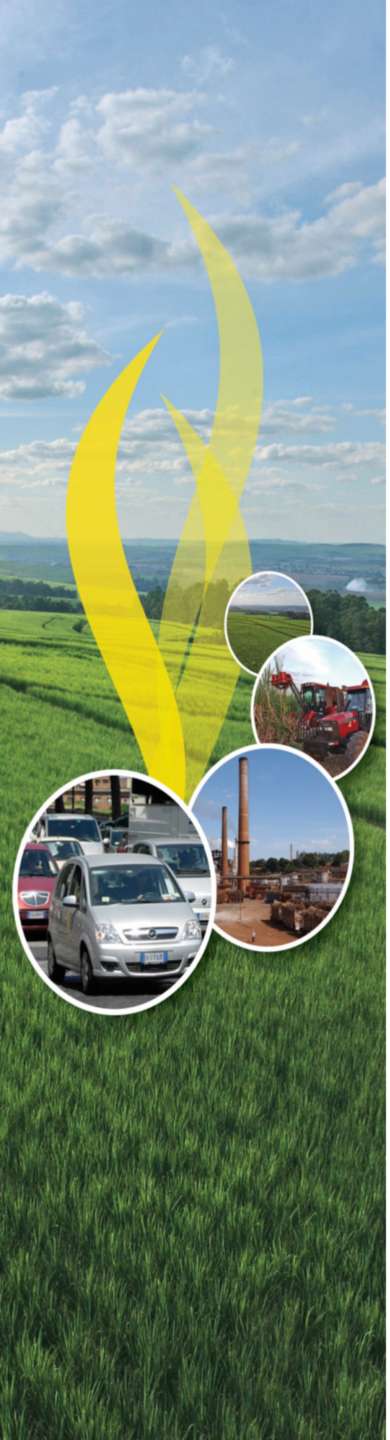
Markets should be compatible!



Integrated concepts /incentives

- Carbon credits and sustainability criteria (RTFO, RED, RSB, RFS, GBEP, etc.)

- How to spread impacts over co-products?
- GHG emissions allocated to co-products on the base of their energy content? or market value? or...?



Developing countries experience

- Most commercial microalgae operations are located in China, Taiwan and India. In 1997 there were around 110 commercial producers of microalgae in the Asia Pacific region, with capacities ranging from 3 to 500 tons /year.

- Experiences in China, Taiwan, Thailand, Philippines, Indonesia, Myanmar, Vietnam, South Korea, Mexico, Chile, Cuba, Chad, South Africa

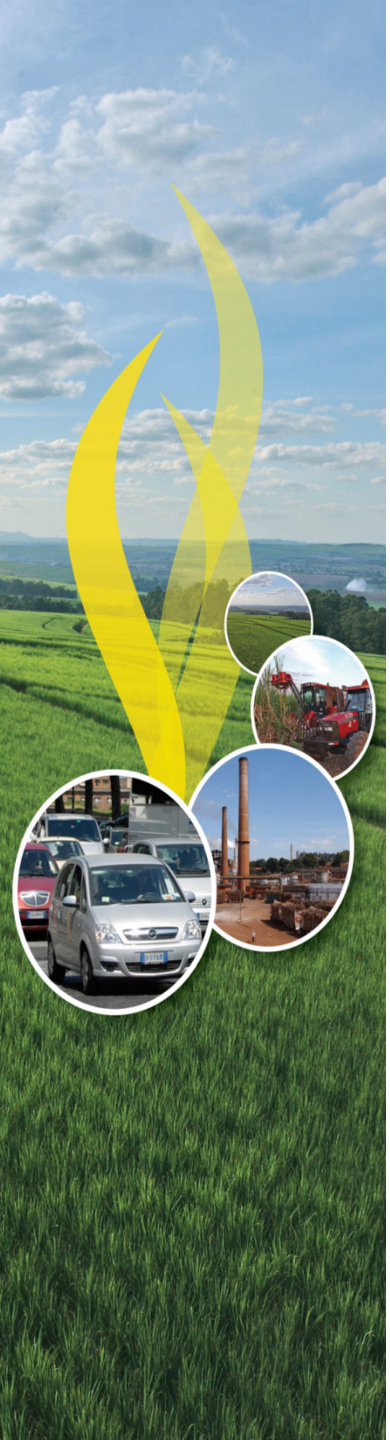
Two scenarios for scale of operations

→ Algal biodiesel plant
> 1000 ha (Um and Kim 2009)

→ Small-scale, community operated systems

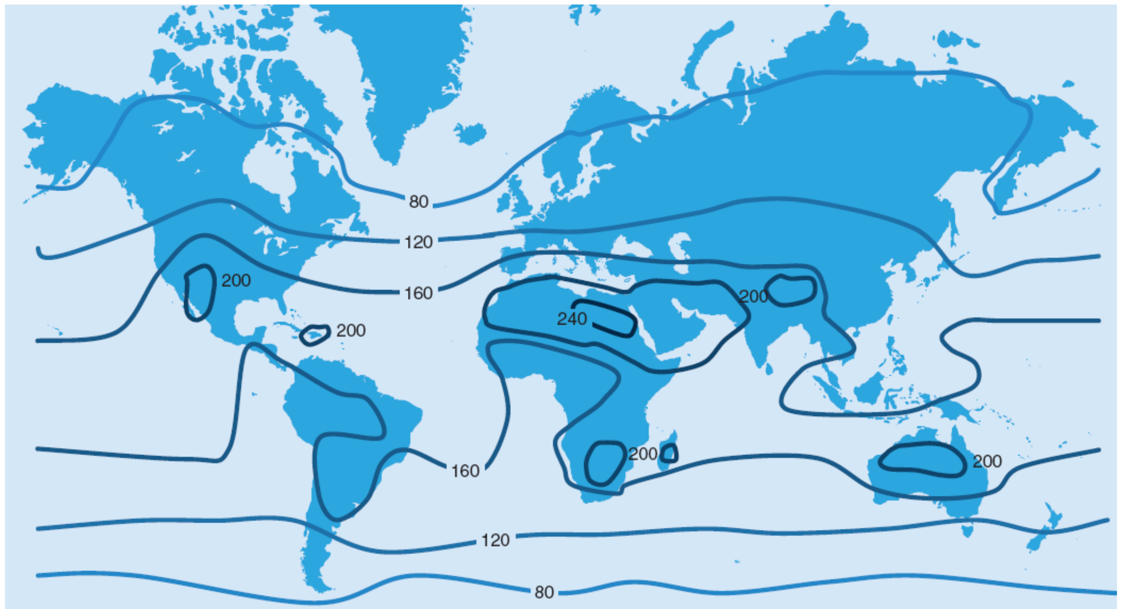
- Open ponds (Limited no. of species)
- Filamentous species
  Fish feed
- Sun drying
  Mech. press

No willingness to pay for 'greener' products!



Productivity

World map of algae biomass **productivity** (tons/ha/year) at 5% photosynthetic efficiency considering an energy content of 20 MJ/kg dry biomass

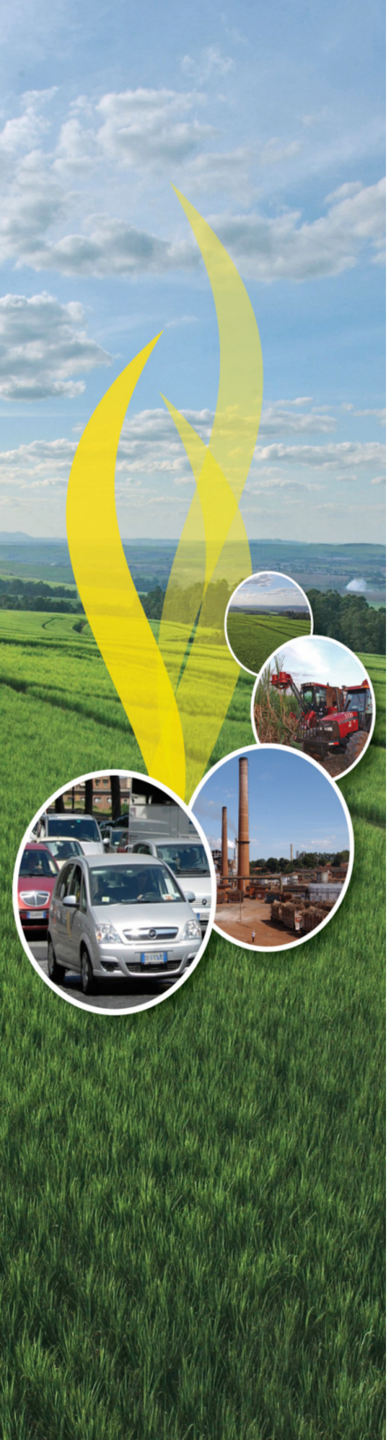


(Tredici 2010)

≠ grow rate

40-80 tons DW /ha/year

?

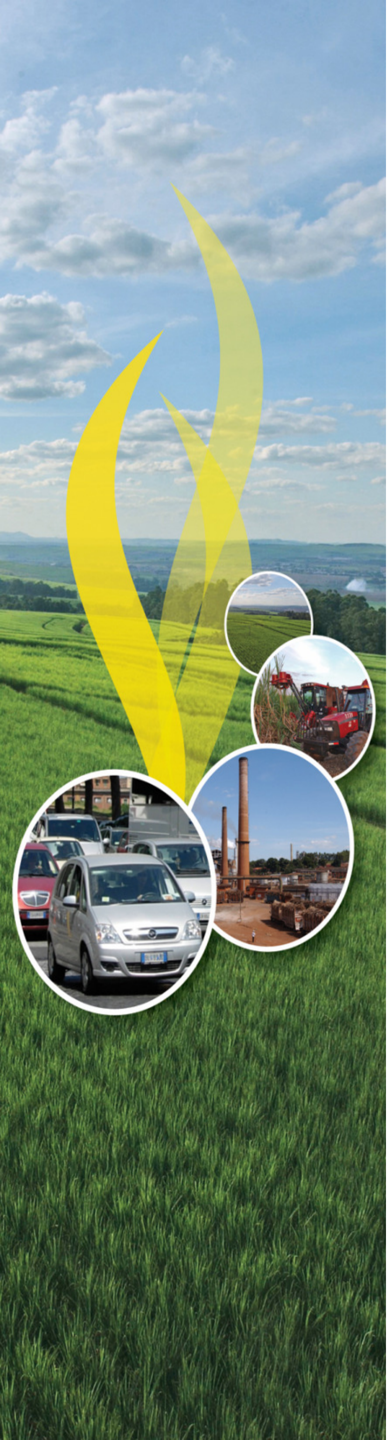


Some conclusions

- Lack of collaboration and information-sharing leads to inefficient use of capital due to overlap and duplication of research by independently funded working groups

- no solution at present to achieve large scale yields (100s Ha) comparable to C4 plants (e.g. sugarcane)
- no company has a mature technology to be on the market and compete with fossil fuels

- high yields and large scale production can be successfully achieved only through a comprehensive and well-funded RD&D programme which promotes business models that look not only at algae to displace the transportation fuels market, but also consider the cascading of algae chains with other higher-value products



Thank you!

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