Quickscan: Emissions to Biofuels

Opportunities of algae cultivation for
Rotterdam Industrial Complex

Colofon

Prepared by:
Bass & Gill B.V.

Editors:
Huib van der Kroon, Gilbert Curtessi &
Bas Greiner

Visit Address:
World Trade Centre Rotterdam
Beursplein 37, 3011 AA Rotterdam

Post address:
Postbus 30086, 3011 DB Rotterdam

Telephone & Email:
+31(0)10-2053451
info@happyshrimp.nl

Abstract

Algae play a crucial role in the natural cycles of our planet. These small organisms effectively transform inorganic 'waste' into complex organic material. In a world troubled with climate change, algae have the potential to reduce CO_2 *while, in the process, generating a new stream of commercial products. This potential is studied extensively in this document, with special interest going to the impact of algae cultivation for the port of Rotterdam Industrial Complex (HIC).*

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Preface

Our contemporary reality is global. In a global reality actions are not confined to a specific geographical area, but instead impact an overarching system in multiple places in multiple ways. Technological breakthroughs have made it possible for many of us to enjoy exotic foods, visit far-away places and meet our daily consumption needs at affordable prices. However, as easily as these benefits, negative consequences spread through the system almost untraceable to a specific origin.

The real state of the world[1] is one where companies are asked to be 'socially responsible' and where governments are asked to properly balance between *profit*, *people* and *planet* dimensions of affluence. *Both* are being held responsible for the impact we, as individuals, unwarily have when we live our daily lives. 21st century institutions are currently transforming themselves to meet *consumer*, as well as *citizen* demand, *simultaneously* and *together* with each other in new, cooperative forms[2].

Organizations serious about meeting the challenge to realize consumer as well as citizen benefits, know that it is imperative to orchestrate beyond their conventional network boundaries. In a new *social responsibility* paradigm, it is imperative that governments, business and civil society together set the stage for the sustainable society of the 21st century.

Introduction

This quickscan has been performed on account of the Rotterdam Climate Initiative (RCI), whose primary objective is to significantly reduce CO_2 outflow by the year 2025. In accordance with the need for 'new cooperative forms', put forward in the preface, the RCI sets out to accomplish this objective by working with others on ambitious initiatives.

Bass & Gill BV, an eco-industrial company, has developed plans for such an ambitious initiative. Their latest project, called AlComm, aims to contribute to the RCI's objectives of CO_2 reduction, while initiating an economically viable, new enterprise. The concept that will be elaborated on is called 'emissions to biofuels'.

In four chapters this quickscan discusses all aspects that determine future success of project 'AlComm'. These will be discussed in the following sequence:

- **Basic principles** of deriving value from algae
- **Demand for concept** 'emissions to biofuels'
- **Discussing the industry** for algal production
- **Positioning AlComm** within Port of Rotterdam Industrial Complex

The quickscan concludes with a summary of what has been discussed and reiterates the unique benefits of AlComm for the Rotterdam port area.

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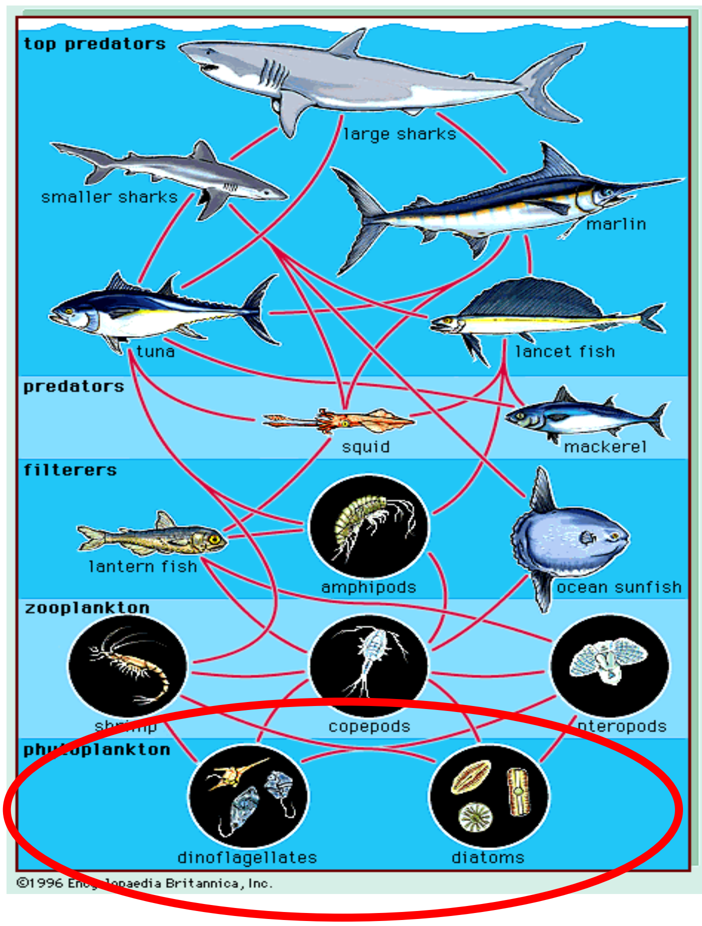
[1] Reference to the ICCP report that discusses human impact on global warming
[2] Explained in the article: 'Communicating to Joan Citizen and Joan Consumer'

Deriving Value from Algae: Basic Principles

Algaculture is a special branch of aquaculture where algae are being produced on an industrial scale. Business-wise, algae have a high value potential that, until this day, has remained under explored and underutilized. Due to being one of the fastest growing organism on the planet, algae are able to produce vast quantities of product. Add to that the fact that there are about 100.000 known species, it is possible to deliver these large amounts of product in a very broad range of potential applications. In the course of the 21st century, it is generally expected that increasingly larger amounts of research euro's will be spend to tap into this potential in countries all over the world. In this chapter, the basic principles of deriving value from algae will be discussed in more detail.

General information about algae

At the very basis of the concept 'emission to biofuel' are, of course, algae. Algae are simple organisms that belong at the bottom of marine food chains. The importance of algae for our ***global*** ecosystem is much greater than most people will credit them for. For example that much of the world's net oxygen supply is created by algae and in this process they fix about 435.000.000.000 tons of carbon per year (Behrenfeld and Falkowski, 1997). This is a disproportional large amount when you consider that it is equal to the amount of CO_2 fixed by all *terrestrial* vegetation, and algae account for less than 1% of the world's total biomass.



Algae come in a wide variety of sizes and shapes. For this paper the group of small plantlike algae, called phytoplankton, are of interest. In this category, over 100.000 unique species have been identified. Micro-algae exist in almost any habitat on the planet where water can be found: from hot springs, to deserts, to snow; in both fresh as saline water.

Algae are the cornerstone of life on our planet. They transform large quantities of 'simple' flows of material and energy, such as carbon dioxide and sunlight into complex organic material. Even the by-product resulting from this process, oxygen, is put to good use by other organisms.

In addition to being the major driver behind *biological* life, it has been argued that our economic lives ***too*** are indirectly algae-fuelled. That is to say, a group of researchers have speculated that died-off layers of algae are responsible for much of our worldly oil reserves.

All interesting facts aside, what is exciting about micro-algae from a commercial point of view, is that they are capable of creating economic value for our current society. The value comes both *directly* as *indirectly* from algal production. Directly from a range of components obtained from algal biomass. And *indirectly* from the ecological benefit of elevating 'waste streams' into production factors.
The commercial value of the *direct* benefits is obvious: these are the marketable prices of algal products. Less obvious is the *indirect* commercial value which are intangibles. Examples of these intangibles are carbon credits; avoidance of regulatory penalties, and increased social recognition/reputation.

When you consider the possibilities for commercialising an algal production system, it is easy to get lost in an ocean of opportunities. Currently the main challenge is in developing business cases that match an output product with the right production process. That is to say, the production process, and the output is generates, will have to be well attuned to the opportunities and constraints of a location. We will discuss this in more detail in a later chapter.

Whatever fit between ***location***, ***output product*** and ***production process*** you chose, the system always involves production of living organisms. This implies that you will always have to take into account the constraints put forward by biological limitations of the algae strain you have selected to cultivate. Optimizing your production system will therefore be subjected to the following generic 'rules of engagement':

- **Product**: Every algae strain has its biological ceiling for
    - Composition of biomass (% valuable ingredients of total biomass)
    - Product quality (suitability for a commercial application)
    - Product quantity (growth rate of biomass)

- **Process**: All algae strains place a different demand on bio-reactor design
    - Nutrients diet
    - A-biotic requirements
    - Contamination control

In the remaining sections of this chapter these two points of product and process limitations will be expanded on in more detail. The chapter is concluded by integrating all that has been told into a commercial perspective. This section is especially important when you consider that few enterprises have succeeded in turning cultivation of algae into a profitable business.

Product: Chemistry of algae

Commercial success requires understanding of *value creation processes*. Especially important is how algae production adds value to a target audience; it is the foundation for economic viability. Understanding how to add value to your target audience mostly comes down to solving limitations of their value chain. In other words, next to understanding **your** production process, you will have to thoroughly comprehend those of others.

Based on this understanding, a properly designed algal production system, helps generate output that is attuned to a previously identified demand. Knowledge about the intrinsic properties of your product, algae, contributes to your ability to find the most attractive markets in terms of commercial exploitation. This is why in this section attention will be paid to the composition of algae biomass. Generally speaking, biomass from algal species consists of three main components.

- Carbohydrates
- Proteins
- Natural Oils

In addition to these, there are some 'ingredients' present in algal biomass at much lower quantities. These are vitamins, pigments and fatty acids, to name a few. The composition of algal biomass varies from species to species and depends *first and foremost* on the biological blueprint of the algae strain that is selected. Within the biological boundaries of the strain it is possible to change the composition of the biomass by inducing stress on the cells. Under these stress conditions many algae strains respond by changing their biomass composition. For example by accumulating more lipids.

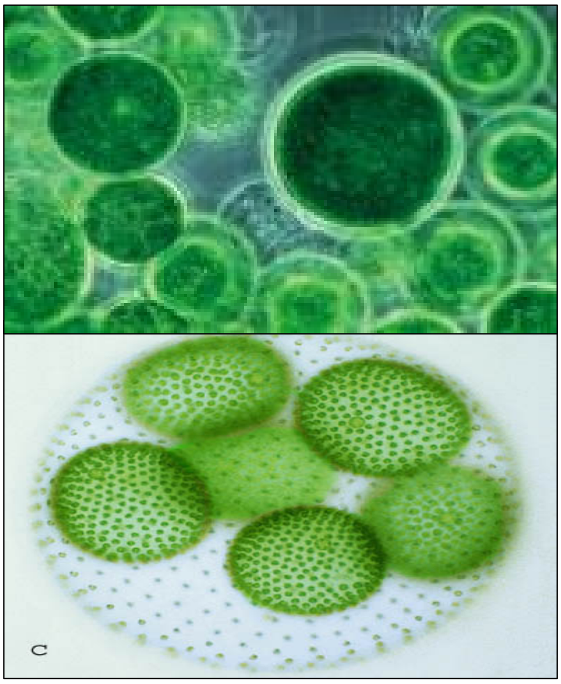
To illustrate how the composition of the major components varies between strains, **table 1** (Marinova 2007) provides an overview for those that are most cultivated. Worth noticing is that for most the primary component is protein, followed by carbohydrates and lipids. With over 100.000 species however, the variation is immense.

Composition of different algae (% of dry mass)

Alga	Protein	Carbohydrates	Lipids
Anabaena cylindrica	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
Scenedesmus dimorphus	8-18	21-52	16-40
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

Building a business in algae production demands ***efficient*** translation of the intrinsic potential of algal biomass into commercial applications. On the last page of this chapter, a table demonstrates the broad applicability of components in algal biomass. Some of these applications are complementary. For example, after oil extraction for biofuel, the residual biomass can be used either as feed or fibres.

For these low value applications it is critical to find complementary revenue streams. That is, low value applications require ***more volume*** to be sold to cover expenses and investments. If this volume does not come from higher productivity p/acre it has to be realized by a higher saleable percentage of the biomass through complementary channels.



Process: Algae growth factors

Now that algae are more thoroughly understood with regard to their intrinsic potential, we will discuss how to effectively ***realize*** this potential. We have seen that component availability in different algae strains are the foundation for commercial applications. The process design however, is the determining factor in how well the intrinsic potential translates into saleable outputs. By creating favourable conditions, algal production system allows algae to approach what they are maximally capable of given their biological blueprint.

Basic requirements for algae growth

Not surprisingly, the first condition that needs to be satisfied for algae to grow, is a watery environment. This can be either fresh, salt, or brackish water. Consider the following chemical equation:

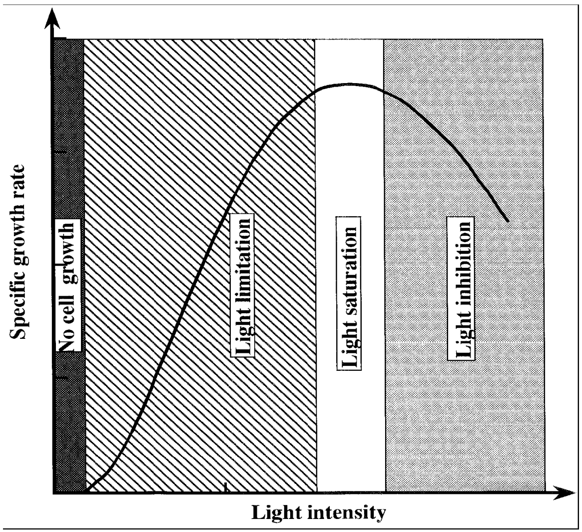
$$6CO_2 + 12H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6O_2 + 6\,H_2O$$

Here you can see that next to water two other basic requirements are carbon dioxide (CO_2) and light. This process is called photosynthesis, and is the cornerstone of life on earth; the sun's energy is converted into complex, organic material. It also demonstrates that in essence very few things are needed to grow algae. However, when you are interested in growing them commercially, there are much more things to get right. For large-scale production, you need to create what in biology is called an **algal bloom**[3]

[3] Refers to natural events where an algal population explodes and dominate their natural eco-system.

Building a bloom

Why and how *exactly* algal blooms occur in nature is not known. There are however changes in environmental conditions that are typically associated with them. One of the most obvious factors affecting blooms are the local weather conditions. On hot summer days, for example, algal blooms typically occur much more frequently. It may be due to an abundance of light that becomes available for the photosynthetic process, but research has shown that this cannot be the complete story. The image here right shows that algae growth rate has an optimum for light intensity, after which more light negatively affects growth. This is called 'photo inhibition'. It seems that only when the optimum has not yet been reached extra illumination can contribute to algal blooms.



An equally plausible explanation for the correlation that exists between hot summer days and algal blooms, is the overall temperature rise of the water. This creates advantages for specific algae species over others. That is to say, every algae strain has its unique optimal temperature in which it grows fastest. Should the temperature in a watery ecosystem substantially rise in a short period, it can positively impact the growth rate of a specific algae strain. At the same time it can negatively impact growth rates of competing organisms, multiplying the effect.

One might also expect to find a strong correlation between CO_2 exposure and algal blooms, as it is quintessential in the photosynthetic process. It is however generally assumed that CO_2 is no limiting factor in natural ecosystems. That is to say, under normal conditions there is more CO_2 available than is consumed. Increasing CO_2 therefore, will not *initiate* an algal bloom. However, although it cannot be a considered a ***trigger*** of algal blooms, CO_2's essential role in the photosynthetic process makes it an absolute necessity to *sustain* high growth rates.

The most significant factor associated with algal blooms is the availability of nutrients. Strong increases in nutrient availability in ecosystems can be a powerful initiator of algal blooms. A striking example, that happens to be very recent, are problems some Chinese cities are experiencing with algae in their rivers. Because they are frequently used for dumping purposes, the nutrients available to (micro)algae increases dramatically allowing them to grow exponentially. To explain how a proper nutrient diet can initiate (and sustain) blooms, the next section will discuss the varying importance of nutrients.

Nutrient diets[4]

Being plant-like organisms, algae require much of the same factors as terrestrial plants for growth and development. Like all plant-like organisms, they need water and access to just the right amount of sunlight. They also require CO_2, either directly from the atmosphere, or dissolved in water. Together these elements (water, light and CO_2) are the main components of the photosynthetic process. But what about the 'soil' in which plant-like organisms grow? What do algae obtain from what ***they*** consider soil: their watery environments? In the following section we will discuss the nutrients that should exist in algal production systems.

Algae require various inorganic elements to grow. These are called micro-nutrients. Micro-nutrients are obtained from watery environments as long as they are *fully dissolved* and *inorganic* by composition. When they are *not* dissolved, or *not* inorganic, it is impossible for algae to extract them from water by means of osmosis. The table below shows an overview of micro-nutrients requirements for algae. Most of these are needed in small quantities, when compared to the main building blocks carbon, oxygen and hydrogen, which are all obtained via photosynthesis.

Element	**Quantity**
Nitrogen	High
Potassium	High
Phosphorus	High
Calcium	Med
Magnesium	Med
Sulphur	Med
Other micro-nutrients like: Fe, Cu, Mn	Low

Nutrients are building blocks used by algae to construct a high variety of complex, organic matter. At the basis of almost all organic matter, is the element carbon (C). Carbon is the cornerstone of life as we know it and can be found in several million combinations with other elements. As mentioned, algae obtain carbon, oxygen and hydrogen via photosynthesis. Other elements have to be purposely fed to algae in a properly balanced diet. These fall in the category '*nutrients*'.

On the next page a table demonstrates the contribution of six important elements in terms of growth and development of algae. These nutrients have to be introduced into algal production systems to optimize output and quality. The elements described in the table are: Nitrogen (N), Potassium (K), Phosphorus, (P), Calcium (Ca), Magnesium (Mg) and Sulphur (S).

[4] Generic information about growth, through photosynthesis, in plant-like organisms

About Primary Nutrients

The strongest correlation between increases in algal populations and exposure to nutrients, has been found with phosphorus and nitrogen. In nature, it seems that limited availability of phosphorus and nitrogen are keeping algal populations down. It is however not only the *absolute* amount of these specific micro-nutrients that is important. Research has demonstrated that the ratio in which these two are used *as well*, plays a crucial role in determining algal growth.

Researchers have studied the role of varying nitrogen levels on algal populations extensively. Beside the ratio with phosphorus, they found that *increasing* absolute nitrogen levels has the potential to alter biomass composition; it can result in both higher protein and chlorophyll content. *Decreasing* nitrogen-exposure, can result in increasing percentages of lipids. It should be mentioned though that results vary considerably between species. Especially green algae species demonstrate a strong reaction to different levels of nitrogen exposure.

PRIMARY NUTRIENTS	
NITROGEN	• Formation of amino acids, building blocks of protein • Essential for cell division • Directly involved in photosynthesis • Necessary component of vitamins • Aids in production and use of carbohydrates
PHOSPHORUS	• Involved in photosynthesis • Energy storage, cell division, and enlargement • Increases water-use efficiency
POTASSIUM	• Carbohydrate metabolism • Increases photosynthesis • Essential to protein synthesis • Activates enzymes and controls their reaction rates
SECONDARY NUTRIENTS	
CALCIUM	• Continuous cell formation • Involved in nitrogen metabolism
MAGNESIUM	• Key element of chlorophyll production • Improves utilization and mobility of phosphorus • Activator and component of many enzymes
SULPHUR	• Integral part of amino acids • Helps develop enzymes and vitamins • Necessary in chlorophyll formation

Growing Algae Commercially

What makes a design for an algal production system *effective,* is inherently linked to the goal one wants to achieve with that particular design. When it is designed for research purposes alone, the goal is generally to accumulate specific knowledge. A typical goal concerning algae production systems could be: '*to design a production system that maximises growth of algal strains*' or '*establish biomass alteration resulting from changes in its diet'*. Although research driven goals accumulate the knowledge that forms the very basis for future enterprise, commercial exploitation requires an extra dimension to take into account.

For business, this knowledge **must** be complemented by an economic dimension of some sort. This complicates, and in fact constrains, the goal to a different operating framework. Adding an economic constraint results in a new directive that resembles a different form. The generic goal of any economic venture in algae production is: '*to design a production system that maximises growth of algae strains in such a way that Δ **value** exceeds Δ **cost** by the highest marginal difference*'. This is saying nothing more than: 'all adjustments to the production system are desirable as long as the costs involved in the process, are offset by the benefits resulting from it'.

There are some general rules for effective process design, when you are in pursuit of a commercial objective. Strategically speaking, with reference to Michael Porter, the highest marginal difference between **costs** and **value** results from a very consistent choice for a specific position in the industry in which one wants to compete. This position, whatever industry, reflects the commitment of a business to one of two dimensions of differentiation:

- Differentiation on **product specificity**
  - Specifically Tailored Products
    - Quality
    - Uniqueness
    - Service
- Differentiation on **costs**
  - Cost-minimization every step of value chain
    - Cost benefits from scale advantages
    - Standardization / Automatisation of production

From this perspective the 'Emission to Biofuel' concept seems to be a *contradictio in terminis*. That is to say, many emissions take place within highly industrialized area's, where land and labour are expensive. This brings along formidable challenges as the market for fuels falls into the '**commodity category'.** In commodity markets, low costs per unit of output, is more important than anything else. Differentiation by any other means is near to impossible.

Attuning your production process to these contextual factors[5] is critical in realizing the commercial potential of algae production. Expensive production factors require justification for their use in a business case. Turning them into low value, commodity products will demand either significant increases in productive output, or additional cash flow resulting from their deployment. One possibility is to increase the viability of algae production on expensive locations, is by focussing on high value applications first, before selling off the lower value residue.

[5] Netherlands: expensive labour and land, but also excellent knowledge infrastructure

Market: Commercial Applications
High protein content in some algae species, availability of unsaturated ω3 and ω6 fatty acids, pigments and almost all essential vitamins make algae attractive for high value, commercial production. The current market for algae products of all sorts is approximately US$ 1,25 billion per year and is expected to grow (Pulz and Gross). Especially in these high-value applications lie great chances for 'emission to biofuel' programs when the oil fraction can be sold as a complementary, residual product. Oil companies too, depend for more than 40% on high-value downstream products, teaching us that there is a great commercial opportunity in tending to both low, as high value markets. The table on the next page shows commercial applications for algae biomass and the most appropriate strains used for that purpose.

The question is how to *optimize output levels* of your production system, where output is measured in terms of revenues. Maximizing revenues, given that you are utilizing some expensive production factors, means you should focus on two things:

- **Total** biomass output (productivity)
- **Value** of biomass (functionality)

A commercial perspective demands that these two are integrated into a singular output figure where '*total volume * marketable price of biomass*' is maximized. That is, focusing on *only one* of these two, leads to suboptimal output in terms of revenues. When you are, for example, using an algae strain that produces a very high value component, but it takes growing them 5 years before you can harvest, it doesn't make much sense cultivating them. The other way around, highly productive algae with worthless biomass composition, generate tons of biomass that cannot be sold profitably in the market. The expensive production factors should therefore be expected to actively contribute to this integrated output figure.

Another potential way in which the more expensive production factors, land and labour, can be justified is by regulatory stimulation or by other intangible effects of producing on that specific location. Firstly, regulatory stimulation means that the government can stimulate algae production both indirectly and directly. An indirect way of stimulation is by taxing waste streams that can be used as input factors in algae production (CO_2, manure). This can either stimulate companies, that produce these waste streams, to invest in algae production or deliver these input factors for free. Regulatory stimulation can also be direct. This means that government subsidize algae production programs directly because of their potential as a renewable source of raw material, as well as their capacity to solve waste problem issues. One can also think of tax exemptions, instead off, or complementary to, government subsidies.
Another way the expensive production factors can be justified is when the specific location offers other, intangible benefits. This can be in the shape of access to unique knowledge, closeness to suppliers or customers, or a well suited infrastructure of the area. All these things together should eventually result in enough revenues. That is, enough cash flow should be generated to earn back investments and costs.

Table 2. Main algal products

Application field	Products	Main algae strains used
Human nutrition	Tablets, capsules, liquids. Powder can be incorporated into candies, snacks, pastas, beverages	Chlorella, Dunaliella salina, Arthrospira, Aphanizomenon flos-aquae
Animal nutrition	Feeds for aquaculture, farm animals and pets	Arthrospira, Chlorella, Tetraselmis, Isochrysis, Pavlova, Phaeodactylum, Chaetoceros, Nannochloropsis, Skeletonema, Thalassiosira
Pigments	Astaxanthin, β-carotene, phycobiliproteins, Lutein, zeaxantin, canthaxantin	H. pluvialis, Arthrospira, Haematococcus, Haslea Ostrearia, Dunaliella, Arthrospira, Cyanobacteria,
Cosmetics	Face, skin and hair care, sun protection,	Arthrospira, Chlorella vulgaris, Nannochloropsis oculata, Dunaliella Salina
Fatty acids	ω3 and ω6, γ-linolenic	Crypthecodinium cohnii, Schizochytrium, Arthrospira, Prohpyridium, Nannochloropsis, Phaeodactylum, Nitzschia, Ulkenia, Odontella
Polysaccharides	Agar, alginates carrageenans, immunologically relevant effects	Cyanobacteria; Rhodophyta, Chlorophyta
Energy/Fuel Applications	Biodiesel, hydrogen, not commercially produced yet	
Biofertalizers, plant protection	not commercially produced yet	
Pharmaceutical applications	in research stage	

Demand for 'Emission to Biofuel' concept

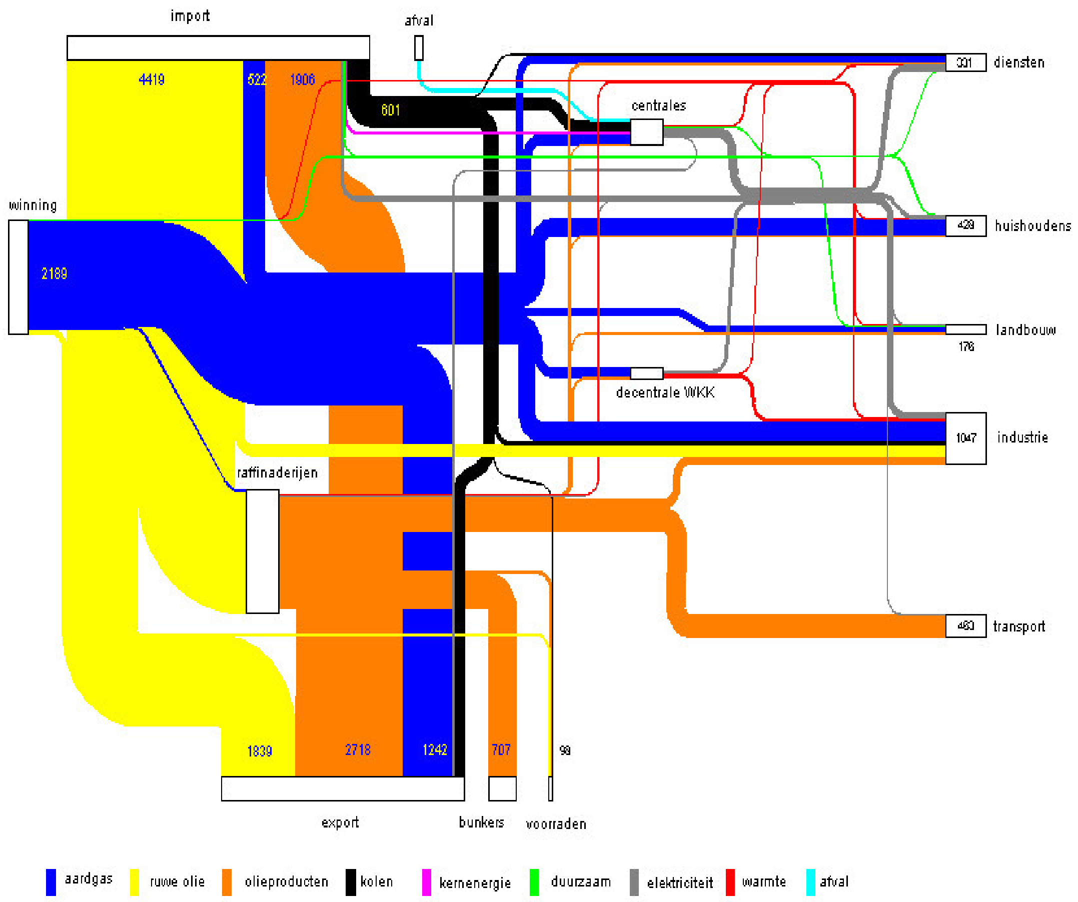
In June 2007 the Rotterdam Climate Initiative (RCI), together with Bass+Gill B.V. hosted a congress on '*algae'*. Algae where discussed both in light of their potential to address global warming as well as the commercial opportunities full scale production brings along. The congress was a great success both in terms of the turn-out and the media attention it generated. Additionally, for the first time in the Netherlands, research and business were given the opportunity to exchange experience and ideas.
When you consider that algae have been used by man for many centuries, and their effectiveness in CO2 conversion is no recent discovery, the question one has to ask is: 'Why this overwhelming interest, and why now?' The answer to this question can be found in what is called the macro-context of algae production systems; which determines the ***general demand for the concept*** of 'emission to biofuels'.

Commercial production of algae in general and the 'emission to biofuel' principle in particular, has become such an exciting new field of interest due to two major trends of our time. These trends, global in nature, have such a high impact on our daily lives that they are gradually beginning to change our societies. These two trends are both embodied in the 'emission to biofuel' slogan, where '*emission*' refers to growing concerns about global warming and '*bio-fuels'* to radical changes that are expected in the 21^{st} century energy market.

Biofuels

Modern society is ***addicted to energy***, and more specifically, to oil. Oil usage is embedded into almost all value-creating processes of modern societies. In some cases, it is used as a raw material that is processed into a range of oil-based products, such as plastics. In most cases, oil finds its way into value chains as the dominant source of energy. Energy required for transportation, but also in powering machinery required for processing other materials.
Because our modern lifestyles depend on energy so heavily, it has become a political imperative to secure as much stable sources of energy for the future. Governments that fail to succeed in this, increasingly risk destabilization of their entire society. For a long period of time, oil has been this source of stability. Recent developments in the global arena however, have raised serious doubts about whether this can stability can be guaranteed in the future.

The most important reason why this stability is threatened, is that oil is only in limited supply. It has taken millions of years to produce the world's current natural oil supply. We are depleting this supply at a pace far greater than it can be regenerated; we have already used up most in a mere two centuries. Using basic marketplace principles, when supply can not keep up with demand, it leads to sharp increases in price. And unfortunately enough, demand is only growing while it is getting harder and harder even to keep supply at a constant level.
When the oil price can't be controlled, entire economies will suffer the consequences. Consequences of a scale not easy to predict, but seeing the integration of oil with almost all economic processes, they are likely to be severe. Given these very basic facts, it is not surprising that alternatives to oil are embraced with open arms. Some of these alternatives come in the form of other 'fossils' such as coal and natural gas, others from a renewable origin.



Sankey Diagram: Dutch Energy Flows
This diagram demonstrates the heavy reliance on oil

Biofuels is such a source of energy coming from a renewable origin. The range of potential sources for biofuels is large, ranging from rape-seed flowers, to palm oil, to maize. The bottom line of all of them is the same however: they are produced from organic material, which can be purposely produced in a never ending supply.

Being able to *produce* energy within national borders is very desirable for supply stability. Currently, a very large part of the natural oil reserves are in countries with unstable political regimes. A growing dependence on countries such as Russia, Venezuela and Iraq, is not something to look forward to for many countries. Other fossil energy sources are subjected to the same problem: it does not solve the problem of dependence on others.
The choice of biofuels over fossil sources of energy is also the better choice on the long run. This is because *all* fossil energy sources are in ending supply; sooner or later they will get depleted. The moment when to switch to renewables is currently held back by the favourable economics behind fossil energy sources: it is cheaper to harvest an existing supply than having to produce it. Governments are expected to play a stimulating role in this transition by stimulating developments in technology and by removing economical barriers.

Emissions
Emissions refers rather specifically to the gaseous 'waste' that is created in the process of fuelling our economies. Our industries, cars and planes, for example, all require substantial amounts of energy, most of which is generated by burning high energy-content material. Seeing our societies require substantial amounts of power since the first industrial revolution, this *gaseous 'waste'* is no stranger to our economic activities. What is new however, is that for the first time in history we seem to have reached, or perhaps passed, a threshold in the amount of emissions our planet can deal with. The recent IPCC report concluded that it is more than plausible that human activity is causing the planet's climate to change.

If one would have to identify a turning-point that triggered public interest for the emissions issue, it is easy to point to the Al Gore documentary '*An inconvenient Truth*'. Although this truly is a **milestone event** in the debate around emissions, a great many people *before* Al Gore have been pushing the debate to where it is now. Since this documentary however, the momentum has become tremendously favourable for ideas that claim to solve emission problems.
Within the term 'emissions', the word 'waste' is implicitly present: emissions are a by-product of a value adding activity for which is no further use. There are a few approaches to solving emissions problems. Firstly, one can try to make processes create fewer emissions. Industries can be forced to take such measures by government regulations. The Kyoto treaty and its trading mechanism for CO_2 credits is an example of this. Because waste creation results from sub-optimal process design, it can easily be combined with better financial performance.
Secondly, it is possible to find new commercial applications for the gaseous waste. There is for example already a programme underway where a Shell refinery in Pernis transports its excess CO_2 to greenhouses for horticulture purposes. This is what is called eco-industrialism, where waste streams of several companies, with diverse activities, are exchanged resulting in net less waste and higher financial performance.
Lastly there is the option of CO_2 storage: taking it out of the system and store it in a secure place. Plans have be made for example on using depleted natural gas fields, as large CO_2 storage facilities.

Search for Alternatives
The emission problem is actually an extension of the 'addiction to energy' problem described in the first section. Usage of oil on the current scale, leads to a *whole range* of negatively consequences for ecological health. In business these non-monetary complications are termed as 'externalities'. Increasingly, businesses are held responsible for these externalities. Even though no law needs to have been violated, pressure is nonetheless put on companies to raise their ethical and environmental standards. The common expression used in business literature to describe this movement, is ***corporate social responsibility (CSR)***.

Corporate Social Responsibility implies that next to making profit, businesses are expected to deliver more to society than consumer benefits that results in profits to the owners. Many ideas to properly balance this traditional approach to affluence, with ecological and social dimensions, are nature-inspired. Adult eco-systems for example, are so complex in their diversity and wealth, and waste so little precious energy, that economic systems can use them as a role model. Eco-industrialism is a good example of a nature inspired economic paradigm. Flows of energy and material in industrial areas are optimally used by several participants, like they would be in natural eco-systems. Algae production is a potential instrument to transform production in industrial areas from linear (waste creation), to cyclical (optimal use of energy and matter). In this way, instead of ***creating*** externalities, they are ***solved*** in the course of the production process.

Using algae biomass as a source of biodiesel for example, has a lot of ecological benefits when it is done within the context of an industrial area. One of these benefits is the potential to sequestrate large quantities of CO_2. In addition to that, emissions of particulates with a size of less than 10 microns decreases by 68% and emissions of sulphur-oxides is eliminated completely. This reduction has been a major driver behind adopting the *'Biofuels Directive'* within the European Union, which compels member states to consume 5,75% of biofuels as part of the total national fuel consumption, by the year 2010.
Next to general benefits that apply to all biofuels (renewable, cleaner, energy security) the use of algae offers some unique benefits over others. A major *economic* driver for example, is the unprecedented growth rate of algae. Being simple, micro-scopic organisms, algae strains high in oil content are able to out produce other sources of biofuels by an average of 10 times. Next to that, algae have the following list of exclusive benefits:

- Non competitive with food production
  - No fresh water required
  - Marginal land, and less acres, required
- Diversity of algae strains allow for complementing, high value, products
  - Nutrition, vitamins, pigments
- Injection of wastestreams into algae reactors
  - CO_2 enriched water
  - Agricultural effluent

Status-quo the state of the industry

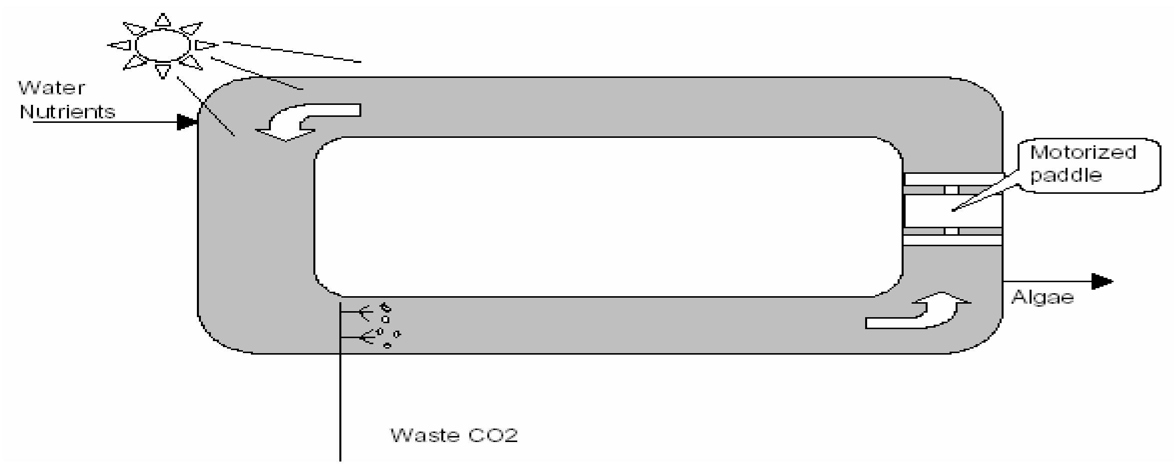
Recently, algaculture has attracted quite some attention. Ever increasing research effort, from both companies and research institutions, has come to show that these humblest of organisms have many useful applications in our current industries. The application that is getting proportionally more attention than any other, is the use of algae bio-mass as a renewable energy source; one with distinct beneficial features over current alternatives, such as rapeseed, sunflower and palm oil.

Emission to biofuel; a historical perspective

The first in-depth research into micro-algae is about 50 years old. Following shortly after the Second World War, it was hailed as the solution to hunger in the world. Very soon however, it was shown a mere illusion, as the species of algae researched proved to be unsuitable for direct human consumption. Although some research did take place after that, commercial interest was slack.

In the 1970's interest for micro-algae was rekindled by the energy crisis of that time. The focus shifted to energy purposes. A serious research effort was started by the Americans on technologies that could **significantly impact** their fossil fuel consumption. As part of this general research initiative, the aquatic species section, focused on the realization of algae farms.

The concept of an algae farm, from the NREL[6] perspective, is a pond where algae, water and nutrients circulate a raceway-shaped production system. The water is kept in motion by paddlewheels, meaning that algae are kept suspended in water. The algae circulate back to the surface on a regular frequency, distributing the available light evenly over the cultivated population. The ponds are kept shallow because the limited extent to which sunlight can penetrate the water surface. The system is operated continuously; water and nutrients are constantly fed into the pond, while algae-containing water is removed at the other end. A harvesting system recovers the algae, which contains substantial amounts of natural oil.



[6] National Renewable Energy Laboratory: A look back at the aquatic species programme

The NREL report was straightforward in its vision: open ponds are to be preferred over photo bioreactors because of low investment and operating costs. With only a need for some available land, digging to prepare shallow ponds, CO_2 and nutrients, bio-fuels could be produced more competitively than with high-tech systems that require large sums of investment. A logical reasoning, as the market for energy is a commodity market where the most prominent feature to distinguish between alternatives is **price**.
In practice however, it was shown that commercial exploitation of these low cost systems was not as easy as expected. Mediocre control over production factors meant that many pilot systems of the open-pond design failed. This was mostly due to contamination with invasive species; one of the factors photo bioreactors effectively helps eliminate.

Some twenty years after the NREL report paved the path for commercial production of algae, it is worth looking at the current status of the algae industry. By looking at recent research and current commercial initiatives, it will be explored whether open pond systems are indeed 'the way to go' or whether technological breakthroughs have made photo bioreactors the preferred choice. In this chapter a closer look will be taken at the current status of the algae industry.

The debate: open vs closed production systems

Cultivation of algae is interesting to companies and governments alike because producing algae biomass comes with a distinct set of unique benefits. These benefits include unparalleled growth rate, valuable components like proteins and fats, ability to fix CO_2, and the use of marginal lands and waste water in the process.
The way *how* to do tap into this potential best, is highly debated and solved by scientists and entrepreneurs all over the world in a variety of different ways. Considering the extreme diversity[7] of habitats algae prefer, and each species' different physiology, the fact that a best practice has not yet evolved is no more than logical. Each algae production system in the world has to cope with a unique set of constraints, the result of which is a wide array of different systems that are designed to function best with regard to these constraints.
For Western Europe and especially the Netherlands land and labour prices are important constraints. The same goes for Japan and almost all highly populated areas in the world. The consequence for countries where land and labour area are at a premium, is that it calls for optimal use of these production factors with regard to algae production systems. On the other hand, countries like Japan and the Netherlands are less constrained on a knowledge dimension. Photo bioreactors therefore seem to be the more logical choice, as it suits the specific context of these countries best.

Generally speaking there are two approaches of producing algae biomass: open systems and photo bioreactors. A comparison between these two approaches, and their major benefits and constraints, is presented in a table at the end of this section. As this table shows, both approaches have barriers to overcome. Simply put, for open systems this is land area and minimal control over impacting growth factors, while for photo bioreactors the large investment costs form a formidable barrier. In the following sections both approaches will be discussed in more detail.

[7] To date over 100.000 species of algae have been identified of which only a small proportion (roughly 500) have been studied intensively

Open systems

Open systems for algae production comprise natural waters, artificial shallow ponds, tanks, circulation ponds and raceway ponds. They are relative cheap and easy to construct and maintain, but do not allow control over key factors like temperature, pH and light conditions. In addition to that they are vulnerable to invasive species and plagues. In dry and hot conditions evaporation is also likely to be significant, while on the other hand dilution due to rainfall is also an ever present risk. These changes in growth conditions in the algae pond may decrease/increase salinity in such a way that it could seriously hamper algae growth.

Open ponds have to be shallow in order to prevent mutual shading of the cells. This makes the open pond system unattractive to countries where land is expensive, as much land is needed for large scale production. Paddle wheels are used in open systems to mix in atmospheric air in order to increase the level of CO_2 in the water. In addition, this improves the light conditions for the average cell, impeding the development of a thin dense upper layer.

For some, open ponds represent a dead-end for the development of micro-algal biotechnology (with exception for certain geographical niches and special purposes). Yet their relative low entry capital makes them the predominantly used systems. The biggest share of the present total world algal production of about 5000 – 6000 M/T per year comes mainly from these open systems.

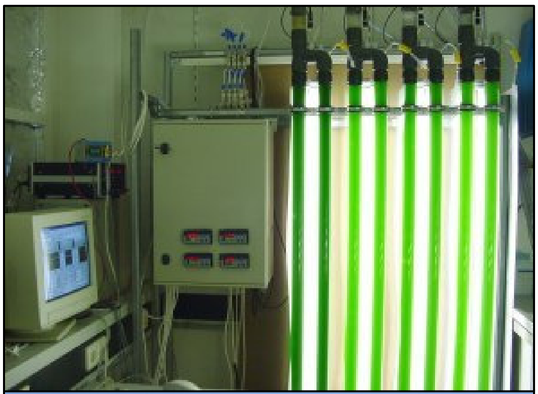
Example of Open System: Ingrepro

Although you would not expect it, our country's largest company in algae production uses an open pond system. Although this indeed has lower average output than the more sophisticated bioreactors, the minimal investment costs have allowed **Ingrepro** to build a thriving business.

Ingrepro has built an international reputation on algal biomass production. Its strength however is derived not from its production system, but much more importantly, from its ability to generate enough revenues from algae biomass by excellent knowledge of potential applications. Ingrepro gets most of its revenues by focussing on **high value** applications in feed.

The ingrepro example makes one thing clear: algae production is about satisfying market conditions. This has been described in a previous chapter in detail: knowing how your product is useful for a wide variety of applications determines for a large degree the potential of your business.

Photobioreactors



Most of the problems plaguing open systems, are solved by photo bioreactors, as they offer much greater control on most parameters and allow a considerable extension of the cultivation period. There are many designs: horizontal, vertical and inclined; tubular, plate-type and ultrathin immobilised configurations with inclined lanes and membrane technology using solar collectors.

The controlled environment of photo bioreactors allows higher productivity to be achieved. The increase in productivity is accompanied by high cell densities. This has an implication for the light regime to which algae are exposed. The light regime inside bioreactors plays a **key role** in productivity. As this inside zone becomes "dark" with increases in algal populations, maintaining the density within the optimal limits for a given algae strain become more and more difficult. Proper mixing is therefore considered critical in bioreactors. Different concepts of mixing (airlift, bubble column) are being used to this extend. The fundamental principle in all designs is to increase the amount of light available to each cell by reducing the *light path*, preventing at the same time photo inhibition and damage to cells due to shear stress.
Productivity is the most important indicator for the success of the technology behind a bioreactor. It is difficult to compare the productivity of bioreactors however, because of the different strains and scales that are used. The biggest operating unit of this design is a one-hectare system with horizontal tubes near Wolfsburg, producing 130-150 M/T dry mass per year.

Example of Photobioreactor: LGem
In a previous section Ingrepro demonstrated that performance is most strongly correlated with knowledge of (high value) applications of algal biomass and finding suitable sale channels. This is also the case for LGem, which uses a photobioreactor to produce its algae.

LGem, like Ingrepro, focuses on high value ingredients in algal biomass. For the commercial application that LGem produces, a photobioreactor is much more suited than an open system. LGem has chosen to produce fatty acids (omega 3 & 6), for human consumption. The contamination free environment a photobioreactor provides makes it much easier for their biomass to get a 'food grade'.

Although LGem does indeed obtain higher cell densities, the investment and operating costs of their system only allows for high value products to be produced. It would therefore be highly unlikely that photobioreators be used for low-value output products like biofuels.

Algaculture in the Netherlands

Research programs on commercial production of micro-algae have been common for decades in many countries such as the USA, France, Germany and Japan. In contrast, the topic has received little attention from Dutch national research institutions. In recent years however, this has changed and many nationally produced reports on micro-algae production and applications are now readily available.
There are two reasons why it is logical to assume that our country can make a serious contribution to the development of algaculture. Firstly, The Netherlands take a remarkable position in the world market for agricultural products. Although being one of the smallest countries in the world, The Netherlands consistently rank among the top 3 of net exporters in this category. This is the result of a knowledge intensive, and highly productive agricultural sector, supported by top-notch research institutions in the field, such as the Wageningen University.
Next to being a dominant player in the world market for (processed) agricultural products, the Dutch have a reputation to uphold when it comes to their knowledge of watery environments. With around half its land area below sea-level, the Dutch are constantly fighting, and working together, with water. As a result of this, there is much knowledge available on how to successfully work with watery systems. When these two branches of knowledge (watery environments; agricultural production) are dedicated to commercial exploration of production of micro-algae, it is likely to add significantly to development of the algaculture industry.

Using and expanding the knowledge base

Increasingly, the current knowledgebase in the Netherlands is being used to explore and develop the potential of commercial production of algae species. Within the WUR a program has been initiated that is specifically dedicated to aquatic species. Head of this program, Dhr Wijffels comments that many of recent pending patents in medicine, for example, are on account of enzymes found in aquatic species. He believes that this is just the tip of the iceberg when it comes to the total potential of aquatic species, and algae among them.
In 2002 a research programme on commercial production of algae was dedicated to the co-production of multiple products from algae biomass. Funded by the Dutch Centre of Energy, the combination of ***low value*** products with ***high value*** products was investigated in a multiple year research effort. The report concluded that there is a lot of potential, but more research is required to make the concept fully operational. Especially the integration of algae production in industrial areas was marked as interesting to investigate further because the presence of waste heat creates multiple benefits. Waste heat, for example, allows the production of thermophilic algae species. It can also be applied in drying algal biomass, which results in lower production costs. Next to the availability of waste heat, flue gases from electricity companies can also improve commercial viability. Directly through carbon credit trading (now obligatory for many industries) and **indirectly** though increases in productivity that high CO_2 levels bring along.

International initiatives

In *appendix A* a list of international initiatives on commercial production of algae is included. No information on financial performance of these companies could be obtained. What can be said is that many initiatives that focus solely on biofuel production have recently failed, or have yet to prove themselves. It seems that most of these programs fail to take into account the constraint a low value product brings along. Especially the combination of a low value product with the investment intensive photobioreactor approach, is proving to be difficult to realize. The table below (Marinova 2007) summarizes the advantages and disadvantages of the two approaches to commercial production of algae.

Cultivation system	Advantages	Disadvantages
Open	- Relative cheap - Easy to construct & maintain - Low energy consumption	- Little control on culture conditions - Poor productivity -> Large land area required - Limited to few strains - Contamination - Evaporation and dilution - High volumes to process
Photo bioreactors	- High productivity - Control temperature, nutrients - Protection against invasive species and plagues - High cell densities - Less subjected to light inhibition due to the mixing - Low CO_2 losses - reduced harvesting volumes and processing costs - Standardisation of processes and production quality - manipulation of conditions allows increases in quantity and component content	- Expensive - Difficult to scale-up - Higher densities increase mutual shading of cells - Possibility of hydrodynamic stress - Possibility of O2 build-up - Some degree of wall growth - Energy-intensive

Positioning within the HIC

The previous chapters have shown that growing micro-algae commercially is far from science fiction, but instead, has the potential to mature into a booming, international industry. To exploit the generally favourable competitive position of Dutch initiatives, now is a good time to invest considerably into making the translation of this potential into commercial initiatives. We have seen that some Dutch companies have already ventured into this industry, but the scale of these operations until this day remains small. Additionally, there is still a lot to be won by capturing the synergy with waste stream reduction such as CO_2 emissions, agricultural effluent and industrially heated water. For this reason we will now delve deeper into the micro-context of realising an 'emission to biofuel' concept in the Rotterdam port area.

Port of Rotterdam Industrial Complex (HIC)

The Netherlands is one of the wealthiest countries of the world, and disproportional to its small land area, has considerable influence over Europe and its economy. A major contributing factor to its wealth comes from its geographical location: from The Netherlands it is easy to transfer goods to and from other wealthy European countries such as Germany, France and the UK. Rotterdam specifically, plays a crucial role in the logistics of much of Europe's import and export movements by sea.
Rotterdam is such a unique geographical location, because two major European rivers mound into the sea at this place, making it possible to transport goods into and from Europe at affordable prices. Seeing the strategic character of the area, Rotterdam has attracted many industries to settle here. Next to the **natural** beneficial characteristics of the location, the municipality and the national government together, have ensured that the logistical attractiveness of the area remains high. Only very recently a major railway infrastructure program called, the betuwe route, was completed. This multi billion euro program facilitates easy transportation by railway between Rotterdam and industrial areas in Germany.

As mentioned, the Port of Rotterdam Industrial Complex (HIC) has attracted many major companies to settle in the area. Due to this, it has become one of Holland's most important mainstays. With all these companies situated in the HIC, the area hosts a remarkable competence in many industrial activities. Most notably, it is known for a dominating presence of petrochemical companies. Within this category fall both the immense storage capacity of oil, as well as the processing capacity of this oil into a wide variety of products.

It does not mean however that the area is exclusively for petrochemical companies; there is a diversity of other companies present. From the perspective of this quickscan one industry is interesting when it comes to commercial production of algae. This is the food processing industry. In the remainder of the chapter we will come back to the reason why this specific industry, next to petro-chemistry, is considered interesting.

HIC: an area in transition

As illustrated in a previous chapter, powerful trends are building up considerable pressure on many value adding activities, especially in high energy & resource consuming, industrial companies. It is easy to understand that many companies that are dependent on energy, have been among the first to notice the peculiar situation on the world markets for crude oil. Due to this volatility of the oil market, many energy companies, for example, are quickly expanding their focus to alternatives. Some of these alternatives come from other fossil sources, such as natural gas and coal; others from a renewable origin. Next to the obvious sources such as energy from windmills, energy from solar cells and energy from waterpower, an increasing part of these '*renewables'* is on account of biomass.

Even though these trends on the energy markets are very realistic and easy for everyone to see, the percentage renewable energy, until this day, remains only a fraction of total energy consumption. The sankey diagram in a previous chapter provides a striking illustration of this. It would be *un*realistic to expect any sudden changes in this picture overnight; within the scope of only a few years. However, there is no getting by the fact that at some point we *will* have depleted all of the planet's oil at our current, ever increasing rate of consumption. And long before that is going to happen, general dynamics of the marketplace dictate that prices of oil will reach a level that allows many other alternatives to become serious competitors for the much desired number one spot. Not only the absolute (estimated) amount of oil still present in the earth's crust is the figure that will be dictating this price: factors such as the rate at which demand is developing and the easy accessibility, and consequently supply, of that oil are large determinants of that price.

Because the HIC currently plays an important role in the industry for oil storage and processing, there is a lot at stake when this transition gets fully underway. Not only will this directly impact oil companies in the area in their activities, also companies who rely on oil as a significant part of their daily operations are affected. This is for example the transportation sector and bulk chemical companies that use crude as a raw material source, The current high uncertainty and high volatility in the oil markets is pushing these companies to explore alternatives, one of which is similar materials obtained from biomass. Examples of this are the oil fraction in palms and the sugar fraction in high sugar/starch-content crops.

As major as this transformation already is, it is *just one* of two major trends many of the companies in the HIC have to deal with. Current concern about emissions, the other trend identified in a previous chapter, is creating other threats to operational stability. The most straightforward way in which this reaches the company's strategic agenda, is by stricter regulations on companies by local and national governments. Those companies who can't keep up with ever increasing regulations, risk large fines, or in the worst case, their license-to-operate altogether. A more positive approach to raising environmental standards has been introduced by the Kyoto treaty: instead of only charging offenders, 'good companies' that succeed in performing better than required, are rewarded with saleable credits. This mechanism is called carbon credit trading, and has been working with marketplace dynamics for many industrial companies since early 2005.

Algae production and the HIC

Even though everything discussed in this quickscan until now is indicating that commercial production of algae is likely to increase in the nearby future, the question of the *specific relevance* for the HIC still has remained largely unanswered. The previous section illustrated roughly that the two macro-trends that drive the demand for the **concept**, apply to a very large extent to the micro-environment of the HIC as well. It is however useful to make a distinction beforehand between two different ways commercial production of algae could impact activities within the HIC. In the coming sections these two different ways will be worked out in more detail, especially with regard to their specific relevance to commercial algae production within the context of the HIC.

Impact of mass availability for the HIC

Introducing the first of two different ways the HIC can be impacted by algae production, is the mass availability of algal biomass worldwide. That is, when more and more companies succeed in producing substantial amounts of algal biomass, the price can become competitive as a raw material to many different industries. In this mass availability of a cheap (or at least competitively priced) new raw material source lays a great opportunity for many companies within the HIC, most specifically for those that are currently still very dependent on oil.

When algal biomass can be acquired from many different locations around the globe, the opportunity for companies arises to buy from multiple sources. This has a stabilizing effect on the price of the commodity. But algal biomass can become **more than a commodity**: because different algae strains have different intrinsic properties, there are many opportunities for unique algae derived products. With the large majority of species still under explored, and the broad range of possibilities already identified, algae production is by no means only suitable for undifferentiated production. This first impact on the HIC is in essence about being prepared for the wide range of new opportunities mass availability of biomass brings about for the existing (and new) industries of the HIC, including both undifferentiated and high value components.

Beside the direct input into the industrial activities of the HIC, the mass availability creates new logistical movements in goods. Firstly, it is not unimaginable that much of future algae production, aimed at large quantities of commodity products, will move to areas in the world where production factors such as land and labour are relatively cheap. This would imply that developed economies, with expensive labour and land area, require import of algae biomass to foresee in their demand. Rotterdam could continue to act as a point of entry to many European economies. That is, only if **enough knowledge** is available on processing, storing and transferring this new raw material source. Making the location attractive among alternative locations to transfer the biomass to, should therefore be high on the HIC's agenda.

In summary mass availability of algal biomass creates opportunities both in new logistical movements through the Port of Rotterdam Industrial Complex as well as comprising a whole new input material. The scale of this impact is hard to determine at this moment, but there is no doubt that seeing the potential productivity of algal production systems, together with their great diversity, large scale deployment of this technology is only a matter of time.

Complementary activity within the HIC

Although mass availability of algal biomass is likely to come about somewhere in the undetermined **future**, the scale of current algae production is small. There are however some unique benefits associated with algae production that can impact an area such as the HIC already in the **present**. These benefits result from capturing the synergy with specific characteristics of the area. This second potential impact on the HIC is described by the complementary nature of algae production within the infrastructure of an existing industrial complex.

The drivers behind algae production systems within the context of an industrial area are both ***ecological*** as ***economical***. Compliance to a more environmentally conscious paradigm, be it enforced by government or demanded by the general public, is associated with the ecological dimension. Commercial benefits resulting from the added value of the infrastructure to production by using waste streams as input factors, is associated with the economical dimension.

Unlike the impact of mass availability of a new raw material source, the impact from being complementary to current activities, is not directly focused on providing input to the current industry with algae biomass. This is mainly because the scale that is required for these large scale industrial activities is hard to reach within the context of the HIC alone. Nonetheless, *extra synergy* could be realized when existing knowledge of the area is used in the development phase of the algae reactor's design. By co-developing the production system, it might be possible to work towards realization of enough capacity on other locations to foresee in enough supply.

The use of waste streams that add to the commercial viability of the production design, can take many forms. For example, effluent from the agricultural sector can be used as a nutrient source, driving down waste problems while lowering purchasing costs at the same time. Because the HIC hosts companies that process agricultural products, such waste streams should be in abundant supply. In addition to that, within The Netherlands there are plenty of other waste streams from agricultural production that can be used, when these prove to be more suitable.

Another use of waste stream is CO_2 from flue gasses within the HIC. Because it is such a crucial part of the photosynthetic process, the availability of enough CO_2 in the vicinity ensures that high level of productions can be realized. When production reaches a certain scale that CO_2 requirements for the algae production system become substantial, it becomes all the more interesting for energy consuming companies. Through investments in these systems they decrease their dependence on carbon credit trading and can produce under much cleaner standards.

The last potential of industrial waste streams lies with industrially heated water. Added value comes directly from using the warmth in drying algal biomass. Indirectly the warm water can be used to heat basins in which thermophilic species can be produced. These have the advantage of great stability when applied in industrial processes, which mostly take place at high temperatures.

Realizing algae production within the context of an industrial location means taking full benefit of the HIC's specific character. As noted earlier, algae production can take place on many locations in the world. There must therefore be a very good justification for doing it in a relatively expensive area with regard to land prices and labour. This can be compensated by good knowledge of (high-value) applications, in addition to creating synergy with the location in terms of waste stream utilization.

An integral approach

In both possible impacts on the HIC, knowledge is the crucial component. Only with sufficient knowledge within the area, will the HIC be able to benefit from the growing industry of products derived from algae biomass. It is therefore obvious that investment in knowledge at this stage of the industry is more than welcome; it is essential. The question is how this process of knowledge accumulation can best be dealt with. For local production, aimed at synergy with characteristics of the HIC, the following knowledge is important
:

- How do the ecological benefits of waste stream utilization (in waste heat, CO_2, agricultural effluent) translate into commercial value
- Which high value ingredients can be competitively obtained from algal biomass (strains) within the context of the HIC, that offset high investment costs in labor, land and bioreactor design
- How can productivity be substantially raised by moderations in algae reactor design that allows the production of low-value products, such as oil for energy purposes.

In the process of answering these questions, knowledge is accumulated that is useful when mass availability of algal biomass is realized worldwide. **Involvement** of a large stakeholder network from the HIC around algae might be crucial. So firstly, it is essential to start bringing people and companies together. Companies who are directly involved with algae production, but also researchers, buyers of algae biomass, and experts from agriculture & aquaculture. Exchanging ideas between people from all these different backgrounds, allows knowledge to be accumulated at a much faster pace. A **knowledge platform** in which all these backgrounds are united makes it possible to find answers to the questions above, among many others that have remained outside the scope of this quickscan.

Talking alone, will not be sufficient. First of all because many practical issues surrounding algae production within an industrial context are easily overlooked. In parallel with the knowledge platform a ***practival*** initiative should be initiated that maps practical challenges towards commercial viability. As stressed time and again in this quickscan, it is the financial challenge around algaculture that comprises the most formidable barrier.

The added value of a commercial initiative running in parallel with the knowledge platform confronts exactly this barrier. Beside that, issues raised within the platform find in the commercial initiative the possibility to develop empirically based answers. The other way around, the platform is a good place to discuss practical obstacles that have been encountered by the commercial initiative. This dual approach will eventually add significantly to the overall competence of the region.

Summary and USP AlComm

Realization of AlComm in the Rotterdam Port Area will most likely not centre *solely* around bio fuel production. It is fundamental to commercial viability that two expensive production factors, labour and land, are justified by the extra revenues they bring about, or costs they help mitigate. This implies a multiple revenue approach where the benefits of *algae production* are sold to multiple parties, instead of focusing on just one end product. The port of Rotterdam Industrial Complex in general adds the following to the business case:

1. Flue Gases (CO_2, NO_x)
2. Waste heat from energy production
3. Waste from agro-production (processing)

Ad 1: The CO_2 has the potential to add to the business case directly by earning carbon credits. Indirectly it results in lower costs of otherwise necessary production factors and sustained high growth rates of the biomass.
Ad 2: Waste heat has three effects on the business case. Firstly, algae can be grown *year-round* at their biological optimum, increasing output. Secondly, it can be used in drying the biomass, resulting in lower processing costs. Lastly, there are algae species that require high temperatures to grow and bring along interesting commercial applications, such as pigments and thermo stable enzymes.
Ad 3: The use of waste from agro-production (processing) comes both in a direct and an indirect form. Directly from mitigation of environmental tax on agricultural waste. Indirectly from lower costs of acquiring nutrients to grow algae species on.

Within the breakwater cluster on the maasvlakte, these elements are all available. There are even additional advantages: there is a salt water source present, and shrimp production benefits from algae-produced oxygen. For all these reasons, the cluster is excellently suited for piloting algae production within the HIC.

For the HIC, the pilot plant ***especially*** is interesting as it helps accumulate a kind of knowledge that, for example, a knowledge platform cannot: practical answers to very practical questions. This comes down to the fundamental truths that some things cannot be accurately known without having tried them in practice.

With a stronger knowledge base, the HIC is much better prepared to play a prominent role in the growing industry for products from algal biomass.

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Appendix A

International initiatives on commercial Algae production

International Commercial Initiatives

- **Enhanced Biofuels & Technologies** (***http://www.ebtplc.com/***) - The EBT algae process combines a bioreactor with an open pond, both using waste CO_2 from coal fired power plant flue gases as a fertilizer for the algae. The biodiesel and ethanol produced can be sold, or used as an alternative fuel on site. Emissions are reduced up to 82%.

- **GreenFuel Technologies** (***http://www.greenfuelonline.com/index.htm***) Emissions-to-Biofuels™ (E2B™) process harnesses photosynthesis to grow algae, capture $CO_2$and produce high-energy biomass. Retrofitting fossil-fired power plants and other anthropogenic sources of carbon dioxide, the algae can be economically converted to solid fuel, methane, or liquid transportation fuels such as biodiesel and ethanol.

- **GreenShift** (***http://www.greenshift.com/news.php?id=97***) has a license agreement with Ohio University for its patented bioreactor process based on a newly discovered iron-loving cyanobacterium (blue-green algae), through their subsidiary Veridium (*http://www.veridium.com/*), for the purpose of air pollution control of exhaust gas streams from electrical utility fossil-fueled power generation facilities. Once the algae grow to maturity, they fall to the bottom of the bioreactor and are harvested for fuel or fertilizer.

- **Solazyme** (***http://www.solazyme.com/***) - Devoted to harnessing the energy-harvesting machinery of various species of algae to produce valuable products. The Company utilizes proprietary genetic engineering methods to develop and optimize commercially relevant biochemical pathways for production of hydrocarbons (for energy and specialty chemicals) & bioactive compounds.

- **LiveFuels** (***http://www.livefuels.com/***) - A national alliance of labs and scientists dedicated to transforming algae into biocrude by the year 2010. Working on breeding various strains of algae, driving down the costs of harvesting algae and extracting fats and oils from the algae. Theoretically, the U.S. could grow enough algae on 20 million acres to replace imported oil.

- **Valcent Products** (***http://www.valcent.net/news_detail.sstg?id=36***) - Has developed a high density vertical bio-reactor for the mass production of oil bearing algae while removing large quantities of carbon dioxide (CO_2) from the atmosphere. This new bio-reactor is tailored to grow a species of algae that yields a large volume of high grade vegetable oil, which is very suitable for blending with diesel to create a bio-diesel fuel.

- **Aquaflow Bionomics** (***http://aquaflowgroupcom.axiion.com/***) - Many vegetable and biomass derived oils could replace petroleum as its scarcity and price increase. The search for new faster growing species will intensify as demand increases.

- **Infinifuel Biodiesel** (***http://www.infinifuel.com/***) - Wabuska Nevada is home to the world's first geothermally powered and heated biodiesel plant. We have over 300 acres to grow oilseed and develop algae ponds on site.

- **Solix Biofuels** (***http://www.solixbiofuels.com/***) - A developer of massively scaleable photo-bioreactors for the production of biodiesel and other valuable bio-commodities from algae oil. Solix' closed photo-bioreactors allow fossil-fuel power plant exhaust to be captured through the growing system. The algae growth rates increase in the presence of the carbon dioxide that would otherwise be emitted into the atmosphere.

- **Algoil** (***http://213.79.36.6/algoil/index.htm***) - A pioneer project focusing on the production of Biodiesel / Biomass from micro algae. The target is also to use the rest of the extracted biomass to make food, biofuel, hydrogen, paper, or simply burning it like charcoal. The extraction of oil suitable for Biodiesel is now a confirmed success.

- **OriginOil** (***http://www.originoil.com/***) - Novel technology at the microscopic scale can enhance the efficiency of algae production as a high-yield, cost-competitive replacement for petroleum. In the growth phase, nutrients are fractured and injected into algae culture. In the extraction phase, fracturing breaks the tough outer membrane of the algae in an energy-efficient manner.

- **PetroAlgae** (***http://www.petroalgae.com/***) - Commercializing an environmentally-friendly algae developed by a research team at ASU that generates over two hundred times more oil per acre than crops like soybeans. Using a cost-effective, modular cultivation process that can be massively scaled, PetroAlgae will produce renewable feed stock oils for use in applications such as transportation fuels (e.g. biodiesel), heating oil, and plastics.

- **New England Clean Fuels** (***http://www.newenglandcleanfuels.com***) - Developing a bioreactor for growing all kinds of photosynthetic microoganisms as fast and profitably as possible. The bioreactor is called "MOPS" - an acronym for Micro-Organism Production System. The MOPS can be used for both carbon dioxide sequestration and biofuel feedstock production simulateously, which kills two birds with one stone. It requires dramatically less land and water than soybeans & corn farmers use, which will alleviate pressure on farmland prices & food prices. This will allow the biofuels industry to continue to grow without causing inflation