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Case Study for the Use of Emitted CO_2 of an Austrian Thermal Power Plant for Growing of Algae and Burning the Algae Based Biomass

A Master's Thesis submitted for the degree of
"Master of Science"

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26.10.2013, Vienna

Affidavit

I, **DI (FH) Thomas Aichhorn** hereby declare

1. that I am the sole author of the present Master Thesis, " Case Study for the Use of Emitted CO_2 of an Austrian Thermal Power Plant for Growing of Algae and Burning the Algae Based Biomass ", 81 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

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Abstract

The master thesis reviews whether it is possible to use emitted CO_2 of a thermal power plant which runs on coal as feedstock for algae instead of emitting to the atmosphere.

In a detailed analysis, case studies for the production of electricity from algae have been performed. Key parameters such as CAPEX, OPEX, output, revenues from Omega 3 fatty acid, and price of CO_2 allowances have been systematically varied and their impact on the business plan quantified.

From an economical point of view, the production of algae based biofuels is not profitable yet. Therefore, the algae based product has to be a high value product such as Omega 3 fatty acid. Nevertheless, the combination of a thermal power plant with an algae growing and refining facility, which includes an additional artificial light system, can be recommended. Consequently, natural solar radiation and artificial light radiation will be used during the photosynthesis process of algae. Further, the economic model indicates that the output and the CAPEX of an algae growing and refining facility influence the economic result most.

All in all, the use of CO_2 from a thermal power plant as feedstock for algae is not a magic bullet and cannot solve environmental problems regarding global warming. Nevertheless, it can become a bridge technology until a solution for such problems has been found.

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List of Abbreviations and Systems

appr.	approximately
a.s.o.	and so on
AWS	Austrian Wirtschafts Service
CAPEX	capital expenditure
CCS	carbon dioxide capture and storage
CDM	Clean Development Mechanism
CH_2	methane
cm	centimeter
CO	carbon monoxide
CO_2	carbon dioxide
DHA	docosa hexaenic acid
ecoduna©	ecoduna© productions- GmbH
el	electricity
EPA	eicosa pentaenoic acid
ETS	emission trading system
EU	European Union
EUR	Euro
FC	fluorocarbon
FIT	feed in tariff
g	gram
GLP	good laboratory practice
GMA	genetically modified algae
GMP	good manufacturing practice
h	hour
H	hydrogen
ha	hectare
HHV	higher heating value
IRR	internal rate of return
JI	Joint Implementation
k	kilo
l	liter
J	Joul
KPC	Kommunalkredit Public Consulting
m	meter
m^2	square meter
m^3	cubic meter
N	nitrogen
NO_x	nitric oxide
NPV	net present vale
O_2	oxygen
Omega 3	Omega 3 fatty acid
OPEX	operational expenditure
OTC	over the counter
P	phosphor
PAR	photo-synthetically active radiation
PBR	photobioreactor
PC	phosphatidylcholine

PE	photosynthetic efficiency
PFC	perfluorocarbon
SEPPL	CO_2 separation plant
SF_6	sulfur hexafluoride
SME	small and medium-sized enterprises
SO_x	sulfur oxide
t	tons
th	thermal
TPP	thermal power plant
US	United States of America
USD	US Dollar
UV	ultraviolet
W	Watt
ZAMG	Austrian Central Institution for Meteorology and Geodynamics
λ	wavelength
%	percentage
Σ	sum
€	Euro
°C	degree Celsius

SI-Prefixes

exa	peta	tera	giga	mega	kilo
E…10^{18}	P…10^{15}	T…10^{12}	G…10^{9}	M…10^{6}	k…10^{3}
a…10^{-18}	f…10^{-15}	p…10^{-12}	n…10^{-9}	µ…10^{-6}	m…10^{-3}
atto	femto	pico	nano	micro	milli

1 Introduction

Different theories state that the first protozoons, which are also defined as algae (an exact definition of algae can be found in chapter 3), on earth were formed in water and have created the atmosphere of the earth by using photosynthesis for growing and reproduction. Figure 1 (Groom, 1999) illustrates the enormous amount of algae in the ocean in front of Cornwall, which can be seen from the orbit.

Figure 1: Algae in front of Cornwall

Some historians found the first signs for using algae as food source by researching the tribe of the Aztec (Chapman, 1989). In the modern world, three phases for the usage of algae took place. The first phase was after the Second World War in the 1950s; Germany, Japan and the USA exploited microalgae as food source. The second one emerged in the 1970s, when the USA, again, conducted extensively research for algae as food source. In the end, algae could not supplant agricultural products, since corn was totally common for farmers. Furthermore, the algae technology was completely new and too expensive. The third trend has already started some years ago and is still in force (Gilmour, 2012). It is primarily based on the exploration of biofuels from algae. Also, the President of the United States of America (US) Barack Obama, announced algae in his speech of the cash-flow budget for the US for 2013, “We are expanding our investments in research, development, and demonstration of cellulosic ethanol and other advanced biofuels such as algae-derived biofuels and “drop-in” replacements for diesel and jet fuel, including through collaborations with the Navy and US Department of Agriculture”. The interest in algae is also based on the climate change, the discussion whether crops should be used for biofuels instead of food, the advantage that algae can grow in non-agricultural areas, the fact that algae grow faster than agricultural crops, and so on (a.s.o.) (see also chapter 3 and 3.1) (Hobson, 2011). Especially in the future, the climate change will have a deep impact on mankind, and therefore algae based products will be more and more in the focus of politicians, different industries as well as research and development. Figure 2 (Wikipedia, 2006) shows the natural carbon dioxide (CO_2) absorption on earth, further it can be seen that algae as well as biomass are large natural absorber of CO_2. The main CO_2 absorbing areas on earth are forests, permafrost soils, and the oceans. Consequently, photosynthesis can be taken as an indicator for natural CO_2 storage, due to the fact that photosynthesis and CO_2 absorption are directly in relation (see also chapter 4.1).

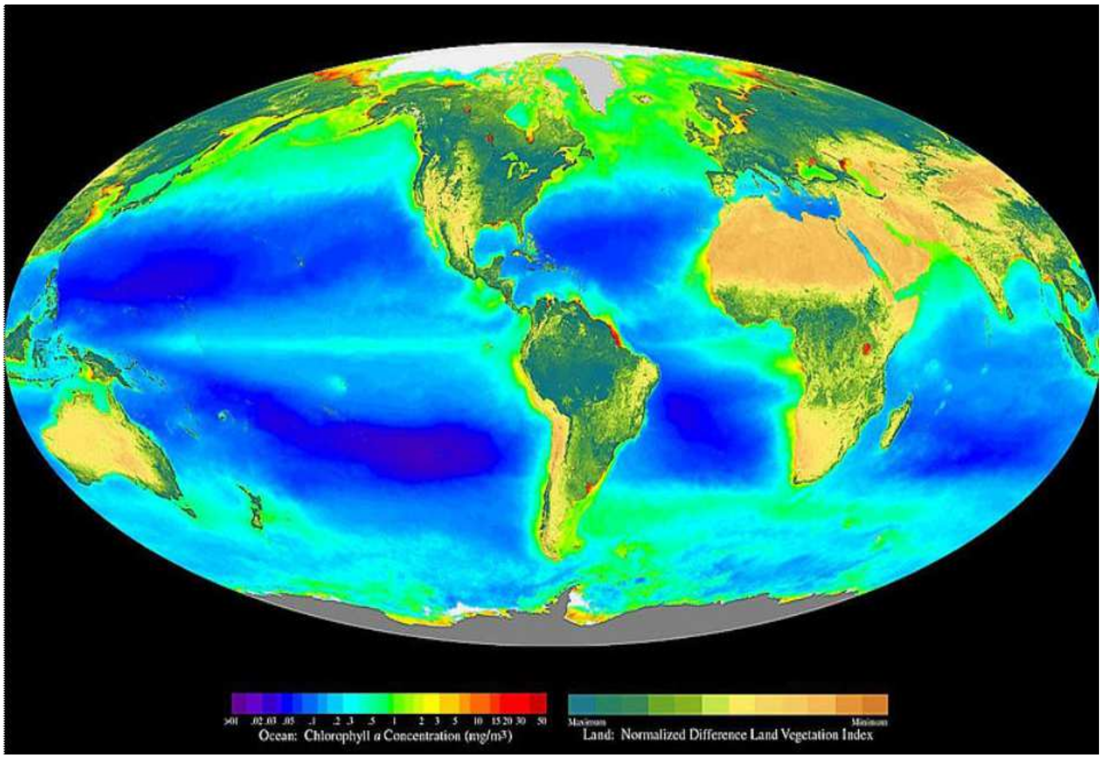


Figure 2: Natural CO_2 Absorption

Figure 3 illustrates a simplified example, which should give an idea about the amount of microalgae in the oceans and their importance in the natural food chain.

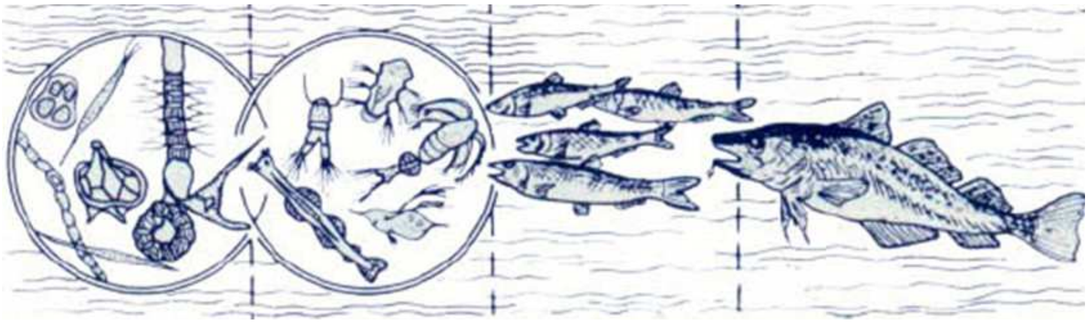


Figure 3: Food Chain of Fish

A humpback whale eats around 5,000 herrings per day. Further, each herring eats small fishes and zooplankton daily, which is equal to 6,000 copepods, and one copepod consumes approximately 130,000 diatoms (which are microalgae) per day. As a result, one humpback eats about 400,000,000,000 diatoms daily (Schnell, 2012).

1.1 Motivation

Both energy and electricity (el) demand in Austria and the whole world increase constantly. Just in times of global financial and economic crises those demands stayed on the same level or decreased a bit. As long as there is no technological revolution in the energy producing industry, the CO_2 emissions of that industry is going to rise, since the conversation of energy emits CO_2. The more CO_2 is emitted to the atmosphere, the quicker the climate is going to change. Consequently, natural phenomena such as thunderstorms, floods, and dry season's a.s.o. will become stronger and causes more human catastrophes.

The largest Austrian thermal power plants (TPP) (see also table 18), which generate on the one hand electricity and on the other hand heat, are running on fossil fuels (see also chapter 6). From an economic point of view, the European Union (EU) has planned that, in the future, the operation of TPP will become more and more expensive due to the fact that the European Union emissions trading system (ETS) will be readjusted. Consequently, the price of emitted CO_2 will rise in member countries of the ETS (see also chapter 4.2). Another possibility to avoid ETS costs would be to capture and store CO_2. Some research and development projects are running under the name CCS (carbon dioxide capture and storage). The goal of these projects is to find save solutions to capture CO_2 in a proper way. However, at the moment there is no such technology on the market which could store CO_2 cheaper than the ETS costs for CO_2 emitting certificates (allowances) are. Another idea, to use emitted $CO_{2,}$ is as feedstock (see chapter 4.1 and 6.2) for growing algae instead of, on the one hand buying allowances for emitted CO_2 or, on the other hand capturing and storing emitted CO_2.

Algae can be converted into several different types of end products, e.g. renewable (naturally replenished) biofuels, biogas, pharmaceutical products, nutraceutical products, food, feed, fertilizer, a.s.o. (see also table 1).

At the moment there are different technologies for growing algae and refining algae biomass to different products in research. Consequently, no standards are defined for the algae based biomass production and refining algae based biomass. Nevertheless, the yields of small scale experiments cannot be reached by the yields of big scale production yet. Therefore, a lot of technological, as well as economic challenges have to be faced in order to become a serious competitor in different markets (see also chapter 8 and 9) (Cheng, 2011 and Richardson, 2010).

Table 1 (modified from oilgae.com, 2012) is categorized in terms of their economic value of some algae based products, however, this overview is not complete. Consequently, it can be stated that algae based products have a wide range of use.

Table 1: Algae Based Products

High Value	Medium to high Value	Low to medium Value	Low Value
Nutraceuticlas - Astaxanthin - Betacarotene - Poly unsaturated fatty acid (DHA/EPA – Omega 3) - Coenzyme Q10	**Nutraceuticals** - Sinlge cell protein	**Fertilizer and Animal Feed** - Aquaculture feed (shrimp feed, shellfish feed,…) - Animal feed - Fertilizer	**Biofuels** - Biodiesel - Biogas - Biofuel - Jet fuel - Bio oil
Pharmaceuticals - Antimicrobials, antivirals and antifungals - Neuroprotective products	**Hydrocolloids** - Agar, alginate, carrageenan	**Substitutes for synthetics** - Biopolymers and bio plastics - Lubricants	
Cosmetics - Anti-cellulite - Skin anti-ageing and sensitive skin treatment – alguronic	**Chemicals** - Paints, dyes and colorants; pigments - Chlorophyll,	**Bioremediation** - Wastewater treatment and nutrient credits, - CO2 capture and	

acid	Phycocyanin, Phycoerythrin, Fucoxanthin	carbon credits	

More or less, depending on the industry, the price range of algae based products differs very much and varies between 1.40 to 1,500 US Dollars (USD)/kg.

The aim of this thesis is to give an economic overview of an algae growing and refining facility in combination with a TPP based on the conditions prevailing in Lower Austria. The master thesis focusses on Omega 3 fatty acid (Omega 3), which represents a high price algae based product, which can also be seen in table 1. That concentration is based on two facts. Firstly, different articles and reports (e.g. ter Veld, 2012 and Sills, 2012) state that, the production costs of algae based biofuels compared to fossil fuels are too expensive yet (see also chapter 5.2). Consequently, from an economic point of view, algae based biofuels producing companies cannot survive without subsidies. Secondly, the company ecoduna© produktions- GmbH (ecoduna©) has provided necessary data for the economic model of this master thesis, which rest upon algae based Omega 3 from their algae growing and refining facility in the city Bruck an der Leitha (Bruck), which is located in Lower Austria. The company ecoduna© is a world market leader in the construction of algae growing and refining facilities.

All in all, if the algae technology makes a breakthrough, it is not a magic bullet which will solve all environmental problems, hunger, as well as energy problems (Ferell, 2010). However, it can become a bridge technology until a solution for all the above mentioned problems has been found.

1.2 What are the core Objectives/Questions?

The core objectives of the master thesis are to explain briefly the growing process of algae and what has to be taken into consideration for this process. Further, the question, how does the growing process of algae from a technological point of view look like, should be answered. The photosynthesis process will be explained, however, not in detail because it is commonly known and explained in the secondary literature. Moreover, the master thesis focusses on the economics of an algae growing and refining facility, however, not on the biological details of algae (see chapter 3).

Due to the fact that CO_2 is required for the growth of algae (see chapter 4), the question, which impact has the algae growing and refining facility in combination

with a TPP regarding the ETS (see chapter 4.2) have, will be discussed (see chapter 8.3 and 9).
Furthermore, the comparison of the calorific values of algae based biomass with fossil fuels and biomass (see chapter 5.3 and 5.4) will give the answer to the questions, if it is possible to burn algae based biomass in a TPP (see chapter 5.4) and which impact it has on a TPP in general (see chapter 7).
An economic model, which takes the legal framework (see chapter 8.1) in consideration, will give an answer to the question if the combination of a TPP with an algae growing and refining facility can be recommended (see chapter 8.3). Possible subsidies (see chapter 8.2) are described but are not considered in the economic model, since all used technologies are already known. Chapter 5.2 gives an overview of markets for algae based products.
In the end, sensitivity analysis will show which factors have major economic influence on the result of an algae growing and refining facility (see chapter 8.3 and 9). Consequently, it will illustrate which improvements have to be made in order to become a serious competitor at different markets (see chapter 8.3 and 9).

1.3 Citation of main Literature

Chapter 1 is based on articles and reports from different companies and institutions. These should give a brief overview of algae and algae related topics, as well as problems, which are normally discussed in debates concerning algae.
The biological knowledge of algae, photosynthesis, growing of algae a.s.o. relies on biological literature because this knowledge was discovered a long time ago and is still valid. In general, the process engineering of refining algae products is based on other industries such as chemical- and oil industry. However, this process has to be adapted due to the fact that microalgae have a size of a few microns and are located in the water. Regarding the adaption of this process in this master thesis, nearly all information is from papers and interviews with ecoduna©. Furthermore, data such as the amount of input and output of feedstock, yield, facility size, capital expenditures (CAPEX), and operation expenditures (OPEX) are based on the ecoduna© algae growing and refining facility in Bruck.
The legal framework relies on applicable Austrian laws, acts and rules of action, and on industry standards. Furthermore, an overview of possible subsidies is based on information provided by various homepages.
In general, it can be stated that the master thesis combines numbers and figures from the literature with numbers and figures of the existing algae growing and

refining facility of ecoduna© in order to arrive at a conclusion and further recommendations.

1.4 Structure of Work

Chapter 1 is a general introduction which gives an overview of the following chapters, the potentials, the problems, advantages and disadvantages of algae, algae based biomass, and algae based products. The introduction should help to get a basic understanding of the advantages of algae. Moreover, chapter 1 gives an overview whereby the core objectives and core questions are going to be answered in the thesis.

Chapter 2 describes the approach and methodology of the master thesis, as well as which economic method is used for the calculation of the economic model of an algae growing and refining facility.

Chapter 3 explains the basic knowledge of algae, cultivation systems, and all needs for growing. These are the basic data for the economic model in this thesis, which will be described in more detail in chapter 8.

Chapter 4 explains that CO_2 is a feedstock for algae. Furthermore, chapter 4 illustrates the details of the consequences for a TPP, if the CO_2 is used as feedstock for algae instead of emitting the CO_2 to the atmosphere within the ETS. Additionally, chapter 4 gives an overview of the ETS.

Chapter 5 compares algae based biomass with fossil fuels and explains, if it is possible to co-fire algae based biomass together with fossil fuels in the combustion chamber of a TPP.

Chapter 6 provides a general overview of a TPP. Further, it illustrates how much area for an algae growing and refining facility would be needed, if the whole amount of CO_2 of a TPP is fed to algae.

Chapter 7 depicts examples of demonstrator projects of the combination of a TPP with an algae growing and refining facilities. Furthermore, the need of adaptions at an existing TPP for the combination with an algae growing and refining facility, as well as, how the combination of a new TPP with an algae growing and refining facility could look like, will be described.

Chapter 8 summarizes the economic information of all previous chapters and describes the economic results in combination with the sensitivity analysis. Moreover, the legal bases, as well as possible subsidies are explained.

Chapter 9 provides the conclusion of the thesis and indicates which factors do have major economic influence on the combination of a TPP with an algae growing and refining facility.

Chapter 10 illustrates briefly the major findings of the master thesis.

2 Approach and Methodology

In general, it has to be stated that there is no academic agreed method to calculate algae based products, as well as algae growing and refined production costs. In the secondary literature, a wide range of different methods to calculate production costs of algae based products (especially for algae based fuels) can be found. Further, most of the different methods assume different yields, efficiencies, cultivation systems, as well as sizes of the facilities. In this paper, the techno economic method is used for the economic model, which evaluates the production costs of growing and refining algae. Used parameters are predominantly based on the data of the ecoduna© algae growing and refining facility in Bruck. However, data of pilot projects and laboratory scale experiments of publicized articles and reports are used too. At this point, it has to be stated critically that some assumptions and data of the literature are dated back to the 1970's, due to the fact that there are only limited numbers of sources in the applied literature.

In this thesis, the techno economic model is divided into four parts, which are described in different chapters:

1. A flow chart illustrates the algae growing processes and all necessary inputs and outputs (see figure 7);
2. The condition specification specifies the process condition as temperature, pH-values, cultivation systems, a.s.o. (see chapter 3);
3. The algae based product specification defines all further process steps (see chapter 4 and 8);
4. The economic model (see figure 4, modified from Bauen, 2011) in combination with a sensitivity analysis is used to achieve economic results of this case study;

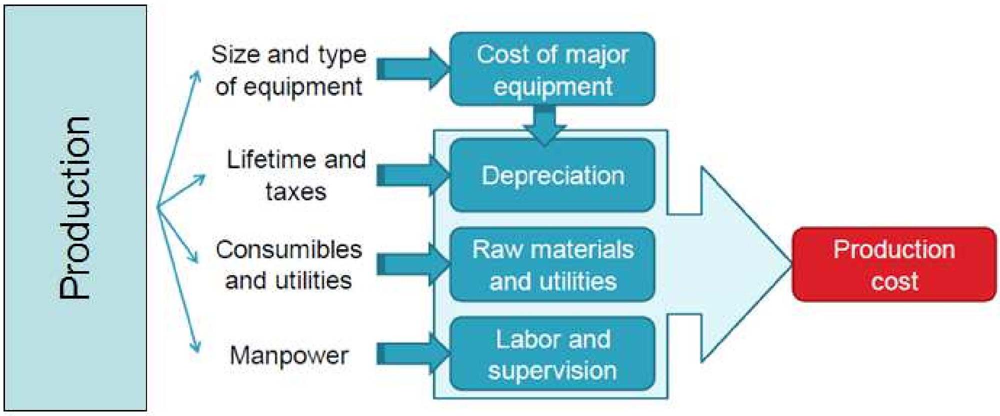


Figure 4: Cost Modeling Scheme

In general, it has to be stated that the economic result of the algae growing and refining facility is expressed by the net present value (NPV) and the internal rate of return (IRR). The IRR and NPV are defined in chapter 8. Further, two different scenarios have been calculated which are called, 'base scenario' and 'best scenario'. The difference is also explained in chapter 8. Nevertheless, all indicated numbers are based on the base scenario, only in chapter 8 and 9, the results of both scenarios will be shown.

It is important to consider that some of the used numbers in the economic model are based on assumptions and uncertainties. As a result, the sensitivity analysis will show which parts of the economic model influence the result most (see chapter 8.3 and 9). Therefore, changes of CAPEX, OPEX, the output and the revenues have been done in the sensitivity analysis. The sensitivity analysis gives an assessment of the robustness of the results, assumptions, methodological choice, and uncertainties.

The chosen size of the algae growing and refining facility is one hectare (ha). The scaling effect on the economic results to a larger size will not be examined in this thesis.

3 Algae

Barsanti and Gualtieri define algae as “a polyphyletic (i.e., including organisms that do not share a common origin, but follow multiple and independent evolutionary lines), noncohesive, and artificial assemblage of O_2-elaborating, photosynthetic organisms (with several exceptions of colorless members undoubtedly related to pigmented forms)” (Barsanti, 2005). This definition is also the basis for the master thesis. Generally, not all species of algae have been explored yet; therefore, estimations of the amount of different algae are ranging from 1,000,000 to 10,000,000. According to the secondary literature, only about 35,000 to 40,000 algae are described and just approximately 50 different algae are used for refining algae based products.

A simple classification is to categorize algae into micro-, macro- and genetically modified algae (GMA). The size of microalgae ranges from a few microns to hundreds of microns (see on the left side of figure 5) (Aurora Algae, 2007). Macroalgae are much bigger and can grow to a length of 60 meters (see on the right side of figure 5) (Prachensky, 2006). GMA possess different genes from different algae which are transferred together in the laboratory in order to maximize the output (Cheng, 2011).

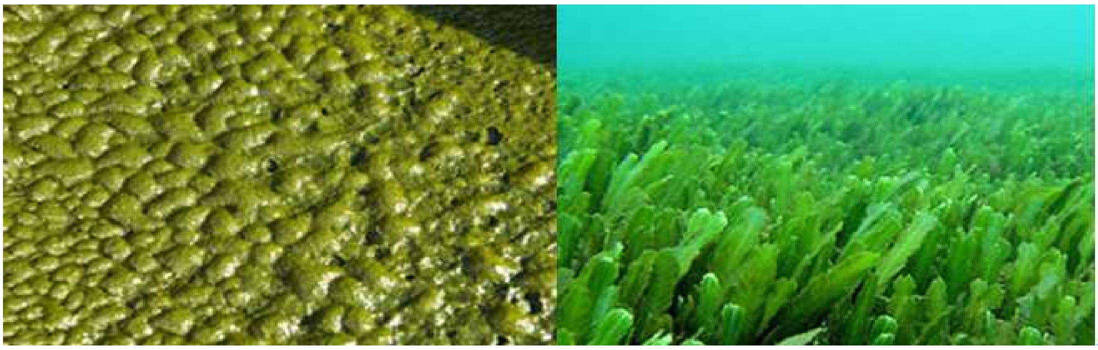


Figure 5: Micro- and Macro Algae

Another classification is to divide algae into their colour spectrum, green algae, red algae, brown algae, gold algae, yellow algae, blue algae or cyanobacteria, and diatoms (Wijffels, 2011). In general, algae are one of the oldest and most robust organisms, which are able to grow and can reproduce themselves in extreme environments and conditions from freshwater puddles to extreme salinity bodies of water (Chen, 2011).

From a chemical point of view, algae based biomass can be described by means of the molecular formula of $CO_{48}H_{183}N_{11}P_1$ (Grobbelaar, 2004). Further, each algae has its own specific oil content, which differs between 15 – 80% by dry weight. Table 2 gives an overview of oil contents of different algae (modified from Khalid, 2010).

Table 2: Oil Content of Microalgae

Microalgae	Oil content [% dry weight]
Botryococcus braunii	25 – 75
Chlorella spirella	28 – 32
Crypthecodinium cohnii	20
Dunaliella primolecta	23
Nannochloris spirella	20 – 35
Nannochloropsis spirella	31 – 68
Tetraselmis sueica	15 – 23

As a result, each algae is able to produce a different amount of lipids, hydrocarbons, and oils (Chisti, 2007). Consequently, each algae growing and refining facility should identify the best algae, depending on the needed oil content for the algae based product to maximize the output. ecoduna© states, that the algae growing and refining facility is running on the algae Chlorella, due to the fact that Chlorella is very well explored and documented, the oil content (see also figure 2) is high, the fatty acid profile is high, and the reproduction time is short. Moreover, table 3 shows the chemical content of the algae Chlorella (Oh-Hama, 1998).

Table 3: Chemical Content of Chlorella

Element	Content [% dry weight]
Carbon	51.4 – 72.6
Oxygen	11.6 – 28.5
Hydrogen	7.0 – 10.0
Nitrogen	6.2 – 7.7
Phosphor	1.0 – 2.0
Lead	0.85 – 1.62
Magnesium	0.36 – 0.80
Sulfur	0.28 – 0.39
Iron	0.04 – 0.55
Calcium	0.005 – 0.08
Zinc	0.006 – 0.005
Copper	0.001 – 0.004
Manganese	0.002 – 0.001

Currently, the most important driver of the algae industry is the oil industry. This is due to the vision that sooner or later fossil fuels have to be replaced by CO_2 neutral biofuels. However, as mentioned in chapter 1.1, at the moment, algae based biofuels are not competitive to fossil fuels from an economic point of view. Depending on the date of publication of the different literature, algae based biofuels are defined as second or third generation of biofuels. In this thesis, algae based biofuels are defined as third generation of biofuels as shown in figure 6 (modified from Singh, 2011).

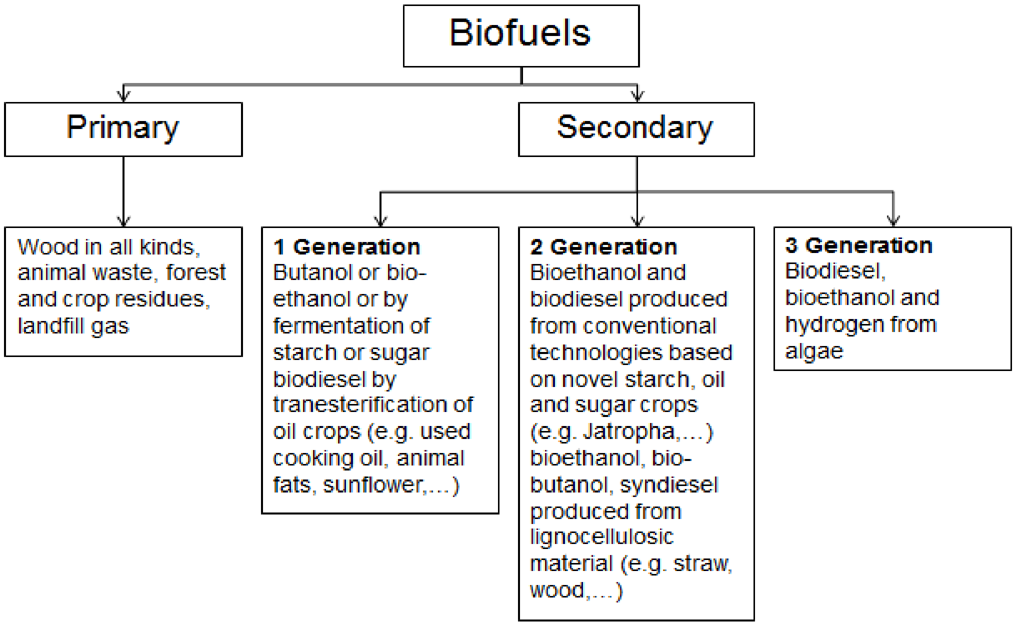


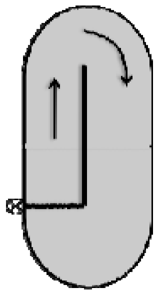
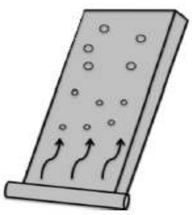
Figure 6: Classification of Biofuels

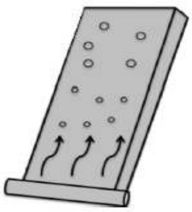
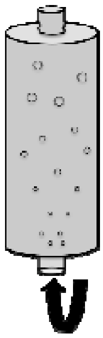
The advantages of the algae based products are, for example, CO_2 is a feedstock to algae, unsuitable land can be used for algae production, algae based biofuels degrades faster than fossil fuels in the environment and has a higher yield per area than other agricultural biomass. Further advantages are, for instance, algae based biomass producing countries are getting more and more energy independence from energy supplying countries, algae based biomass is 100% renewable, creates new high qualified jobs, and reduces the CO_2 emissions (Richardson, 2010).

3.1 Growing Process of Algae

As mentioned above, in nature, different algae grow in different ecosystems, e.g. ecosystems with extreme conditions such as volcano lakes, normal water bodies, and also weed surroundings in forests (Chen, 2011). Consequently, industry has to develop the best conditions for growing of algae in so called cultivation systems. At the moment, there is no state of the art of cultivation system, which provides the best conditions for algae to grow. Table 4 gives a short overview of the currently most discussed and used cultivation systems with their advantages and disadvantages. Nevertheless, more research and development has to be invested in the different cultivation systems in order to get a higher output and to decrease the CAPEX as well as the OPEX. As a result, algae based products become cheaper and consequently, become more competitive with regard to different markets (Dragone, 2010; Cheng, 2011; Richardson, 2012). Table 4 shows the advantages and disadvantages of various microalgae cultivation systems (modified from Dragone, 2010 and ecoduna©).

Table 4: Advantages- and Disadvantages of various Microalgae Cultivation Systems

Cultivation system	Advantages	Disadvantages
Open pond system 	Low investment costs, easy to clean up, easy maintenance, utilization of non-agricultural land, low energy inputs, most experienced system	Little control of culture conditions, poor mixing, light and CO_2 utilization, difficult to grow algae cultures for long periods, poor yield/area, limited to few algae, cultures are easily contaminated, little control of water temperature, evaporation and lighting
Tubular photobioreactor 	Large illumination surface area, suitable for outdoor cultures, good biomass productivities	Gradients of pH, dissolved O_2 and CO_2 along the tubes, fouling, some degree of wall growth, requires large land space, photo inhibition
Fixed flat panel photobioreactor 	Easy to clean up, large illumination surface area, suitable for outdoor cultures, low power consumption, good light path, readily tempered, low O_2 build-up, shortest O_2 path	Difficult scale-up, difficult temperature control, some degree of wall growth, hydrodynamic stress to some algae, low photosynthetic efficiency

Tracking flat panel photobioreactor 	Easy to clean up, large illumination surface area, suitable for outdoor cultures, always the best light path, readily tempered, low oxygen build-up, shortest oxygen path, never too much light	Difficult scale-up, some degree of wall growth, hydrodynamic stress to some algae, higher electricity demand
Column photobioreactor 	Low energy consumption, readily tempered, high mass transfer, good mixing, best exposure to light-dark cycles, easy to sterilize, reduced photo inhibition, reduced photo-oxidation, high photosynthetic efficiency, best controllable growth conditions	Small illumination surface area, sophisticated construction materials, shear stress to algae cultures, decrease of illumination surface area upon scale-up, expensive compared to open ponds, support costs, modest scalability

One major challenge of cultivation systems and the installed pumping system is to guarantee that the gas concentration in the system is stable. This means that CO_2 has to be delivered constantly and O_2 has to be conveyed out of the system constantly due to the fact that O_2, at a high concentration, is toxic to algae (Wijffels, 2011). Another very important challenge of cultivation systems and the installed pumping systems is to ensure a constant flow in the system in order that the algae will not accumulate on one place and that the nutrients will be in the optimum mixture in the designated place.

At the moment, scientists do not arrive at a clear conclusion, if algae grow best, from an economical point of view, in photobioreactor (PBR) or in open systems. In general, however, it can be stated that, on the one hand PBR compared to open pond systems have a higher yield, due to the fact that the surface area to volume ratio (see chapter 3.3) is higher. On the other hand, the investment costs for PBR are higher. Currently, PBR systems are in the phase of prototyping and demonstration. As a result, experiences of large scale system are rare or have not been published yet (Weyer, 2010). Figure 7 (Garvin, 2009) shows all necessary inputs for the algae growing process in an open pond system (left side of figure 7) and a PBR (right side of figure 7).

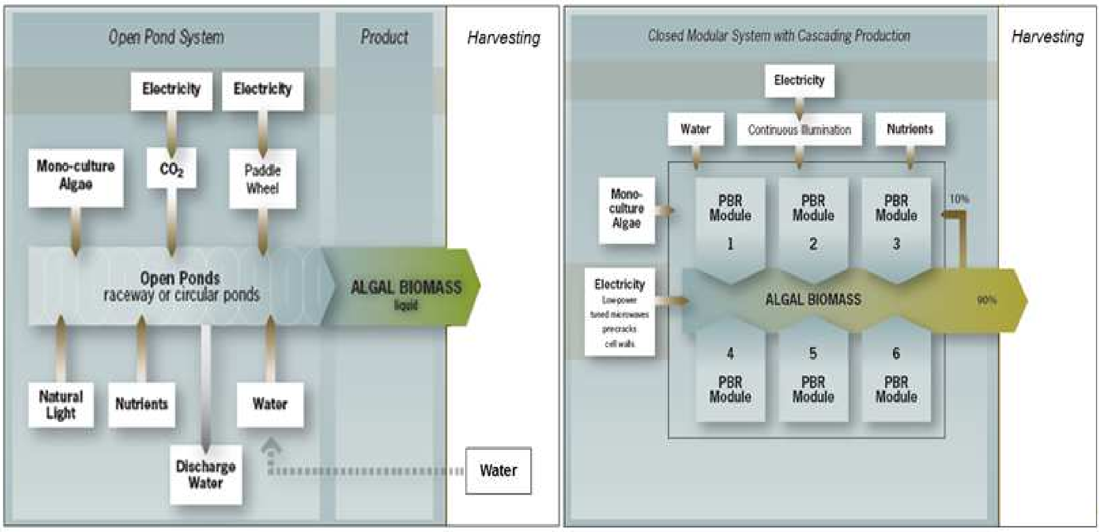


Figure 7: Algae Growing Process and needed Inputs

One of the major inputs, which influence the yield of the algae growing process the most, is water itself. In Austria, water is not a major issue due to the fact that Austria has enough water resources. Nevertheless, in Lower Austria are some laws, acts and rules of action defined, which have to be fulfilled (see chapter 8.1). The provisions concerning water usage, downstream water, water quality, ground water, and aquifer infiltration have to be obeyed. However, in other countries water usage and supply to the algae growing and refining facility could cause comprehensive regulations due to the lack of water supply for the people, as well as the use for agricultural production.

Figure 8 shows a tracking flat panel of a PBR which is located in the growing and refining facility of ecoduna© in Bruck (ecoduna©, 2012) and has been developed by ecoduna©. Furthermore, 12 panels have been built on-line, which have a ground size of 300 m². As mentioned in chapter 2, the algae growing and refining facility has a size of one ha. Consequently, the growing system of the algae growing and refining facility consists of 33 lines.

Figure 8: PBR

The relation between photosynthesis efficiency and temperature has been discovered during the first algae phase (see chapter 1). The increase, as well as the decrease of the temperature has almost the same effects on algae as the reduction of the lipid content, the reduction of the doubling rate of algae, the change of the chemical formula of algae based biomass, and the reduction of protein content of algae. The major difference of temperatures highly above the optimal temperature and strongly below the optimal temperature is, that heat can destroy the algae cell. Consequently, the temperature should be on the same level (see also table 11) (Semenko, 1969). As a result of the guarantee of constant temperature, heating and cooling, costs may occur. These costs are higher for the open pond systems than for PBR because PBR can control and regulate the temperature in its closed system easier. Nevertheless, there are different options to get rid of this problem. Firstly, if the cultivation system is in a greenhouse, the temperature should never be too low because of the greenhouse effect and it can be opened with the effect that wind can cool it down. Secondly, a heat exchanger extracts the temperature from the CO_2 separator in the TPP and heats or cools the PBR. Thirdly, different algae with different temperature resistances are given to the system. As a result, the most adapted algae will displace the others and maximize the output, as well as reduce the heating and cooling costs. Furthermore, this method reacts to the changing temperature conditions during the year. Fourthly, the core business of a TPP is to produce and sell heat.

Another important factor regarding the output is the pH-value in the cultivation system. Depending on the algae, the pH-value varies slightly; normally the pH-value should be around 7.5 to 8. If the pH-value is not within the optimal range, the algae cell growing rate decreases (Matsumoto, 1997). Generally speaking, the pH-value is controlled by the mixture of nutrients, which are fed by the pumping system to the algae. As mentioned above, the cultivation system and the installed pumping system should feed the algae with the optimal mixture of feedstock to control the pH-value and to get the maximum yield. In general, 7% of the dry weight of the algae based biomass output is not CO_2 or H_2. Consequently, the 7% have to be nutrients. Moreover, the pumping system is needed for the regulation of the pH-value with nutrients and the transport of the water and algae from the beginning to the end of the cultivation system. The pumping system is working with compressed air. Figure 9 (ecoduna©, 2012) shows the measured solar radiation in the ecoduna© algae growing and refining facility in Lower Austria in winter, on December 20, and in summer, on June 21. Further, the dashed line shows the absorbed solar radiation of a tracked PBR and the continuous line depicts the absorbed solar radiation of a fixed PBR.

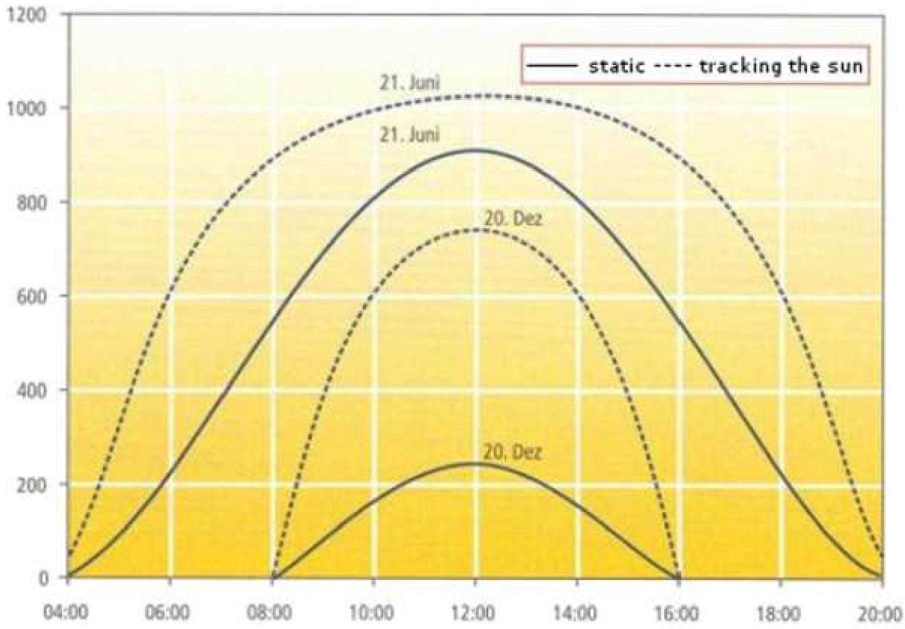


Figure 9: Solar Radiation to the Algae Growing Process of ecoduna©

As mentioned above and shown in figure 8, a tracking PBR is chosen. The CAPEX for the tracking systems are considered in the CAPEX named infrastructure. The OPEX are considered in the pumping system. Regarding less solar radiation in Lower Austria compared to the equator region, an additional artificial light system could be installed to compensate that disadvantage and raise the yield. The sensitivity analysis will show the influence of additional artificial light on the output, as well as on the economic result. Another major problem of cultivation systems is the contamination of algae. Contamination can be caused by polluted water, polluted air, a.s.o. Contamination can result in the worst case, namely in the death of algae. At best, the output only decreases a bit. Therefore, equipment regarding water treatment and water recycling is installed in the algae growing and refining facility.

3.2 Photosynthesis

The term ‘photosynthesis’ is the combination of the two Greek words ‘photo’ and ‘synthesis’. The translation of the word ‘photo’ is ‘light’, and ‘synthesis’ has the meaning of ‘putting together’ and/or ‘composition’. In general, photosynthesis is a natural process, which is used by algae, plants, and other different organisms to convert energy from the sunlight into chemical energy, which will be used for growing and reproduction.

Further, (sun)-light is electromagnetic radiation, which can be classified as broad band radiation.

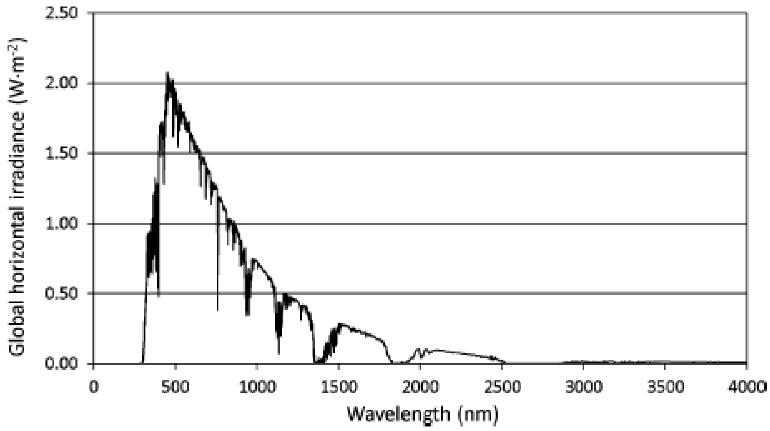


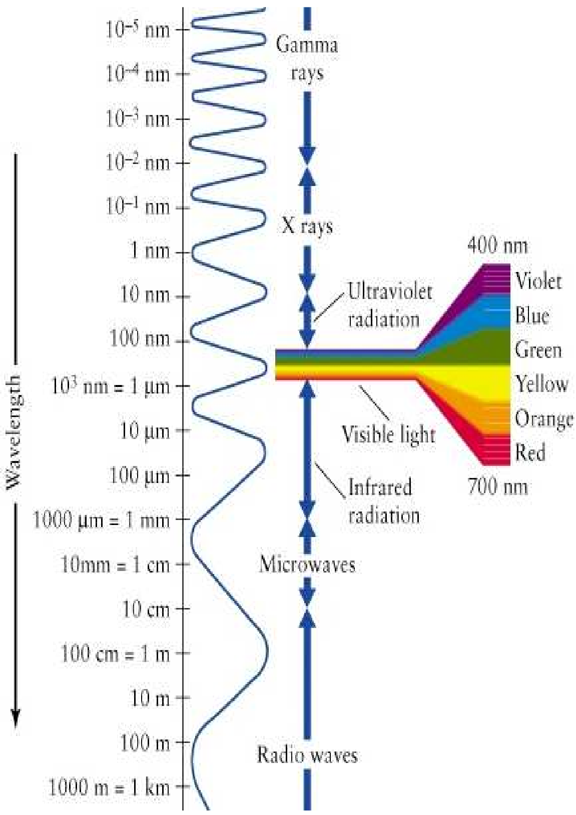
Figure 10: spectral distribution of solar irradiance

The wavelength (λ) range of natural rays is between 10^{-3} nm to 10^{12} nm. Nevertheless, nearly the whole solar radiation (appr. 99%) is concentrated within the range of 100 nm – 4,000 nm (see also figure 10). Therefore, it is defined as broadband or total solar radiation (Weyer, 2010).

The range from 100 nm – 4,000 nm is divided into three different categories:

- Ultraviolett (UV) radiation 100 – 400 nm
- Visible light 400 – 700 nm
- Infrared radiation 700 – 4,000 nm

Figure 12 (nasa, 2011) depicts the categorization of the wavelength.



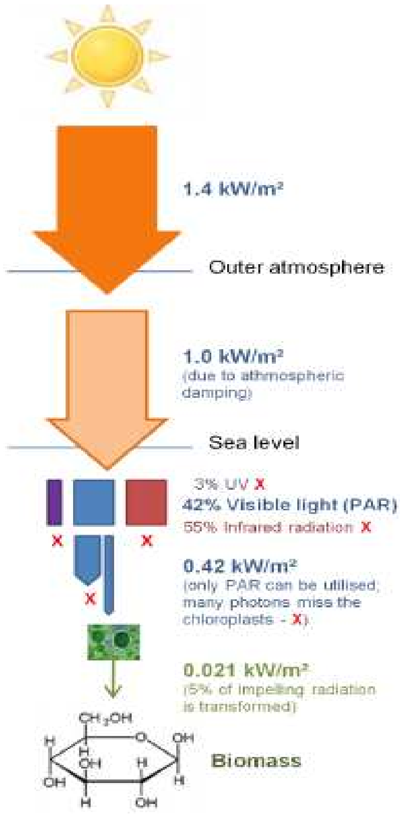


Figure 12: Wavelength Spectrum **Figure 11: Photosynthetic Efficiency**

Different wavelengths transport different amounts of energy. The shorter the wavelength is, the higher is the amount of transported energy. In general, only visible light causes photosynthetic processes due to the fact that UV radiation transports too much energy, and infrared radiation does not provide enough energy for the photosynthetic process. The visible light, which causes photosynthesis, is defined as “photo-synthetically active radiation (PAR)” with a wavelength between 400 – 700 nm.

The solar radiation in the outer atmosphere is around 1.4 kW/m², its wavelengths consist of 8% UV radiation, 41% visible light and 51% infrared radiation. After entering the atmosphere, the fraction of the sunlight decreases to around 1 kW/m² and the wavelengths transforms to 3% UV light, 42% visible light, and 55% infrared light. These numbers are not stable and can vary due to different weather conditions. Additionally, water reflects 3% to 50% of the incoming light. Moreover, depending on the depth of the algae in the water, the algae can absorb different fraction and wavelength. As mentioned above, 42% of the fraction of sunlight at sea level is visible light. As a result, the intensity of PAR at sea surface is around 0.42 kW/m² and under water the PAR is even less. Consequently, approximately 95% of the remaining energy of sunlight cannot be used for the photosynthetic process. Hence, in nature, only about 5% of the energy of sunlight or 0.021 kW/m² can be used for photosynthetic processes by algae. The photosynthetic efficiency (PE) of organisms is defined as the fraction of light that is transformed into biomass by organisms, which can also be seen in figure 11 (Mühlbacher, 2010).

In laboratory small scale experiments, PEs between 7% - 9% can be reached (Zijffers, 2010). Consequently, one major challenge of the algae industry is to increase the PE of algae growing process.

3.3 Light depending Growth over one Year

As mentioned in the previous chapter, the depth of algae in the water body plays a major role for the PE. Figure 13 (ecoduna©, 2013) illustrates on the left side the light conditions for algae in an open pond system and on the right side the light conditions for algae in a PBR.

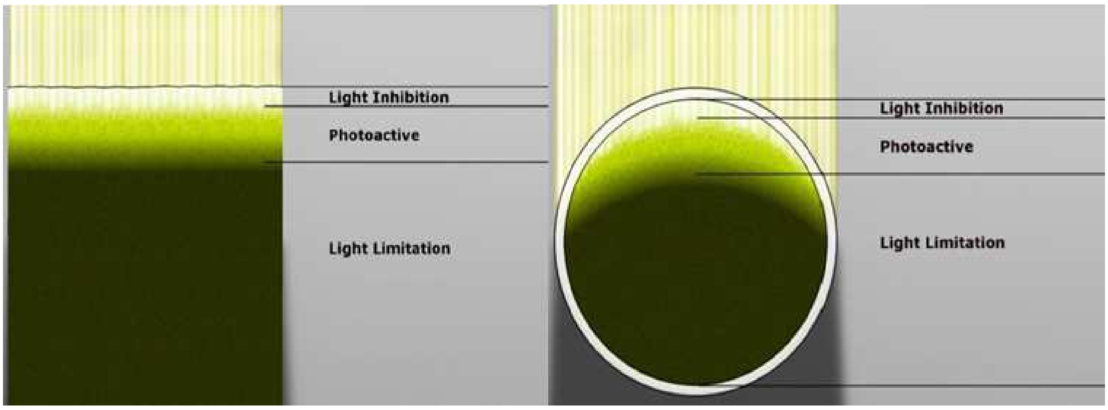


Figure 13: Light Conditions in open Pond and PBR

The layers of an open pond cultivation system, as well as the layers of a PBR have the same names. The top layer is called ‘light inhibition zone’; the next layer ‘photoactive zone’, and the rest is named ‘light limitation zone’. In the top layer (the first 2 – 3 mm), the light density is too high for algae and can cause serious damages to algae. The photoactive zone provides the best light conditions for algae and results in the highest PE in the cultivation system. Under the photoactive zone the light density is getting less and algae do not get so much light; consequently, the PE is decreasing. Open pond systems and PBR have the same zones but the light surface area is different. The light surface area of PBR is larger than that of open pond systems. Consequently, the PE of PBR is higher than that of open pond systems (ecoduna©, 2013). Table 4 illustrates the light surface area differences between open pond systems and different PBR. Further, figure 8 shows the PBR, which is developed by ecoduna© and is chosen for the business plan. Due to the fact that the PBR consists of 12 panels with a height of 6 m, the surface area duplicates compared to an open pond system. Summarized, it can be stated that the main criteria for the output of the algae growing process is the amount of light which can be absorbed by algae. That ratio is defined as surface area to volume ratio.

Figure 14 (ZAMG, 2012) shows the average solar radiation all over Austria. That data are from the Austrian Central Institution for Meteorology and Geodynamics, also called ZAMG, which belongs to the Austrian Ministry for Science and Research.

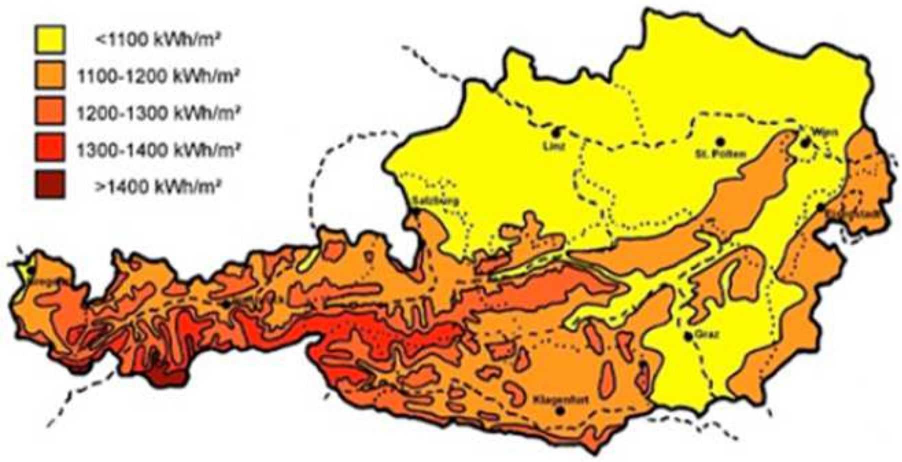


Figure 14: Average Solar Radiation in Austria

The solar radiation of Lower Austria in figure 14 is the basis for the calculation in table 5. Furthermore, the calculation shows the numbers of the PBR of ecoduna©, as well as the theoretical output of open pond systems in Austria and in Spain. The comparison of the open pond systems in Austria and Spain illustrates the importance of the solar radiation for the growth of algae.

Table 5: Calculation of Algae Biomass Growth

	Unit	Results		
Factory	-	PBR of ecoduna©	open pond Austria	open pond Spain
Solar radiation p.a.	[kWh/m²]	1,100	1,100	2,100
Solar radiation p.d.	[Wh/m²]	3,000	3,000	5,800
PE	[%]	4	4	4
Biomass generation p.d.	[Wh/m²]	120	120	232
HHV Microalgae	[MJ/kg]	23	23	23
HHV Microalgae unit conversion	[Wh/kg]	6,500	6,500	6,500
Biomass generation p.d.	[g/m²]	18	18	36
Plant availability	[%]	88	88	88
Biomass generation p.a.	[kg/m²]	6	6	11
Biomass generation p.a.	[t/ha]	500	59	114
Transformation to end product	[l/ha]	60,000	7,000	14,000
Transformation to algae by product	[l/ha]	90,000	11,000	21,000
Burnable algae biomass	[t/ha]	350	41	80

The algae based biomass output of the algae growing and refining facility is around 500 t/ha. Moreover, the algae based biomass output of an algae growing and refining facility in Austria increases up to 40% with an additional artificial light system which is around 700 t/ha.

Furthermore, the oil content of the generated dry biomass is 30%. In addition, 40% of this oil has the proper fatty acid chain lengths, which are necessary for refining the algae biomass to Omega 3. As a result, 70% of the generated biomass cannot be refined to Omega 3. Consequently, that amount can be either co-fired in combination with coal in the combustion chamber of the TPP, or another by product may be generated.

3.4 Costs/Incomes for other needed Inputs/Outputs of the growing Process of Algae

During operation hours, electricity can be delivered directly from the TPP to the algae growing and refining facility for a lower price than the market price. As a matter of fact, electricity prices are difficult to estimate. That may be due to the fact that future electricity market prices are impossible to foresee and the amount of the operation hours of the TPP cannot be either. All in all, the electricity price is set at 0.0525 € per kWh, which is also shown in table 6.

Table 6: Cost of Electricity (own data)

Costs	Unit	Value
Electricity	€/kWh_{el}	0.0525

The electricity demands per year of the different equipment can be seen in Annex I and Annex II. As explained in heading 3.1, neither heating nor cooling system is necessary. Therefore, the CAPEX and OPEX for a heating and cooling system are zero, which can be seen in table 7. Also, the CAPEX and OPEX for controlling the pH-value are zero, due to the fact that the pH-value is controlled by the supplied mixture of nutrients. The nutrients, CO_2 and water are transported to the cultivation system via the pumping system. Consequently, there are just OPEX for the nutrients supply, which are based on an average price of 5 € per needed kg. The CAPEX and OPEX of the pumping system can be seen in table 7. Further, the labor costs are divided into two positions. It is assumed that one biologist has to be hired and all the other operations can be done by stuff of the TPP. The OPEX for the TPP stuff is called pro rata labor costs. The used cultivation system is explained in chapter 3.1, the CAPEX for the cultivation system can be seen in table 7. In order to avoid expensive costs for buying algae, an own breed cultivation system is included. Consequently, just a short amount of algae has to be bought; the rest can be produced in the breed cultivation system. The CAPEX infrastructure includes the CAPEX of water treatment and recycling, CO_2 warning system, cables, piping and chemicals for cleaning the cultivation system. The OPEX of water treatment and recycling, as well as cleaning are listed in an extra line in table 7. Water treatment and recycling is necessary to reuse water from all different process steps and bring it to a certain quality. Periodical cleaning of the panels with chemicals is necessary to avoid contamination of the algae. The OPEX for spare part and the services second level support and application service guarantee a higher reliability and further improvements for the whole algae growing and refining facility.

Table 7: Cost Overview (own data)

Costs	Unit	Value
CAPEX of the heating system	€	0
Annual OPEX of the heating system	€	0
CAPEX pH-value	€	0
Annual OPEX pH-value	€	0
Annual OPEX pH-value	€	0
Annual OPEX of nutrients	€	185,000
CAPEX for the pumping equipment	€	297,000
Annual OPEX for the pumping equipment	€	191,000
CAPEX cultivation system	€	10,197,000
CAPEX breed cultivation	€	495,000
CAPEX infrastructure	€	429,000
Annual OPEX pro rata labour costs	€	50,000
Annual OPEX labour costs (Biologist)	€	70,000
Annual OPEX for water treatment and recycling	€	7,000
Annual OPEX for cleaning/chemicals	€	152,000
Annual OPEX spare parts	€	138,000
Annual OPEX second level support	€	132,000
Annual OPEX application service	€	66,000

Figure 15 (wallstreet online, 2013) shows the world market price of coal in USD per ton for a defined period of time.

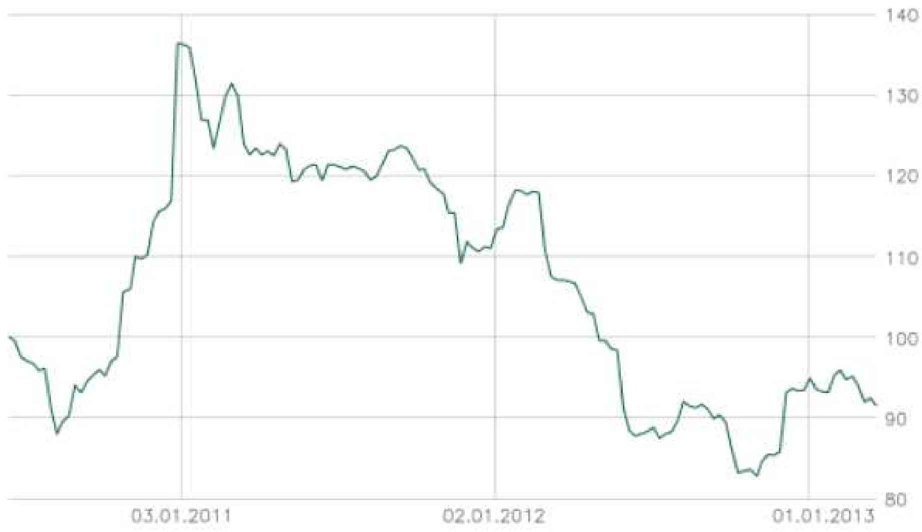


Figure 15: Coal Price

This price is used in the economic model as algae based biomass savings for coal, which can be seen in table 8.

Table 8: Savings of Coal (own data)

Savings	Unit	Value
Savings of coal	€/t	73.08

4 Use of CO_2 for Algae Growth

Figure 2 (see chapter 1) depicts the natural CO_2 absorption on earth. Furthermore, it illustrates that the oceans and, in particular algae, have a deep impact on the natural CO_2 absorption on earth. The CO_2 absorption by algae takes place in combination with the photosynthesis of algae. A simplified explanation for that process is that the algae cell generates food out of nonorganic substances (water, CO_2 and nutrients) by using light. Further, the molecular formula of algae (see chapter 3) shows that other substances, such as phosphor and nitrogen are also needed for the algae growing process. Consequently, algae can alternatively be used as waste water treatment; especially for the agricultural industry. Agricultural waste water is rich of phosphor, as well as nutrient, and can cause eutrophication of water in the worst case. For example, the Mississippi river at the Mississippi Delta is polluted by agricultural waste water and causes eutrophication in that region. Although this is an interesting topic, it is not taken into consideration in my thesis.

Furthermore, the growing process emits O_2 into the surroundings, which can be toxic to algae in a too high concentration. Therefore, the cultivation system has to guarantee that enough CO_2 will be provided to the algae, as well as that O_2 will convey out of the system (Wijffels, 2011).

One major factor regarding CO_2 can influence the CAPEX and OPEX significantly. Depending on the algae based product, the purity of CO_2 has to be different. Due to industrial standards which are explained in chapter 8.1, CO_2 for algae based products for the pharmacy-, food- , cosmetic-, medical- and feed industry has to be purer than for the biofuel industry. Consequently, CO_2 of a TPP can be used directly for the growing process of algae if any kind of biofuels is the algae based product. With respect to algae based biofuels, all other products have to use $CO_{2,}$ which was brought to the claimed industry standard. As a result, an additional process step has to be added to the CO_2 process cycle. EnBW (EnBW, 2011) and RWE (RWE, 2009) are large utilities in Germany. They have included a CO_2 separation process step to the CO_2 process cycle of TPP. Furthermore, in Austria a small separation plant (SEPPL) for CO_2 has been added to the CO_2 process cycle of a TPP (eco, 2011). All in all, this leads to further CAPEX and OPEX which can be seen in table 9. The CAPEX are from SEPPL of EnBW, the OPEX are assumed from the electricity demand of the EnBW SEPPL, as well as additional 10 € for each ton of CO_2.

Table 9: Costs of SEPPL (own data)

Costs	Unit	Value
CAPEX of SEPPL	€	2,000,000
Annual OPEX of SEPPL	€	13,000

4.1 CO_2 Absorption of Algae

From a theoretical point of view, 1 kg dry algae based biomass requires 1.83 to 2 kg CO_2. The value of 1.83 kg results from the carbon value of the chemical molecular formula of $CO_{48}H_{183}N_{11}P_1$. Nevertheless, the aquaFUELS report (Bauen, 2011) states that the theoretical value does not exactly fit the real value. Table 10 (modified form Dragone, 2010) illustrates the CO_2 fixation efficiency of different cultivation systems. The conversion factor of 1.83 is used in the economic model.

Table 10: CO_2 Fixation Efficiency of some Cultivation Systems

Cultivation system	CO_2 fixation efficiency
Open pond system	10%
Thin layer cultivation system	35%
PBR	50%
PBR with advanced control systems	90%

Furthermore, the CO_2 fixation depends on the algae strain. Table 11 (Chinnasamy, 2009) shows the growth rate of the algae Chlorella depending on the temperature and the amount of CO_2.

Table 11: Growth Rate of the Algae Chlorella

CO_2 fixation [%]	Temperature [°C]	Growing rate [%, after 10 days]
Air (3.6)	30	880
	40	360
	50	0
6	30	1,850
	40	870
	50	380

All in all, the CO_2 concentration in the cultivation system has to vary, due to the fact that CO_2 is a feedstock to algae, and in general, the pH-value is regulated by the feedstock mixture in the cultivation system.

Table 19 (see chapter 6.1) depicts the area which would be needed for an algae growing and refining facility to use the whole amount of emitted CO_2 from a large sized TPP.

4.2 Cost Effect on the ETS Allowances

In 2005, the EU launched the ETS with the aim of reducing CO_2 emissions in the most cost effective way by putting a limit on the overall emissions. The ETS is based on the EU directive 2003/87/EG, which had to be implemented by the member states. The ETS is designed in three different phases, first-, second - and third trading period. The first trading period was launched in 2005 and ended in 2007. This trading period was introduced as a three year “learning by doing” period to prepare the member states, as well as the involved companies for the second - and third trading period. The ETS was legally obligated for the power generator industry, as well as energy intensive industries. The ETS trading units are called ‘emission allowances (allowances)’. In general, such allowances provide a company for the right to emit one ton of CO_2, from the second trading period onwards also an equivalent amount of nitrous oxide (N_2O), and from the third trading period onwards also an equivalent amount of perfluorocarbon (PFC). PFC emissions are caused by the aluminum producing industry. Three more greenhouse gases named ‘methane’ (CH_4), ‘fluorocarbon’ (FC) and ‘sulfur hexafluoride’ (SF_6) could be traded on the ETS but this was not obligatory for the member states. Further, free allowances were granted to the concerned companies for free based on national allocation plans made by the national governments. Penalties for each emitted ton CO_2, which was not covered by allowances were set at 40 €/t CO_2. On the one hand, phase one succeeded in terms of price fixing for CO_2, free trade across the EU and established the infrastructure for monitoring, reporting and verifying emissions. On the other hand, phase one did not have any reliable emission data as the allowances were based on mere estimates from the national governments. As a result, too many allowances regarding the demand were on the market and the price for allowances fell to zero. To date, anyone with an account in the EU registry is able to trade allowances and it does not matter if the registered company is covered by the ETS or not. The second trading phase was launched in 2008 and ended in 2012. Furthermore, the second trading period of the ETS was extended to three non EU member states (Iceland, Norway and Liechtenstein), and N_2O emissions had also to be traded on the ETS. The amounts of free allowances for companies were cut by 6.5%. One major change of the ETS was that companies got the possibility to invest in either Clean Development Mechanism (CDM) or Joint Implementation (JI) credits instead of buying allowances. JI means that if a company makes CO_2 reducing actions in a declared Annex B state of the Kyoto Protocol, these savings can be converted into allowances in another declared so called Annex B state, which are defined in the Kyoto Protocol. Another possibility is to invest in environmental projects carried out in development countries instead of buying allowances; this is the so called CDM. Furthermore, the aviation sector of the EU was integrated into the ETS in 2012. This was based on the EU directive 2008/101/EG, Nevertheless, the second trading period ended with too much allowances regarding the demand on the ETS. Further, the economic crisis led to less consumption, which resulted in less production and consequently less CO_2 emissions. As a result, the price for traded allowances fell down to around 4 to 6 € per ton CO_2 or an equivalent amount of the other greenhouse gases.

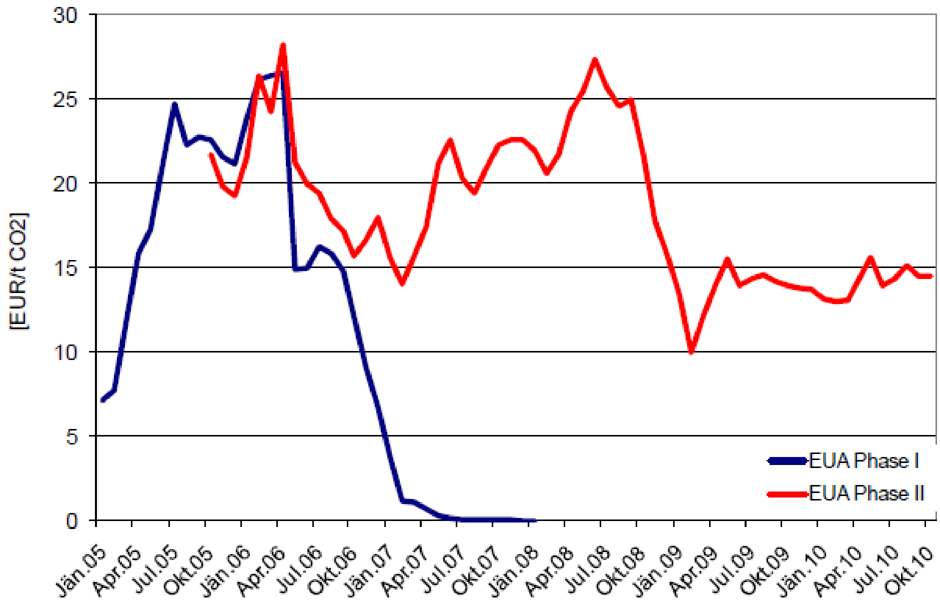


Figure 16: Price of Allowances on the ETS

Figure 16 (Redl, 2012) shows, as mentioned above, the drop down of the allowances prices in the first trading period.

Figure 17 (EU, 2013) illustrates the daily trading volume of allowances in the second trading period. Total exchange depicts the daily traded allowances on the different trading opportunities and OTC points out the over the counter trading allowances.

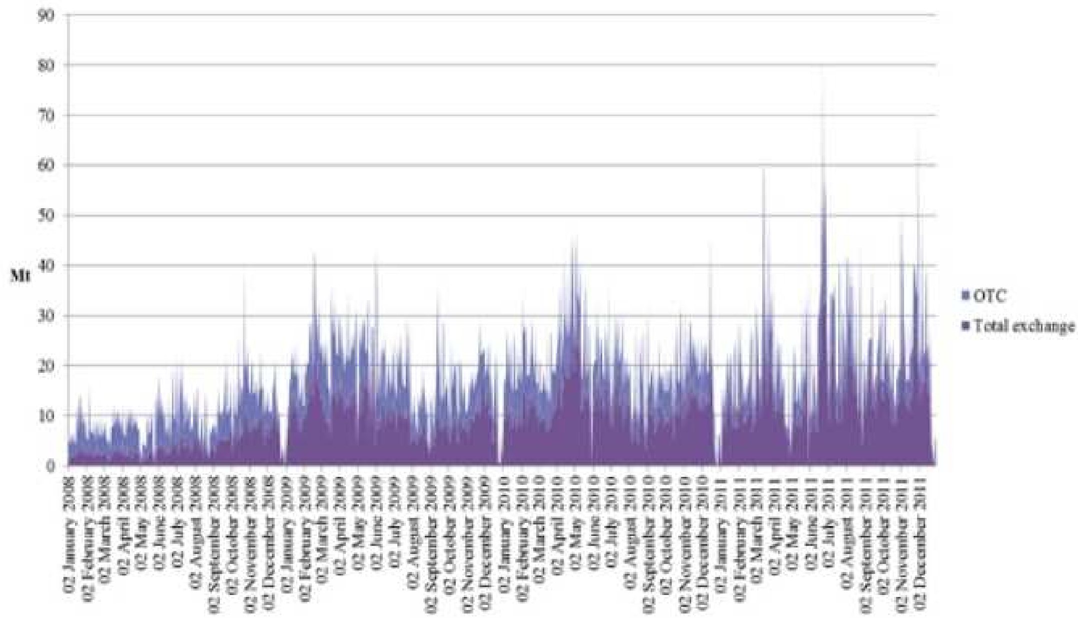


Figure 17: Daily ETS Trading Volume

The third trading phase was launched in 2013 and will end in 2020. The regulatory basement is also based on the EU directive 2003/87/EG with extension of the EU directive 2009/29/EG. The major changes were that the EU hosted auctions for allowances instead of allocation of allowances by the member states. Moreover, PFC has to be traded on the ETS. Furthermore, a benchmark system of the EU was introduced, which indicates how many allowances are needed by the industry instead of national allocation plans made by the national governments. Allowances are valid as long as they are not traded instead of a validity of one year. Another major change of the third trading period compared to the second trading period is that an EU wide emission cap is set and this cap will be reduced by 1.74% per year. The penalty for too less allowances is set at 100 €/t CO_2 and will be raised by an amount of the annual inflation. In general, the electricity producing industry does not get free allowances anymore.

The EU parliament has the right to backload a certain amount of allowances by a majority of a vote for one year. Nevertheless, the price for traded allowances is nearly the same as in the second trading period. All in all, it can be stated that there are still too many allowances regarding the demand on the ETS. After the phase out of the third trading period, currently no further plans are in place regarding the development of the ETS.

Table 12 summarizes the changes between the three trading periods of the ETS (EU, 2013).

Table 12: Differences of the ETS Trading Periods

Trading period	First period	Second period	Third period
Traded emissions	CO_2	CO_2 and N_2O	CO_2, N_2O and PFC
Involved states	EU member states	EU member states, Iceland, Norway and Liechtenstein	EU member states, Iceland, Norway, Croatia and Liechtenstein
Trading possibilities	Allowances	Allowances, CDM and JI	Allowances, CDM and JI
Total amount of emissions which are traded on the ETS	20%	30%	45%
Allocation of allowances	National plan	National plan but 6.5% less than in the first trading period	Annual auction with a cap; the cap will be annually reduced by 1.74%
Penalties	40 €/t CO_2	100 €/t CO_2	100 €/t CO_2 plus the additional annual inflation

Due to the fact that the price of allowances is currently at around 3 €/t CO_2, this number has also be used in the economic analysis (see chapter 8). Furthermore, the effect of any increase of the allowances prices on the NPV and the IRR can be seen in the sensitivity analysis (see chapter 8 and 9).

Table 13: Cost of Allowances (own data)

Costs	Unit	Value
Allowances	€/t	3

5 Algae Based Products

In chapter 3.1, the growing process of algae is explained; especially figure 7 gives an overview of the growing process of algae with all necessary feedstock and outputs. After the growing process, the harvesting process starts, which is a very important process due to the fact that it is the starting point of refining the algae based biomass. Figure 18 (modified from Cheng, 2011) is a flow chart, which illustrates the production process from the breed algae cell culture to an end product.

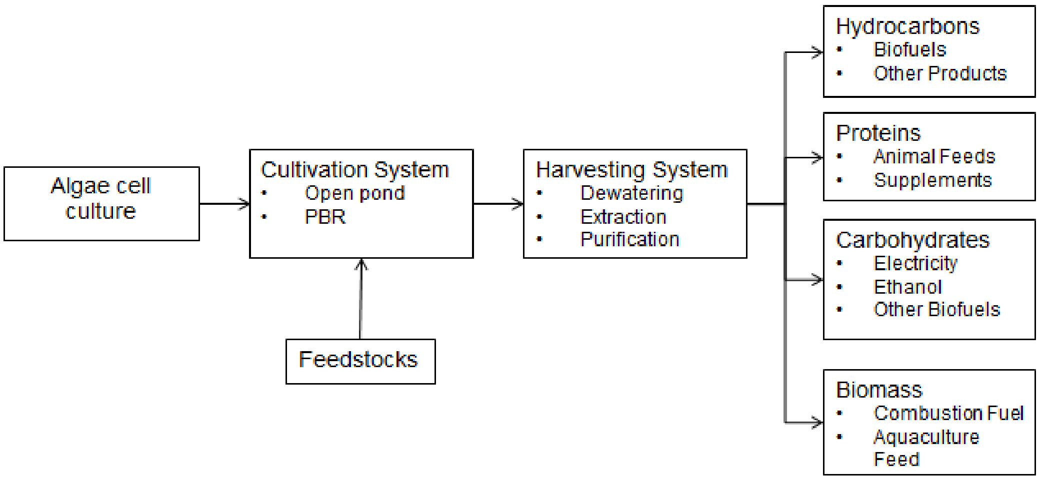


Figure 18: Production Flow Chart of Algae Based Products

5.1 Process Costs of the Harvesting and the Refining Process

Many companies develop and deliver different types of harvesting equipment. The main challenge for the harvesting equipment is to recover a small amount of algae out of a large amount of water with low electricity costs. Due to the fact that the algae concentration in the water body in PBR is higher than in open pond systems, the harvesting costs of PBR are lower in comparison to open pond systems (Chisti, 2007). In general, it can be stated that currently no state of the art harvesting technology has been established on the market yet.

All in all, the developed harvesting equipment and the refining equipment from ecoduna© are chosen in the economic model of this master thesis. This harvesting equipment is based on filtration with capillary action. The refining equipment is currently in the final development phase. Therefore, no further information can be stated (or "given") in the master thesis because of confidentiality. Table 14 shows the CAPEX and OPEX of that harvesting equipment and the refining equipment.

Table 14: Costs of Harvesting (own data)

Costs	Unit	Value
CAPEX of the harvesting equipment	€	1,485,000
Annual OPEX of the harvesting equipment	€	29,000
CAPEX of the refining equipment	€	5,610,000
Annual OPEX of the refining equipment	€	79,000

5.2 Market Analysis of different Algae Based Products

Table 15 (oilgae.com, 2012) shows the global market sizes of some algae based products. The table does, for example, not include the world market of different fossil fuels. Nevertheless, table 15 gives an idea how enormous the potential of algae based products is, and how many different markets for algae based products exist. Omega 3 belongs to eicosa pentaenoic acid (EPA) and docosa hexaenic acid (DHA), which had a market volume of around 25,400 million USD in 2011; and the market size is still growing. In general, algae are more common as food, dietary supplements, as well as feed source for fish farms in Asia. Further, algae based oils are common in cosmetic products but this is not well known in Europe. Consequently, the level of awareness and acceptance is in Asia higher than in Europe. For example, in China there was an algae plague in the South China Sea in the summer of 2013. Due to the acceptance, people on site took a bath in it, this would never happen in Europe.

Table 15: Market Value of Algae Products

Algae product	Market value [million USD]	year
EPA and DHA	**25,400**	**2011**
- EPA and DHA	10,200	
- Fortified food and beverage	7,900	
- Dietary supplement	3,200	
- Pharmaceutical	1,900	
- Clinical nutrition	1,350	

- Pet food, treats and supplements	700	
Natural astaxanthin	**330**	**2012**
- Animal feed colouring agents	300	
- Antioxidant nutraceutical	30	
Carotene	**766**	**2007**
Lutein	**233**	**2010**
Polymers from macroalgae	**2,100**	**2003**
- Carrageenan	240	
- Alginate	213	
- Agar	137	
- Extracts	10	
- Nori (food) only in Japan	1,500	
Σ (sum)	**28,829**	

Regarding algae based biofuels, in Europe appr. 400 billion litres of oil are yearly consumed for transport. If algae based biofuels should replace the needed fossil fuel for transport and assuming a yield of 40,000 litres of oil/ha/year, around 10 million ha for algae growing and refining facilities would be needed. This area is comparable with the size of Iceland (Wijffels, 2011).

5.3 Calorific Value of Algae Based Products

The European Biomass Industry Association (EUBIA, 2012) defines the higher heating value (HHV) and the lower heating value (LHV) as 'calorific value'. The difference between these values is, on the one hand the water in the material and, on the other hand the moisture in the material, which has an impact on the heat of the evaporation of the material. Furthermore, the chemical composition of the reviewed material has an impact on the difference between the HHV and LHV. In general, the HHV indicates the maximum energy which occurs at complete oxidation. Consequently, the HHV is higher as the LHV (see also table 16 and 17). Table 16 (ECN, 2012) indicates the different HHV and LHV of some microalgae, algae based products and algae based by products.

Table 16: Calorific Values of Algae and Algae Based Products

Product	LHV [MJ/kg]	HHV [MJ/kg]
Algae, Chlorella	23.52	25.09
Chlorella residue after ethanol extraction	22.36	23.84
Chlorella residue after hot water extraction	23.49	24.97

Algae, Monodus	22.67	24.31
Algae, Monodus Lipids extraction	22.36	23.84
Algae, Monodus residue after extraction	16.35	17.57
Algae, Monodus subterraneous	24.90	26.36
Algae, Synechoccus	20.20	21.69
Algae, Synechoccus residue after PC extraction	22.42	23.92
Algae, Spirulina	18.32	19.82

Furthermore, table 16 illustrates that the difference between LHV, as well as HHV of different algae can be more than 5.2 MJ/kg. From a technical point of view, a difference of 5.2 MJ/kg is quite a lot and can harm the combustion chamber of a TPP. Further, it can be stated that the higher the calorific value is the higher is the efficiency of a TPP and, consequently, the higher is the electricity output.

5.4 Comparison of the Calorific Values of Algae Based Products with Fossil Fuels and Biomass

Table 17 (ECN, 2012) shows the HHV and LHV from fossil fuels and different sources of biomass.

Table 17: Calorific Value of Fossil Fuels and Biomass

Product	LHV [MJ/kg]	HHV [MJ/kg]
Methane 100%	50.19	55.65
Motor gasoline	43.74	46.88
Kerosene	43.42	46.50
Diesel oil	42.82	45.70
Groningen, natural Gas	38.05	42.13
Charcoal	33.86	34.20
Coal, Polish bituminous coal	29.20	30.23
Coal, lignite	23.64	24.63
Algae, Chlorella	**23.52**	**25.09**
Peat	20.00	21.22
Energy Willow	18.42	19.75
Beech	17.58	18.80
Wheat	17.04	18.15
Straw	16.51	17.69

For a better comparison, the algae Chlorella and its LHV, as well as HHV is indicated in table 17. It can be seen that the LHV and the HHV of the algae Chlorella and of lignite are nearly the same.

The most critical issue of co-firing coal and biomass is corrosion for the equipment of a TPP. Furthermore, the sulfur to chlorine ratio of biomass is an indicator for corrosion. The smaller the ratio is the higher is the risk of corrosion for the equipment of a TPP. Due to the fact that the chosen algae do not have any chemical elements of chlorine (see also table 3), corrosion for the equipment of a TPP should not be a problem (Mäkelä, 2000).

The National Renewable Energy Laboratory stated in a technical report (Kadam, 2001) that co-firing algae based biomass and coal in a TPP are possible and do not harm the technical equipment of the TPP. Furthermore, it is stated that an algae based biomass and coal co-fired TPP compared to a coal fired TPP has:

- less sulfur oxide (SO_X) and nitric oxide (NO_X) emissions;
- less particulates;
- less CO_2 emissions;
- less methane;
- less fossil energy consumption;
- the same CO and hydrocarbon (except methane) emissions;
- higher waterborne emissions;

6 Basic Information of a Thermal Power Plant

Table 18 (Wiki, 2013) gives an overview of medium and large sized TPPs of Austria (the capacity of the listed TPPs is higher than 55 MW_{el}), which run on fossil fuels. In general, there are more large sized TPPs in Austria, which are not listed in table 18. These grid stabilization TPPs are not continuously running and are called reserve for unforeseeable events. For example, an unforeseeable event was the cold winter 2012/2013 in Germany. Due to the fact that there was a lack of electricity in Germany, these TPPs started the production and delivered electricity to Germany.

Table 18: Overview of large Austrian TPP

Name	electrical capacity [MW_{el}]	thermal capacity [MW_{th}]	fuel	start up	state
Mellach	832	-	Gas	2012	Styria
Kraftwerk Theiß	775	-	Gas, oil	1974	Lower Austria
Kraftwerk Simmering 1	700	450	Gas	2009	Vienna
Kraftwerk Simmering 2	60	150	Gas	2009	Vienna
Kraftwerk Simmering 3	365	350	Gas, oil	1992	Vienna
Kraftwerk Dürnrohr Block 1	405	-	Coal, gas	1986	Lower Austria
Dampfkraftwerk Donaustadt	347	250	Gas	2001	Vienna
Kraftwerk Dürnrohr Block 2	370	-	Black coal, gas; Municipal waste, biomass	1986	Lower Austria
Mellach	246	-	Black coal	1986	Styria
Riedersbach 2	176	-	Coal	1986	Upper Austria
Neudorf-Werndorf 2	164	-	Gas, oil	1976	Styria
Leopoldau	142	170	Gas	1975	Vienna
Korneuburg	154	-	Gas	-	Lower Austria
Timelkam 3	120	-	Gas	1974	Upper Austria
Fernheizkraftwerk Linz-Mitte	217	171	Gas, oil	1970	Upper Austria
Timelkam 2	66	-	Coal	1962	Upper

					Austria
Riedersbach 1	55	-	Coal	1969	Upper Austria
Linz Süd	171	150	Gas, oil	1993	Upper Austria

As a result, it can be stated that in Austria are a lot of TPP installed, which are potential objects for the combination with an algae growing and refining facility.

6.1 Schematic of a Thermal Power Plant

Figure 19 (bergbau und energie, 2002) shows the schematic of a coal fired TPP from coal dust to electricity. The schematic will not be explained in detail. Further, figure 21 shows at which point CO_2 will be conveyed out of the TPP to use it as feedstock for the algae growing process.

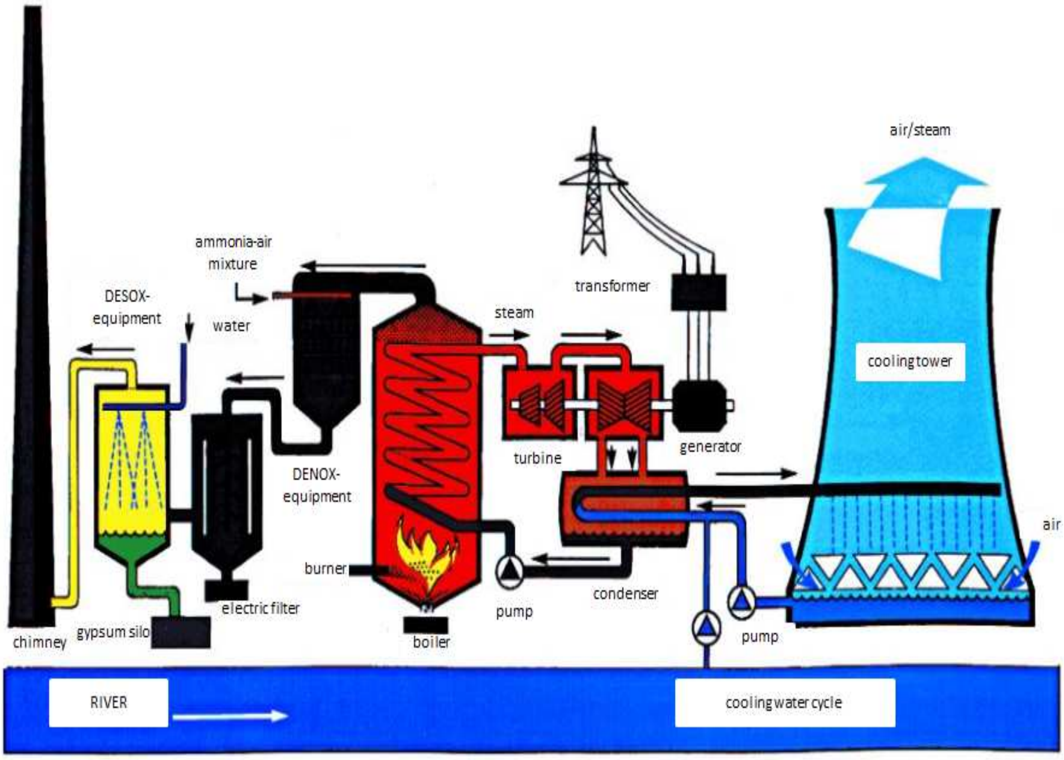


Figure 19: Schematic of a Coal Fired TPP

A 400 MW block of a TPP, which runs on coal, emits between 1,500,000 to 2,500,000 t of CO_2 per year (see also table 20). The exact amount of emitted CO_2 is depending on the operating hours of the TPP per year.

Table 19 shows the needed area of an algae growing and refining facility which would be necessary for the full absorption of the emitted CO_2 from a large sized TPP in Lower Austria (the data of the TPP are given in table 20).

Table 19: Required Area for full Absorption of a TPP (own data)

Subject	Unit	Value
Annual algae based biomass yield	t/ha	500
Annual CO_2 absorption	t/ha	900
Annual TPP CO_2 emissions	t	2,482,000
Needed area for full CO_2 absorption	ha	2,760

It can be seen that an area of 2,760 ha would be needed for an algae growing and refining facility to use the whole amount of the emitted CO_2 of the TPP Dürnrohr in Lower Austria in 2010. As a result, it can be stated that an algae growing and refining facility can use only one part of the whole amount of emitted CO_2 of a large TPP.

6.2 Amount and Concentration of emitted CO_2 and the other Exhaust Emissions

Table 20 (EVN and Verbund, 2011) illustrates the operating numbers of the Verbund block of the TPP in Dürnrohr, which are publicized in the Umwelterklärung 2010.

Table 20: Operating Figures of a TPP

Operating figures of TPP Dürnrohr in 2010		
Subject	**Unit**	**Value**
Energy production		
Gross production el.	MWh	3,305,232
Heating	MWh	194,064
Internal consumption el.	MWh	196,678 (appr. 6%)
Energy input		
Gas	Nm³/MWh	3
Coal	kg/MWh	280
Amount of fossil fuel		
Coal	t	980,289
Gas	Nm³	9,921,990
Emissions		
CO_2	kg/MWh	750.79
	t	2,481,536
CO	g/MWh	17.17
	t	57
NO_X	g/MWh	413.55

	t	1,367
SO_2	g/MWh	150.76
	t	498
Dust	g/MWh	46.79
	t	155
Average NO_X concentration (limit value*)	mg/Nm³	140.1 (200)
Average SO_2 concentration (limit value*)	mg/Nm³	48.9 (200)
Average dust concentration (limit value*)	mg/Nm³	15.5 (50)
Average NH_3 concentration (limit value*)	mg/Nm³	0.2 (3.8)
Average CO concentration (limit value*)	mg/Nm³	6.1 (250)

*Limit value by firing with coal based on 6 Volume -% oxygen

Due to the fact that Omega 3 is the produced algae based product of the algae growing and refining facility, the good laboratory practice (GLP) and good manufacturing practice (GMP) regulation have to be followed. Consequently, the flue gas of the TPP has to be cleaned before it will be supplied to the algae growing and refining facility. Therefore, the concentration of the TPP does not harm the algae.

7 Algae based Fuels and Biomass in Thermal Power Plants

As mentioned in chapter 1, algae based biofuels are not competitive to fossil fuels. Nevertheless, a lot of companies across the world are working on algae based biofuels in order to make them competitive to fossil fuels.
Furthermore, as indicated in chapter 5.4, the remaining dried algae based biomass from each process step can be seen as biomass. Further, biomass can be co-fired with coal in the combustion chamber of the TPP. That issue was also confirmed by the experts of ecoduna©.
An additional question need to be answered, if the separated algae based biomass can be further refined to other products. Consequently, it has to be decided if the installed equipment can be used or new equipment has to be purchased. Which impact does that topic have on the economic result of an algae growing and refining facility? All in all, that additional issue is not part of the master thesis and therefore it is not discussed.

7.1 Case study for an adaption of an existing thermal power plant

In Germany, nearly all large utilities have installed pilot projects for the adaption of a thermal power plant with an algae growing and refining facility, e.g. Vattenfall in Senftenberg (Germany), RWE in Bergheim (Germany), and EnBW-Heizkraftwerk in Stuttgart Gaisburg (Germany). Starting point of most pilot projects of the combination of a TPP and an algae growing and refining facility was the fixation of CO_2. In the end the ETS did not work (see chapter 4.2), therefore the focus of the pilot projects has slightly changed and is now on the economic production of biofuels.
Table 18 gives an overview of large sized TPP in Austria. For the adaption of an existing TPP with an algae growing and refining facility, a TPP, which is not in a city located, is preferred since TPP normally owns more land than is needed for the operating. As a result, the land costs can be neglected. Figure 20 shows the TPP Dürnrohr in Lower Austria. An area of 120 ha belongs to the TPP. This area can be

divided into three different parts; the first part is used for the TPP itself, the second part is unused area, and the third part is leased area by farmers. In figure 20 is a blue indicated area which has a sized of appr. 8 ha and is unused land. Parts of this area could be used for an algae growing and refining facility. The advantage of this area is that there are neither land- nor rental costs (see also table 21).

Table 21: Land Costs (own data)

Costs	Unit	Value
CAPEX land	€	0
OPEX land	€	0

Figure 20: TPP Dürnrohr by Google earth

Figure 21 (RWE, 2008) shows a simplified CO_2 flow chart of the algae growing and refining facility pilot project of RWE, which was in operation from 2008 to 2011. After that period this algae growing and refining facility was given up and dismantled.

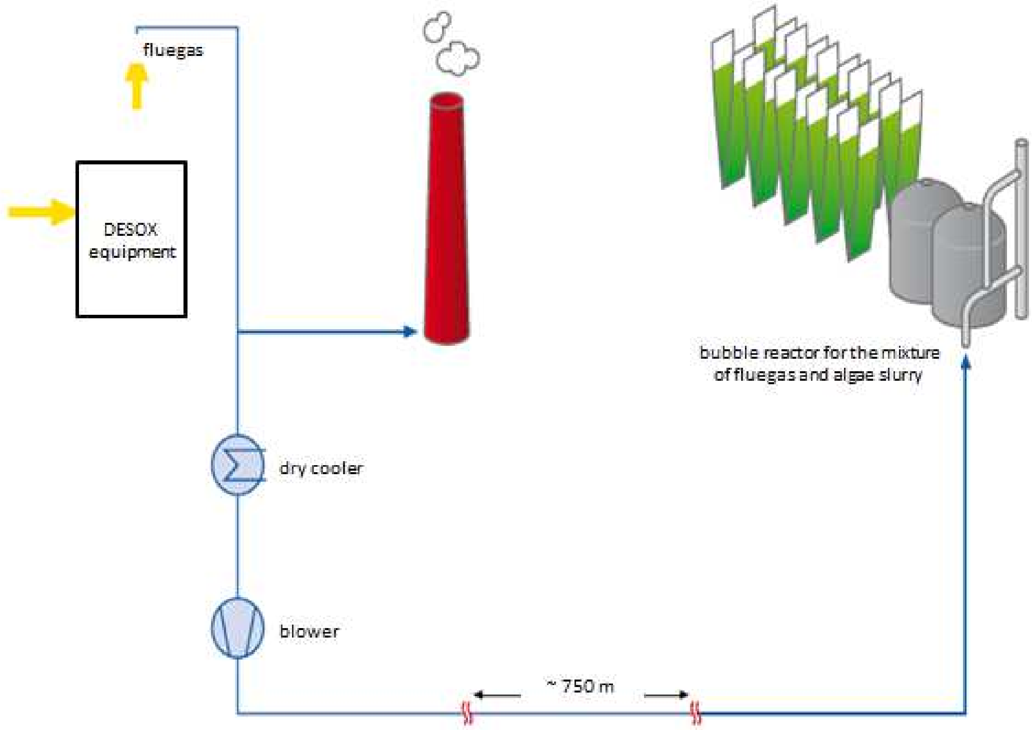


Figure 21: RWE Algae Pilot Project

7.2 Case Study for a new Thermal Power Plant

In 2008, EOn Hanse in Hamburg started a pilot project for the production of algae based biogas. Therefore, a small block heat and power station (it is located in the container in the back of the left picture) was installed only for this pilot project. Furthermore, two different algae cultivation systems made by two different companies were installed for further research and development. Figure 22 (Subitec, 2008) shows on the left side the tracking flat panel PBR made by SSC, and on the right side the flat panel PBR made by Subitec.

Figure 22: EOn Hanse Algae Facility

From an economic point of view, the main differences between a new installed TPP in combination with an algae growing and refining facility and an existing TPP in conjunction with a new added algae growing and refining facility are the adaption costs and, if necessary, the pipeline costs (see also chapter 3). These costs are slightly lower for a newly installed TPP since they can be considered in the designing and planning phase of the TPP.

After researching new projects of installing a new TPP in combination with an algae growing and refining facility, no projects could be found. From the author's point of view, the following factors are crucial for this situation:

- The prices for CO_2 certificates are too low;
- The third phase of the ETS does not take place within the planned scope;
- The electricity price is very low and, therefore, electricity producing companies are not willing to invest in new technologies;
- The algae technology is not fully developed yet;
- The prices for fossil fuels are too low;
- For small TPPs the investment costs for an algae growing and refining facility are too high;
- The full amount of CO_2 of large or medium sized TPP cannot be used by an algae growing and refining facility.

7.3 Process of the Combination of a Thermal Power Plant and an Algae growing and refining Facility

With respect to the GLP and GMP regulation (see also chapter 8.2), the direct use of emitted CO_2 from a TPP is not allowed for the production of algae based products for the pharmaceutical industry, food and feed industry, a.s.o. As a result, a SEPPL has to be added to an existing TPP as well as to a newly installed TPP. Consequently, from a process cycle point of view, it does not matter if an existing TPP will be adapted with an algae growing and refining facility. Or a newly constructed TPP will be combined with an algae growing and refining facility, due to the fact that a SEPPL has to be installed to the TPP anyway (see also figure 23). The only differences regarding costs are the adaption costs at an existing TPP. These costs do not occur at a new installed TPP since they can be considered in the planning phase. The assumed CAPEX of the adaption at an existing TPP for the combination with a SEPPL can be seen in table 22.

Table 22: TPP Adaption Costs (own data)

Costs	Unit	Value
CAPEX adaption TPP	€	200,000

Figure 23 illustrates, simplified, the process flow of the combination of an existing TPP or a new installed TPP (left side of figure 23) with an algae growing and refining facility (right side of figure 23). The combustion process of the TPP generates flue gas. The flue gas of the TPP has to be recycled in order to get CO_2 in the required quality due to the GLP and GMP regulation. CO_2 can be pumped through a pipe to the algae growing and refining facility or it can be filled into tanks and the tanks will be brought to the algae growing and refining facility. In the end, the recycled CO_2 will be fed with other substances through the pumping system into the cultivation system to the algae. Before algae will get into the cultivation system, they will be bred in a previous breed process. When algae have been grown and reproduced to the required amount, the harvesting process removes the water. Consequently, algae dry mass is the result of the harvesting process. Afterwards, the algae dry mass is the basis for the transformation to an algae based product in the refining process. In this case, the algae refined product is Omega 3. Thus, Omega 3 can be sold and the separated algae dry mass will be co-fired with coal in the TPP.

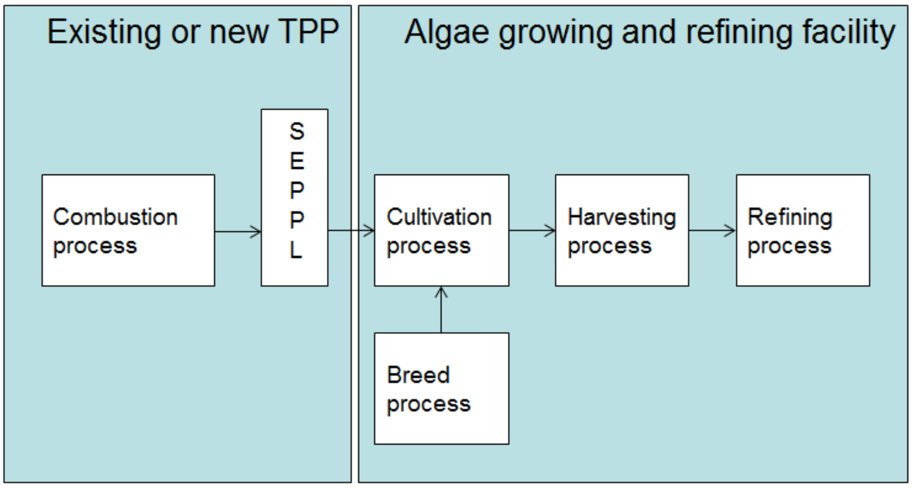


Figure 23: Process Flow Chart (own figure)

8 Economics

The results of the economic model and the additional sensitivity analysis will give an answer to the questions, whether the combination of a TPP with an algae growing and refining facility can be recommended from an economic point of view, or not. Respectively, the sensitivity analysis depicts which factors do have a major influence on the economic result. Consequently, these factors should be in the focus of further efforts for algae growing and refining facilities in order to make algae based products more competitive on different markets. As mentioned in chapter 2, the economic result is expressed by the NPV and IRR. The NPV (investopedia, 2013) is defined as sum between present value of all cash inflows in the project period and the present value of all cash outflows in the project period. Furthermore, the NPV shows if a project is profitable or not. The IRR (investopedia, 2013) is defined as the discount rate that makes the NPV of all cash inflows and outflows of a project equal to zero.

In general, the economic model consists of a profit and loss statement in combination with a balance sheet. Further, to complete the economic model, a liquidity plan shows the cash flow of the economic model. The assumptions for the economic model are the following:

- The life time for the algae growing and refining facility is 15 years due to the fact that the TPP is already 20 years in operation and the overall life time is around 35 years;
- The panels of the PBR should be renewed between 7 and 10 years of operation, in the economic model in the 7th year of operation, the panels of the PBR will be renewed, this leads to a decrease of the OPEX and the output to the half in that year;
- Annually, the OPEX rise for the same amount as the annual inflation, in the last 23 years, the average inflation was 2.22% (wko, 2012);
- The revenues are linked to the annual inflation, as a result, the revenues are rising annually by 2.22%, only the prices for Omega 3 will not rise due to the assumption that more Omega 3 will be on the market and, therefore, the price stagnates;
- In the first year, the whole facility will be under construction, as a result, no revenues can be generated and no OPEX have to be spent;

- The currency exchange rate from EUR to USD is set to 1:1.3;
- No further research has been done for the assumption of the adaption costs at the TPP;
- All used technologies exist already, therefore no subsidies are considered;
- To be in the position to sell Omega 3, GLP and GMP certifications for the algae growing and refining facility are needed, these costs are currently not considered but have to be taken into account in a final business plan;
- The WACC is set above 6%;
- The paid in capital is estimated at 5,500,000 €, which results in an equity ratio of 25%, which is the average equity ratio of small and medium-sized enterprises (SME) stated by the Austrian Institute for SME Research in 2010 (SME, 2010);
- The debt are estimated at 16,600,000 €, which results in a debt ratio of 75%;
- There are no requirements for the NPV and IRR which have to be reached;

8.1 Legal Framework in Austria

Due the fact that Austria is a landlocked country, growing algae in the ocean is not possible in Austria. Therefore, the United Nations Convention on Law of the Sea (UNCLOS), as well as the EU regulatory framework (proposals for a framework for community action in the field of Marine Environment Policy 16976/06) are not applicable (van Beilen, 2007).

Regarding the characterization of algae business according to the Austrian law, two factors are crucial. Firstly, algae count as vegetable products and secondly, due to the fact that a greenhouse is necessary for the chosen PBR, the algae business belongs, from a legal point of view, to the agricultural industry. Furthermore, the agricultural industry is divided in further sectors. All in all, the algae industry belongs to the nursery industry in Austria. Further, the nursery industry in Austria is a regulated industry. Consequently, to run an algae growing and refining facility in Austria, it is obligatory to own the nursery licence (Sec. 94 of the Austrian Trade Law). Due to the fact that the algae business is relatively new in Austria and still in a research and development phase, it could be possible that the Ministry of Economics makes an exception and a nursery licence will not be necessary. However, it is recommended to clarify this point in advance.

Depending on the algae based product, further rules of actions have to be fulfilled. Algae based biofuels need to comply with specifications of the petroleum industry. Consequently, the final challenge is that all algae based biofuels must meet a multitude of performance specifications which include volatility, initial and final boiling point, auto ignition characteristics, flashpoint, and cloud point (Cheng, 2011).

GMP and GLP represent rules of action for the quality management of the production process in the pharmacy-, food- , cosmetic-, medical- and feed industry. Depending on the country into which the algae based product will be exported, different GLP and GMP are valid. The EU has implemented the so called "EU-GMP-code of practice", the USA has introduced the so called "Current Good manufacturing Practice". GMP and GLP have defined that the use of waste materials for the production of products of the above mentioned industry are not allowed. Further, emitted CO_2 from a TPP is defined as a waste product. Consequently, the emitted CO_2 of a TPP must be cleaned to a specified purity to be allowed as material by the GMP and GLP.

8.2 National and International Subsidies

Regarding subsidies and feed in tariffs (FIT) for the combination of a TPP with an algae growing and refining facility analyzed in the master thesis, first of all, it has to be clarified, if a new technology, a new process or any other new innovation has been developed or not. From the author's point of view, nothing new has to be developed to run a TPP in combination with an algae growing and refining facility in the analyzed economic model. Due to the fact that the algae growing and refining facility of ecoduna© already exists in Bruck, TPP have been in operation for years and also different SEPPL have been developed and do already exist on the market. As a result, the subsidies and FIT in the economic model are set to zero.

Table 23: Sponsored Subsidies (own data)

FIT/Subsidies	Unit	Value
Subsidies	€	0

Nevertheless, all possible sponsors should be informed about the economic model to generate sponsorships or get credits at more favorable terms than from a bank; for example, a credit from the Austrian Wirtschafts Service (AWS). For the economic model it is not relevant from which economic institution or political unit (community, region, state, government, EU, research institutions or companies) subsidies come from. Further, possible sponsors could be the European Agricultural Guidance, Guarantee Fund and the European Agricultural Fund for Rural Development or the 7^{th} Framework Program for research and technological development, for example the InteSusAl project (Hobson, 2011) on the EU level. Possible sponsors on government level are, - as mentioned above, - AWS, Kommunalkredit Public

Consulting (KPC) and the Austrian Research Promotion Agency also called FFG. KPC is responsible to manage subsidies of the Federal Ministry of Agriculture and Forestry, Environment and Water Management. To find the right sponsors on state level, from the author's point of view, it is more efficient to contact the state government directly. For example, in Lower Austria it is recommended to contact the state government department: Gruppe Wirtschaft, Sport und Tourismus or the Gründer-Agentur für Niederösterreich also called RIZ. These state government departments or institutions are specialists in helping startup companies to found a company and to get an overview of which subsidies are available and can be generated. Furthermore, the state government can answer, if it is essential to have the nursery licence or if an exceptional case can be made for the algae growing and refining facility due to the fact that it is a new business and does not directly belong to the traditional nursery business. Further, to find the right sponsor at the community level, it would be the best to contact the major directly.

This enumeration of possible sponsors is not complete. Nevertheless, it gives a good overview of the wide range of different possible sponsors.

All in all, subsidies are not considered in the economic model. Nevertheless, in chapter 8.3 the sensitivity analysis indicates the effect of a decrease of the CAPEX on the economic result (see also figure 24). This effect can also be regarded as the generation of different subsidies.

8.3 Economics of the Combination of a Thermal Power Plant with an Algae growing and refining Facility

The economic model of the combination of a TPP with an algae growing and refining facility results in CAPEX of 22,073,000 €, annual OPEX of 1,312,000 € and annual revenues of 3,628,000 €. Further, the economic model turns out to be profitable regarding the NPV of -3,176,000 € and an IRR of -2.3%. As a result, it can be stated that, under the described and assumed circumstances, the combination of a TPP with an algae growing and refining facility cannot be recommended. However, the sensitivity analysis (see also figure 24) illustrates the most influencing factors and their impact on the economic result.

The sensitivity analysis is based on two different scenarios, which are called base scenario and best scenario. The economic model of the base scenario, the profit and loss statement, the liquidity plan, as well as the balance sheet can be seen in

Annex I. The economic model of the best scenario, the profit and loss statement, the liquidity plan, as well as the balance sheet can be seen in Annex II. In the base scenario, algae use just the natural solar radiation of Lower Austria for the photosynthesis. In the best scenario, algae utilize the natural solar radiation of Lower Austria and additional radiation of an artificial light system. The additional artificial light system is installed to provide the optimum radiation for algae during operation for the photosynthesis process of algae. As a result, the output increases from about 500 t algae based biomass to appr. 700 t algae based biomass. This indicates an increase of roughly 40%. Further, the reviewed influencing factors of the sensitivity analysis are the following:

- allowances price increase;
- OPEX decrease;
- CAPEX decrease;
- output increase;
- Omega 3 price increase;
- coal price increase as well as the price increase of an additional by product;

The additional by product is also Omega 3 but the purity is not as high as it is in the main Omega 3 product. Therefore, the price for the additional by product is set on a price of 0.75 € per liter. Figure 24 depicts different calculated changes for the base scenario which hopefully will be realized in the near future.

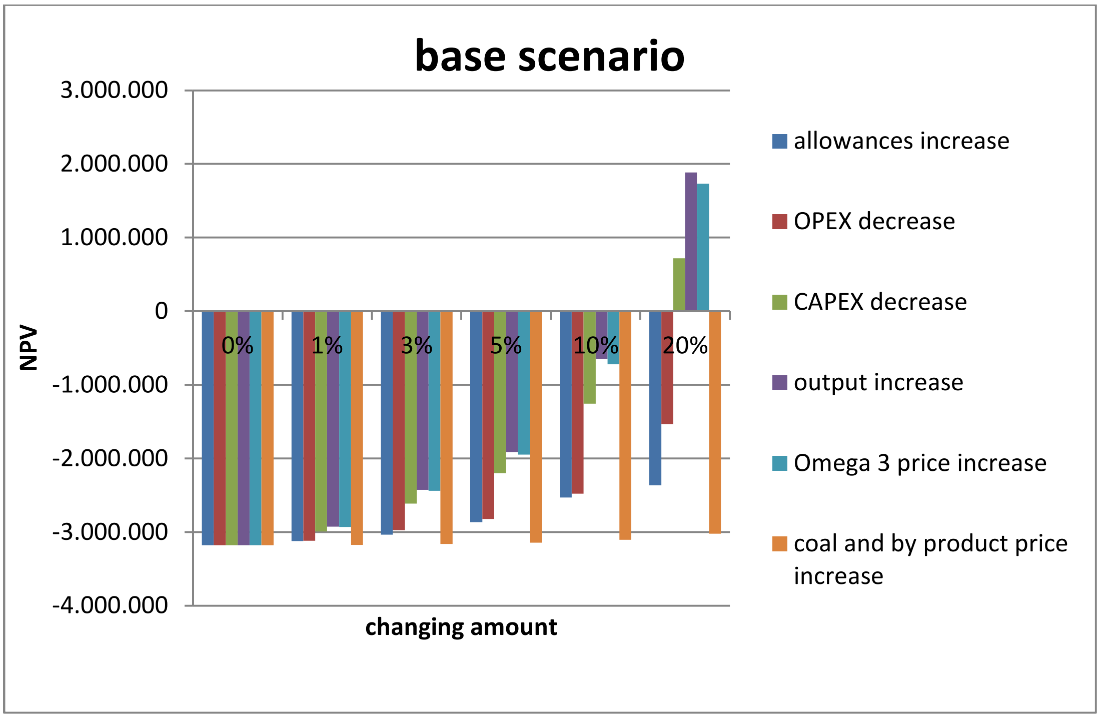


Figure 24: Sensitivity Analysis Result on the NPV of the Base Scenario (own graph)

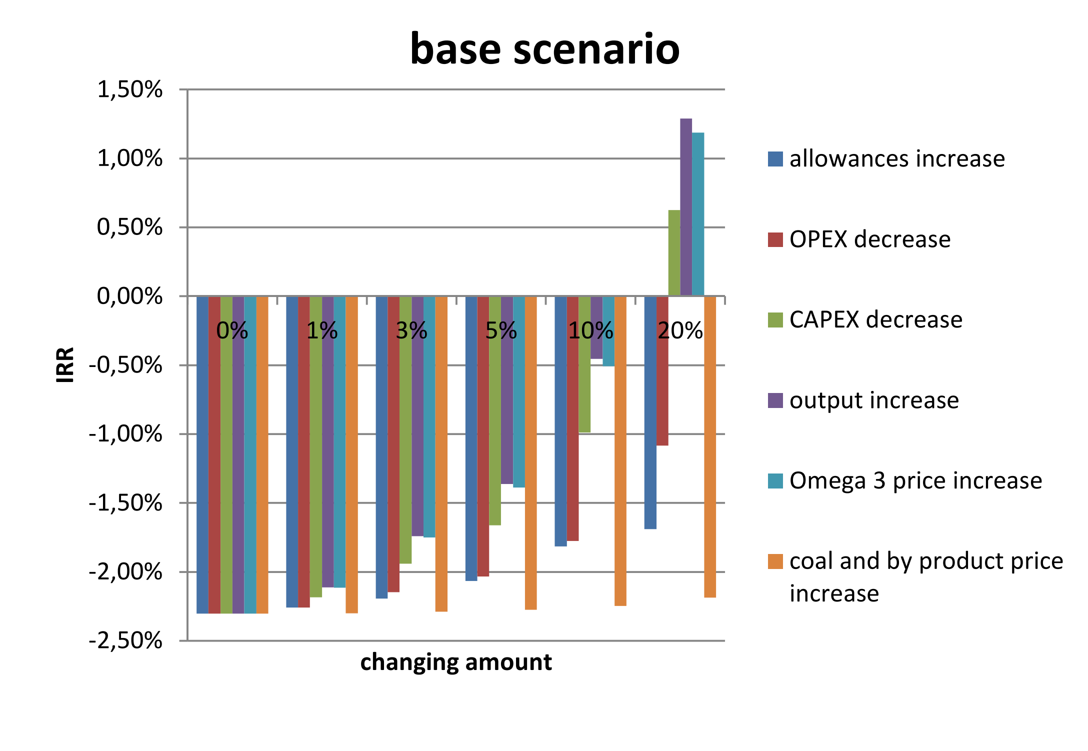


Figure 25: Sensitivity Analysis Result on the IRR of the Base Scenario (own graph)

Figure 24 and 25 illustrate the effect of the increase of the output, the Omega 3 price and the coal and by product price, as well as the decrease of the OPEX and CAPEX on the NPV, as well as on the IRR of the base scenario. Furthermore, figure 26 and 27 illustrate the same effects on the NPV, as well as on the IRR of the best scenario.

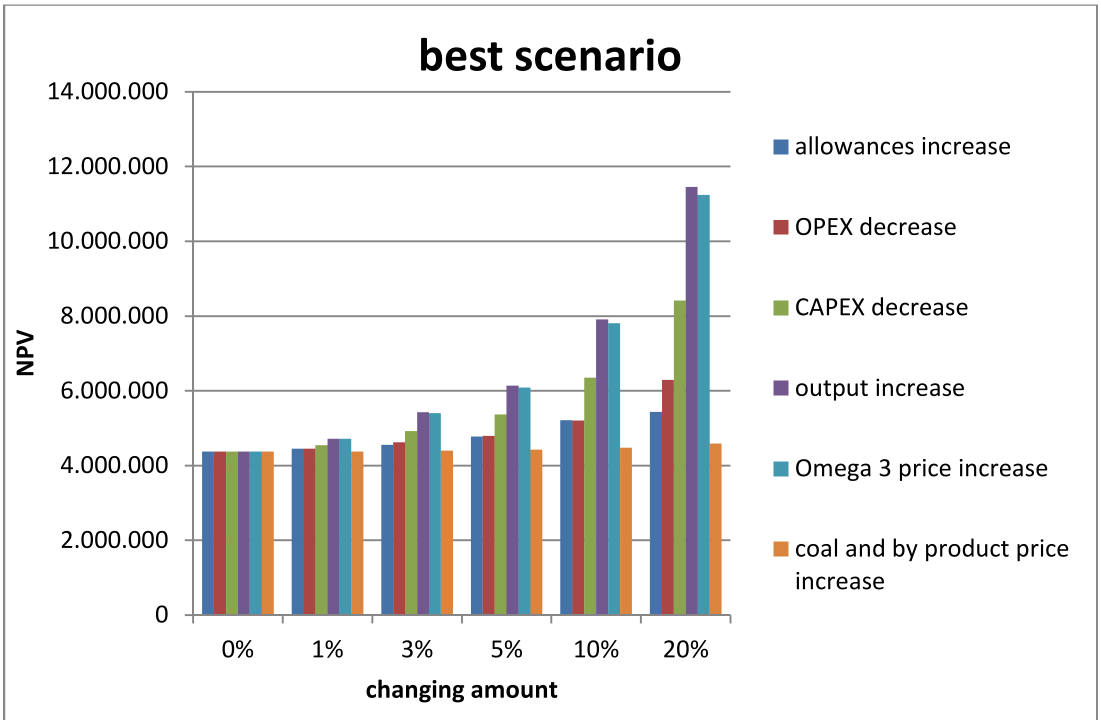


Figure 26: Sensitivity Analysis Results on the NPV of the Best Scenario (own graph)

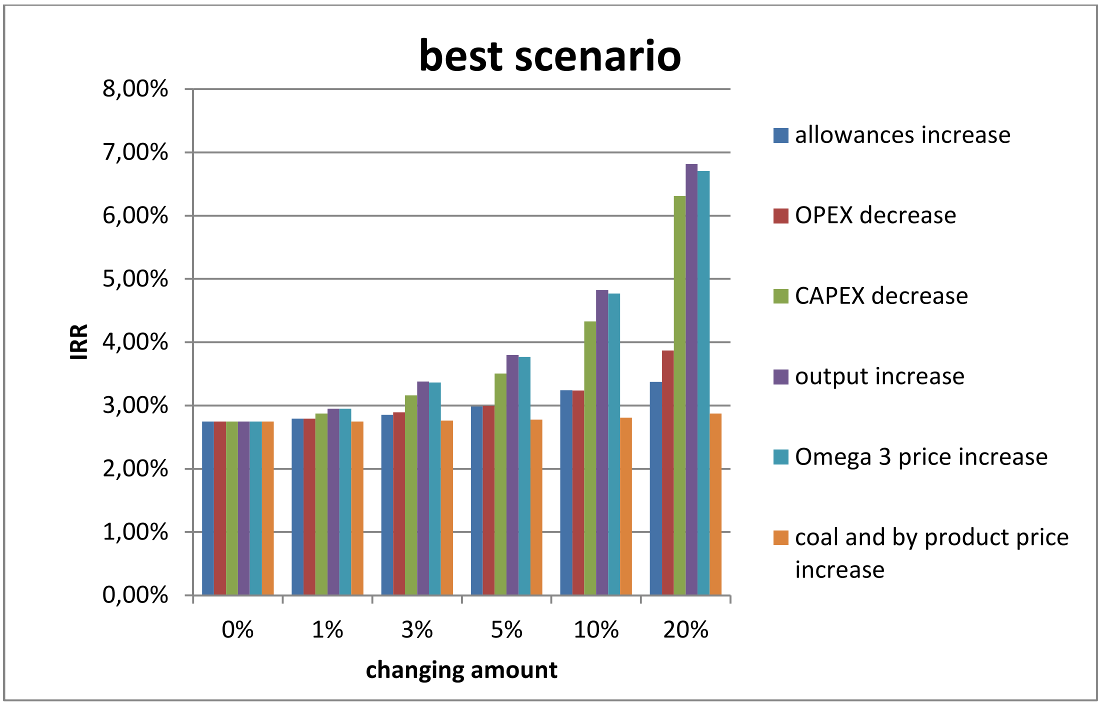


Figure 27: Sensitivity Analysis Results on the IRR of the Best Scenario (own graph)

The starting point is the economic result of the particular scenario. The increasing and decreasing steps have been set to 1%, 3%, 5%, 10% and 20%. The allowance price is 3 € and the increasing steps have been set to 10 €, 20 €, 40 €, 80 € and 100 €. The coal price and the by product have a higher starting point due to the higher revenues in the first years of operation. In general, it can be seen that the increase of the coal price and the by product, as well as the allowances price increase do not have a deep impact on the economic result. Furthermore, the influence of decreasing OPEX on the economic result is slightly better than the influence of the increase of the coal price and the by product, as well as the increase of the allowances price. The decrease of the CAPEX, in comparison to the decrease of the OPEX has nearly the double effect on the economic result. In general, it can be stated that the increase of the output, as well as the Omega 3 price has the largest influence on the economic result. Due to the fact that the increase of the world market Omega 3 price cannot be influenced by one small algae growing and refining facility, however, the highest priority of improving the algae growing and refining facility should be to maximize the output. Annex I and Annex II illustrated the exact results of the sensitivity analysis of the base scenario and the best scenario.

As stated above, the output of an algae growing and refining facility with an additional artificial light system (best scenario) is around 40% higher than without an additional artificial light system (base scenario). Figure 28 and 29 depict the effect of the increase of the output on the economic result for each scenario on the NPV and on the IRR. Therefore, it can be stated that the higher the output is the more profitable is the economic result. With respect to the base scenario, it is recommended that an algae growing and refining facility should be constructed with an artificial light system. Further, the comparison of the best scenario with the base scenario illustrates that the CAPEX are only slightly higher but the output and, as a consequence, the revenues are in relation much higher.

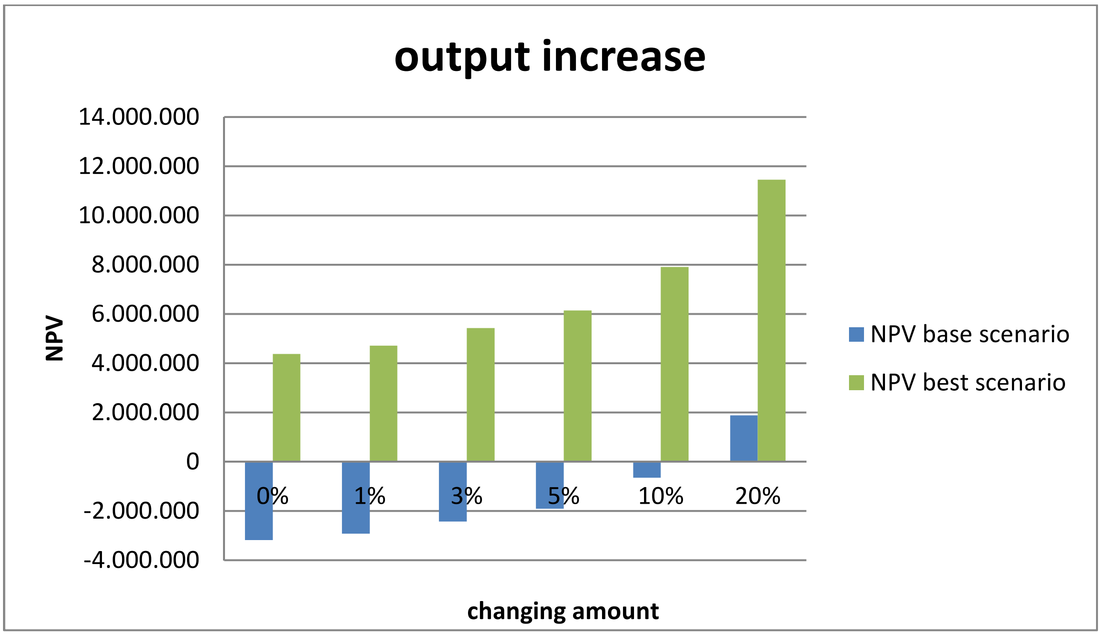


Figure 28: Economic Influence on the NPV of the Output Increase (own graph)

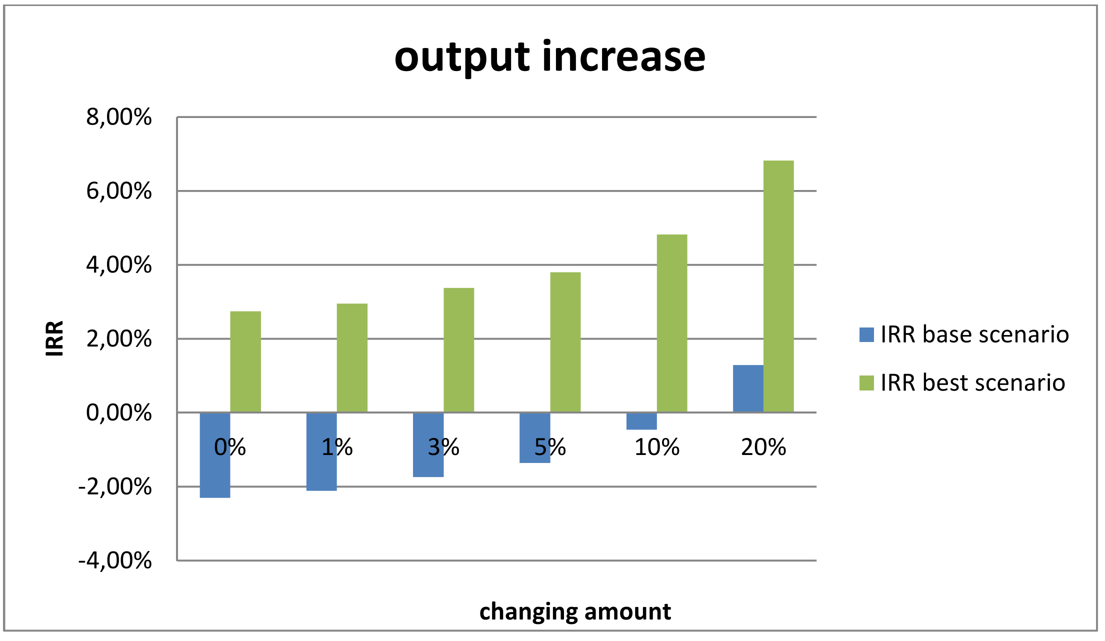


Figure 29: Economic Influence on the IRR of the Output Increase (own graph)

The economic model of the combination of a TPP with an algae growing and refining facility, which includes an additional artificial light system results in CAPEX of 23,558,000 €, annual OPEX of 1,492,000 € and annual revenues of 5,079,000 €.

Moreover, the economic model turns out to be profitable regarding the NPV of 4,376,000 € and an IRR of 2.75%. In general, under the described and assumed circumstances the combination of a TPP with an algae growing and refining facility, which includes an additional artificial light system, can be recommended. From a company's point of view, it is depending on the internal requirements regarding the NPV and the IRR.

9 Conclusions

From an economic point of view, the combination of a TPP with an algae growing and refining facility in Lower Austria to use emitted CO_2 and produce high valued Omega 3 cannot be recommended at the moment. Nevertheless, the combination of a TPP with an algae growing and refining facility in Lower Austria, which includes an artificial light system, seems feasible because an additional artificial light system increases the algae based biomass output by about 40%. Furthermore, with additional electricity demand for the artificial light system, the output is not primarily depending on weather conditions. As a result, the location of the algae growing and refining facility does not only correlate with the natural solar radiation.

The economic model in combination with the sensitivity analysis indicates that the output of an algae growing and refining facility influences the economic result most. Consequently, the highest efforts priority for improving the algae growing and refining facility should be to maximize the output. The aquaFUELs Report (Bauen, 2011) underlines the result of the economic model of the master thesis. It mentions that the focus of US scientists is on the research of GMA, the focus of Chinese scientists is on the bioinformatics, and the focus of European scientists is on the technological research of the process itself. Consequently, if the worldwide interchange between the scientists could be improved, the possible breakthrough of algae technology could be earlier.

Hand in hand with the efforts of maximization of the algae based biomass output, the CAPEX should be decreased. The OPEX of an algae growing and refining facility do not have that high impact on the economic result as the increase of the output and the decrease of the CAPEX. Nevertheless, the OPEX should be considered by all efforts in the future. The increase of the allowance price has an insignificant effect on the economic result. Therefore, it can be stated, that, for the economic result of an algae growing and refining facility it does not matter if the ETS works or not. Furthermore, the increase of the coal price and the increase of the price for additional lower quality Omega 3 have an insignificant influence on the economic result too. Thus, no subsidies are considered in the economic model. Hence, possible subsidies should be reviewed by the search of the location, if the algae business will be realized.

Another finding is that the whole amount of the emitted CO_2 of a large TPP with a capacity of 400 MW_{el} cannot be fed to algae due to the fact that an area of appr. 2,760 hectares for an algae growing and refining facility would be needed.

Depending on the algae based product, GLP and GMP regulations have to be fulfilled. Especially products of the pharmacy, food, cosmetics, medical and feed industry are concerned in terms of the GLP and GMP regulations. Further, GLP and GMP regulations state that the use of any kind of waste product in the production process is not allowed. Consequently, the emitted CO_2 of a TPP is not allowed to be fed to the algae growing and refining facility directly in case Omega 3 is the algae based product. As a result, a CO_2 separation plant has to be installed additionally to the TPP to use parts of the emitted CO_2. All in all, GLP and GMP certifications for the algae growing and refining facility are necessary. Nevertheless, costs of such certifications are not considered in the economic model. If the CO_2 cycle of a TPP is extended with a CO_2 separation plant and the cleaned CO_2 is not emitted to the atmosphere, a green image campaign for the TPP can increase the goodwill of the company. However, the increase of the goodwill of the company, as well as the image improvement of the company and its consequences are not included in the economic model. Furthermore, economy of scales of the size of the algae growing and refining facility are not considered in the economic model.

The combination of a TPP with an algae growing and refining facility causes some synergies which are not described and considered in the economic model. However, these synergies are important to guarantee a smooth construction, as well as operation. Normally, project managers from TPP are used to the construction of similar facilities. Consequently, the scheduled time plan should be on time as well as the claiming costs should be kept at a reasonable level. Further, the labor workers of a TPP are well educated and can immediately operate the algae growing and refining facility after a designated introduction training. Moreover, labor workers are already familiar with shift operation. All blue collar operations can be handled without additional costs due to the fact that all operations have to be done anyway by running the TPP. The parallel operation of the TPP and the algae growing and refining facility can be optimized and further, more produced electricity can be directly used by the algae growing and refining facility. Consequently, the electricity price may possibly decrease. No additional allowances trading department and electricity trading department have to be installed.

A future scenario for the economic model could be that the technologies of all processes of an algae growing and refining facility are getting more efficient and cheaper. Consequently, the output increases, the CAPEX and OPEX decrease, the allowances price increases, the high quality Omega 3 price increases and the coal price, as well as the additional low quality Omega 3 price increase. If those events occur, an algae growing and refining facility, with and without artificial light system, can be recommended. Therefore, all possible efforts should be made in order to realize at least parts of the future scenario. The economic consequences of that future scenario can be seen in figure 30 and 31.

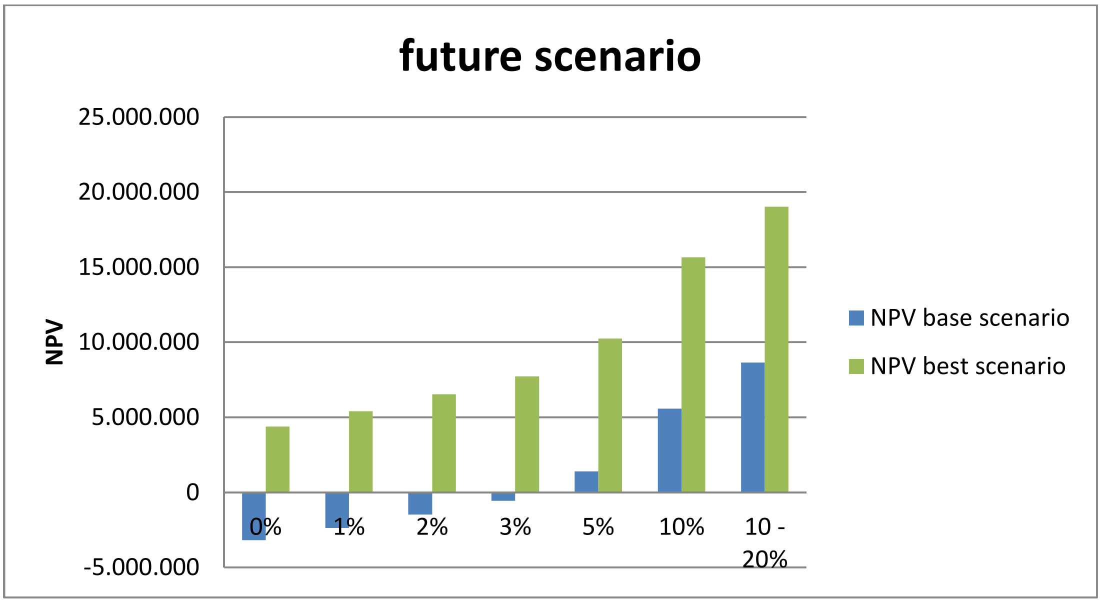


Figure 30: Economic Result on the NPV of the Future Scenario (own graph)

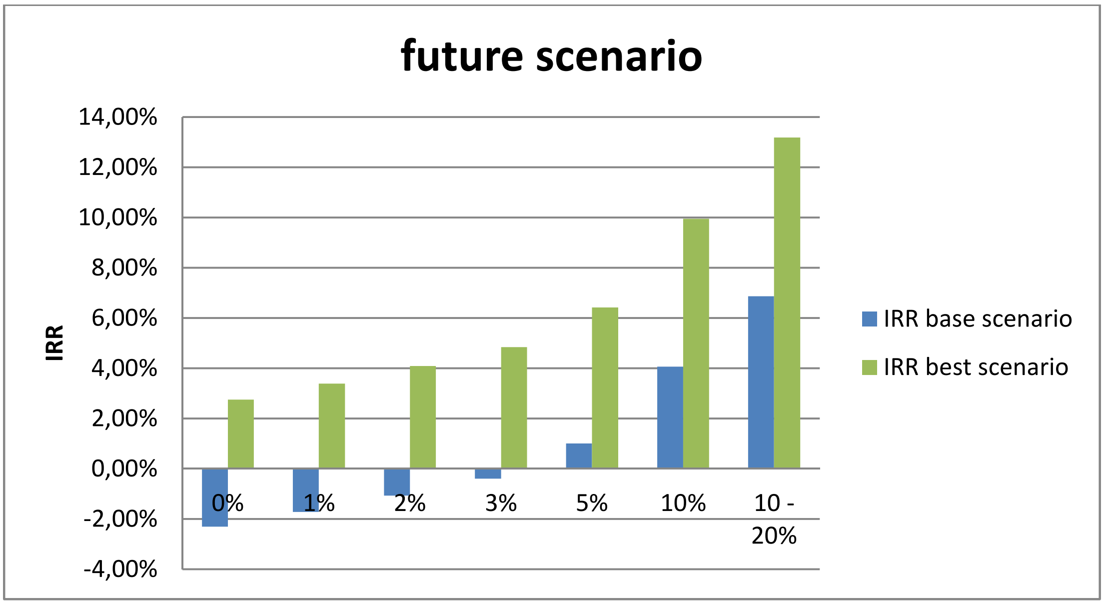


Figure 31: Economic Result on the IRR of the Future Scenario (own graph)

10 Final Summary

The main findings of the master thesis are summarized in the following points:

- From an economical point of view, the production of algae based biofuels is not profitable yet. Therefore, the algae based product has to be a high value product, such as Omega 3 fatty acid.
- The combination of a thermal power plant with an algae growing and refining facility is currently economically not feasible. If an additional artificial light is added to the algae growing and refining facility, the algae based biomass output increases to about 40%. As a result, the economic result is positive.
- The upside potentials which can be influenced are prioritized:
  - higher conversion rate,
  - lower CAPEX and
  - lower OPEX.
- The combination of a biogas plant with an algae growing and refining facility is suitable due to the fact that similar sizes regarding the emitting amount of CO_2 and the needed amount of CO_2 for algae growing.
- The following costs and effects are not considered in the economic model:
  - GMP certification costs,
  - GLP certification costs,
  - economy of scale and
  - no subsidies are considered in the economic model.
- If a thermal power plant will be combined with an algae growing and refining facility and the end product will be sold to the pharmaceutical industry, cosmetics industry, food and feed industry, a.s.o., it is not allowed to use directly emitted CO_2 of a thermal power plant because of the GMP and GLP regulations. As a result, a CO_2 separation plant for cleaning the emitted CO_2 of the thermal power plant to the required quality is added to the economic model. If biofuels are the refined end product, an additional CO_2 separation plant is not essential.

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Annexes

Annex I – economic model of the base scenario

Outcome	Unit	Amount
Photosynthesis efficiency	%	4
Algae based biomass	t	500
Burnable algae based biomass	t	350
Omega 3	l	60,000
By product	l	90,000

OPEX	Unit	Prices / Cost per Item	Items	Prices / Costs
Nutrients	€/kg	5	37,000	185,000
Cleaning/chemicals	€/t	152,000	1	152,000
Pumping system	€/kWh_{el}	0.05	3,635,000	191,000
Pro rata labor costs	€	50,000.00	1.00	50,000
Water treatment and recycling	€/kWh_{el}	0.05	135,000	7,000
Second level support	€/line	4,000	33	132,000
Service and maintenance	€	200,000	1	200,000
Application service	€/line	2,000	33	66,000
Harvesting	€/kWh_{el}	0.05	550,000	29,000
Refining	€/kWh_{el}	0.05	1,500,000	79,000
SEPPL	€/kWh_{el}	0.05	66,000	13,000
Labor costs (Biologist)	€	70,000	1	70,000
Spare parts	€	138,000	1	138,000
Σ OPEX	€			**1,312,000**

Revenues				
Burning algae based biomass instead of coal	€/t	73.08	350	26,000
Omega 3 acid	€/l	58.85	60,000	3,531,000
Selling of by product	€/l	0.75	90,000	68,000
Selling of allowances	€/t_{CO2}	3	1,000	3,000
Σ Revenues	€			**3,628,000**

CAPEX				
Cultivation system	€/line	309,000	33	10,197,000
Housing (greenhouse)	€/m²	70	10,000	700,000
License costs	€/line	20,000	33	660,000

Breed cultivation	€/line	15,000	33	495,000
Algae refining equipment	€/line	170,000	33	5,610,000
Infrastructure	€/line	13,000	33	429,000
Adaption costs (TPP)	€/m	1	200,000	200,000
SEPPL	€	2,000,000	1	2,000,000
Pumping equipment	€/line	9,000	33	297,000
Harvesting equipment	€/line	45,000	33	1,485,000
Σ CAPEX	€			**22,073,000**

Subsidies				
Investment subsidy	€	0	0	0
FIT	€	0	0	0
Σ FIT/Subsidies	€			**0**

Profit and Loss Statement of the base scenario

Period			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Year			2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	TOTAL
Revenue	Sales	€	0	3,630,000	3,632,000	3,635,000	3,637,000	3,639,000	3,642,000	3,644,000	1,881,000	3,649,000	3,652,000	3,655,000	3,657,000	3,660,000	3,663,000	3,666,000	52,941,837
Subsidies	Subsidies	€	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Costs	Total	€	0	-1,137,000	-1,162,000	-1,188,000	-1,214,000	-1,241,000	-1,269,000	-1,297,000	-943,000	-1,355,000	-1,385,000	-1,416,000	-1,447,000	-1,480,000	-1,512,000	-1,546,000	-19,592,000
EBITDA		€	*0*	*2,493,000*	*2,470,000*	*2,447,000*	*2,423,000*	*2,398,000*	*2,373,000*	*2,347,000*	*938,000*	*2,294,000*	*2,267,000*	*2,239,000*	*2,210,000*	*2,180,000*	*2,151,000*	*2,120,000*	*33,350,000*
		%	0.00	68.68	68.01	67.32	66.62	65.90	65.16	64.41	49.87	62.87	62.08	61.26	60.43	59.56	58.72	57.83	62.99
Depreciation		€	0	-1,472,000	-1,472,000	-1,472,000	-1,472,000	-1,472,000	-1,472,000	-1,472,000	-1,472,000	-1,472,000	-1,472,000	-1,472,000	-1,472,000	-1,472,000	-1,472,000	-1,472,000	-22,080,000
EBIT		€	*0*	*1,021,000*	*998,000*	*975,000*	*951,000*	*926,000*	*901,000*	*875,000*	*-534,000*	*822,000*	*795,000*	*767,000*	*738,000*	*708,000*	*679,000*	*648,000*	*11,270,000*
		%	0.00	28.13	27.48	26.82	26.15	25.45	24.74	24.01	-28.39	22.53	21.77	20.98	20.18	19.34	18.54	17.68	21.29
Interests	Annuity	ı	0	-1,599,000	-1,599,000	-1,599,000	-1,599,000	-1,599,000	-1,599,000	-1,599,000	-1,599,000	-1,599,000	-1,599,000	-1,599,000	-1,599,000	-1,599,000	-1,599,000	-1,599,000	-23,985,000
	Repayment	ı	0	-769,000	-807,000	-848,000	-890,000	-935,000	-981,000	-1,030,000	-1,082,000	-1,136,000	-1,193,000	-1,253,000	-1,315,000	-1,381,000	-1,450,000	-1,522,000	-16,592,000
	Interests	€	0	-830,000	-792,000	-751,000	-709,000	-664,000	-618,000	-569,000	-517,000	-463,000	-406,000	-346,000	-284,000	-218,000	-149,000	-77,000	-7,393,000
	remaining credit	ı	-16,600,000	-15,831,000	-15,024,000	-14,176,000	-13,286,000	-12,351,000	-11,370,000	-10,340,000	-9,258,000	-8,122,000	-6,929,000	-5,676,000	-4,361,000	-2,980,000	-1,530,000	-8,000	
EBT		€	*0*	*191,000*	*206,000*	*224,000*	*242,000*	*262,000*	*283,000*	*306,000*	*-1,051,000*	*359,000*	*389,000*	*421,000*	*454,000*	*490,000*	*530,000*	*571,000*	*3,877,000*
		%	0	5.26	5.67	6.16	6.65	7.20	7.77	8.40	-55.87	9.84	10.65	11.52	12.41	13.39	14.47	15.58	7.32
Carry over loss		€	0	0	0	0	0	0	0	0	0	-1,051,000	-692,000	-303,000	0	0	0	0	
Taxable profit		€	0	191,000	206,000	224,000	242,000	262,000	283,000	306,000	-1,051,000	-692,000	-303,000	118,000	454,000	490,000	530,000	571,000	
Income Tax		€	0	-48,000	-52,000	-56,000	-61,000	-66,000	-71,000	-77,000	0	0	0	-30,000	-114,000	-123,000	-133,000	-143,000	-974,000
Profit / Loss		€	*0*	*143,000*	*154,000*	*168,000*	*181,000*	*196,000*	*212,000*	*229,000*	*-1,051,000*	*359,000*	*389,000*	*391,000*	*340,000*	*367,000*	*397,000*	*428,000*	*2,903,000*
		%	0.00	3.94	4.24	4.62	4.98	5.39	5.82	6.28	-55.87	9.84	10.65	10.70	9.30	10.03	10.84	11.67	5.48
	accumulated	€	0	143,000	297,000	465,000	646,000	842,000	1,054,000	1,283,000	232,000	591,000	980,000	1,371,000	1,711,000	2,078,000	2,475,000	2,903,000	

Balance Sheet of the base scenario

Periode		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
ASSETS																	
Non current assets	€	22,073,000	20,601,000	19,129,000	17,657,000	16,185,000	14,713,000	13,241,000	11,769,000	13,696,000	12,224,000	10,752,000	9,280,000	7,808,000	6,336,000	4,864,000	3,392,000
Cash	€	27,000	873,000	1,692,000	2,484,000	3,247,000	3,980,000	4,683,000	5,354,000	1,294,000	1,989,000	2,657,000	3,267,000	3,764,000	4,222,000	4,641,000	5,019,000
Total Assets	€	**22,100,000**	**21,474,000**	**20,821,000**	**20,141,000**	**19,432,000**	**18,693,000**	**17,924,000**	**17,123,000**	**14,990,000**	**14,213,000**	**13,409,000**	**12,547,000**	**11,572,000**	**10,558,000**	**9,505,000**	**8,411,000**
LIABILITIES																	
Paid In Capital	€	5,500,000	5,500,000	5,500,000	5,500,000	5,500,000	5,500,000	5,500,000	5,500,000	5,500,000	5,500,000	5,500,000	5,500,000	5,500,000	5,500,000	5,500,000	5,500,000
Profit from previous years	€	0	0	143,000	297,000	465,000	646,000	842,000	1,054,000	1,283,000	232,000	591,000	980,000	1,371,000	1,711,000	2,078,000	2,475,000
Profit/Loss	€	0	143,000	154,000	168,000	181,000	196,000	212,000	229,000	-1,051,000	359,000	389,000	391,000	340,000	367,000	397,000	428,000
Debt	€	16,600,000	15,831,000	15,024,000	14,176,000	13,286,000	12,351,000	11,370,000	10,340,000	9,258,000	8,122,000	6,929,000	5,676,000	4,361,000	2,980,000	1,530,000	8,000
Total Liabilities	€	**22,100,000**	**21,474,000**	**20,821,000**	**20,141,000**	**19,432,000**	**18,693,000**	**17,924,000**	**17,123,000**	**14,990,000**	**14,213,000**	**13,409,000**	**12,547,000**	**11,572,000**	**10,558,000**	**9,505,000**	**8,411,000**

Liquidity Plan of the base scenario

Periode			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Year			2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	TOTAL
Revenue	Sales	€	0	3,630,000	3,632,000	3,635,000	3,637,000	3,639,000	3,642,000	3,644,000	1,881,000	3,649,000	3,652,000	3,655,000	3,657,000	3,660,000	3,663,000	3,666,000	**52,942,000**
Subsidies	on Investment	€	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	FIT	€	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Costs	Total	€	0	-1,137,000	-1,162,000	-1,188,000	-1,214,000	-1,241,000	-1,269,000	-1,297,000	-943,000	-1,355,000	-1,385,000	-1,416,000	-1,447,000	-1,480,000	-1,512,000	-1,546,000	**-19,592,000**
Debt Service	Repayment	€	0	-769,000	-807,000	-848,000	-890,000	-935,000	-981,000	-1,030,000	-1,082,000	-1,136,000	-1,193,000	-1,253,000	-1,315,000	-1,381,000	-1,450,000	-1,522,000	**-16,592,000**
	Interests	€	0	-830,000	-792,000	-751,000	-709,000	-664,000	-618,000	-569,000	-517,000	-463,000	-406,000	-346,000	-284,000	-218,000	-149,000	-77,000	**-7,393,000**
Paid In Capital		€	5,500,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5,500,000**
Cash In from Bank - Credit		€	16,600,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**16,600,000**
Tax		€	0	-48,000	-52,000	-56,000	-61,000	-66,000	-71,000	-77,000	0	0	0	-30,000	-114,000	-123,000	-133,000	-143,000	**-974,000**
Investment		€	-22,073,000	0	0	0	0	0	0	0	-3,399,000	0	0	0	0	0	0	0	**-25,472,000**
Cash Flow		€	27,000	846,000	819,000	792,000	763,000	733,000	703,000	671,000	-4,060,000	695,000	668,000	610,000	497,000	458,000	419,000	378,000	**5,019,000**
	accumulated	€	27,000	873,000	1,692,000	2,484,000	3,247,000	3,980,000	4,683,000	5,354,000	1,294,000	1,989,000	2,657,000	3,267,000	3,764,000	4,222,000	4,641,000	5,019,000	
Free Cash Flow	free CF	€	-22,073,000	2,445,000	2,418,000	2,391,000	2,362,000	2,332,000	2,302,000	2,270,000	-2,461,000	2,294,000	2,267,000	2,209,000	2,096,000	2,057,000	2,018,000	1,977,000	**6,904,000**
	discounted = NPV	€	-22,073,000	2,301,000	2,142,000	1,994,000	1,854,000	1,723,000	1,601,000	1,486,000	-1,516,000	1,330,000	1,237,000	1,135,000	1,013,000	936,000	864,000	797,000	**-3,176,000**
	accumulated	€	-22,073,000	-19,628,000	-17,210,000	-14,819,000	-12,457,000	-10,125,000	-7,823,000	-5,553,000	-8,014,000	-5,720,000	-3,453,000	-1,244,000	852,000	2,909,000	4,927,000	6,904,000	

Sensitivity analysis of the base scenario

	OPEX decrease		**CAPEX decrease**		**Output increase**		**Omega 3 price increase**		**Coal and by product price increase**		**Allowances increase**			**Future scenario**	
	NPV [€]	IRR [%]	NPV [€]	IRR [%]	NPV [€]	IRR [%]	NPV [€]	IRR [%]	NPV [€]	IRR [%]	Price	NPV [€]	IRR [%]	NPV [€]	IRR [%]
0%	-3,178,000	-2.30	-3,178,000	-2.30	-3,178,000	-2.30	-3,178,000	-2.30	-3,178,000	-2.30	3 €	-3,178,000	-2.30	-3,178,000	-2.30
1%	-3,119,000	-2.18	-2,990,000	-2.18	-2,925,000	-2.11	-2,929,000	-2.12	-3,175,000	-2.30	10 €	-3,121,000	-2.26	-2,364,000	-1.71
3%	-2,972,000	-1.94	-2,614,000	-1.94	-2,425,000	-1.74	-2,438,000	-1.75	-3,161,000	-2.29	40 €	-3,033,000	-2.19	-553,000	-0.40
5%	-2,823,000	-1.66	-2,198,000	-1.66	-1,911,000	-1.36	-1,946,000	-1.39	-3,142,000	-2.28	80 €	-2,866,000	-2.07	1,394,000	1.01
10%	-2,477,000	-0.99	-1,254,000	-0.99	-648,000	-0.46	-722,000	-0.51	-3,105,000	-2.25	100 €	-2,530,000	-1.81	5,573,000	4.06
20%	-1,533,000	0.62	718,000	0.62	1,885,000	1.29	1,731,000	1.19	-3,024,000	-2.19	120 €	-2,363,000	-1.69	8,652,000	6.86

Annex II – economic model of the best scenario

Outcome	**Unit**	**Amount**
Photosynthesis efficiency	%	4.5
Algae based biomass	t	700
Burnable biomass	t	490
Omega 3	l	84,000
By product	l	126,000

OPEX	**Unit**	**Prices / Costs per Item**	**Item**	**Prices / Costs**
Nutrients	€/kg	5	51,000	255,000
Cleaning/chemicals	€/t	152,000	1	152,000
Pumping system	€/kWh_{el}	0.05	3,635,000	191,000
Pro rata labor costs	€	50,000.00	1	50,000
Water treatment and recycling	€/kWh_{el}	0.05	135,000	7,000
Second level support	€/line	4,000	33	132,000
Service and maintenance	€	200,000	1	200,000
Application service	€/line	2,000	33	66,000
Harvesting	€/kWh_{el}	0.05	550,000	29,000
Refining	€/kWh_{el}	0.05	1,500,000	79,000
SEPPL	€/kWh_{el}	0.05	66,000	16,000
Labor costs (Biologist)	€	70,000	1	70,000
Artificial light	€	0.05	2,047,000	107,000
Spare parts	€	138,000	1	138,000
Σ OPEX	**€**			**1,492,000**

Revenues				
Burning algae based biomass instead of coal	€/t	73.08	490	36,000
Omega 3 acid	€/l	58.85	84,000	4,944,000
Selling of by product	€/l	0.75	126,000	95,000
Selling of allowances	€/t_{CO2}	3	1,300	4,000
Σ OPEX	**€**			**5,079,000**

CAPEX				
Cultivation system	€/line	309,000	33	10,197,000
Housing (greenhouse)	€/m²	70	10,000	700,000
License costs	€/line	20,000	33	660,000
Breed cultivation	€/line	15,000	33	495,000
Algae refining equipment	€/line	170,000	33	5,610,000

Infrastructure	€/line	58,000	33	1,914,000
Adaption costs (TPP)	€/m	1	200,000	200,000
SEPPL	€	2,000,000	1	2,000,000
Pumping equipment	€/line	9,000	33	297,000
Harvesting equipment	€/line	45,000	33	1,485,000
Σ CAPEX	**€**			**23,558,000**

FIT/Subsidies				
Investment subsidies	€	0	0	0
FIT/Subsidies	€	0	0	0
Σ FIT/Subsidies	**€**			**0**

Master Thesis

MSc Program
Renewable Energy in Central & Eastern Europe

Profit and Loss Statement of the best scenario

Periode			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Year			2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	TOTAL
Revenue	Sales	€	0	5,082,000	5,085,000	5,088,000	5,091,000	5,095,000	5,098,000	5,101,000	2,633,000	5,109,000	5,112,000	5,116,000	5,120,000	5,124,000	5,128,000	5,132,000	74,113,000
Subsities	Subsities	€	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Costs	Total	€	0	-1,321,000	-1,350,000	-1,380,000	-1,411,000	-1,442,000	-1,474,000	-1,507,000	-1,050,000	-1,574,000	-1,609,000	-1,645,000	-1,682,000	-1,719,000	-1,757,000	-1,796,000	-22,717,000
EBITDA		€	*0*	*3,761,000*	*3,735,000*	*3,708,000*	*3,680,000*	*3,653,000*	*3,624,000*	*3,594,000*	*1,583,000*	*3,535,000*	*3,503,000*	*3,471,000*	*3,438,000*	*3,405,000*	*3,371,000*	*3,336,000*	*51,397,000*
		%	0.00	74.01	73.45	72.88	72.28	71.70	71.09	70.46	60.12	69.19	68.53	67.85	67.15	66.45	65.74	65.00	69.35
Depreciation		€	0	-1,571,000	-1,571,000	-1,571,000	-1,571,000	-1,571,000	-1,571,000	-1,571,000	-1,571,000	-1,571,000	-1,571,000	-1,571,000	-1,571,000	-1,571,000	-1,571,000	-1,571,000	-23,565,000
EBIT		€	*0*	*2,190,000*	*2,164,000*	*2,137,000*	*2,109,000*	*2,082,000*	*2,053,000*	*2,023,000*	*12,000*	*1,964,000*	*1,932,000*	*1,900,000*	*1,867,000*	*1,834,000*	*1,800,000*	*1,765,000*	*27,832,000*
		%	0.00	43.09	42.56	42.00	41.43	40.86	40.27	39.66	0.46	38.44	37.79	37.14	36.46	35.79	35.10	34.39	37.55
Interests	Annuity	€	0	-1,715,000	-1,715,000	-1,715,000	-1,715,000	-1,715,000	-1,715,000	-1,715,000	-1,715,000	-1,715,000	-1,715,000	-1,715,000	-1,715,000	-1,715,000	-1,715,000	-1,715,000	-25,725,000
	Repayment	€	0	-825,000	-866,000	-910,000	-955,000	-1,003,000	-1,053,000	-1,106,000	-1,161,000	-1,219,000	-1,280,000	-1,344,000	-1,411,000	-1,482,000	-1,556,000	-1,634,000	-17,805,000
	Interests	€	0	-890,000	-849,000	-805,000	-760,000	-712,000	-662,000	-609,000	-554,000	-496,000	-435,000	-371,000	-304,000	-233,000	-159,000	-81,000	-7,920,000
	remaining credit	€	-17,800,000	-16,975,000	-16,109,000	-15,199,000	-14,244,000	-13,241,000	-12,188,000	-11,082,000	-9,921,000	-8,702,000	-7,422,000	-6,078,000	-4,667,000	-3,185,000	-1,629,000	5,000	
EBT		€	*0*	*1,300,000*	*1,315,000*	*1,332,000*	*1,349,000*	*1,370,000*	*1,391,000*	*1,414,000*	*-542,000*	*1,468,000*	*1,497,000*	*1,529,000*	*1,563,000*	*1,601,000*	*1,641,000*	*1,684,000*	*19,912,000*
		%	0	25.58	25.86	26.18	26.50	26.89	27.29	27.72	-20.58	28.73	29.28	29.89	30.53	31.25	32.00	32.81	26.87
carry over loss		€	0	0	0	0	0	0	0	0	0	-542,000	0	0	0	0	0	0	
taxable profit		€	0	1,300,000	1,315,000	1,332,000	1,349,000	1,370,000	1,391,000	1,414,000	-542,000	926,000	1,497,000	1,529,000	1,563,000	1,601,000	1,641,000	1,684,000	
Income Tax		€	0	-325,000	-329,000	-333,000	-337,000	-343,000	-348,000	-354,000	0	-232,000	-374,000	-382,000	-391,000	-400,000	-410,000	-421,000	-4,979,000
Profit / Loss		€	*0*	*975,000*	*986,000*	*999,000*	*1,012,000*	*1,027,000*	*1,043,000*	*1,060,000*	*-542,000*	*1,236,000*	*1,123,000*	*1,147,000*	*1,172,000*	*1,201,000*	*1,231,000*	*1,263,000*	*14,933,000*
		%	0.00	19.19	19.39	19.63	19.88	20.16	20.46	20.78	-20.58	24.19	21.97	22.42	22.89	23.44	24.01	24.61	20.15
	accumulated	€	0	975,000	1,961,000	2,960,000	3,972,000	4,999,000	6,042,000	7,102,000	6,560,000	7,796,000	8,919,000	10,066,000	11,238,000	12,439,000	13,670,000	14,933,000	

Balance Sheet of the best scenario

Periode		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
ASSETS																	
Non current assets	€	23,558,000	21,987,000	20,416,000	18,845,000	17,274,000	15,703,000	14,132,000	12,561,000	14,389,000	12,818,000	11,247,000	9,676,000	8,105,000	6,534,000	4,963,000	3,392,000
Cash	€	42,000	1,763,000	3,454,000	5,114,000	6,742,000	8,337,000	9,898,000	11,423,000	7,892,000	9,480,000	10,894,000	12,268,000	13,600,000	14,890,000	16,136,000	17,336,000
Total Assets	€	**23,600,000**	**23,750,000**	**23,870,000**	**23,959,000**	**24,016,000**	**24,040,000**	**24,030,000**	**23,984,000**	**22,281,000**	**22,298,000**	**22,141,000**	**21,944,000**	**21,705,000**	**21,424,000**	**21,099,000**	**20,728,000**
LIABILITIES																	
Paid In Capital	€	5,800,000	5,800,000	5,800,000	5,800,000	5,800,000	5,800,000	5,800,000	5,800,000	5,800,000	5,800,000	5,800,000	5,800,000	5,800,000	5,800,000	5,800,000	5,800,000
Profit from previous years	€	0	0	975,000	1,961,000	2,960,000	3,972,000	4,999,000	6,042,000	7,102,000	6,560,000	7,796,000	8,919,000	10,066,000	11,238,000	12,439,000	13,670,000
Profit/Loss	€	0	975,000	986,000	999,000	1,012,000	1,027,000	1,043,000	1,060,000	-542,000	1,236,000	1,123,000	1,147,000	1,172,000	1,201,000	1,231,000	1,263,000
Debt	€	17,800,000	16,975,000	16,109,000	15,199,000	14,244,000	13,241,000	12,188,000	11,082,000	9,921,000	8,702,000	7,422,000	6,078,000	4,667,000	3,185,000	1,629,000	-5,000
Total Liabilities	€	**23,600,000**	**23,750,000**	**23,870,000**	**23,959,000**	**24,016,000**	**24,040,000**	**24,030,000**	**23,984,000**	**22,281,000**	**22,298,000**	**22,141,000**	**21,944,000**	**21,705,000**	**21,424,000**	**21,099,000**	**20,728,000**

Liquidy Plan of the best scenario

Periode			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Year			2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	TOTAL
Revenue	Sales	€	0	5,082,000	5,085,000	5,088,000	5,091,000	5,095,000	5,098,000	5,101,000	2,633,000	5,109,000	5,112,000	5,116,000	5,120,000	5,124,000	5,128,000	5,132,000	**74,114,000**
Subsidies	on Investment	€	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
	FIT	€	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Costs	Total	€	0	-1,321,000	-1,350,000	-1,380,000	-1,411,000	-1,442,000	-1,474,000	-1,507,000	-1,050,000	-1,574,000	-1,609,000	-1,645,000	-1,682,000	-1,719,000	-1,757,000	-1,796,000	**-22,717,000**
Debt Service	Repayment	€	0	-825,000	-866,000	-910,000	-955,000	-1,003,000	-1,053,000	-1,106,000	-1,161,000	-1,219,000	-1,280,000	-1,344,000	-1,411,000	-1,482,000	-1,556,000	-1,634,000	**-17,805,000**
	Interests	€	0	-890,000	-849,000	-805,000	-760,000	-712,000	-662,000	-609,000	-554,000	-496,000	-435,000	-371,000	-304,000	-233,000	-159,000	-81,000	**-7,920,000**
Paid In Capital		€	5,800,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5,800,000**
Cash In from Bank - Credit		€	17,800,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**17,800,000**
Tax		€	0	-325,000	-329,000	-333,000	-337,000	-343,000	-348,000	-354,000	0	-232,000	-374,000	-382,000	-391,000	-400,000	-410,000	-421,000	**-4,979,000**
Investment		€	-23,558,000	0	0	0	0	0	0	0	-3,399,000	0	0	0	0	0	0	0	**-26,957,000**
Cash Flow		€	42,000	1,721,000	1,691,000	1,660,000	1,628,000	1,595,000	1,561,000	1,525,000	-3,531,000	1,588,000	1,414,000	1,374,000	1,332,000	1,290,000	1,246,000	1,200,000	**17,336,000**
	accumulated	€	42,000	1,763,000	3,454,000	5,114,000	6,742,000	8,337,000	9,898,000	11,423,000	7,892,000	9,480,000	10,894,000	12,268,000	13,600,000	14,890,000	16,136,000	17,336,000	
Free Cash Flow	free CF	€	-23,558,000	3,436,000	3,406,000	3,375,000	3,343,000	3,310,000	3,276,000	3,240,000	-1,816,000	3,303,000	3,129,000	3,089,000	3,047,000	3,005,000	2,961,000	2,915,000	**19,461,000**
	discounted = NPV	€	-23,558,000	3,235,000	3,018,000	2,815,000	2,625,000	2,447,000	2,280,000	2,123,000	-1,120,000	1,917,000	1,710,000	1,589,000	1,476,000	1,370,000	1,271,000	1,178,000	**4,376,000**
	accumulated	€	-23,558,000	-20,122,000	-16,716,000	-13,341,000	-9,998,000	-6,688,000	-3,412,000	-172,000	-1,988,000	1,315,000	4,444,000	7,533,000	10,580,000	13,585,000	16,546,000	19,461,000	

Sensitivity analysis of the best scenario

	OPEX decrease		**CAPEX decrease**		**Output increase**		**Omega 3 price increase**		**Coal and by product price increase**		**Allowances increase**			**Future scenario**	
	NPV [€]	IRR [%]	NPV [€]	IRR [%]	NPV [€]	IRR [%]	NPV [€]	IRR [%]	NPV [€]	IRR [%]	Price [€]	NPV [€]	IRR [%]	NPV [€]	IRR [%]
0%	4,376,000	2.75	4,376,000	2.75	4,376,000	2.75	4,376,000	2.75	4,376,000	2.75	3	4,376,000	2.75	4,376,000	2.75
1%	4,450,000	2.79	4,547,000	2.87	4,715,000	2.95	4,715,000	2.95	4,376,000	2.75	10	4,448,000	2.79	5,403,000	3.39
3%	4,623,000	2.89	4,926,000	3.16	5,429,000	3.38	5,403,000	3.36	4,401,000	2.76	40	4,557,000	2.85	7,728,000	4.84
5%	4,790,000	2.99	5,367,000	3.50	6,142,000	3.80	6,090,000	3.77	4,425,000	2.78	80	4,774,000	2.98	10,238,000	6.42
10%	5,203,000	3.24	6,352,000	4.33	7,907,000	4.82	7,807,000	4.77	4,475,000	2.81	100	5,214,000	3.24	15,668,000	9.95
20%	6,289,000	3.87	8,413,000	6.31	11,452,000	6.82	11,242,000	6.70	4,585,000	2.87	120	5,435,000	3.37	19,027,000	13.18