Algae as renewable energy

Eemeli Hytönen, Ph.D.
VTT

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About the author

- Mr. Eemeli Hytönen is a Senior Scientist at VTT Technical Research Centre of Finland.
- Team leader (Process concepts) and project manager of various research and development projects focusing on early-stage design, modeling and simulation, and economic and environmental assessment of bio-based process concepts
- The main research focus areas
  - investment project decision-making
  - assessment of production systems under uncertainty
  - pulp and paper industry and biotechnology

- MSc in applied physics from the University of Jyväskylä (2005)
- PhD in Chemical Engineering from Ecole Polytechnique de Montreal (2011)

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Outline

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- Challenges
- State-of-the-art
- Examples
- Conclusions
- Acknowledgements

Introduction

Terminology – Wikipedia definitions

- **Algae** are a very large and diverse group of simple, typically autotrophic **eukaryotic** organisms, ranging from unicellular to multicellular forms (Protista Kingdom)
  - **Macroalgae** – seaweed
  - Microphytes or **microalgae** are microscopic algae, typically found in freshwater and marine systems… It has been estimated that about 200,000-800,000 species exist of which about 35,000 species are described…
- **Bacteria** constitute a large domain of **prokaryotic** microorganisms
- A **fungus** is a member of a large group of **eukaryotic** organisms that includes microorganisms such as yeasts and molds, as well as the more familiar mushrooms (Fungi Kingdom)

- **Phototrophs** are the organisms that carry out photon capture to acquire energy… Many, but not all, phototrophs often photosynthesize: they anabolically convert carbon dioxide into organic material…
- A **heterotroph** is an organism that cannot fix carbon and uses organic carbon for growth
- A **mixotroph** is an organism that can use a mix of different sources of energy and carbon

Introduction
Why algae

- High oil containing crops are adequate to meet only the current demands for bio-diesel
  - some plant oils (soy, sunflower, rapeseed) raise important questions concerning food versus fuel
  - some plant oils (e.g. oil palm) raise questions concerning indirect food versus fuel conflicts
  - used vegetable oils provide a limited source (~5% total desired bio-diesel)

	Litres per hectar per year
Oil palm	5940
Jatropha	1890
Rapeseed	1400
Sunflower	955
Camelina	560
Soybean	450
Microalgae	3800-50000

Darzins et al. 2010. IEA Bioenergy Task 39 Report T39-T2.
Antoni et al. 2007. *Appl. Microbiol. Biotechnol.* 77: 23-35.

Introduction
Why algae

- Focus of this presentation is on microalgae as renewable energy source – potentially high yield, flexible end environmentally sound source of energy
  - Suitable also for brackish and salty waters
  - CO_2/sugars as carbon source
  - light as energy source
  - wastes as nutrient source
  - Potential for CO_2 sequestration

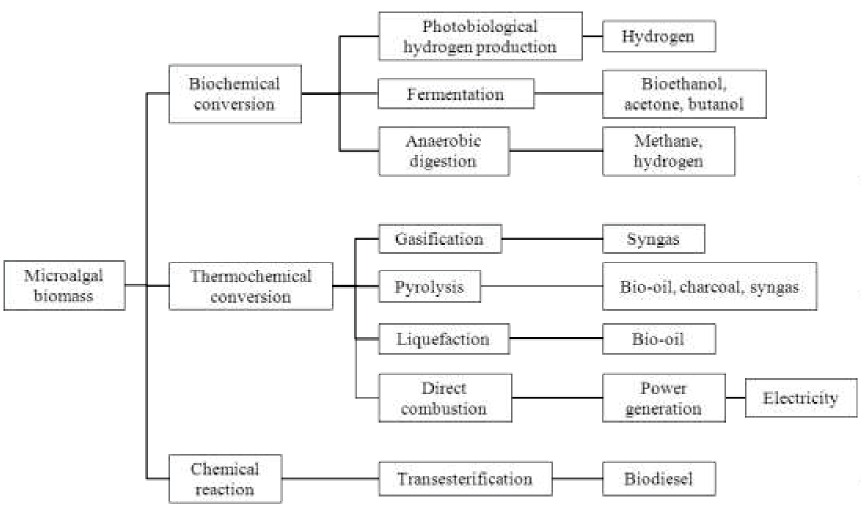
		Lipid content (% DW)
Yeast	Cryptococcus	> 65
	Lipomyces	64
	Rhodotorula	> 72
Fungi	Aspergillus	57
	Humicola	75
	Mortierella	86

		Lipid content (% DW)
Bacteria	Arthrobacter	40
	Acinetobacter	27-38
Algae	Botryococcus	25-**75**
	Chlorella	28-32
	Dunaliella	23
	Nannochlopopsis	31-**68**

Subramaniam et al. 2010. *J. Ind. Microbiol. Biotechnol.* 37: 1271-1287.

Introduction

Why algae – Many alternatives of microalgae based energy



EXAMPLE

Comparison of typical properties of petroleum oil and bio-oils from fast pyrolysis of wood and microalgae

Properties	Typical values		
	Bio-oils		Petroleum oil
	Wood	Microalgae	
C (%)	56.4	62.07	83.0–87.0
H (%)	6.2	8.76	10.0–14.0
O (%)	37.3	11.24	0.05–1.5
N (%)	0.1	9.74	0.01–0.7
Density ($kg\,l^{-1}$)	1.2	1.06	0.75–1.0
Viscosity (Pa s)	0.04–0.20 (at 40 °C)	0.10 (at 40 °C)	2–1000
HHV ($MJ\,kg^{-1}$)	21	29–45.9	42

Brennan L, Owende P. Renew. Sust. Energ. Rev. 2010; 14: p. 557-577.

Edited from:
- Brennan L, Owende P. Renew. Sust. Energ. Rev. 2010; 14: p. 557-577.
- Tsukahara K, Sawayama S. J. Jpn. Petrol. Inst. 2005; 48(5): p. 251-259.
- Wang B, Li Y, Wu N, Lan CQ. Appl. Microbiol. Biotechnol. 2008; 79(5): p. 707-718.

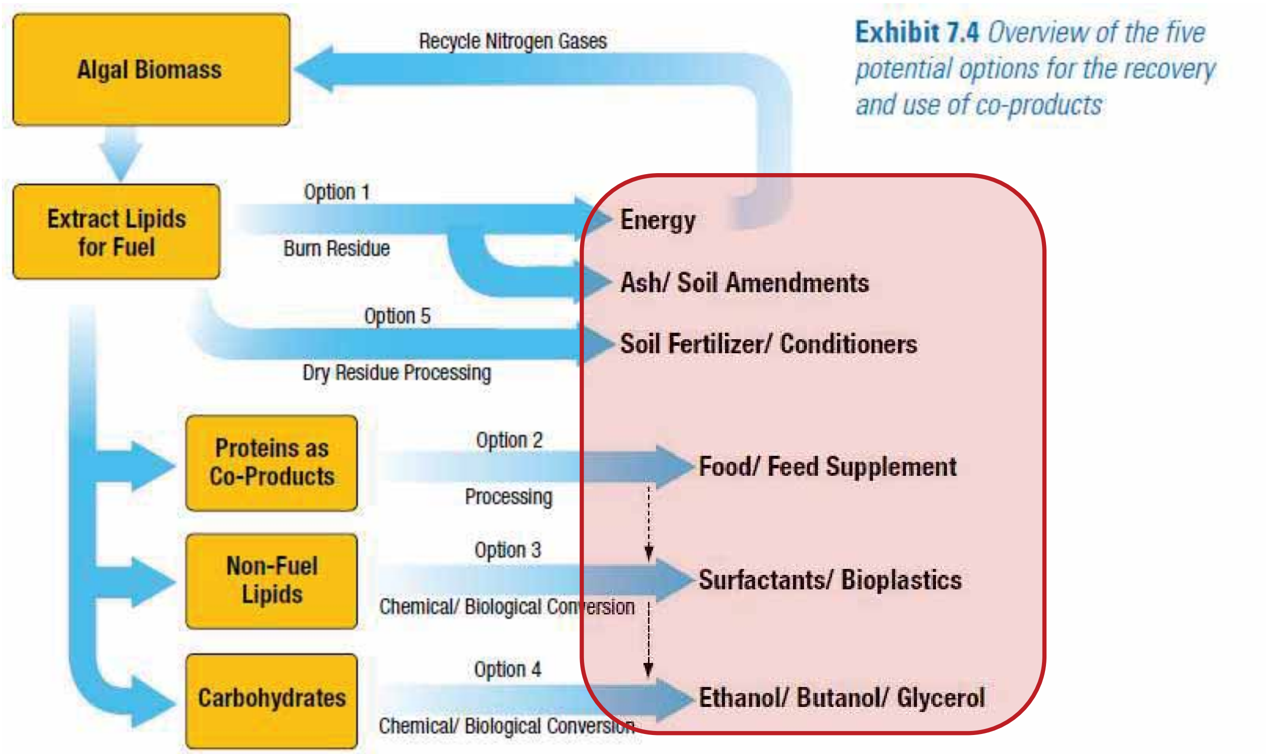
Challenges

Many algal species with different capabilities

Marine and freshwater microalgae species	Lipid content (% dry weight biomass)	Lipid productivity (mg/L/day)	Volumetric productivity of biomass (g/L/day)	Areal productivity of biomass ($g/m^2/day$)
Ankistrodesmus sp.	24.0–31.0	–	–	11.5–17.4
Botryococcus braunii	25.0–75.0	–	0.02	3.0
Chaetoceros muelleri	33.6	21.8	0.07	–
Chaetoceros calcitrans	14.6–16.4/39.8	17.6	0.04	–
Chlorella emersonii	25.0–63.0	10.3–50.0	0.036–0.041	0.91–0.97
Chlorella protothecoides	14.6–57.8	1214	2.00–7.70	–
Chlorella sorokiniana	19.0–22.0	44.7	0.23–1.47	–
Chlorella vulgaris	5.0–58.0	11.2–40.0	0.02–0.20	0.57–0.95
Chlorella sp.	10.0–48.0	42.1	0.02–2.5	1.61–16.47/25
Chlorella pyrenoidosa	2.0	–	2.90–3.64	72.5/130
Chlorella	18.0–57.0	18.7	–	3.50–13.90
Chlorococcum sp.	19.3	53.7	0.28	–
Crypthecodinium cohnii	20.0–51.1	–	10	–
Dunaliella salina	6.0–25.0	116.0	0.22–0.34	1.6–3.5/20–38
Dunaliella primolecta	23.1	–	0.09	14
Dunaliella tertiolecta	16.7–71.0	–	0.12	–
Dunaliella sp.	17.5–67.0	33.5	–	–
Ellipsoidion sp.	27.4	47.3	0.17	–
Euglena gracilis	14.0–20.0	–	7.70	–
Haematococcus pluvialis	25.0	–	0.05–0.06	10.2–36.4
Isochrysis galbana	7.0–40.0	–	0.32–1.60	–
Isochrysis sp.	7.1–33	37.8	0.08–0.17	–
Monodus subterraneus	16.0	30.4	0.19	–
Monallanthus salina	20.0–22.0	–	0.08	12
Nannochloris sp.	20.0–56.0	60.9–76.5	0.17–0.51	–
Nannochloropsis oculata.	22.7–29.7	84.0–142.0	0.37–0.48	–
Nannochloropsis sp.	12.0–53.0	37.6–90.0	0.17–1.43	1.9–5.3
Neochloris oleoabundans	29.0–65.0	90.0–134.0	–	–
Nitzschia sp.	16.0–47.0			8.8–21.6
Oocystis pusilla	10.5	–	–	40.6–45.8
Pavlova salina	30.9	49.4	0.16	–
Pavlova lutheri	35.5	40.2	0.14	–
Phaeodactylum tricornutum	18.0–57.0	44.8	0.003–1.9	2.4–21
Porphyridium cruentum	9.0–18.8/60.7	34.8	0.36–1.50	25
Scenedesmus obliquus	11.0–55.0	–	0.004–0.74	–
Scenedesmus quadricauda	1.9–18.4	35.1	0.19	–
Scenedesmus sp.	19.6–21.1	40.8–53.9	0.03–0.26	2.43–13.52
Skeletonema sp.	13.3–31.8	27.3	0.09	–
Skeletonema costatum	13.5–51.3	17.4	0.08	–
Spirulina platensis	4.0–16.6	–	0.06–4.3	1.5–14.5/24–51
Spirulina maxima	4.0–9.0	–	0.21–0.25	25
Thalassiosira pseudonana	20.6	17.4	0.08	–
Tetraselmis suecica	8.5–23.0	27.0–36.4	0.12–0.32	19
Tetraselmis sp.	12.6–14.7	43.4	0.30	–

Mata, T.M., Martins, A.A., and Caetano, N.S., *Renewable and Sustainable Energy Reviews*, 14(1): 217(2010).

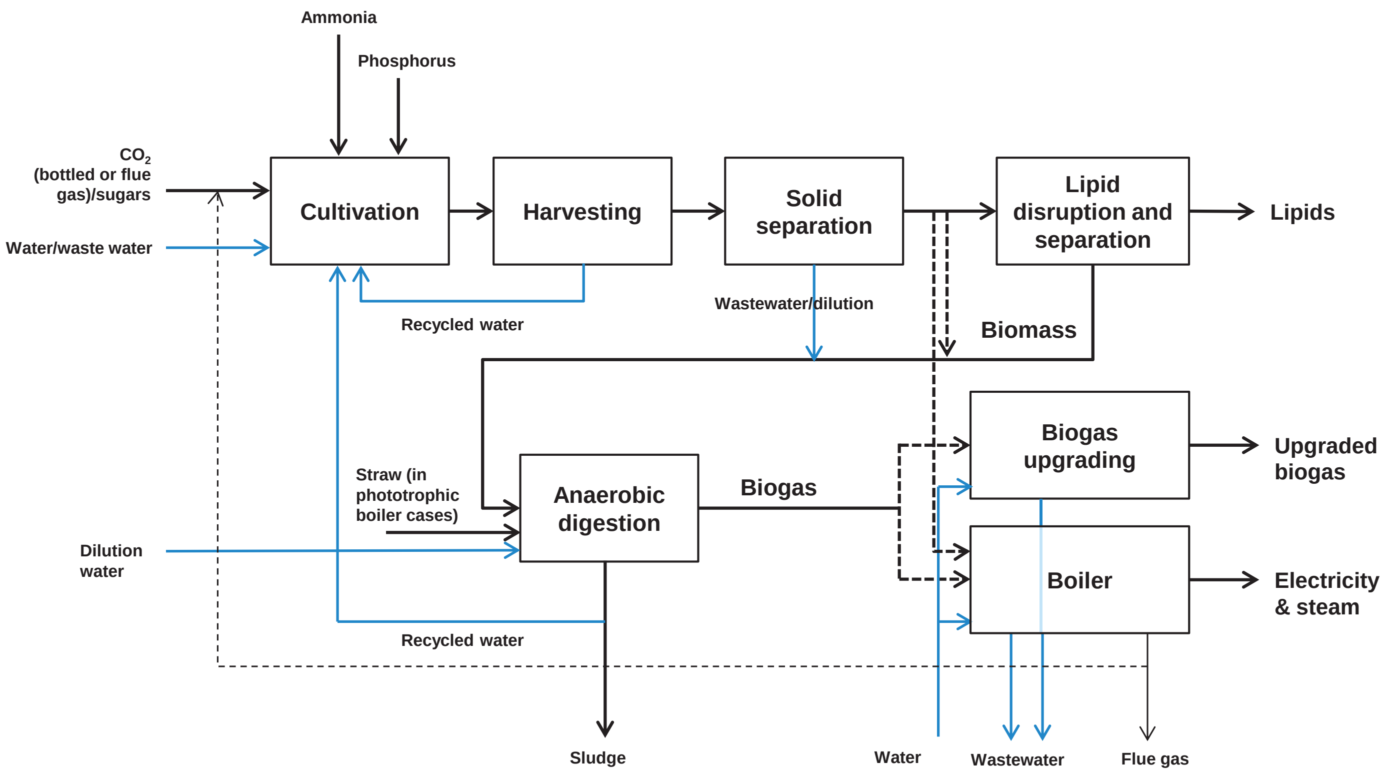
Challenges
Many potential co-products



Source: National Algal Biofuels Technology Roadmap

Challenges

Many possible process configurations

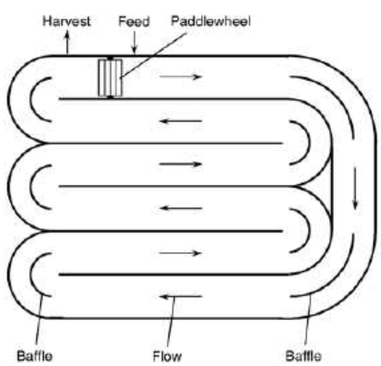


Block-flow diagram of microalgae-based energy production. Dashed lines represent alternative configurations

Challenges

Many methods for each process step… design analysis and selection process challenging

- The cultivation: traditional open ponds, photobioreactors, etc.
- Harvesting methods: centrifugation, flocculation, filtration, flotation
- Lipid extraction include mechanical separation, solvent or hot oil extraction, supercritical fluid extraction using CO_2 or other fluids, subcritical water extraction,

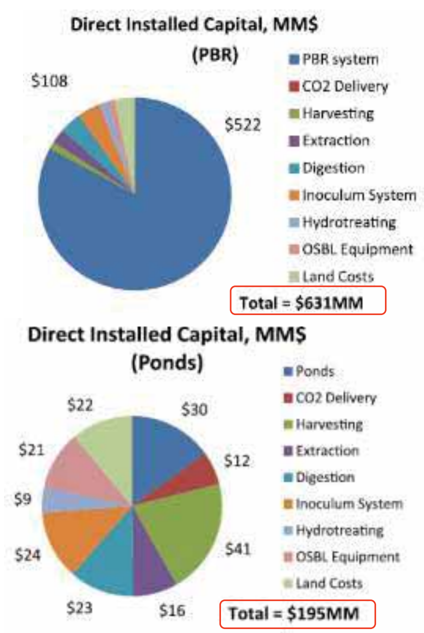


Chisti Y., Biotechnology Advances 25 (2007) 294–306

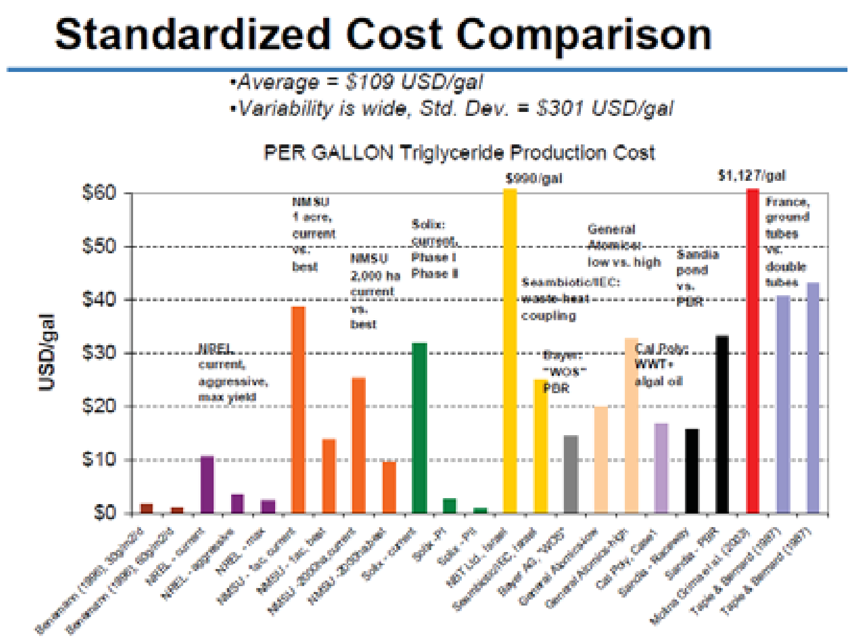
Waldeck P., ABO Algal Biomass Summit 2012

Challenges
Feasibility

- Costs & benefits → technology comparison difficult due to different assumptions
  - Strain, product, yields, scale, process parameters, prices, equipment providers



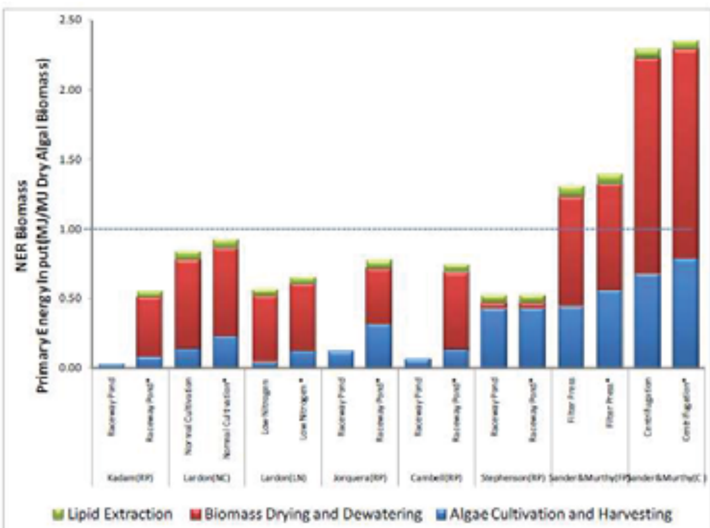
Davis, R., Aden, A., and Pienkos, P.T., *Applied Energy*, 88(10): 3524(2011).



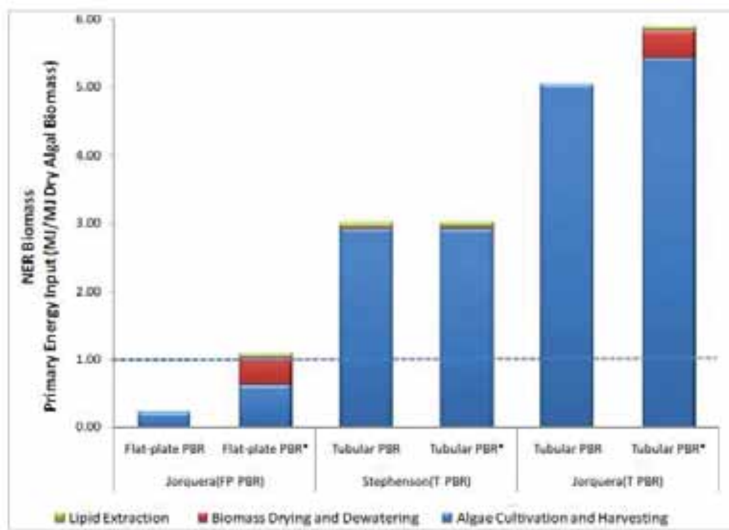
Philip T. Pienkos, DOE Algal Biofuels Workshop, December 2008

Challenges
Feasibility

- Environmental performance (NER: primary energy input/dry algal biomass output)
  - Downstream processing excluded
  - Targets: EU – 60% lower greenhouse gas emissions compared to fossil diesel
  - Main contributors: electricity demand of harvesting, heat demand of drying (if needed)



NC: Normal Cultivation; LN: Low Nitrogen Cultivation; FP: Filter Press; C: Centrifuge; RP: Raceway Pond
**=Normalised system boundary*



FP PBR: Flat-plate Photobioreactor; T PBR: Tubular Photobioreactor
**Normalised system boundary*

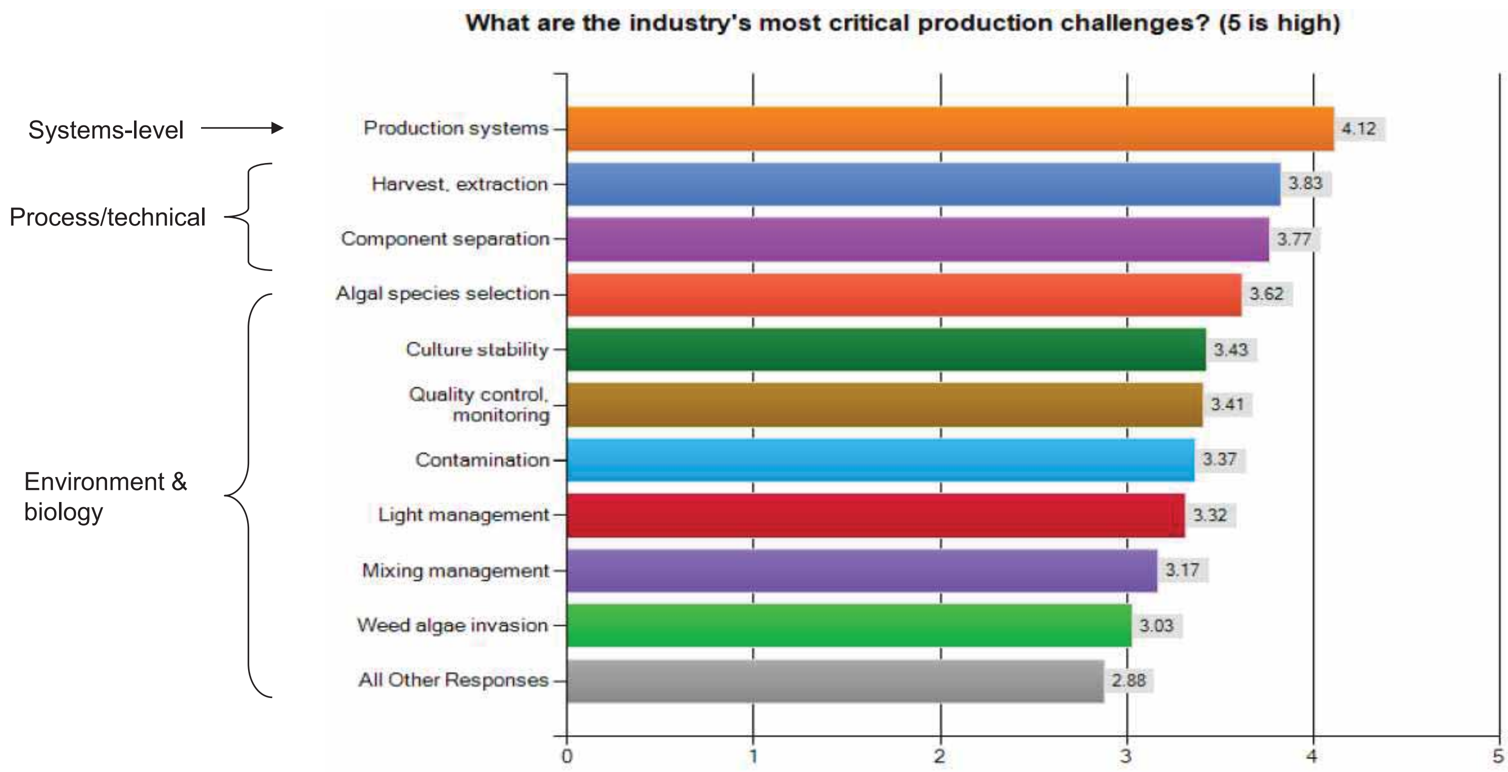
AquaFUELs – EU project (FP7), www.aquafuels.eu

Challenges
Feasibility

- Investor expectations
  - *"If an algae venture is not (a) able to demonstrate and prove its technology works on a small scale or (b) produce more than 1,000 tonnes of algal biomass or at least 100 gallons of algal oil with its partners, it is unlikely investors will take serious notice"* (Algae 2020 Vol 2: Biofuels, Drop-In Fuels, Biochems & Market Forecasts)
- Scale-up
  - *"The implications are that the supply of CO_2, nutrients, and water, in particular, can be expected to severely limit the extent to which US production of algae biofuel can be sustainably expanded unless approaches are developed to mitigate these resource constraints in parallel to emergence of a viable algae technology. Land requirements appear to be the least restrictive…"* (Pate R. et al., Applied Energy, Volume 88, Issue 10, pp. 3377–3388)
    - → Nutrient availability & recycling need more attention in addition to process technology development
  - *"The share of microalgal biodiesel and renewable jet fuel produced from it (microalgal biomass) in total global final energy consumption over the time horizon 2010–2100 is 5.1% in the case without CO_2 constraints compared with 3.9% and 0.7% in the case of CO_2 stabilization at 550 ppmv and 400 ppmv, respectively"* (Takeshita T., Applied Energy, Volume 88, Issue 10, pp. 3481–3491)
    - → Potential CO_2 stabilization constraint has an impact on CO_2 fixing energy sources

Challenges

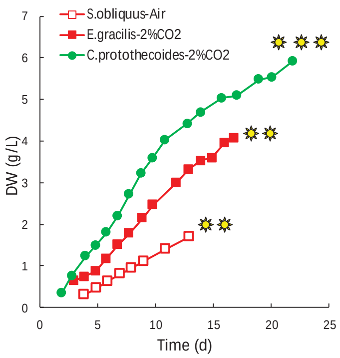
Top challenges based on the algae industry



Edwards, M., Algae World 2010 Industry Survey, Arizona State University & Centre for Management Technology, **(2010)**

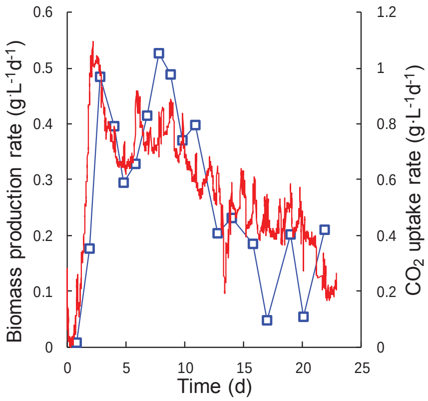
State-of-the-art
Algae strains

- **<u>Phototrophic</u>** oil production = direct harvesting of light and CO2
    - CO2 feeding enhances growth rate and biomass production



Strain	Light*	CO_2 (%)	Growth rate ($g \cdot L^{-1}d^{-1}$)#
S. obliquus	++	0.03	0.15
E. gracilis	++	2	0.32
C. protothecoides	+++	2	0.41

* 2 or 3 light sources, each ~400 µmol $s^{-1}m^{-2}$
\# Average linear growth rate

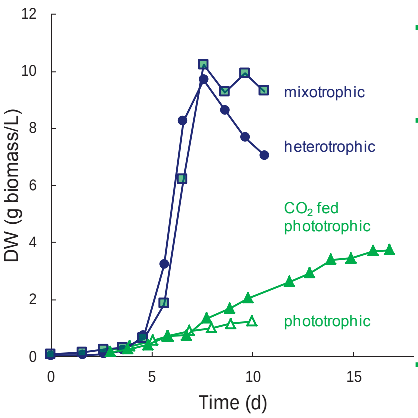


Source: VTT

State-of-the-art

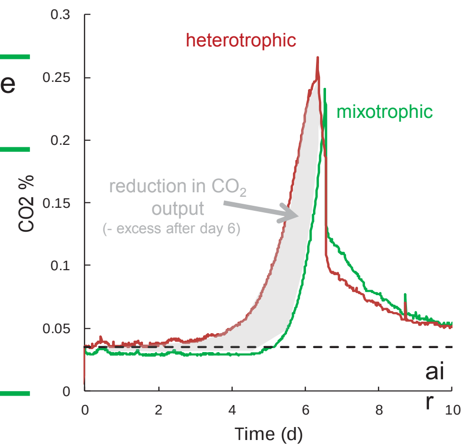
Algae strains

- Biomass densities in phototrophic cultures will always be limited by light penetration
  - Solution: grow algae with organic carbon (**heterotrophic**)



Growth	Growth rate $(g \cdot L^{-1}d^{-1})$	Lipid production rate $(g \cdot L^{-1}d^{-1})$
phototrophic	0.1	0.05*
phototrophic + CO_2	0.3	n.d.
heterotrophic	1.3	0.1*
mixotrophic	1.3	0.2*

* not optimized



- **Mixotrophic** oil production - reduced CO_2 output
  - maintain the benefit of high biomass and high growth rate
  - reduce loss from cell lysis
  - utilize 'waste' biomass & recycle nutrients
  - measurably less CO_2 is produced

Source: VTT

State-of-the-art

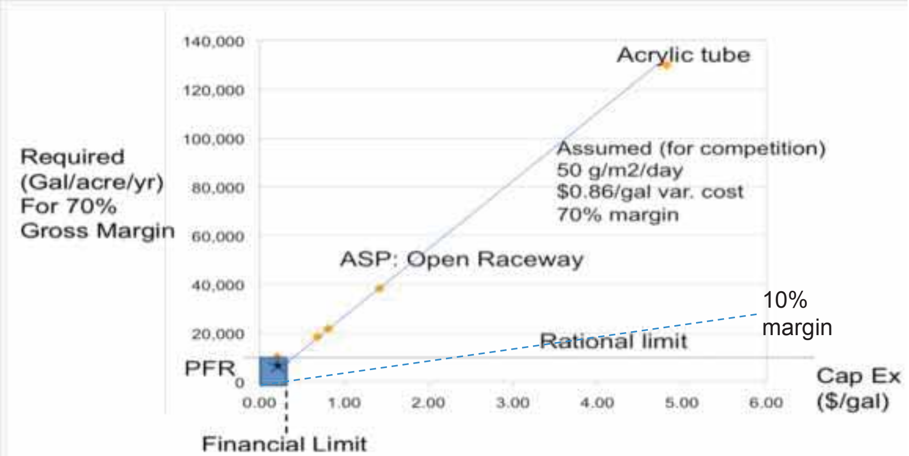
Processes – overall production concept

- Financial limit assumptions:
  - 70% gross profit margin if sold directly into blenders
  - no subsidy assumed
  - 5% price increase/year
  - year 5 of production
  - 8% interest rate for 1st facility capital loan
  - 20% down payment
- Rational limit assumptions
  - 45% lipids in dry algae, 50g/m2/d productivity

→ cost ~$1.00/gal (70% gross margin, ~0.2$/gal CAPEX), or ~$3.1/gal (10% gross margin, ~2.5$/gal CAPEX)

→ Latest published costs ~$10/gal (open pond) and ~$20/gal (PBR) (Davis R. et al. Applied Energy, Volume 88, Issue 10, pp. 3524–3531)

Investment costs (mainly cultivation)

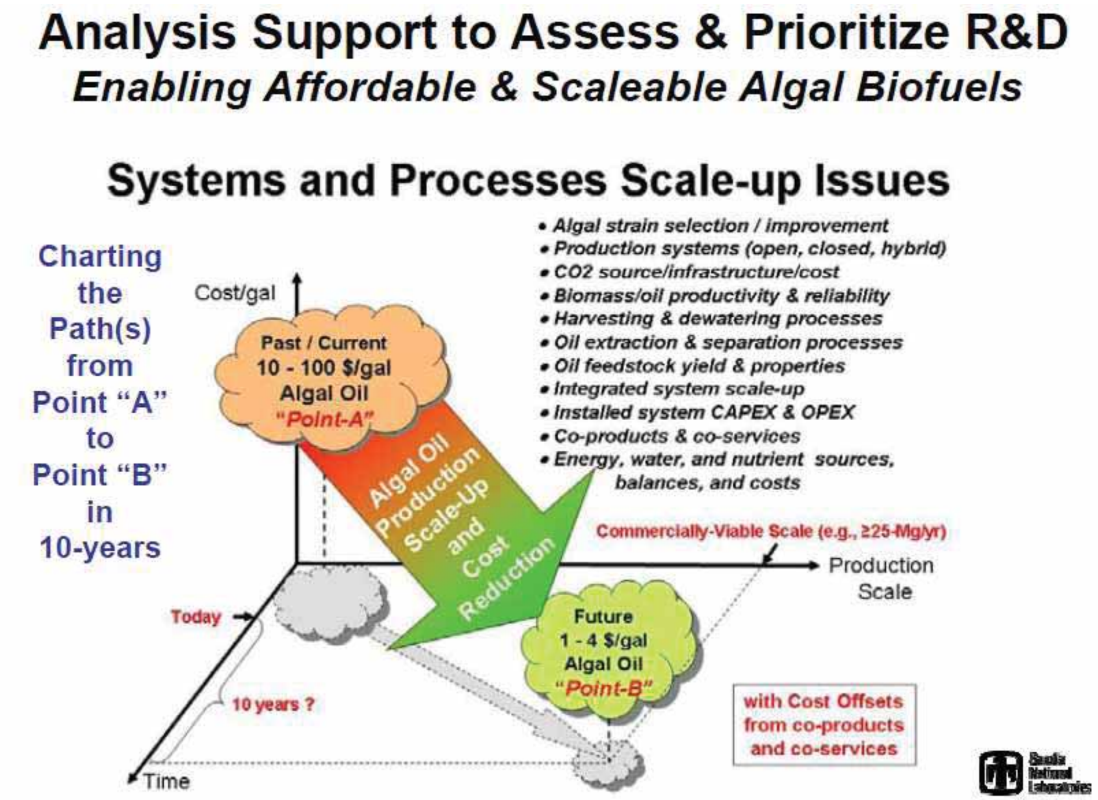


Edited from Algae Industry Magazine, October 14, 2010, by Brad W. Bartilson

http://www.algaeindustrymagazine.com/techno-economic-modeling-an-invaluable-tool-for-invention-and-investment/

State-of-the-art

Processes – Costs and reduction potential

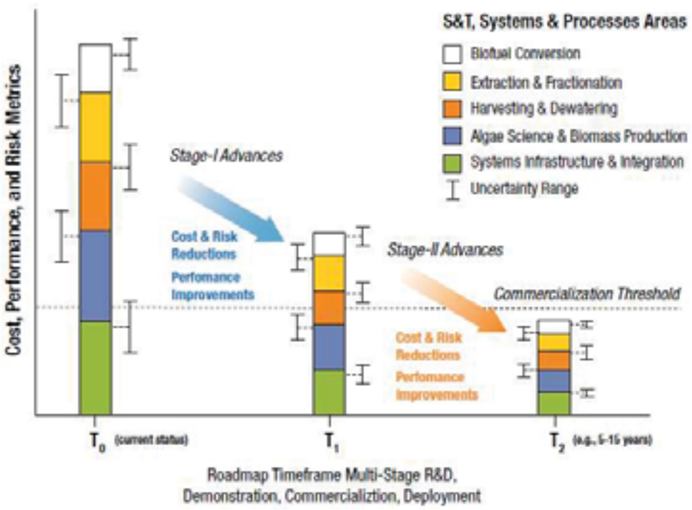


Pate R. DOE Algal biofules workshop (2008)

State-of-the-art

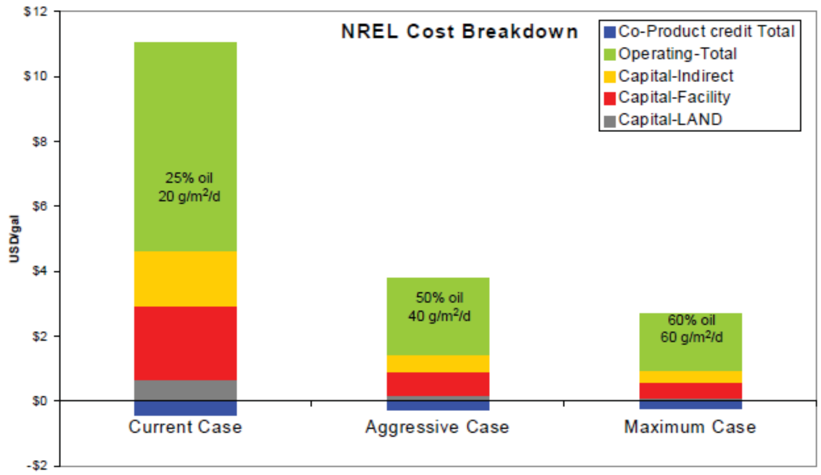
Processes – Costs and reduction potential

Development process timeframe



National Algal Biofuels Technology Roadmap

Potential cost reduction (NREL) for algal diesel production (similar values announced by Solix)



Pienkos P. DOE Algal biofules workshop (2008)

Development some 20-25 years late from bioethanol development

State-of-the-art

Many alternative process steps under development – huge opportunity

- Cultivation
  - Most of the operational and biological factors favor closed systems over open systems, but open systems have lower investment and operation costs compared to closed systems
  - The main benefit of closed systems is their better control of operation (e.g. contamination, mixing, light, CO2 losses, and alga specie flexibility).
- Harvesting
  - some of the methods need to be combined with a pre-harvesting method such as dissolved air flotation to reach a suitable input concentration defined either by physical separation requirement or the capital cost of the separation equipment.
- Lipid extraction
  - mechanical separation (70-75% lipid extraction can be obtained)
  - solvent or hot oil extraction (90-95% efficiencies)
  - supercritical fluid extraction using CO_2 or other fluids (90-95% efficiency), or subcritical water extraction and

→ Suitable combination for many conditions and algal strains

State-of-the-art

Processes – harvesting

- Harvesting algae is the most energy consuming unit operation, e.g.
  - PBR cultivation ~20 kWh/t flow
  - DAF + centrifugation ~60 kWh/t flow
- EVODOS claimes to have significantly lower consuming centrifuge system (~1.7 kWh/t flow)
- Challenge is the low starting concentrations (0.05… 0.5% for pond and PBR respectively)

Dewatering process	Highest possible yield	Energy usage
Centrifugation	>22% TSS	Very high - 8 kWh/m^3
Flocculation	>95% removal of algae	Low for slow mixing: varies largely
Natural filtration	1-6% TSS	Low (vibrating screen) - 0.4 kWh/m^3
Pressure filtration	5-27% TSS	Moderate (chamber filter press) - 0.88 kWh/m^3
Tangential flow filtration	70-89% removal of algae	High - 2.06 kWh/m^3
Gravity sedimentation	0.5-1.5% TSS	Low (lamella separator) - 0.1 kWh/m^3
Dissolved air flotation	1-6% TSS	High - 10-20 kWh/m^3
Dispersed air flotation	90% removal of algae	High
Electrocoagulation	99.5% TSS	Medium to high - 0.8-1.5 kWh/m^3
Electroflotation	3-5% TSS	Very high
Electrolytic flocculation	>90% removal of algae	Low to medium - 0.33 kWh/m^3

Udumann N. et al., Renew. Sustain. Energy. 2010; 2(1 - 012701): p. 1-15

State-of-the-art

Processes – biogas production

- Relatively low C/N-ratio of algae → co-digestion with other wastes gives higher methane yield
- Upgrading of biogas to vehicle fuel and electricity production from biogas are also potential approaches – existing technologies

Theoretical methane potential and theoretical ammonia release during the anaerobic digestion of the total biomass

Species	Proteins (%)	Lipids (%)	Carbohydrates (%)	CH_4 (L CH_4 g VS^{-1})	N–NH_3 (mg g VS^{-1})
Euglena gracilis	39–61	14–20	14–18	0.53–0.8	54.3–84.9
Chlamydomonas reinhardtii	48	21	17	0.69	44.7
Chlorella pyrenoidosa	57	2	26	0.8	53.1
Chlorella vulgaris	51–58	14–22	12–17	0.63–0.79	47.5–54.0
Dunaliella salina	57	6	32	0.68	53.1
Spirulina maxima	60–71	6–7	13–16	0.63–0.74	55.9–66.1
Spirulina platensis	46–63	4–9	8–14	0.47–0.69	42.8–58.7
Scenedesmus obliquus	50–56	12–14	10–17	0.59–0.69	46.6–42.2

Experiments with anaerobic digestion of microalgae species and algal sludge

Substrate	T[a] (°C)	HRT[b] (d)	Loading rate (g VS L^{-1} j^{-1})	Methane yield (L CH_4 g VS^{-1})	CH_4 (% vol)
Algae sludge (*Chlorella–Scenedesmus*)	35–50	3–30	1.44–2.89	0.17–0.32	62–64
Algal biomass	35	28	1	0.42	72
Spirulina	35	28	0.91	0.32–0.31	
Dunaliella	35	28	0.91	0.44–0.45	
Tretraselmis (fresh)	35	14	2	0.31	72–74
Tretraselmis (dry)	35	14	2	0.26	72–74
Tretraselmis (dry) + NaCl 35 g/L	35	14	2	0.25	72–74
Chlorella vulgaris	28–31	64	–	0.31–0.35[d]	68–75
Spirulina maxima	35	33	0.97	0.26	68–72
Spirulina maxima	15–52	5–40	20–100	0.25–0.34	46–76
Chlorella–Scenesmus	35	10	2–6	0.09–0.136	69

Sialve B. et al. Biotechnology Advances 27 (2009) 409–416

State-of-the-art

Microalgae Products

Microalgae	Annual production	Producer country	Application and product
Spirulina	3000 tonnes dry weight	China, India, USA, Myanmar, Japan	Human nutrition Animal nutrition Cosmetics Phycobiliproteins
Chlorella	2000 tonnes dry weight	Taiwan, Germany, Japan	Human nutrition Cosmetics Aquaculture
Dunaliella salina	1200 tonnes dry weight	Australia, Israel, USA, Japan	Human nutrition Cosmetics B-carotene
Aphanizomenon flos-aquae	500 tonnes dry weight	USA	Human nutrition
Haematococcus pluvialis	300 tonnes dry weight	USA, India, Israel	Aquaculture Astaxanthin
Crypthecodinium cohnii	240 tonnes DHA oil	USA	DHA oil
Shizochytrium	10 tonnes DHA oil	USA	DHA oil

Brennan L, Owende P. Renew. Sust. Energ. Rev. 2010; 14: p. 557-577.

- World conventional biodiesel production 2010 5.02 billion gallons/yr (12.5 B$/yr, $2.5/gal)
- World diesel production 2010 ~1 billion tons/yr (~900 B$/yr, $2.5/gal)

COMMERCIAL PRODUCT	MARKET SIZE (TONS/YR)	SALES VOLUME (MILLION $US/YR)
BIOMASS		
Health Food	7,000	2,500
Aquaculture	1,000	700
Animal Feed Additive	No available information	300
POLY-UNSATURATED FATTY ACIDS (PUFAs)		
ARA	No available information	20
DHA	<300	1,500
PUFA Extracts	No available information	10
GLA	Potential product, no current commercial market	
EPA	Potential product, no current commercial market	
ANTI-OXIDANTS		
Beta-Carotene	1,200	>280
Tocopherol CO_2 Extract	No available information	100-150
COLORING SUBSTANCES		
Astaxanthin	< 300 (biomass)	< 150
Phycocyanin	No available information	>10
Phycoerythrin	No available information	>2
FERTILIZERS/SOIL CONDITIONERS		
Fertilizers, growth promoters, soil conditioners	No available information	5,000

National Algal Biofuels Technology Roadmap

State-of-the-art

Scale of production in 2012

“Consolidated ‘algae ventures’ at present worldwide: approx. 50 ha (123 acres) in surface, = max. 1.000 ton/year ? ” (Vieira V. A4F, ABO Algae Biomass Summit 2012)

Sapphire Energy

State-of-the-art
Investments & interest

(Algae 2020 Vol 2: Biofuels, Drop-In Fuels, Biochems & Market Forecasts)

Biofuel aviation tests

FLIGHT	DATE	FEEDSTOCK BLEND	COMPANIES
Japan Air	January 2009	B50 - 50% Jet-A Kerosene, 42% camelina, 8% jatropha, 1% algae biofuels blend	JAL, Pratt & Whitney, Boeing, Sustainable Oils
Continental	January 2009	B50 - 50% JP8, 50% blend algae and Jatropha blend	Continental, UOP, Boeing, CFM Engines, Sapphire
New Zealand	December 2008		
Virgin Air	February 2008		

Source: Emerging Markets Online, Algae 20

Algae-based fuel on sale in Bay Area

San Francisco Chronicle

Peter Fimrite
Published 10:48 p.m., Tuesday, November 13, 2012

Big oil took a small but significant hit Tuesday when Bay Area motorists began filling up their gas tanks with algae, becoming the first private citizens in the world to use a domestically grown product that could revolutionize the fuel industry.

The first alternative fuel made from algae went on sale at four Bay Area gas stations in what advocates insist is the first wave in a tide of clean fuel that will hit the marketplace.

"Today, at this station, we are putting a stake in the ground," said Matt Horton, chief executive officer of Propel Fuels, as he prepared to fill the first tank with the algae-based product at the Valero station on Whipple Avenue in Redwood City. "We hope to build hundreds of stations like this in California."

The fuel, which is actually 20 percent algae and 80 percent petroleum, is available to any vehicle that runs on diesel, and it spews much less smog and ozone-depleting greenhouse gases, Horton said.

Clean, affordable fuel scarce

There are now more than a million Californians driving alternative-fuel-ready vehicles, but there is not enough clean fuel, and the supply line is virtually nonexistent, Horton said.

The product, made from algae grown by the South San Francisco company Solazyme, has been used in trials by the military and industrial companies. The pilot program will make it available on the retail market for a month at Propel's clean fuel fill-up tanks at stations in Redwood City, San Jose, Berkeley and Oakland. After a month, a decision will be made on whether to continue offering the product.

Algae investments in PPPs, private companies and project finance:

Organisation	Investment	Project scope and R&D
Sapphire Energy	$100 million in R&D from Bill Gates' Cascade Investments and Rockefeller Foundation	Algae for biocrude demonstration project in Las Cruces, California
Solazyme	$75 million in R&D finance so far from private investors	Algae for biocrude, jet fuel and biodiesel in San Francisco, California
GreenFuels	$92 Million in project finance	Green fuels plans to produce 25,000 tonnes of algae biomass for Aurantia SA in Spain
UK Carbon Trust	$40 million challenge for algae commercialisation by 2020	In October, UK Carbon trust announced a fund to award up to $40 million in grants for algae projects
Aurora Biofuels	Raised a second round of funding of $20 million from Oak Investment Partners, Gabriel Venture Partners and Noventi	Aurora Biofuels is an algae-to-biodiesel startup with roots at University of California at Berkeley.
Algaelink	Undisclosed amount from KLM airlines, new Chinese ventures	New investments in the Netherlands-based algae production manufacturer.
Petrosun	$40 million in funding from China	Formation of Petrosun China, a 50/50 joint venture with Shanghai Jun Ya Yan Technology Development
NREL	$25 million from 1970s to 1990s	Renewed investment in 2008 from Chevron, the US DOE, and several other firms.

biofuelsdigest.com
http://www.biofuelsdigest.com/bdigest/2012/04/10/two-algal-biofuels-projects-to-launch-in-2013-in-india-developer-says/

Two algal biofuels projects to launch in 2013 in India, developer says

In India, World Health Energy Holdings expects to launch both its $100 million, 250 acre algae biodiesel project with local company Prime Inc. and its $25 million, 45 acre algae farm with another local company SHK Energy Projects both during 2013. Combined sales from the two projects are expected to bring in $200 million in revenue during 2013.

State-of-the-art

Investments & interest

- Current Trends and Strategies for Microalgal Biomass in Korea
- Government support 2010… 2019 – total 320+ M$-US (additional tentative 290 M$)

Related Ministries	Projects Name and Goal	PI/Period Gov't Budget
MEST Ministry of Education, Science and Technology	ABC Advanced Biomass R&D Center (Global Frontier Project) - Development of customized highly efficient biomass including mass production and harvest of biomass - Development of technology for bio-fuels/materials conversion	Yang JW (KAIST) 2010~19 US$150 mil & 250/yr
	Bioenergy Production using Microalgae Absorbed to MBE project starting 2012 -Mass production using raceway technology plus some biorefinery related projects	Kang DH (KIOST) 2000~13 US$4.5 mil
	Novel Bioconversion Platform Technology based on Marine Microorganisms -Bioconversion using marine CA-PEPCase system	Jin ES (Hanyang U) 2010~14 US$2.3 mil & 26/yr
MLTM The Ministry of Land, Transport and Maritime Affairs	Ocean Biotechnology Development (Ocean Korea 21 Project) - Studies on molecular genomics of marine and extreme organisms (Lee JH @ KORDI) - The ocean bio process research (Kim SK @ Pukyeong Univ.) - The ocean a natural substance new medicine research (Kang HJ @ Seoul Univ.)	2004~13 Lee JH US$33 mil Kim SK US$18.2 mil Kang HJ US$33 mil
	CO2 Removal (CDM) by Seaweeds Project -Mass cultivation of seaweeds as a mitigation of climate change -Construction and development of CDM methodology	Chung IK (Pusan U) 2006~11 US$5.5 mil & 150/yr
	MBE Marine Bioenergy Research Consortium -Biodiesel: PBR in ocean, mass cultivation, harvest and biodiesel extraction & manufacturing tech. -Species improvement and ecosystem management	Lee CG (Inha U) 2009~19 US$44.5 mil & 160/yr

Related Ministries	Projects Name and Goal	PI/Period Gov't Budget
MKE Ministry of Knowledge and Economy	Microalgal Biodiesel Production using PBR/Pond Hybrid System - Flue gas treatment from Power Plant	Lee KY (NLP Co.) 2012~17 US$13.5 mil
	CO_2 Fixation and Astaxanthin Production by Microalgae -Funded by Korea District Heating Co. -Hanging plastic bags	Sim SJ (Korea U) 2012~17 US$11.2 mil & 30/yr
	Development of Biofuels Production Technologies using Algae - Renewable energy: sun light, wind, bio, waste, solar heat, Small hydro power and ocean energy (8 fields) - New energy: fuel cell, CTL & IGCC and hydrogen energy (3 fields)	Oh YK (KIER) 2009~13 US$6.8 mil
	Green Carbon Korea - White biotechnology, feedstocks from biomass	Yoo YJ (tentative) 2013~17 US$290 mil
MIFAFF Ministry for Food, Agriculture, Forestry and Fisheries	Forestry Tech. Research and Development -Funded by Korea Forest Service -Wood energy fuel and system for small scale mountain village -Studies on separation of saccharification product and utilization of lignin residue	US$ 0.5 mil
	Bioenergy Crop Production Tech. Development -Funded by Rural Development Administration -Development of commercialization tech. via collaboration among industry, univ., government and institute	Woo HC (PKU) 2009~14 US$3.0 mil

Choul-Gyun "CG" Lee , ABO Algae Biomass Summit 2012

State-of-the-art

Algal business – a growing reality

Algal commodities industry: biofuels, chemicals, feed, fertiliser, waste treatment, research, companies, conferences

~$1 000 000 000 per year industry (J. Benemann, BIO PacRim 2012)

(comparable to enzyme industry a decade ago excluding research etc.)

~10 000 person years labour (FTE – full time equivalent)

	FTE
United States	~3000
Europe	~2000
India	> 500
China	> 500
Australia	400-500
Korea, Brazil…	

projected annual "average growth of 43.1%, that will lead the [algal biofuel] market volume from $271 million in 2010 to $1.6 billion in 2015" (SBI Energy Reports 2012)

State-of-the-art

Algal business – Technology companies pushing forward

American companies

Companies
Acent Laboratories, LLC
Renewable Algal Energy, LLC
Touchstone Research Laboratory, Ltd.
A2BE Carbon Capture, LLC
Alga Technologies
Algae Biofuels
AlgaeWheel
Algaeventure Systems
Algenol
Algodyne
Algoil
AlgroSolutions
Aquaflow Bionomic
Aquatic Energy
Aurora BioFuels Inc.
Bionavitas
Blue Biofuels
Blue Marble Energy
Bodega Algae
Cequesta
Circle Biodiesel & Ethanol
Community Fuels
Diversified Energy
Dynamic Biogenics
Energy Farms
Enhanced Biofuels & Technologies
General Atomics
Global Green Solutions
Green Star
Greenfuel Technologies Corp
GreenShift
GS Cleantech
HR Biopetroleum/Shell (Cellana)
IGV

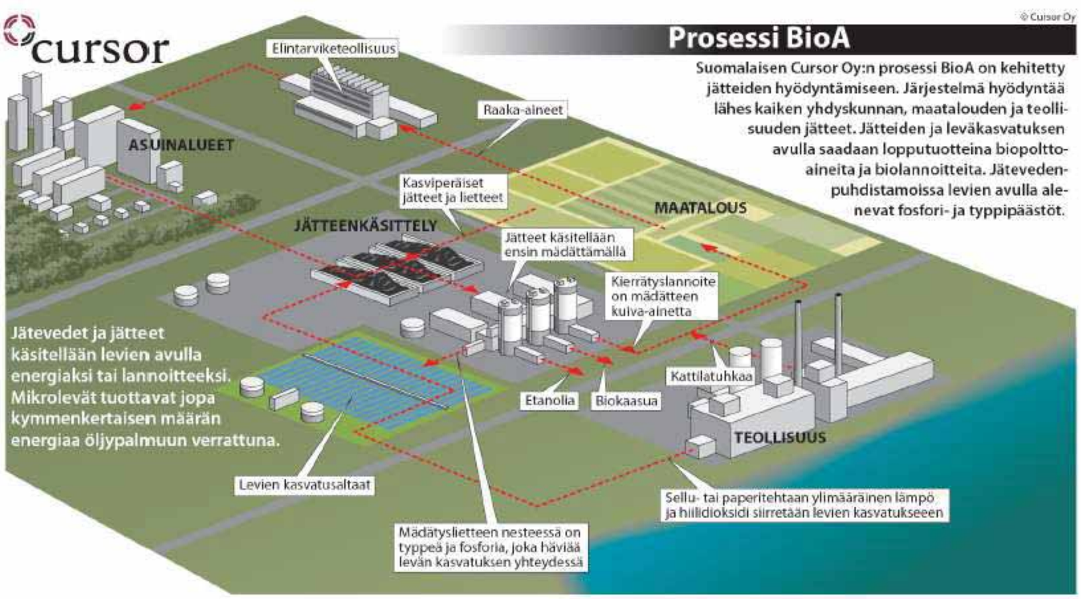
Companies
Imperium Renewables
Infinifuel Biodiesel
Inventure Chemical
Kai BioEnergy
KAS
Kent SeaTech Corp.
Kwikpower
LiveFuels
Mighty Algae Biofuels
Oilfox
Organic Fuels
OriginOil
PetroAlgae
PetroSun
Phycal
Revolution Biofuels
Sapphire Energy
Seambiotic
SeaAg, Inc
Solazyme, Inc.
Solena
Solix Biofuels, Inc.
Sunrise Ridge Algae
Sunx Energy
Synthetic Genomics
Targeted Growth
Texas Clean Fuels
Trident Exploration/Menova
Valcent Products
W2 Energy
XL Renewables

European companies

Companies
Ecoduna
SEE ALGAE Technology GmbH
Provirom
ENVI, Ltd. Třeboň
EcoFuel Lab, Ltd
Phycosource
Alpha Biotech, SARL
Microphyt
Fermentalg
Greensea SAS > Aquamer
Algosud
Algenics
Mikralgen, SARL
Ecosolution
Bioalgostral
Algosource Technologies
Activ'alg
Roquette Klotze GmbH & Co. KG
Blue Biotech GmbH
Cyano Biofuels GmbH
Greenovation GmbH
Bisantech Nuova, GmbH
Phytolutions, GmbH / Jacobs University Bremen
BlueBiotech – Mikroalgen Biotechnologie, GmbH
Hezinger Algaetec GmbH
Astaxa GmbH

Companies
IGV Institut für Getreideverarbeitung, GmbH
Subitec, GmbH
Archimed
EniTecnologie, S.p.A.
Fotosintetica & Microbiologica s.r.l.
Heliogreen technologies
Algae Food and Fuel
AlgaeLink
Ingrepro BV
LGem
A4F - AlgaFuel, S.A.
Necton – Companhia Portuguesa de Culturas Marinhas, S.A.
EEM / BFS – Empresa de Electricidade da Madeira
Aurantia / BTME / Exeleria
Bio Fuel Systems
Algasol Renewables
Fitoplancton Marino, SL
Algae Biotech SL / FeyeCon
CleanAlgae / FeyeCon
Algafluid
Algaenergy SA
ASN Leader
Simris
AstaReal, AB. owned by Fuji Chemical
Neocarbons
Algaebiotechproducts
Boots / PML / Photobioreactor.co.uk
Seasalter Shellfish, Ltd
Varicon Aqua Solutions, Ltd (Biofence)
Supreme Biotech < New Zeland
AlgaeCytes
Merlin Biodevelopments

Examples
Cursor Oy – BioA project



Finnish Cursor Oy:

- Target: evaluate feasibility of microalgae waste water treatment system in Finnish conditions
- Process
  - Pulp and paper mill waste water utilized → excess low grade heat from the mill
  - Anaerobic digestion digestate → nutrients for algae growing
  - Produced algae used as feed for biogas production

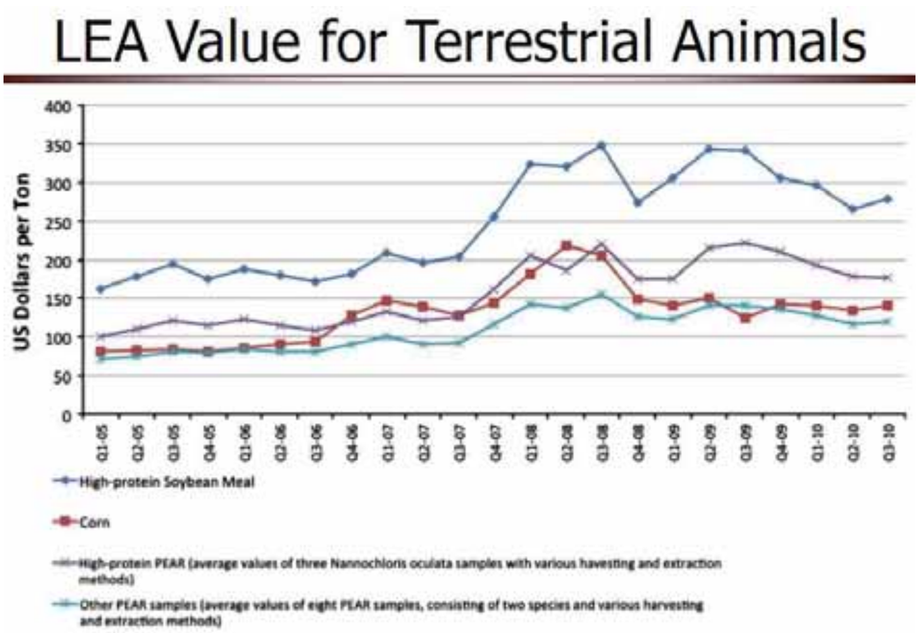
Examples
Solazyme Inc.

- Founded in 2003, publicly held
- Based on heterotrophic microalgae (sugar used as carbon source)
- Initial focus on commercializing products into three target markets: 1) fuels and chemicals, 2) nutrition, and 3) skin and personal care
- Main partners (2012)
  - Bunge Global Innovation LLC (Brazil) – JV (announced Nov 15, 2012), upto 300 000 tons of oil annually for chemicals, based on Bunge sugar mill
  - Archer-Daniels-Midland Company (USA) – collaboration to start 20 000 tons of oil production at ADM's Iowa corn wet mill
- Other partners: Chevron, Dow Chemicals, Quantas, Roquette Freres, Honeywell UOP, United, Unilever, DOE, DOD, Navy
- Main facility (2012) – Illinois, 2 million liters oil/yr (~1820 ton/year)

A month-long pilot program with biofuel retailer Propel Fuels where the companies are selling Solazyme's algae-based diesel (called Soladiesel BD) in California. The fuel (composed of 20% blend Soladiesel BD) is being sold at the same price as conventional diesel fuels

Examples
Value of algal biomass residue

- Fertilizer, terrestrial animal feed, mariculture feed, human food additives production from biomass residue
  - Producing and selling by products can increase or reduce net cost of renewable diesel
  - Best scenarios: produce Poly unsaturated fatty acids (PUFAs) from 10% of total lipids for 33% decrease in diesel cost
  - Next best: sell Rubisco at $1000/ton, 17% decrease in cost to produce diesel
  - Selling animal and fish food reduces costs much less 5% to 10%
  - Selling residue as fertilizer is least profitable use of by products

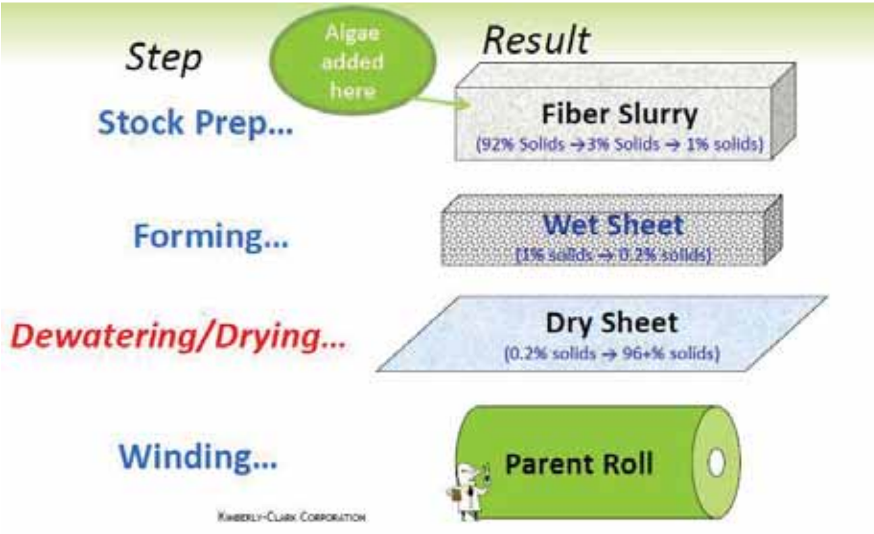


Richardson J. et al., ABO Algae Biomass Summit 2012

Examples

Value of algal biomass residue

- Utilization of algae biomeal in tissue paper
  - Inorganic minerals (Kaolin, $CaCO_3$, TiO_2) used ~30 Million metric tons (2002) as fillers
  - Dried Spirulina (Earthwise Nutritionals) Powder replacing filler
  - → Improved paper properties obtained with 6% - 18% filler replacement (using standard flocculating agents)



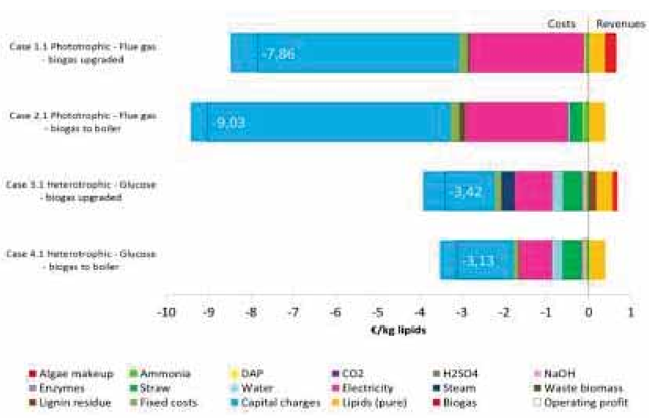
Shannon T., Shi B., ABO Algae Biomass Summit 2012

Examples

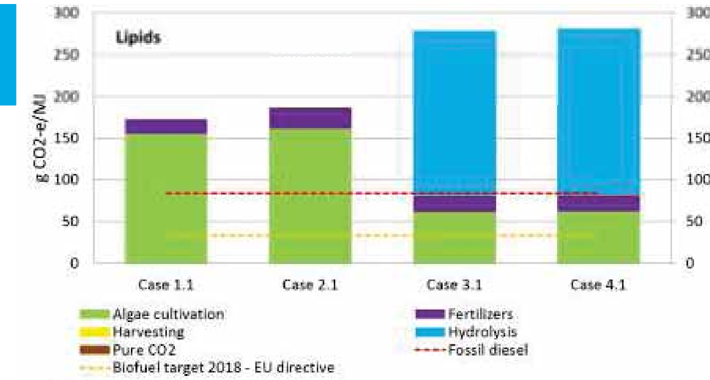
Comparative analysis of algae-based energy in Finnish context – ongoing project

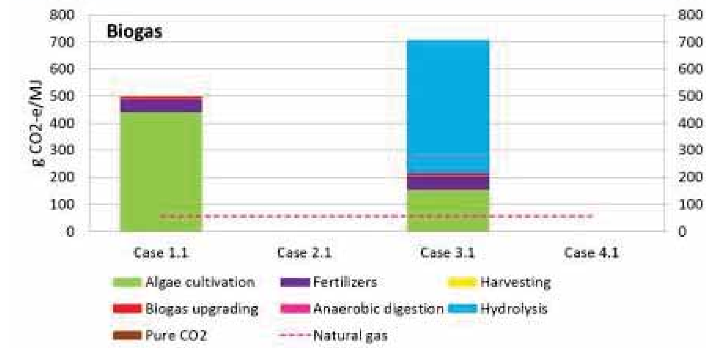
- Concepts developed for phototrophic and heterotrophic production using clean CO_2, fluegas and waste water for producing lipids, biogas or electricity
- National R&D project focusing on strain screening, anaerobic digestion, lipid production optimization and waste waters for cultivation – modelling parameters (TE & LCA – GHG emission, ISO 14040:2006 standard)

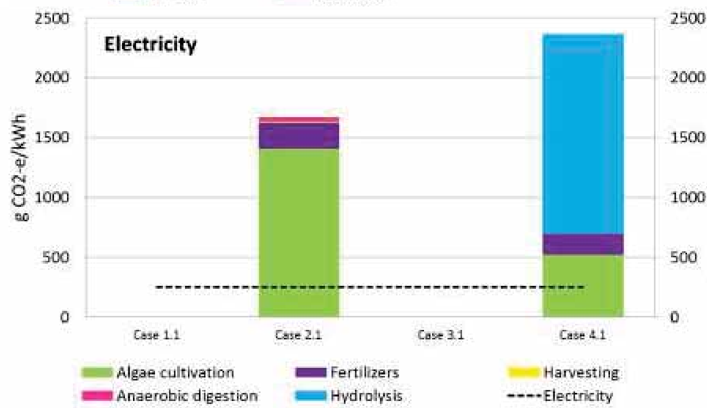
- Selected production concept do not seem profitable, key challenges
  - electricity demand of the production system
  - CAPEX



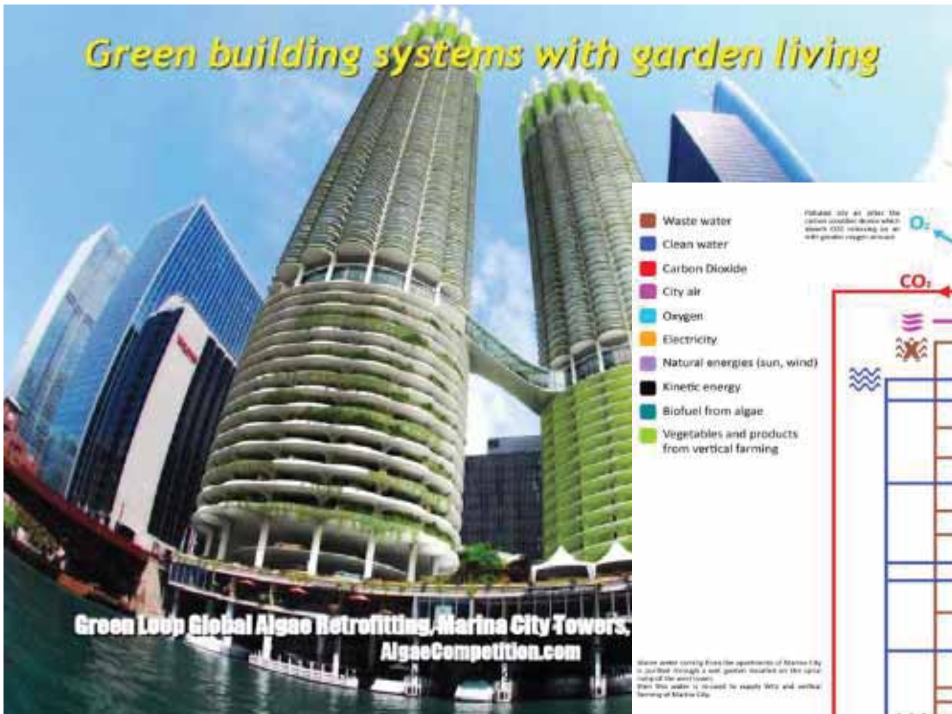
Source: VTT

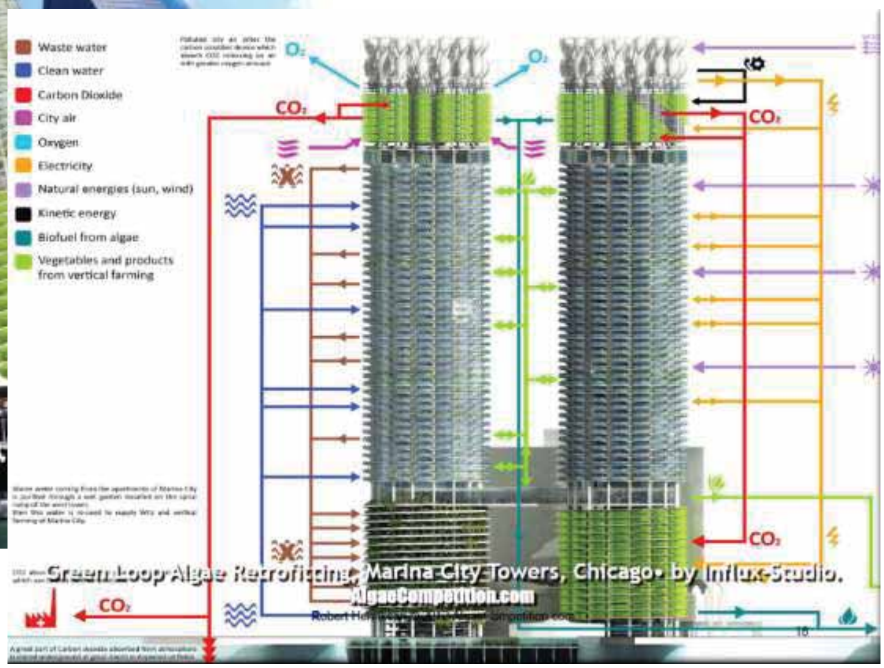






Examples
Future



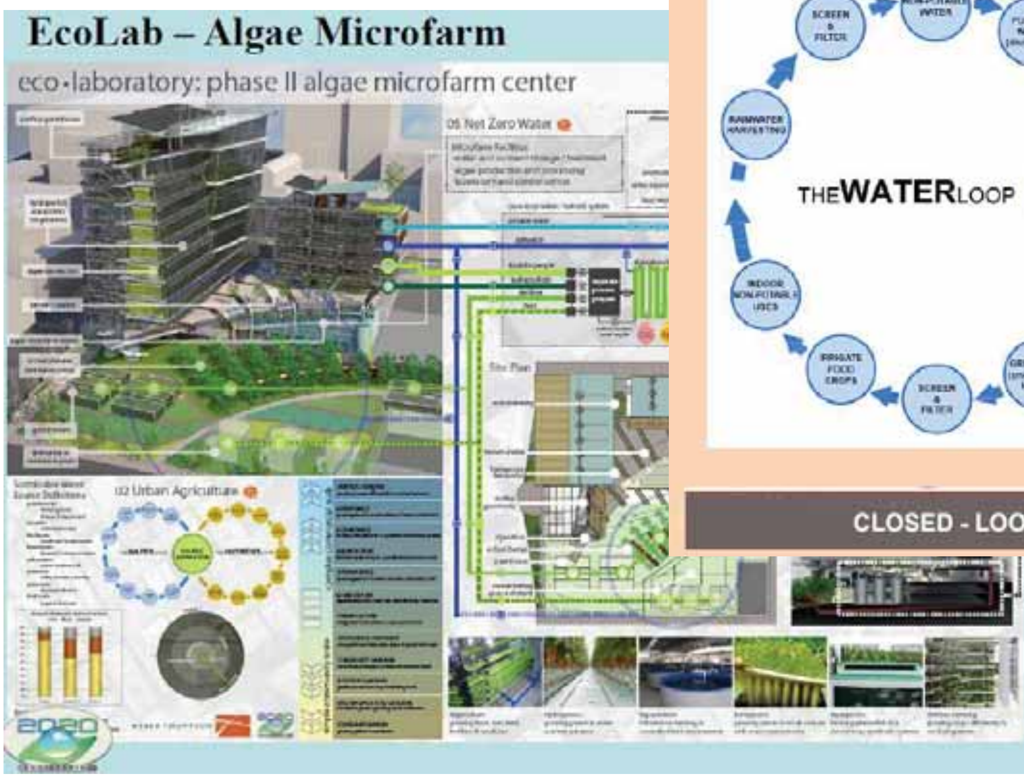


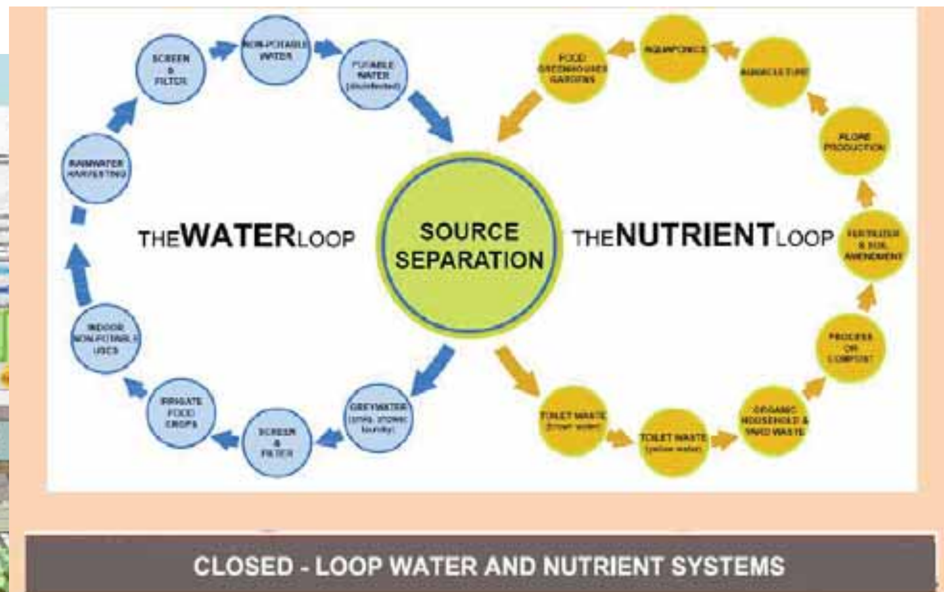
Examples
Future

Examples
Future

Examples

Future





Conclusions

- Challenges
  - Biology – high growth rates and yields of targeted fractions
  - Process – multitude of alternatives (overall concepts & technological options)
  - Systems-level – integration & siting, business models
  - Economics – high capital costs & potentially energy intensive harvesting
  - Environmental performance – potentially high energy, nutrient and water consumption
- Strategies to solve the challenges
  - Step-wise, systematic design process (technology or product driven) combined with experiments
  - Mixotrophic cultivation enables higher yields and utilization of waste carbon sources
  - Identification of local opportunities and constraints (financial & physical) and development of most suitable local solutions for piloting and demonstration
- Future prospects
  - The road ahead for low cost microalgae –based energy will continue attracting significant investments – good experiences (e.g. from Solazyme)
  - even though R&D lies behind the bioethanol development, the potential of algae –based energy sector is even larger

Acknowledgements

- ALDIGA and ALGIND project funding from Tekes – the Finnish Funding Agency for Technology and Innovation

- Dr. Marilyn Wiebe, Dr. Mona Arnold (VTT), MSc worker Ms. Anna Leino

VTT creates business from technology

Back ground for introduction

Lots of interest in academia and applied science – some recent publications

- Applied Energy, Volume 88, Issue 10, Pages 3277-3556 (October 2011) - Special Issue of Energy from algae: Current status and future trends, available through ScienceDirect
- *"National Algal Biofuels Technology Roadmap"* (USA), published in May 2010 (based on workshop held in December 2008), http://www.orau.gov/algae2008pro/default.htm
- Several ongoing EU projects (FP7) with their deliverables
  - BIOFAT, All-gas, InteSusAl (industry-led)
  - AQUAFUELS (www.aquafuels.eu), GIAVAP
- Lundquist, T.J., Woertz, I.C., Quinn, N.W.T. et al., *"A Realistic Technology and Engineering Assessment of Algae Biofuel Production"*, Energy Biosciences Institute, University of California, (2010)
- Emerging Markets Online, *"Algae 2020 Vol 2: Biofuels, Drop-In Fuels, Biochems & Market Forecasts"*, 2011