Technical Feasibility Study of an Aquaculture Facility for Common Cockle Species in the Netherlands

A Preliminary Design, which includes a Functional and Physical Architecture of a Land-based Aquaculture Facility for Common Cockle (Cerastoderma edule L.) Species in the Netherlands

S. Deen
University of Twente
Enschede, November 2006

Colophon

Title:	**Technical Feasibility Study of an Aquaculture Facility for Common Cockle Species in the Netherlands**	
Subtitle:	**A Preliminary Design, which includes a Functional and Physical Architecture of a Land-based Aquaculture Facility for Common Cockle (*Cerastoderma edule* L.) Species in the Netherlands**	
Author:	S. Deen University of Twente (UT) Study: Civil Engineering (CIT) Department: Water Engineering and Management (WEM)	
Contact:	s.deen@alumnus.utwente.nl	
Committee:	Dr. ir. D.C.M. Augustijn	University of Twente (supervisor) *(department: Water Engineering & Management)*
	Dr. A.C. Smaal	Wageningen IMARES
	Ir. K.Th. Veenvliet	University of Twente *(department: Construction Management & Engineering)*
State:	Final	
Pages:	92 (exclusive appendixes)	
Location:	Enschede, the Netherlands	
Date:	23 November 2006	

2006 University of Twente
P.O. Box 217; 7500 AE Enschede; The Netherlands
Phone: +31 (0)53 489 9111; fax: +31 (0)53 489 2000; e-mail: info@utwente.nl

Wageningen IMARES
P.O. Box 77; 4400 AB Yerseke; The Netherlands
Phone: +31 (0)113 672300; fax: +31 (0)113 573477

Technical Feasibility Study of an Aquaculture Facility for Common Cockle Species in the Netherlands

Figure: Land-based aquaculture facility for ragworms in the Netherlands (www.topsybaits.nl).

A Preliminary Design, which includes a Functional and Physical Architecture of a Land-based Aquaculture Facility for Common Cockle (Cerastoderma edule L.) Species in the Netherlands

WAGENINGEN UR
For quality of life

University of Twente
The Netherlands

S. Deen
University of Twente
Enschede, November 2006

Preface

This report is written in the context of a master thesis at the University of Twente (UT), study Civil Engineering (CIT), department Water Engineering and Management (WEM). The report describes a preliminary design of a land-based aquaculture facility for Common Cockle species (infaunal bivalve species) in the Netherlands. Although, this preliminary design is designed for Common Cockle species it can also be used as a format for land-based aquaculture facilities for other infaunal bivalve species.

This report provides technical information of aspects that must be considered before starting designing a land-based aquaculture facility for infaunal bivalve species. In the report case material is used of Common Cockle species for a land-based aquaculture facility in the Netherlands. This case material is mainly based on available literature. Some case material is gathered by making use of extensive contacts with potential stakeholders. However, stakeholders are not explicitly involved during the gathering process of the requirements. This consideration is made to suppress the complexity of the research.

The report is written according to a systematic design approach. This approach is selected due to the early development stage of the project[1]. In this early development stage it is important that the requirements, at which the functional architecture is based, are described in a flexible way. The flexibility is needed, because the requirements can change in the future[2].

In behalf of the flexibility there is chosen to generate a report in which there is much attention for the requirements and its analysis. The requirements are considered as the foundation of the preliminary design. The requirements are described in a way they can be considered as standalone clusters. These clusters have the advantage that they can be easily transformed into clusters with other requirements. Moreover, some of the clusters can also be reused in similar aquaculture facilities. Besides the requirements, and its analysis, there is also attention for the functional analysis and the allocation of requirements to functional components. The functional analysis and allocation are turned into a functional architecture. The functional architecture is considered as a translation of the requirements into an architecture in which the functionality, including the relations between the different functionalities, of the preliminary design are described. The functional architecture can be considered as a blue print for several physical (or spatial) architectures. Based on the functional architecture an example of a physical architecture is described in this report.

This report is meant for entrepreneurs who consider starting land-based aquaculture facilities for infaunal bivalve species. The report provides information of technical issues which need to be considered before constructing such facilities. Furthermore, the report provides a description, and a foundation (technical requirements), of a functional and a physical architecture. However, the data on which the functional- and physical architecture are based, are not simulated, modeled, experimented, or tested. Therefore, for future research it is recommended that the requirements, which are described in this report, are taken to a next level of development, after which the requirements are added or adjusted. After the addition- and adjustment process the functional- and physical architecture, which are described is this report, need to be updated.

[1] The report describes a preliminary (or so-called feasibility) study. After this study it is recommended to simulate, model, experiment, or test the results.

[2] Next development stages will provide new requirements, which implicates that certain requirements need to be added or adjusted. The flexibility of the report helps to add or adjust requirements into the design, after which the design can be easily updated.

The preparation of this report has been a long and interesting project that would not have been possible without the help and encouragement of my family, friends, supervisors, and all other people who were involved in this project. I would like to thank the following people in particular for their contributions: my supervisor Denie Augustijn for his encouragement, enthusiasm and constructive criticism; and the other members of the graduation committee, Aad Smaal and Karel Veenvliet, for their valuable remarks and suggestions. Furthermore, I want to thank: Pauline Kamermans, Tom Ysebaert, Patrick Bliek, Mindert de Vries, René Wijffels, Bert Meyering, and the ladies of secretary of the department of Water Engineering & Management for their insights and support. And last, but certainly not least, I want to thank my girlfriend Karen for being there and for listening to my stories about this graduation project.

Stefan Deen
November, 2006

Table of contents

APPENDIXES:

Summary

The Netherlands have always been an important country for the production of bivalve species. Although, the production of bivalve species has always been an unpredictable business, because of major fluctuations in the yearly production (Ens *et al.*, 2004), the business was profitable (Salz *et al.*, 2001). Recent development has led to a climate in which bivalve activities has become less attractive or has even been prohibited.

Recently, the Common Cockle species are one the bivalve species which are restricted to several governmental regulations and legal frameworks in the Netherlands. These governmental regulations and legal frameworks have led to a prohibition (since the 1st of January 2005) of the use of mechanical harvesting methods at the Netherlands´ largest production area (Dutch Wadden Sea). Another aspect is the rise of new market demands, which requires more controllable and higher quality products. These recent developments can be seen as a national starting point for generating innovative alternatives to make the continuation of Common Cockle production possible in the Netherlands. The starting point for this master thesis is to generate one of these innovative alternatives, by making a preliminary design of a land-based aquaculture facility for Common Cockle species. The preliminary design is designed in a systematic way, so it can be easily adjusted, updated and transformed into a design for other infaunal bivalve species.

The preliminary design is designed according to five steps which are defined by the Systems Engineering approach of the Department of Defense of the United States of America. The first step is defined as the inputs. The second step is the requirements analysis. The third step is the functional analysis and allocation. The synthesis is described in the fourth step, and in the fifth step, the so-called outputs are described.

Inputs

In the Dutch Wadden Sea traditional Common Cockle fish activities encounter several problems. The first main problem is identified as the prohibition of the mechanical Common Cockle fish activities in the Dutch Wadden Sea. The second identified main problem is the rise of new market demands, which require a more predictable and controllable production of a higher quality Common Cockle species. Initiatives for starting land-based aquacultures in the Netherlands are stimulated by different stakeholders. Some of these stakeholders are able to finance these kinds of initiatives.

From the analysis of the solutions constraints it is found that a land-based aquaculture facility for Common Cockle species is a good solution for solving the defined identified problems in the Netherlands. The analysis of the project constraints shows an overall classification of the primary production process, which is identified as the input-processing-output model. The analysis also provide information of the three main aspects (or so-called phases) of the aquaculture facility. Two of these three phases are defined as the algal culture phase and the Common Cockle culture phase (the two phases together are also called the primary production process). The third phase is defined as the general infrastructure phase (or also called the secondary production process).

In the third chapter the design considerations are considered. The design considerations describe the biological, chemical, and physical characteristics of the Common Cockle species. Furthermore, the design considerations also describe the potential culture methods for the land-based aquaculture facility for Common Cockle species. Based on the described design considerations relevant technical requirements are derived.

Requirements analysis

In the requirements analysis technical requirements are described. These requirements are based on the requirements constraints. Each issue in the requirement analysis is divided in one functional and two non-functional requirements. The functional requirements describe what the product (or design) must do. The non-functional requirements describe what properties the product must have.

In the requirements analysis sub-phases of the phases in the primary production process are identified. In the algal culture phase four sub-phases are identified, these sub-phases are: the stock culture, the starter culture, the intermediate-scale culture, and the large-scale culture. In the Common Cockle culture phase five sub-phases are identified. These sub-phases are: the broodstock conditioning, the reproduction, the larval rearing, the settlement, and the growout.

The requirements analysis describes six systems per sub-phase of the primary production process. These six systems are: the culture of algae / Common Cockles system, the seawater treatment system, the enrichment system, the environmental control system, the effluent treatment system, and the harvest of algae / Common Cockles system. In figure s.1, a flow diagram of the identified six systems, including their input and output, is illustrated.

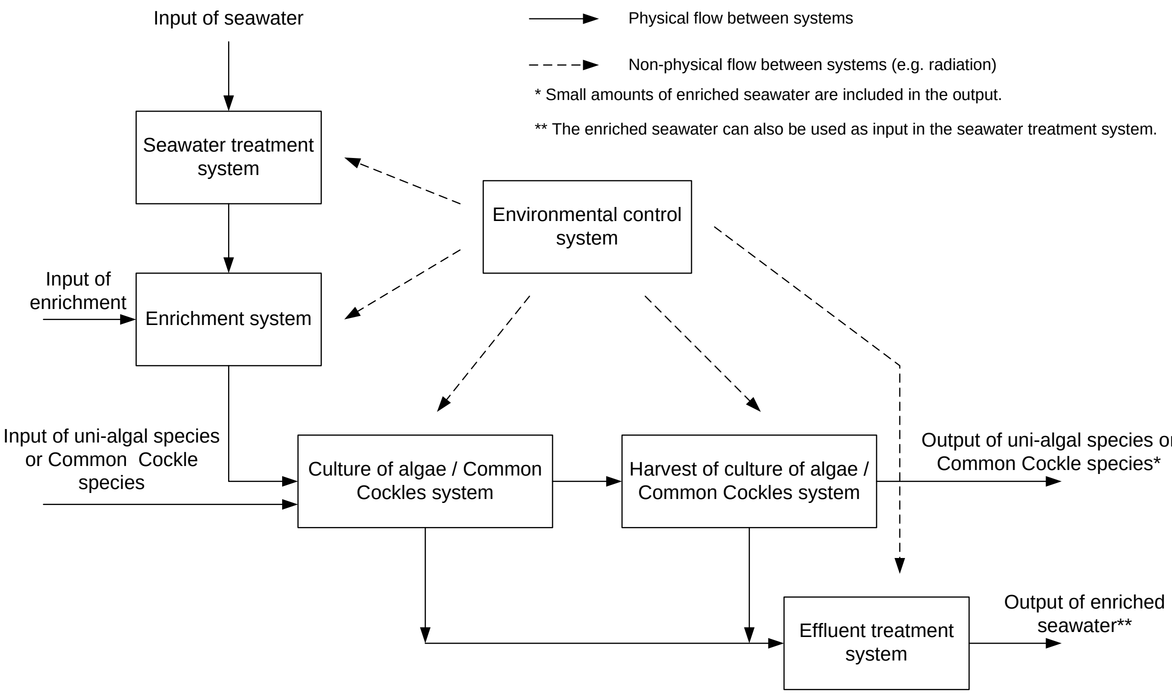


Figure s.1: Flow diagram of the identified six systems.

Functional analysis and allocation

In the functional analysis and allocation a functional architecture is described. This functional architecture describes the relations of the identified sub-systems and units of the aquaculture facility. In addition, all functional requirements are allocated to functional components in the functional architecture. Furthermore, each functional component has two non-functional requirements, which are described in terms of quality and quantity.

Synthesis

In the synthesis the functional architecture is translated into a physical architecture. This architecture is an example of how a functional architecture can be translated into a physical architecture. The physical architecture is derived from the functional architecture.

Outputs

In the outputs the conclusions and recommendation are described. The main conclusion which can be identified is the project is not technical feasible, due to the lack of production capacity of today's 'state-of-the-art' algal production technology. However, in the future an adequate production of uni-algal species can be expected from new technologies (e.g. new generation of photobioreactors). It is recommended to do further research to these new technologies. Furthermore, it is recommended to establish a verification (preferable at the lowest abstraction level as possible) of the systems which are technical feasible.

1 Introduction

Worldwide aquaculture is at an exciting stage of development. World aquaculture production is increasing at a very rapid rate (FAO Inland Water Resources and Aquaculture Service, 2003). It is increasing much more rapidly than animal husbandry and capture (wild) fisheries, which are the two other sources of animal protein for the world's population. There is a wide spread recognition that seafood production from fisheries is at or near its peak, and that aquaculture will become increasingly important as a source of seafood production, and ultimately the main source (Lucas & Southgate, 2003).

This process, which is suggested by Lucas & Southgate (2003), is also noticed in the Netherlands. Traditionally, the Netherlands has a very good position in the European bivalve (mussels, oysters, and clams) markets. In the Netherlands bivalve species are captured (in the wild) or farmed in aquacultures[3], after which they are processed and sold. Recently, these activities are jeopardized, especially of infaunal bivalve species (e.g. Common Cockle species, Surf clam species and Razor shell species), by European and national laws and regulations. On the other side, recent new demands of the market arise. These new demands desire a more sustainable production process, respectively, a more predictable and controllable product.

Figure 1: Infaunal bivalve species, which are native to the surrounding waters of the Netherlands. (a) Common Cockle species (*Cerastoderma edule*), (b) Surf clam species (*Spisula subtruncata*), (c) Razor shell species (*Ensis spp.*) (www.marlin.ac.uk).

Because of European and national laws and regulations, which already have caused a prohibition of the wild mechanical Common Cockle fish activities in the Dutch Wadden Sea[4], and the new demands of the market, a study is started to investigate innovative alternatives to culture infaunal bivalve species in an aquaculture. This report evaluates the technical feasibility of an aquaculture facility for infaunal bivalve species. The evaluation of the technical feasibility is built on a requirements analysis, a functional architecture, and a physical architecture. The starting point of this study is that the aquaculture facility needs to be located onshore, to avoid conflicts with current European (e.g. the European Birds and Habitats Directives) and national laws and regulations that caused the prohibition of the wild fisheries. To avoid the superficiality of the study there is chosen to only make one requirements analysis, one functional architecture, and one physical architecture for one single infaunal bivalve species. For this study, the Common Cockle species are selected, because these species are native in the surrounding waters of the Netherlands and there is a lot of knowledge available of their biological, chemical and physical characteristics. Furthermore, the Common Cockle species still have a high marketable value (Commissie Schadebepaling Kokkelvisserij, 2005). Other candidates of infaunal bivalve species were the Surf clam species, Razor shell species, and the Grooved carpet shell species (*Ruditapes decussates*)[5]. Some of these species are illustrated in figure 1.

---

[3] In the Netherlands most bivalve species are not cultured in intensive land-based aquacultures, but in extensive aquacultures. These extensive aquacultures are located in open water sources, in which bivalve species are transferred from one location to another, to achieve optimal growth.
[4] The background of this problem is further described in the report of LNV (2004).
[5] Kals *et al.* (2005) describes ten potential bivalve species for the Dutch aquaculture sector. The grooved carpet shell species score a fifth place in this list of best potential bivalve species for the Dutch aquaculture sector. The Common Cockle species, Surf clam species and Razor shell species are not included in this list.

Although, there is chosen to investigate the Common Cockle species in this study, it has to be noted that there are only small differences between the Common Cockle species and the other infaunal bivalve species. Because of this reason the functional -and physical architecture are described in a way they can be easily adjusted, updated, and transformed into a functional -and physical architecture for other infaunal bivalve species.

1.1 Problem analysis

In the Dutch Wadden Sea traditional Common Cockle fish activities encounter several problems. These problems can be divided into two main problems, which are legal conflicts and new demands of the market. These two issues are described in this paragraph.

1.1.1 Legal conflicts

On the 1st of October 2004 the Dutch government presented her new long-term national policy for the shellfish sector 2005-2020 (LNV, 2004). In this new policy the Dutch government describes a trend in which they intent to create a sustainable and economically healthy shellfish sector, which production methods respect the natural environment, and, if possible, that these production methods support the natural environment as well. Based on this policy[6] the Dutch government decided to stop giving out new permissions for the mechanical Common Cockle fish activities in the Dutch Wadden Sea per 1 January 2005, because they concluded that these activities were not in line with the sustainable development of this area[7]. Although, wild Common Cockle species are also caught in other areas in the Netherlands, like the Voordelta, Oosterschelde estuary, and the Westerschelde estuary, the largest amounts have always been caught in the Dutch Wadden Sea[8] (Commissie Schadebepaling Kokkelvisserij, 2005).

1.1.2 New market demands

Nowadays, people are living in a 24 hours, 7 days a week, economy. This life style has its effects on the demand of the consumers of the Common Cockle species. These final consumers, which can for example be found in supermarkets, or in the catering industry, require fresh Common Cockle species of an excellent quality throughout the whole year (Luiten, 2004).

Two important aspects which need to be considered in behalf of this second sub-problem are the supply and demand of Common Cockle species. These two considerations have a direct influence on the profitability of the business. It has to be noted that the traditional Common Cockle industry is liable to certain unpredictable (natural) factors. The unpredictable factors have always been a major factor in the supply, demand and price of Common Cockle species, therefore these two issues are further described in this problem analysis.

[6] It should be noted that in the new long-term national policy for the shellfish sector 2005-2020 issues from the European Birds and Habitats have been integrated.

[7] In the Netherlands mechanical Common Cockle fish activities are only allowed if the owners have a permit (which is in fact an exemption of the 'Visserijwet 1963' and the 'Natuurbeschermingswet 1967') of the Minister of 'Landbouw, Natuur and Voedselvoorziening' (LNV).

[8] The prohibition of mechanical Common Cockle fish activities is only restricted to the Dutch Wadden Sea, everywhere else these activities are still legal. Non-mechanical Common Cockle fish activities are still legal through whole the Netherlands (LNV, 2004).

Unpredictability of traditional Common Cockle production

In the Netherlands traditional Common Cockle fish activities are carried out on intertidal flats in the Dutch Wadden Sea, Voordelta, Oosterschelde estuary, and the Westerschelde estuary. Figure 2 illustrates the annual supply (or so-called landing) of Common Cockle species from Dutch coastal water. The trend line in the figure increases every four or five years, when major reproduction is taking place, after which it decreases again (Ens *et al.*, 2004).

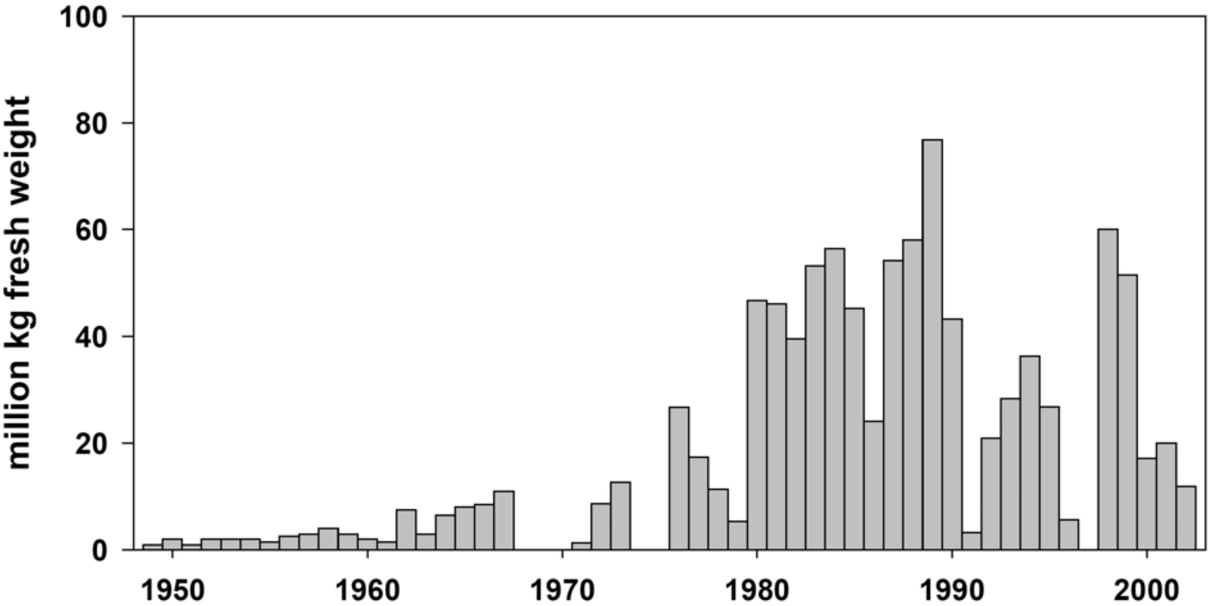


Figure 2: Annual landings of Common Cockle species from Dutch coastal waters (Ens *et al.*, 2004).

Supply, demand and price of Common Cockle species

The Commissie Schadebepaling Kokkelvisserij (2005) describes in their report an average quantity of annual landings of 4 000 ton Common Cockle meat, which is approximately 28 000 ton of fresh weight[9]. In the period 1986-2003 an estimated 30-50% of this 28 000 ton Common Cockle species came from mechanical Common Cockle fish activities from areas in the Dutch Wadden Sea. In the period 2000-2004 it was approximately 85-95% of 14 000 ton (fresh weight).

The demand has, just like the supply, a relation with the price of the Common Cockle species. At the moment the demand of the Common Cockle species is considered as stable (Salz *et al.*, 2001). When the supply is increasing (e.g. in 1998 and 1999) the price of the Common Cockle species is decreasing. The price of the Common Cockle species in the size class 300-400 (amount of individuals per kg) doubles, or has even a higher marketable value than Common Cockle species in the size class 800-1000 (Commissie Schadebepaling Kokkelvisserij, 2005).

As, already has been described, the price of Common Cockle species is a function of supply and demand. In this report is assumed that the price of one kilogram Common Cockles (fresh weight) will be 10 euro in the next eight years. This price is based on Common Cockle species of an 80-100 size class, a stable demand, and a decrease of supply. It is also assumed that the processing and wholesale industry in the Common Cockle sector will not change in the next few years.

[9] The following conversion factor has been used: 1 ton Common Cockle meat (flesh) is equal to 7 ton Common Cockle species in fresh weight (including their shell). Furthermore, in this report 'fresh weight' and 'dry weight' are defined including their shell.

1.2 Objective

Based on the two identified problems an objective for this research has been defined. The objective of this research is to evaluate the technical feasibility of a fully land-based aquaculture facility for Common Cockle (*Cerastoderma edule* L.) species in the Netherlands. In behalf of this evaluation a preliminary design will be made of the aquaculture facility, which includes one requirements analysis, one functional architecture, and one physical architecture.

1.3 Stakeholders

To achieve the objective, which is described above, stakeholders need to be involved. To suppress the complexity of this research there is chosen for a buy-in strategy. In this strategy stakeholders are not directly involved in the design process of the project[10]. Instead, most stakeholders will be involved when most of the preliminary design has been accomplished. The buy-in strategy is chosen because literature sources can provide enough information for making the preliminary design. Nevertheless, it is recommended that stakeholders are involved as soon as possible in the next development stage when a land-based aquaculture facility is proven feasible.

The two most important groups of potential stakeholders of this research are identified as the clients and the potential customers. These two groups are briefly discussed below. Other potential stakeholders, who are identified, are described in appendix I.

Clients

The clients of this research are Wageningen IMARES and the University of Twente. These two institutes have given the assignment to make the preliminary design.

Potential customers

The four Dutch largest Common Cockle processing and wholesale companies[11], which are also major players in the world, are initially identified as the potential customers for this project. These companies are represented by the Dutch Commodity Board of the Common Cockle fisheries (PO Kokkels). These potential customers are chosen because they all have the financial resources to invest in innovative aquaculture facilities in the Netherlands. However, if other companies also have these financial resources they can be added to the list of potential customers.

1.4 Scope of the project

As defined in the objective, this research will evaluate the technical feasibility of a fully land-based aquaculture facility for Common Cockle species in the Netherlands. The technical feasibility is in fact only a part of the overall feasibility of the project, because the overall feasibility of aquacultural projects consists of technical, financial and socio-economic factors (Lucas & Southgate, 2003). The technical, financial and socio-economic factors of the overall feasibility are interrelated with each other, which is illustrated in figure 3.

[10] The opposite of a buy-in strategy is a bought-in strategy. In a bought-in strategy stakeholders are directly involved in the design process (Grinter, 1999). This involvement will get a climax in the requirements gathering process.

[11] The four largest Dutch processing and wholesale companies are Holland Shellfish International, Roem van Yerseke, Prins & Dingemanse, and Landa Conserven (Commissie Schadebepaling Kokkelvisserij, 2005).

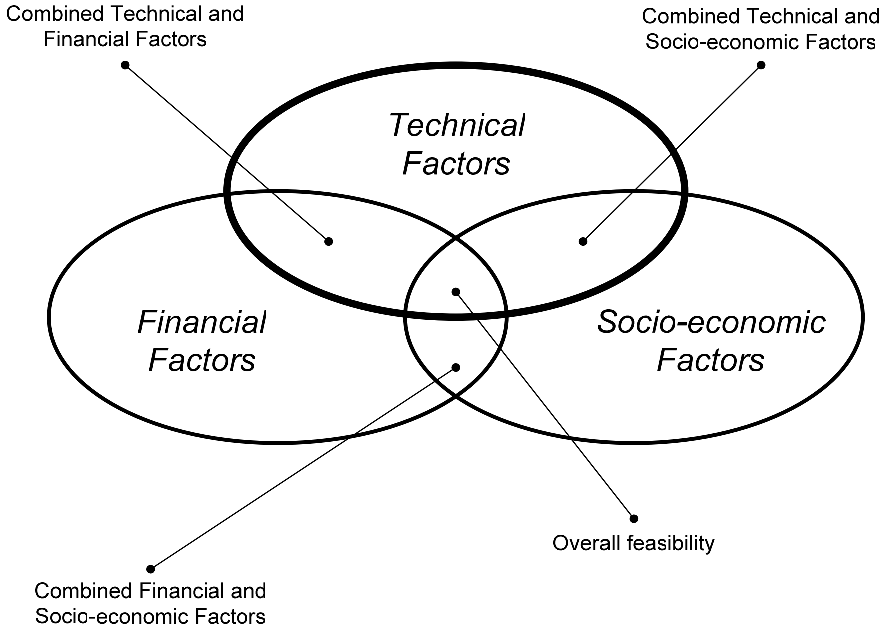


Figure 3: Interrelationship of the factors in the overall feasibility.

Although the financial (or business) -and the socio-economic factors of the overall feasibility are not in the scope of this project, they will not interfere with the development of the design process, due to the early development stage of the project[12]. The technical feasibility is described by a preliminary design of the land-based aquaculture facility for Common Cockle species in the Netherlands. The preliminary design includes one requirements analysis, one functional architecture, and one example of a physical architecture[13]. Based on the defined requirements and the translation of these requirements into the architectures, the output (conclusions and recommendations) determines the technical feasibility of the land-based aquaculture facility for Common Cockle species in the Netherlands.

1.5 Strategy of research

In this chapter the strategy is described which is used to achieve the objective of the research. The strategy is described according to a research model and research questions.

1.5.1 Research model

The preliminary design will be developed according to a systematic design process, which is called the Systems Engineering process. This systematic design process is a comprehensive, iterative, and recursive problem solving process, which ensures that needs and requirements are transformed into a set of system product and process descriptions, information is generated for decision makers, and that input is provided for the next level of development (probably the simulation, modeling, experimenting or testing stage) (Defense Systems Management College Press, 1999).

[12] Although the financial (or business) -and socio-economic factors are not in the scope of the research, it is recommended that they will be considered as soon as possible in the next development stages. If the technical and the socio-economic factors are not considered in next development stages the risks of failure of the project are increasing.
[13] It has to be noted that there is no location defined in which the physical architecture needs to be set. This implies that the physical architecture can not be a detailed physical architecture. Therefore, the physical architecture will only be an example of how a functional architecture can be translated into a physical architecture.

Based on the Systems Engineering process a research model is derived for this specific research. The research model is given in figure 4.

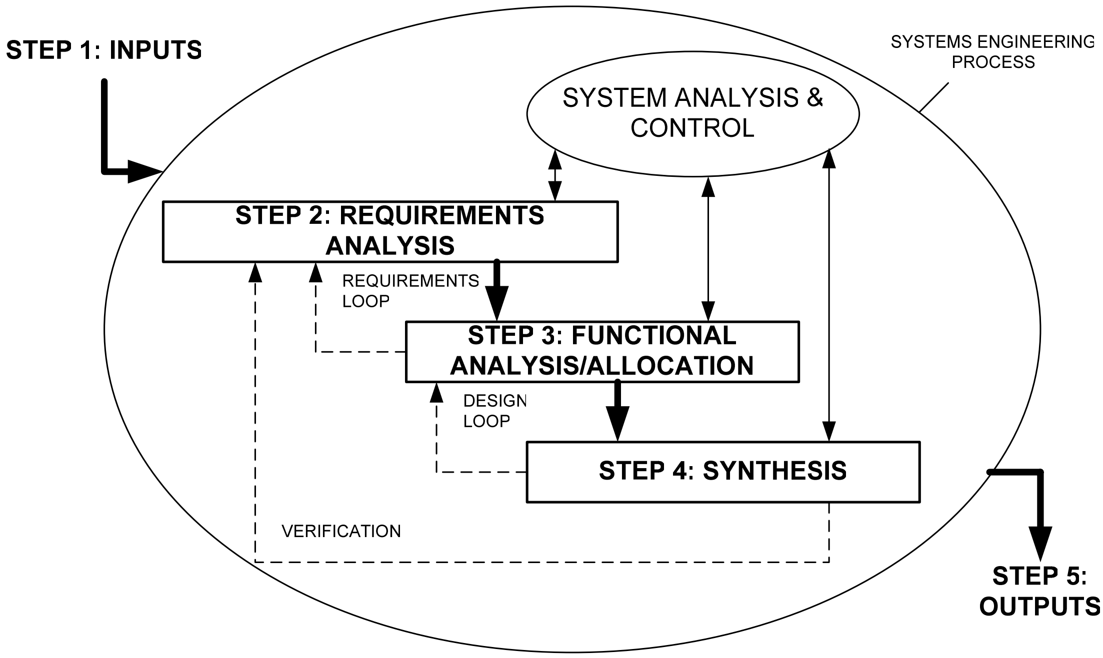


Figure 4: Research model, based on the Systems Engineering process.

The research consists of five steps. Besides the inputs and outputs of the process, the Systems Engineering process, itself, consists of a requirements analysis, a functional analysis and allocation, and a synthesis. Besides the five different steps, the research model also includes a management mechanism, which is called the systems analysis and control, and three different loops. The three different loops are: the requirements loop, the design loop, and the verification. In the next sections the elements of the research model are described in more detail.

Step 1: Inputs

The inputs of the research model consist primarily of the customer needs (described in the problem analysis), the objective, a small stakeholders analysis, the scope of the project, the research strategy, and an overview of used terms and definitions. Furthermore, the inputs describe the requirements constraints and the relevant facts and assumptions (described in the design considerations)[14].

Step 2: Requirements analysis

In the second step of the research model technical requirements are defined. In this project these requirements are mainly derived from available literature sources. After the requirements are defined they are analyzed in a requirements analysis.

[14] Relevant facts and assumptions need to be described in the inputs, because many technical requirements are derived from the relevant fact and assumptions.

Step 3: Functional analysis and allocation

The third step of the research model is to translate (or analyze) the requirements, which are identified in the requirements analysis, into a set of functions. The results of this analysis will be a description of the aquaculture facility in terms of what it must logically do and in terms of the performance (quality and quantity) required. This description is called the functional architecture (Defense Systems Management College Press, 1999).

Functional analysis and allocation allow for a better understanding of what the aquaculture facility must do, in what way it can do it, and to some extent, the priorities and conflicts associated with lower-level functions. It provides information essential to optimizing physical solutions.

Requirements loop

After the third step the technical requirements are reconsidered in the requirements loop, based on the results of the functional analysis and allocation[15]. The requirements loop is necessary because the functional analysis and allocation results in a better understanding of the requirements, which requires updates of the previous steps.

Step 4: Synthesis

The fourth step of the research model is the synthesis. In the synthesis the aquaculture facility is identified in terms of physical elements which together make up, and define, the product. The result is referred to as the physical architecture. Each part must meet at least one functional requirement, and any part may support many functions. The physical architecture is the basic structure for generating the specifications for the final design.

Design loop

Similar to the requirements loop, the design loop is the process of revisiting the functional architecture to verify that the physical architecture meets the required functions at the required level of performance[16]. The design loop permits reconsideration of how the system will perform its mission.

Verification

For each application of the design process, the solutions have to be compared with the requirements. This part of the process is called the verification loop, or more commonly, verification[17].

Step 5: Outputs

In the fifth step of the process outputs are presented. The outputs are the conclusions and recommendations in behalf of the technical feasibility of a land-based aquaculture facility for Common Cockle species in the Netherlands. These conclusions and recommendations are derived from the requirements analysis, functional architecture, and physical architecture. The outputs are meant to provide baselines of specifications which can be used for the next development stages, which are probably simulation, modeling, experimenting, or testing stages[18].

[15] The requirements loops are not found in this report, because the report only describes the final requirements analysis. Nevertheless, the requirements loops are integrated in the design process.

[16] The design loops are not found in this report, because the report only describes the final functional analysis and allocation, after the design loops. Nevertheless, the design loops are integrated in the design process.

[17] In contrast to the requirements loops and to the design loops the verification is described in paragraph 5.6.

[18] It has to be noted that it is very important that not only technical factors are considered for the baseline of specifications, but also financial and socio-economic factors (see paragraph 1.4).

Systems analysis and control (SAC)

In this research systems analysis and control is not considered as a separate step in the research model. The systems analysis and control is considered as a mechanism which include technical management activities required to measure progress, evaluate and select alternatives, and document data and decisions (Systems Engineering College, 2001). These activities apply to all steps of the research model.

Advantages of SAC in SE-processes

The purpose of the systems analysis and control has been an important consideration for choosing the Systems Engineering (SE) approach for this research, because many advantages of the Systems Engineering approach are managed by this mechanism. The considered advantages of the systems analysis and control, and indirectly of the Systems Engineering process, are that it ensures that (Systems Engineering College, 2001)[19]:

(1) Solution alternative decisions are made only after evaluating the impact on system effectiveness, life cycle resources, risk, and customer requirements;
(2) Technical decisions and specifications requirements are based on Systems Engineering outputs;
(3) Traceability from Systems Engineering process inputs to outputs is maintained;
(4) Schedules for development and delivery are mutually supportive;
(5) Required technical disciplines are integrated into the Systems Engineering effort;
(6) Impacts of customer requirements on resulting functional and performance requirements are examined for validity, consistency, desirability and attainability, and;
(7) Product and process design requirements are directly traceable to the functional and performance requirement they were designed to fulfill, and vice versa.

The seven activities, which are described above, can be managed by system analysis activities, which evaluate alternative approaches to satisfy technical requirements and program objectives, and provide a rigorous quantitative basis for selecting requirements. The systems analysis activities include trade-offs studies, effectiveness analyses, and design analyses. The seven activities can also be managed by control activities. The control activities include risk management, configuration management, data management, and performance-based programs (Systems Engineering College, 2001).

Disadvantages of SAC in SE-processes

Although, the seven advantages, which are described above, are very useful for this project at a long-term, it has to be noted that the activities which have to be implemented implicate an enormous effort in the first period after starting the project. Based on this consideration, and by keeping the initial time constraint of 18 weeks[20] in mind, only a few activities are implemented in this report.

Implemented SAC-activities

The systems analysis activities which are implemented in the research are a problem analysis, a small stakeholders analysis, an analysis of the requirements constraints, an analysis of the relevant facts and assumptions (so-called design considerations), an analysis of the technical requirements, a functional analysis (including the allocation of requirements to function components), and a physical design analysis. All the systems analysis activities are mainly based on available literature. This literature is considered as correct information.

[19] It has to be noted that these advantages are overall advantages of the Systems Engineering process.
[20] The initial time constraint (which is in fact one of the project constraints of the research itself) is based on the initial planning of this project. The initial planning is described in the design of research.

The implemented control activities involve mainly process management, configuration management and data management. The three different loops in the process can be considered as examples of process management. The three loops are giving the process an iterative character. The main objective for using a specific configuration management is to make relations between requirements and other components of the functional architecture and the physical architecture directly visible. An example of a specific configuration management element is the traceability code, which is given to every design element in the design process. The objective of the data management is to make the preliminary design flexible, so future requirements can be easily implemented and the preliminary design can be easily updated. A specific element of data management, used in this report, is the different components within the decomposition levels (phases, sub-phases, systems, etc). These components (e.g. the six systems which are identified in the requirements analysis) can be considered as standalone elements. The standalone elements can be easily adjusted or reused in next development stages or other aquaculture facilities.

1.5.2 Research questions

The research questions of this project are derived from the research model, which is described in figure 4. The research questions are divided into five central questions. Each of the central questions is divided into several sub-questions. The five central questions, with its sub-questions, are described below.

Step 1: Inputs

What are the inputs of the research?

1. What are the clients' problems and needs?
2. What is the objective of the research?
3. Who are relevant stakeholders in the research?
4. Which relevant requirements constraints can be identified?
5. Which relevant facts and assumptions, or so-called design considerations, can be identified?

Step 2: Requirements analysis

What are the relevant fundamentals of the land-based aquaculture facility for Common Cockle species, in terms of technical requirements?

1. Which relevant technical requirements can be identified?
2. Which relevant decomposition levels (until systems) can be identified?

Step 3: Functional analysis and allocation

Which relevant functional components, including relations between the functional components, can be identified?

1. Which relevant functional components can be identified, due to the identified decomposition levels?
2. Which relevant relations can be identified between the identified functional components?

Step 4: Synthesis

How can the land-based aquaculture facility for Common Cockle species be identified, in terms of physical elements, based on the functional architecture?

1. Which relevant considerations, in terms of physical elements, can be identified for the land-based aquaculture facility for Common Cockle species, at building level (until system level)?
2. Which relevant considerations, in terms of physical elements, can be identified for the land-based aquaculture facility for Common Cockle species at location level (until system level)?

Step 5: Outputs

What can be learned from this research?

1. Which relevant conclusions can be identified?
2. Which relevant recommendations can be identified?

1.6 Structure of the report

This report consists of eight chapters. In the first chapter the introduction has been described. In this introduction the clients' problem and needs, the objective of the research, and the relevant stakeholders are described. The second chapter describes the requirements constraints. The relevant facts and assumptions, or so-called design considerations, are describes in chapter 3. Chapter 4 describes the functional architecture, which is derived from the requirements analysis, and the functional analysis and allocation. Chapter 5 describes an example of a physical architecture at building level and location level. Chapter 6 describes the conclusions and recommendations. In seventh chapter the terms and definitions, which are used in the report, are described. And in the last chapter, chapter 8, the references of this research are listed.

2 Requirements constraints

The requirements constraints are global requirements, which apply to the entire, or at least most, of the requirements that have to be defined for designing an aquaculture facility (Robertson *et al.*, 1999). They refer to any limitations in the way the facility is designed and build.

Requirements constraints can be divided in solution constraints and project constraints (Robertson *et al.*, 1999). Solution constraints are limitations which provide a framework in which the solution of the problem needs to be found. Project constraints provide limitations of the chosen solution, or alternative.

2.1 Solution constraints

As described in the problem analysis (paragraph 1.1) two major problems are defined for the traditional Common Cockle fish activities in the Dutch Wadden Sea. The first problem is defined as the prohibition of mechanical Common Cockle fish activities in the Dutch Wadden Sea, because these activities were not considered, by governmental authorities, as sustainable. The second problem is defined as the constant demand for high quality Common Cockle species by the market. By analyzing the two problems a vision is established to change the traditional production methods into innovative production methods, which are legal, sustainable and which fits new market demands. A land-based aquaculture facility for Common Cockle species fits within the vision of innovative production methods. Therefore, the land-based aquaculture facility for Common Cockle species is chosen as potential solution to solve the two problems. This solution is actually based on certain criteria, the so-called solution constraints.

The identified solution constraints are defined into four solution constraints in the problem domain, and five solution constraints in the solution domain. The solution constraints are described briefly in this paragraph. More detailed information about the solution constraints can be found in appendix II.

2.1.1 Problem domain

The rationale of the solution constraints in the problem domain is that the solution needs to be able to fill the production gap of the traditional Common Cockle production. Therefore, the solution needs to produce Common Cockle species (SC-1). In addition, the innovative solution needs to be legal (SC-2), sustainable (SC-3), and needs to comply with new market demands (SC-4).

An overview[21], including the fit criteria, of the solution constraints in the problem domain are described below.

Requirement #:	SC-1
Description:	The innovative solution needs to produce Common Cockle species (Cerastoderma edule).
Fit Criterion:	The Common Cockle species which need to be produced need to be of the 'edule' family and of the genus 'Cerastoderma'.

Requirement #:	SC-2
Description:	The innovative solution needs to be legal.
Fit Criterion:	The innovative solution needs to be legal according to Dutch governmental laws and regulations.

[21] The rationale is excluded in the overview, because the rationales of the solution constraints already have been described in the introduction (chapter 1).

Requirement #: SC-3
Description: The innovative solution needs to be sustainable.
Fit Criterion: The production methods of the new innovative solution must not pollute or damage habitats as defined by European and national laws and regulations.

Requirement #: SC-4
Description: The innovative solution needs to fit new market demands.
Fit Criterion: The innovative solution needs to have a production of an adequate quality and quantity. Furthermore, the innovative solution needs to be able to deliver Common Cockle species of a size of 30-40 mm to the market every two months.

Based on these four solution constraints the solution of the land-based aquaculture facility for Common Cockle species is found[22]. It is assumed that this land-based aquaculture facility fits the four solution constraints, which are described above.

2.1.2 Solution domain

The solution constraints in the solution domain provide limitations to the solution. The solution constraints in the solution domain, including their rationale and fit criteria, are described below.

Requirement #: SC-5
Description: The aquaculture facility for Common Cockle species needs to be located onshore.
Rationale: If the aquaculture facility is located onshore governmental laws and regulations, which are the cause the legal conflicts, have no effect on the production of Common Cockle species anymore.
Fit Criterion: At least 90% of all constructions of the aquaculture facility need to be located onshore.

Requirement #: SC-6
Description: The aquaculture facility needs to have its own live phytoplankton supply.
Rationale: Phytoplankton (also called algae) is the main food source of Common Cockle species. Live phytoplankton always needs to be available to feed the Common Cockle species in the Common Cockle culture.
Fit Criterion: Adequate quantity of uni-algal (mono-specific) species of an adequate quality needs to be produced, at a specific location (algal culture) at the site, for the production process of the Common Cockle species (Common Cockle culture).

Requirement #: SC-7
Description: The aquaculture facility needs to have its own seawater supply.
Rationale: An own seawater supply minimizes the risk of no-supply, contamination, etc.
Fit Criterion: The primary production processes (algal culture and Common Cockle culture) in the aquaculture facility needs to have its own seawater supply.

[22] Other alternatives, other than the land-based aquaculture facility for Common Cockles species, are not considered in this study.

Requirement #: SC-8
Description: The aquaculture facility needs to have its own general infrastructure.
Rationale: General infrastructure (or the so-called secondary production process) is needed for supporting the primary production processes (algal culture and Common Cockle culture) like production, distribution and sale of the products.
Fit Criterion: The general infrastructure needs to have functions for general systems (power system, air ventilation systems, emergency systems, and maintenance systems), employees/guest facilities (working facilities, general facilities, and relaxing facilities), and the distribution systems (goods systems, and utility systems).

Requirement #: SC-9
Description: The aquaculture facility needs to be financial profitable.
Rationale: The aquaculture facility for Common Cockle species needs to be a commercial venture, which needs to make profit to survive.
Fit Criterion: The aquaculture facility needs to have a financial break-even point in less than 8 years, and it needs to have an annual internal rate of return (IRR) of 15.0 % or more. Furthermore, the financial risks of the facility need to be kept to a minimum.

2.2 Project constraints

By analyzing the solution constraints it is found that there are four solution constraints which have a functional character. The four solution constraints, which describe the functional character (or so-called functional solution constraints) are SC-1, SC-6, SC-7, and SC-8. After translation of the functional solution constraints into functional components, the following functional components are identified: a Common Cockle production, a live phytoplankton production, a seawater supply, and a general infrastructure. In the project constraints these four functional solution constraints are described in a non-functional[23] way, after which they are called project constraints. The project constraints are described per functional solution constraint-issue, including their rationale and fit criteria. By analyzing the project constraints a structure is identified in the primary production process (PC-1 to PC-18). This structure is defined as an 'input-processing-output'- model. This model (figure 5) is also used to categorize the project constraints of the primary production process.

Figure 5: 'Input-processing- output'-model.

For a detailed overview, the project constraints are also described in appendix III.

2.2.1 Common Cockle production, based at SC-1

Inputs

Requirement #: PC-1
Description: The intake (input) of the Common Cockle species, in the primary production process (Common Cockle culture), needs to be of an adequate quality.
Rationale: The intake of the Common Cockle species needs to be of an adequate quality, to ensure an adequate quality of production at the end of the production process.
Fit Criterion: The Common Cockle individuals (breeders) need to have a size of 30-40 mm, they need to be able to spawn, and males, as well as females, need to be used.

[23] In this report non-functional constraints/requirements are characterized by descriptions of the required quality and the required quantity of diverse functional components.

Requirement #: PC-2
Description: The intake (input) of the Common Cockle species in the primary production process (Common Cockle culture) needs to be of an adequate quantity.
Rationale: The intake needs to be of an adequate quantity to ensure adequate quantity of production at the end of the production process.
Fit Criterion: The quantity of the intake of the Common Cockle species needs to be 20 Common Cockle individuals (breeders) to provide life of 10 000 Common Cockle individuals (measured at the harvest (output) of the Common Cockle culture) per year.

Processing

Requirement #: PC-3
Description: The production (processing) of the Common Cockle species (in the Common Cockle culture) needs to have an adequate quality.
Rationale: If the production is of an adequate quality the Common Cockle species are also of an adequate quality, after which they are supplied to the market.
Fit Criterion: The quality of the production process of Common Cockle species needs to approve market demands and Dutch/European legal demands. For example, the production process of the Common Cockle species and the Common Cockle species itself need to approve the demands of the Dutch Food and Consumer's Product Safety Authority (VWA).

Requirement #: PC-4
Description: The production (processing) of the Common Cockle species (in the Common Cockle culture) needs to supply an adequate quantity.
Rationale: Enough Common Cockle species need to be produced to supply the market and to make profit.
Fit Criterion: The quantity of the annual production of Common Cockle species need to be at least 200 ± 50 ton (fresh weight). This weight is based on 0.7% of the average annual wild production of Dutch Common Cockle species over the period 1986-2003 (Commissie Schadebepaling Kokkelvisserij, 2005).

Outputs

Requirement #: PC-5
Description: The harvest (output) of the production process of Common Cockle species (in the Common Cockle culture) needs to have an adequate quality.
Rationale: The Common Cockle species are sold to the market, therefore they need to have an adequate quality.
Fit Criterion: The quality of the production process of Common Cockle species needs to approve market demands and Dutch/European legal demands. For example, the production process of the Common Cockle species and the Common Cockle species itself need to approve the demands of the Dutch Food and Consumer's Product Safety Authority (VWA).

Requirement #: PC-6
Description: The harvest (output) of the production process of Common Cockle species (in the Common Cockle culture phase) needs to have an adequate quantity.
Rationale: Enough Common Cockle species need to be harvested to supply the market and to make profit.
Fit Criterion: Every two months 1/6th of the annual production of Common Cockle species need to be harvested.

2.2.2 Live phytoplankton production, based at SC-6

Inputs

Requirement #:	PC-7
Description:	The intake (input) of live phytoplankton into the production process of the Common Cockle species needs to be of an adequate quality.
Rationale:	For optimal growth of the Common Cockle species good quality of food (live phytoplankton) is needed.
Fit Criterion:	The live phytoplankton needs to consist of a mix of uni-algal species. Furthermore, the uni-algal species need to be of the right size to ensure optimal feeding behavior of Common Cockle species.

Requirement #:	PC-8
Description:	The intake (input) of live phytoplankton into the production process of the Common Cockle species needs to be of an adequate quantity.
Rationale:	For optimization of the growth of the Common Cockle species an adequate quantity of food (live phytoplankton) is needed.
Fit Criterion:	The quantity of live phytoplankton (or uni-algal species) needs to be of an adequate quantity per life stage of the Common Cockle species.

Processing

Requirement #:	PC-9
Description:	The production (processing) of live phytoplankton (or uni-algal species), in the algal culture, needs to have an adequate quality.
Rationale:	For optimal growth of the Common Cockle species good quality of food (live phytoplankton) is needed.
Fit Criterion:	The live phytoplankton needs to consist of a mix of uni-algal species. Furthermore, the uni-algal species need to be of the right size to ensure optimal feeding behavior of Common Cockle species.

Requirement #:	PC-10
Description:	The production (processing) of live phytoplankton (or uni-algal species), in the algal culture, needs to have an adequate quantity.
Rationale:	For optimization of the growth of the Common Cockle species an adequate quantity of food (live phytoplankton) is needed.
Fit Criterion:	The quantity of live phytoplankton (or uni-algal species) needs to be of an adequate quantity per life stage of the Common Cockle species.

Outputs

Requirement #:	PC-11
Description:	The harvest (output) of live phytoplankton (or uni-algal species) needs to have an adequate quality.
Rationale:	The output of the live phytoplankton (or uni-algal species) is used as a food source for the Common Cockle species. Furthermore, the effluents need to fit governmental laws and regulations, and may not harm the surrounded marine habitats and ecosystems.
Fit Criterion:	Live phytoplankton needs to consist a mix of uni-algal species of an adequate size. Furthermore, the effluents need to be treated to an acceptable quality, before the seawater can be discharged.

Requirement #: PC-12
Description: The harvest (output) of live phytoplankton (or uni-algal species) needs to have an adequate quantity.
Rationale: The output of the live phytoplankton (or uni-algal species) is used as a food source for the Common Cockle species. Furthermore, the effluents need to fit governmental laws and regulations, and may not harm the surrounded marine habitats and ecosystems.
Fit Criterion: The quantity of live phytoplankton (or uni-algal species) needs to be of an adequate quantity per life stage of the Common Cockle species. Furthermore, the volume of effluents need to fit governmental laws and regulations, and do not need to harm the surrounded marine habitats and ecosystems.

2.2.3 Seawater supply, based at SC-7

Inputs

Requirement #: PC-13
Description: The intake (input) of seawater in the algal culture, as in the Common Cockle culture, needs to have an adequate quality.
Rationale: For optimization of the growth of the Common Cockle species (in Common Cockle culture), and the uni-algal species (in algal culture), good quality seawater is needed.
Fit Criterion: The seawater needs to be brought to a level of quality which is achievable with 'state of the art' water treatment equipment.

Requirement #: PC-14
Description: The intake (input) of seawater in the algal culture, as in the Common Cockle culture, needs to have an adequate quantity.
Rationale: For optimization of the growth of the Common Cockle species (in Common Cockle culture), and the uni-algal species (in algal culture) adequate quantity seawater is needed.
Fit Criterion: Common Cockle species and uni-algal species need to be cultured at (assumed) optimal quantity of seawater.

Processing

Requirement #: PC-15
Description: The production (processing) of seawater in the algal culture, as in the Common Cockle culture, needs to have an adequate quality.
Rationale: For optimization of the growth of the Common Cockle species (in Common Cockle culture), and the uni-algal species (in algal culture), good quality seawater is needed.
Fit Criterion: The seawater needs to be brought to a level of quality which is achievable with 'state of the art' water treatment equipment.

Requirement #: PC-16
Description: The production (processing) of seawater in the algal culture, as in the Common Cockle culture, needs to have an adequate quantity.
Rationale: For optimization of the growth of the Common Cockle species (in Common Cockle culture), and the uni-algal species (in algal culture) adequate quantity seawater is needed.
Fit Criterion: Common Cockle species and uni-algal species need to be cultured at (assumed) optimal quantity of seawater.

Outputs

Requirement #: PC-17
Description: The output of seawater in the algal culture, as in the Common Cockle culture, needs to have an adequate quality.
Rationale: The output of the seawater supply is used as input for the production process of live uni-algal species (algal culture) and for the production process of Common Cockle species (Common Cockle culture). Furthermore, the effluents need to fit governmental laws and regulations, and do not need to harm the surrounded marine habitats and ecosystems.
Fit Criterion: The seawater needs to be of a level of quality which is achievable with 'state of the art' water treatment equipment. Furthermore, the effluents need to be treated to an acceptable quality, before the seawater can be discharged.

Requirement #: PC-18
Description: The output of seawater in the algal culture, as in the Common Cockle culture, needs to have an acceptable quantity.
Rationale: The output of the seawater supply is used as input for the production process of live uni-algal species (algal culture) and for the production process of Common Cockle species (Common Cockle culture). Furthermore, the effluents need to fit governmental laws and regulations, and do not need to harm the surrounded marine habitats and ecosystems.
Fit Criterion: The seawater needs to be of a level of quantity which is achievable with 'state of the art' water treatment equipment. Furthermore, the quantity of the effluents need to be of an acceptable quantity.

2.2.4 General infrastructure, based at SC-8

Requirement #: PC-19
Description: The general infrastructure (or so-called secondary production process), which supports the primary production processes of the Common Cockle species (Common Cockle culture) and uni-algal species (algal culture), needs to be of an adequate quality.
Rationale: The secondary production process, like accounting, distribution, etc, has also have its effects on the quality and quantity of the final product (adult Common Cockle species of a marketable size).
Fit Criterion: Accounting and distribution need to be of a quality, so that the final products (Common Cockle species) are not, or very slow (within VWA-constraints), decreasing, after the harvest of the products at the end of the primary production process (implies conditioning).

Requirement #: PC-20
Description: The general infrastructure (or so-called secondary production process), which supports the primary production processes of the Common Cockle species (Common Cockle culture) and uni-algal species (algal culture) needs to be of an adequate quantity.
Rationale: The secondary production process, like accounting, distribution, etc, has also have its effects on the quality and quantity of the final product (adult Common Cockle species of a marketable size).
Fit Criterion: Accounting and distribution need to be of a quality, so that the final products (Common Cockle species) are not, or very slow (within VWA-constraints), decreasing, after the harvest of the products at the end of the primary production process (implies conditioning).

2.3 Analysis of requirements constraints

The project constraints which are described above, and which are based on the functional solution constraints, have a certain relation with each other. These relations are shown in figure 6.

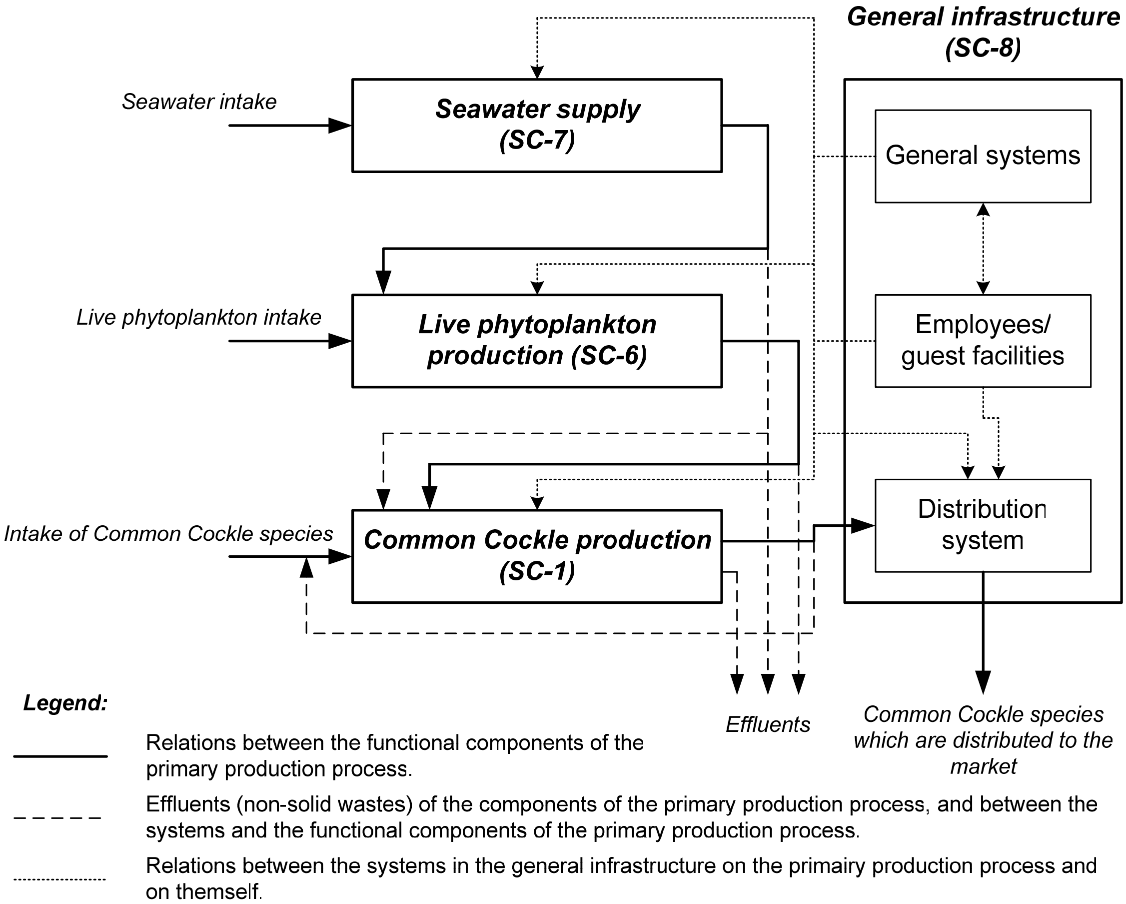


Figure 6: Relations within the primary production process (SC-1, SC-6, and SC-7) and secondary production process (SC-8).

Figure 6 depicts the relations of the primary production process of Common Cockle species, by making use of seawater supply, live phytoplankton production, and adult Common Cockle species (so-called breeders[24]) as inputs. The seawater supply and the live phytoplankton production are having inputs of, respectively, seawater from an open water source, and uni-algal species from culture collections, maintained by reputable national institutes or research laboratories. The output of the Common Cockle production are adult Common Cockle species (of a size of 30-40 mm), which are distributed with the distribution system (part of the general infrastructure). This distribution system distributes the Common Cockle species at the aquaculture facility, but it also ensures that the Common Cockle species are distributed to the market. Effluents of the seawater supply, live phytoplankton production, and Common Cockle production need to be treated to an adequate quality of seawater, after which the seawater is returned to the open water source.

Figure 6 also describes the relations of the secondary production process (general infrastructure) in the whole process. The general systems and the employees/guest facilities of the general infrastructure have also relations with each other, with the distribution system, and with all other functional components (seawater supply, live phytoplankton production, and Common Cockle production) of the primary production process. The rationale of the relations, between the secondary production process and the primary production process, is to support the primary production process.

[24] Breeders are adult Common Cockle species which are used for the reproduction of the Common Cockle stock.

3 Design considerations

For designing a commercial land-based aquaculture facility for Common Cockle species in the Netherlands, and before starting analyzing the requirements, certain relevant facts and assumptions (so-called design considerations) need to be considered first.

Lucas & Southgate (2003) defined four components which are influencing design considerations of a commercial aquaculture facility. These components, which are inter-related, consider the cultured species (biological, chemical, and physical characteristics), the culture methods (structure, intensity, and the type of systems), site considerations, and economical (or financial) considerations. Furthermore, Pillay (1992) suggests that such considerations also need to be set in a social environment, because the importance of governmental laws and regulations, and the rights of other involved participants, like involved civilians, Water Board, etc.

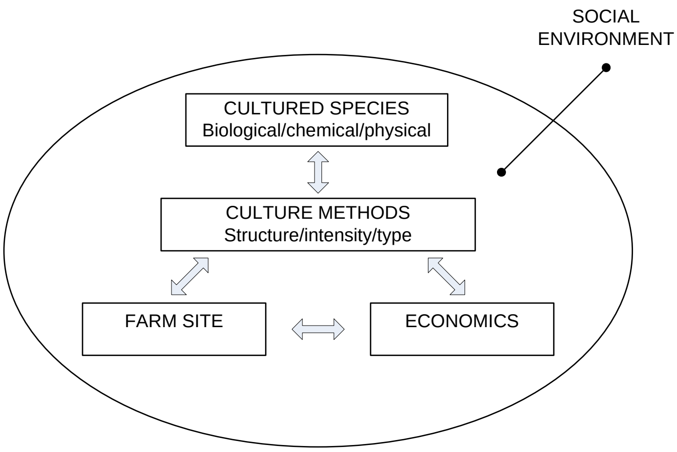


Figure 7: The inter-relationships of design consideration components (cultured species, culture methods, farm site, economics and social environment of a commercial aquaculture facility.

Based on the five components, described in figure 7, the most relevant requirements can be identified for the aquaculture facility for Common Cockle species. Nevertheless, in this report only the relevant technical requirements will be identified. The technical requirements are primarily derived from two components[25], which are: the cultured species and the culture methods. The two components are further described in the next paragraphs.

3.1 Cultured species

In this paragraph the biological, chemical, and physical relevant facts and assumptions are described for the Common Cockle species, as well as for the live phytoplankton species, which are used as food supply for the Common Cockle species.

[25] Although, the technical requirements are primarily derived from the cultured species and culture methods, it has to be noted that other considerations, like the site considerations, financial or (business) considerations, and the socio-economic considerations, can also have an indirect effect on the technical requirements. However, this indirect effect is not integrated in the research.

3.1.1 *Taxonomy and anatomy*

Common Cockle (*Cerastoderma edule*) species belong to the Phylum of Mollusca, in the class of Bivalvia, order Venerioda (Clams, Cockles, Mussels, Oyster, and Scallops).

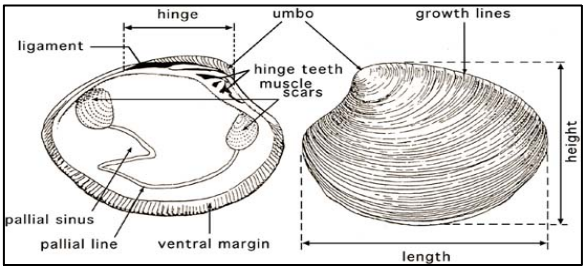


Figure 8: External and internal features of a bivalve clam (Helm & Bourne, 2004).

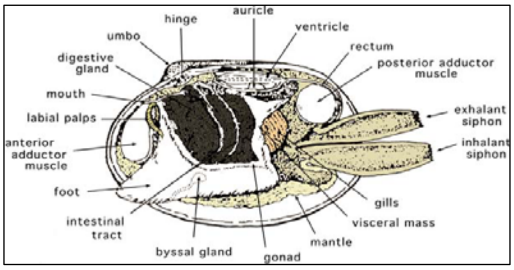


Figure 9: The internal, soft tissue anatomy of a bivalve clam (Helm & Bourne, 2004).

The Common Cockle species is a bivalve mollusk. The most prominent features of these animals are the two valves (or shells) that are joined along an elastic hinge and enclose the body. Each valve usually has a prominence near the hinge, the umbo (figure 8), which is the oldest part of the valve. The valves are solid, thick and broadly oval in outline, which is sculptured with 22-28 radiating ribs, each with numerous scale-like spines, and very fine irregular concentric lines. Growth lines can be seen on the outer surface of the valves, which have a dirty white, yellowish or brownish color. The inner surface of the valves is dull white, with a brownish or light purple stain on or about the posterior adductor muscle scars. The body is connected with two adductor muscles to the valves (figure 9) and is able to close the valves by using these muscles. Another characteristic of the Common Cockle species is the siphon. This is a meaty tube that can be protruded or contracted. It is used for ventilation, feeding and waste excretion when the shellfish is buried in the soil. The tube is divided in two ducts, one for inhaling and one for exhaling.

3.1.2 *Distribution and habitat preferences*

Wild Common Cockle species are widely distributed in estuaries and sandy bays on the western European coast, between the latitudes 15-70^{o} N; from to western Barents Sea and northern Norway to the Iberian Peninsula, and south along the coast of west Africa to Senegal (figure 10).

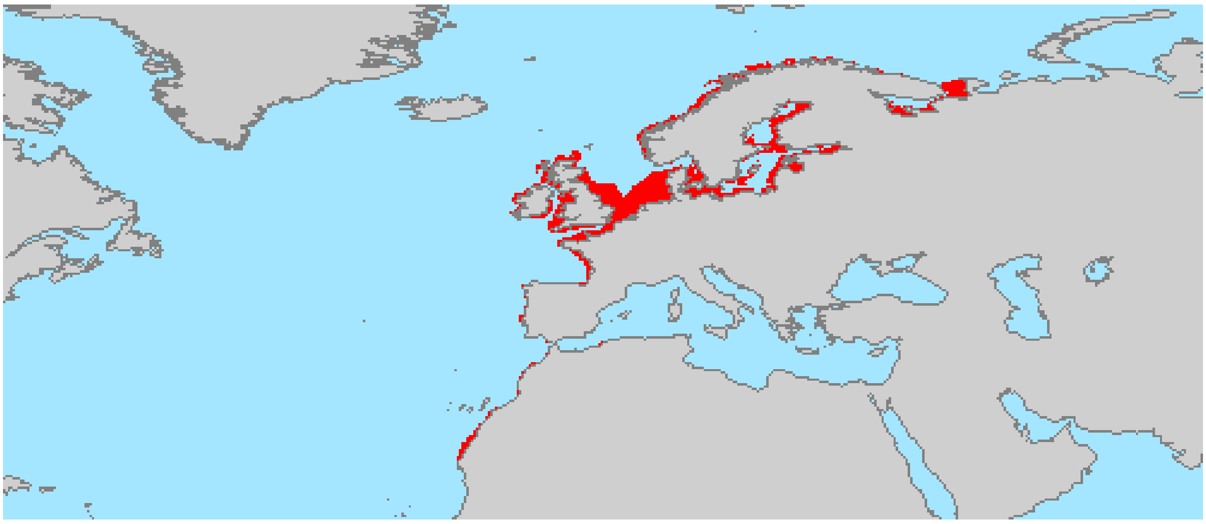


Figure 10: Geographical distribution of the Common Cockle species (FAO, 2006).

In their natural environment Common Cockle species live in the surface of the sea bottom (or sediments), to a depth of no more than 10 cm (Jackson & James, 1979). Therefore, Common Cockle species are called infaunal bivalve species, in contrast to Common Mussels species which are living on the bottom (figure 11).

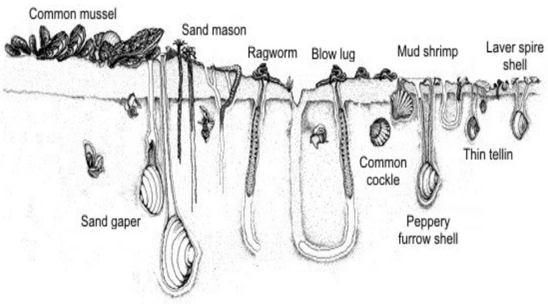


Figure 11: Preferable habitat of diverse benthic species in temperate water (www.seckenberg.de).

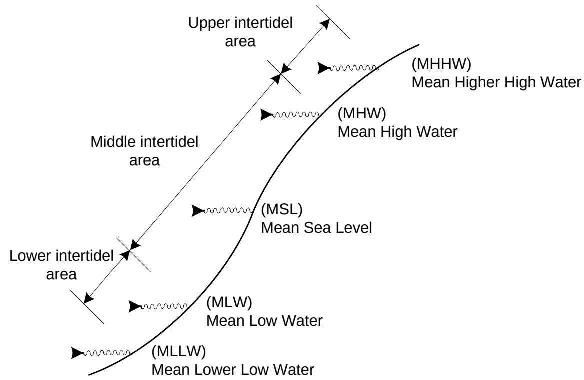


Figure 12: Main existence range of the Common Cockle species in the intertidal ecosystem.

The Common Cockle's favorite substrates consists of clean sand, mud, or muddy gravel from the middle to the lower intertidal and sometimes subtidal (or so-called upper intertidal), areas (figure 12). Their optimal growth lays in a range of 15-20 ^{o}C, poor or erratic growth is shown at temperatures of 10-15 ^{o}C and 20-30 ^{o}C (Kingston, 1973). Vooys (y.u.) and Smaal *et al.* (1997) describe that growth stops at temperatures less then 5 ^{o}C[26]. Their tidal strength preferences vary from very weak (negligible) to moderate strong (1-3 kn or 0.5-1.5 m/s) (www.marlin.ac.uk).

Optimal salinity levels of the Common Cockle species are 15-35 PSU (practical salinity units, equivalent to parts per thousand) (Russel & Peterson, 1973), with a minimum of 10 PSU and a maximum of 55 PSU (Kingston, 1974). Montaudouin & Bachelet (1996) describe that the highest growth rates of early juvenile can be achieved in low densities of 160-200 individuals per m^2. They also describe that densities of more than 2 000 individuals per m^2 suppress the growth rates.

3.1.3 Life cycle

Gonadal development, spawning and fertilization

Common Cockle species' sexual maturity depends on size rather than age. Production of the eggs and sperm is termed as gametogenesis and size of the Common Cockle species along with temperature and quantity and quality of food are undoubtedly important in initiating the process (Helm & Bourne, 2004).

In their natural environment adult Common Cockle species normally mature and spawn in their second summer, when they are about 18 months old and have a size of 15-20 mm in length. However, large Common Cockle species (> 15 mm) may mature and spawn in their first year (Orton, 1926; Hancock & Franklin, 1972; Seed & Brown, 1977). The gametogenesis is then normally initiated in winter (October to March), increases in spring (February to April) (Newell & Bayne, 1980), and the majority of the populations are ripe by mid-summer (Seed & Brown, 1977). In an artificial environment, e.g. in a hatchery operation, Common Cockle species can mature and spawn throughout the whole year, because of a process[27] which stimulates maturation and spawning.

[26] Although, growth stops at temperature of 5 ^{o}C, Common Cockle species can survive below these temperatures.
[27] In the land-based aquaculture facility the process is situated in the reproduction sub-phase of the Common Cockle culture phase. The process is further described in paragraph 5.1.2, section ´reproduction CC-2´.

Fertilization of the Common Cockle species occur external. Males may release about 15 million cells of sperm/sec and females release about 1 900 eggs/sec. The gametes viability is short and André *et al.* (1993) found that fertilization is reduced to 50% in two hours and that no fertilization is observed after 4-8 hours after spawning. The fertilized eggs have a size of 50-60 µm.

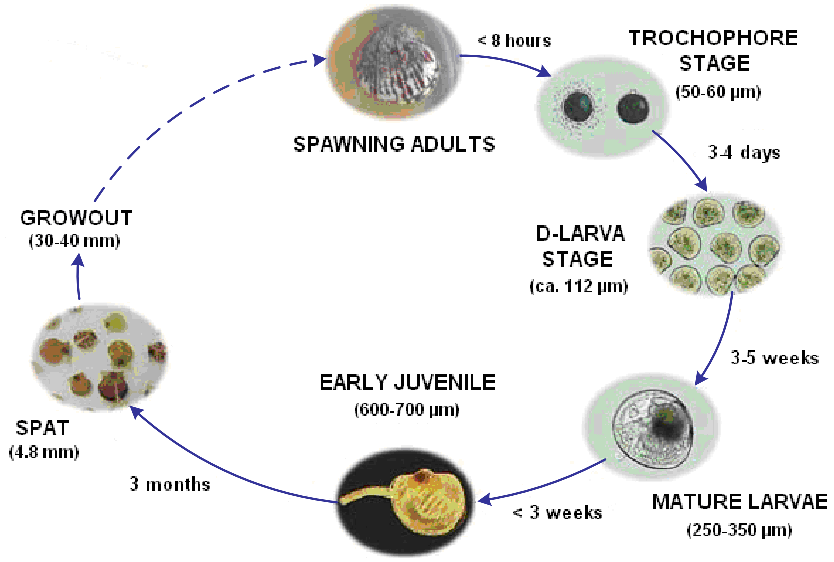


Figure 13: Representation of the biological developmental stages of the Common Cockle species, including their time constraints in a natural situation. Figure is based on Helm & Bourne (2004).

Embryonic and larval development

After fertilization the Common Cockle species develops in a typical bivalve veliger, the D-larva (so called due to the capital "D" shaped shell). After about 3-4 days the D-larva has a size of approximately 112 µm (figure 13). After about 3-5 weeks the D-larvae are mature and have a size of 250-350 µm. After this stage the foot of the bivalve develops and the mature larvae metamorphoses, within three weeks, into an early juvenile (or pediveliger). The early juvenile has a size of 600-700 µm (Lebour, 1938; Creek, 1960). Three months later, the early juveniles are grown to spat (mature juveniles) of a size of 4-5 mm in length (Montaudouin, 1996).

3.1.4 Growth

Adult Common Cockle species are mature at a size of 15-20 mm. In a natural environment this takes approximately 18 months (from fertilization). At this age the growth rate decreases. The Common Cockle species show, in a natural environment, a marked seasonal pattern (Seed & Brown, 1977). Shell growth which starts in May, continues through June until late August. After August the growth rate is almost negligible, which is mainly the cause of low temperature and decreasing food (live phytoplankton) concentrations. The Common Cockle species may live for up to 9 years or more in some habitats, although 3-4 years is normal. The Common Cockles species can reach a maximum size of approximately 60 mm (Gosling, 2004).

Because biologists and culturists are interested in the prediction of the growth of (infaunal) bivalve populations, growth models have been developed. For the Common Cockle species also a growth model (Rueda *et al.*, 2003) exists, which can be a useful tools for designing and controlling the aquacultural operations of a Common Cockle facility. For gathering requirements for designing the aquaculture facility for Common Cockle species, an assumed length-versus-fresh-weight-correlation is used.

The assumed length-versus-fresh-weight-correlation, which has been described by Van Stralen (1990), is defined as:

$$W_{fr} = 0.6162 * L^{2.9582}$$

Where W_{fr} = Total fresh weight[28] of the Common Cockle species in mg, and;
L = Shell length of the Common Cockle species in mm.

Based on this length-versus-fresh-weight-correlation marketable values of Common Cockle species can be estimated, by measuring the length of the Common Cockle species, by multiply it with the price (financial benefits/mass of Common Cockle species).

For converting fresh weight to dry weight a factor of 0.06 is used. This factor is derived by multiplying a fresh weight-dry weight correlation of 0.4 (Utting & Spencer, 1991) with 1/7, which is the correlation of dry weight to dry flesh weight (DFW).

$$W_{DFW} = 0.06 * W_{fr}$$

Where W_{DFW} = Total dry flesh weight of the Common Cockle species in mg.

3.1.5 Food

Common Cockle species are filter feeders that predominantly live of live phytoplankton, or so-called algae. The main diet of the Common Cockle species consists of small phytoplankton, but also includes fine organic solids and dissolved organic material. Preferred live phytoplankton includes both diatoms and flagellates. In artificial environments for infaunal bivalves good growth is also obtained with pasta or frozen dried algae (Helm & Bourne, 2004). However, this alternative of food conflicts with solution constraint 6. D-larvae and mature larvae use the velum to capture food and guide it to the mouth. Early juveniles are using both the velum and the foot for food capture (Jones *et al.*, 1993). Adults pump food to the mouth with the siphon.

Navarro & Widdows (1997) describe that Common Cockle species can feed themselves with a food concentration which is in a range of 1.6 to 300 mg/l. However, the Common Cockle species' feeding rate is declining abruptly when food concentration are higher than 250 mg/l. Pseudofeaces, which is a food selection process of the Common Cockle species, occurs above food concentrations of 4.8 mg/l[29]. Because pseudofeaces is an energy-consuming process for the Common Cockle species it is assumed that 4.8 mg/l of live phytoplankton is the optimal food concentration for Common Cockle species.

Besides the food concentration, the clearance rate is also needed for estimating the required input of live phytoplankton in a Common Cockle culture. Smaal *et al.* (1997) describe a clearance rate for Common Cockle species of:

$$Cl = 1.52 * (W_{DFW} / 1000)$$

Where Cl = Clearance rate of the Common Cockle species in l/hr, and;
W_{DFW} = Total dry flesh weight of the Common Cockle species in mg.

[28] In all defined 'fresh weight' and 'dry weight' the shell is included, unless it is described otherwise.
[29] Navarro & Widdows (1997) also describes that Common Cockle species are very well capable to select their food in an environment where the food concentration is in a range of 4.8 to 97 mg/l.

When the three formulas, which are described above, are combined a formula is obtained which describes the clearance rate as a function of the shell length. This formula is:

$$Cl = 0.1349 * 10^{-5} * L^{2.9582}$$

Where Cl = Clearance rate in m^3/day, and;
L = Shell length of the Common Cockle species in mm.

To calculate the feeding rate, which is needed to feed the Common Cockle species with live phytoplankton per unit of time the optimal food concentration needs to be multiplied with the clearance rate. With an optimal food concentration of 4.8 mg/l of live phytoplankton it will give the following formula:

$$Fr = 0.6474 * 10^{-2} * L^{2.9582}$$

Where Fr = Optimal feeding rate in mg phytoplankton/day per individual Common Cockle species, and;
L = Shell length of the Common Cockle species in mm.

The information of the feeding rate is used for estimating the spatial dimensions of the identified functional components (Common Cockle production, live phytoplankton (uni-algal) production, seawater supply, and general infrastructure).

3.1.6 Mortality & Health

Common Cockle species can die in the larval, juvenile and adult stage from a variety of causes, which can have a biological or environmental origin. The subject is much too large to discuss in detail here, but a brief synopsis is given to highlight a number of pertinent points, which could be important for a land-based aquaculture facility for Common Cockle species.

Physical and chemical environment

The physical environment can cause severe mortalities to Common Cockles species in all three biological development stages. Prolonged periods of high or low temperatures can be lethal to the Common Cockle species, as well as a sudden swing in temperature. Severe extremes in salinities, particularly low salinities after of heavy rain or run off from melting snow, can also cause extensive mortalities. Heavy siltation can smother and kill juveniles and adults (Helm & Bourne, 2004).

Industrial and domestic pollution

Pollution, particularly industrial pollution, can cause extensive mortalities of larvae, juveniles and adults. Both industrial and domestic pollution can cause problems for bivalve operations, and must be avoided.[30] For example, an anti-fouling ingredient added to marine paints, tributyltin (TBT), has been found to be highly lethal to bivalve larvae even at concentrations of a few parts per billion (Helm & Bourne, 2004). Domestic pollution can increase organic and bacterial loads in water as well as contributing a wide range of potentially toxic materials. Little is known of the combined effects of sub-lethal levels of the wide range of organic and organic-metallic compounds of man-made origin that may be present in such effluents.

[30] Treatment of industrial and domestic pollution of seawater is very expensive for the culture process of larval, juvenile and adult Common Cockle species. Furthermore, the risks of failure of this seawater treatment, in reference to contamination risks of the stocks, are very high.

Predation

Bivalves in the larval, juvenile and adult stages are preyed upon by a wide variety of animals that can cause severe mortalities. In the natural environment plankton feeders probably consume large quantities of larvae. In the aquaculture facility predation is kept to a minimum since the water, which is used, is filtered and any predators are removed. Furthermore, the live phytoplankton production and the Common Cockle production are covered or the stocks are submerged with water, so flying predators (birds) are a non-issue.

Parasites and diseases

Mortalities of Common Cockle species can also be caused by parasites[31]. Shell boring worms (e.g. *Polydora sp.*) and sponges burrow into the shells and weaken them, thus causing mortalities. Probably the major causes of mortalities in aquaculture facilities for bivalves are diseases (Helm & Bourne, 2004). When the seawater is adequately treated the risks of parasites and diseases is minimized.

3.2 Culture methods

There are several possible types of culture methods for culturing Common Cockle species in a land-based aquaculture facility. Two extremes of these cultured methods are the open cycle and the closed cycle methods (Huguenin & Colt, 2002). Open or flow-through methods depend on relatively large quantities of good quality incoming seawater to provide life support to the Common Cockle species. When the seawater becomes unacceptable the water is discharged.

3.2.1 Open cycle methods

The advantages of open cycle methods are proportional to the input water quality and water quantity. If the input water parameters are consistently good and no discharge treatment is required, these systems are clearly the simplest, cheapest, most reliable, and have the least risk (see figure 14).

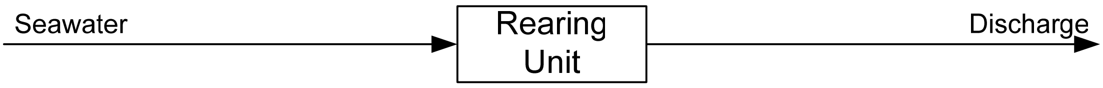


Figure 14: Completely open system.

Few, if any, completely open cycle methods exist. Often the incoming seawater requires some treatment before use. This may include filtering to protect the pumps or remove eggs, larvae or debris, heating/cooling, aeration/degassing or settling of solids. Other water treatment might include adding oxygen, removing uneaten food and fecal matter or reducing the concentrations of pathogenic organisms (see figure 15).

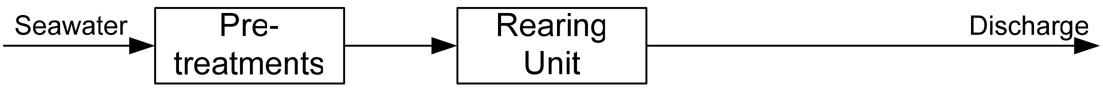


Figure 15: Open system with pre-treatment.

[31] Adult Common Cockle species are more vulnerable for parasites then Common Cockle species of another biological development stage.

Depending on governmental laws and regulations[32], or physical constraints[33] it may be necessary to treat process water prior to discharge (see figure 16).

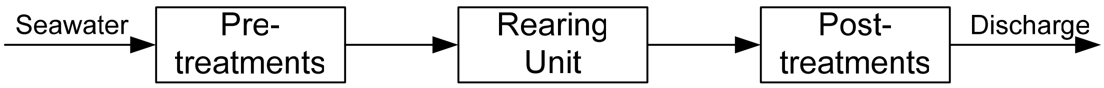


Figure 16: Open system with pre-treatment and post-treatment of discharged water.

3.2.2 Closed cycle methods

A completely closed cycle method, such as a well balanced aquarium, has no water inflow, except to make up for evaporation (Huguenin & Colt, 2002), and no discharge (see figure 17).

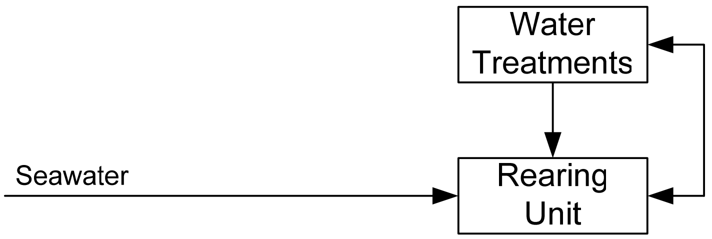


Figure 17: Completely closed systems, with water addition only to make up for evaporation.

The water is treated and reconditioned internally by a series of complex biochemical and physical processes. If everything is working well, all the processes are at equilibrium and good water quality is maintained. Any changes, such as increased feeding, chemical additions, adding or removing animals, or even cleaning parts of the system, can influence the delicate balances. For most practical uses, a completely closed system of any appreciable size is difficult to manage and is often uneconomic if any alternative exists. There can be depletion of necessary trace material and build-ups of other persistent contaminants to troublesome levels. Periodic recharging with new seawater is often required. Thus, even closed methods need access to good quality seawater or use high cost artificial seawater. Therefore, some net flow through the system is preferred and a better label for most closed cycle systems would be a recirculation system (see figure 18).

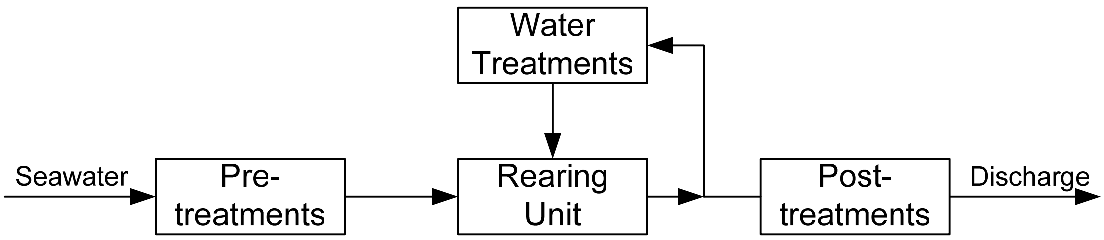


Figure 18: More common recirculation systems, with some net flow-through.

[32] The discharge needs to fit governmental laws and regulations (based on SC-2).
[33] The marine habitats or ecosystems (so-called physical constraints) in which is discharged may not be harmed (based SC-3).

3.2.3 Tradeoff

By considering the objective of this report it can be noticed that there is a wide spectrum of culture methods. If sufficient quantities of good quality seawater are available, the decision tends toward the open cycle methods, due to their greater simplicity, reliability and lower costs. However, when not sufficient seawater is available, the available seawater has a poor quality, or if environmental considerations are paramount, there will be a tendency towards recirculation systems, with some net flow-through. The decision for the best culture method should be made for every sub-phase of the algal culture phase and Common Cockle culture phase.

4 Functional architecture, incl. technical requirements

In this fourth chapter the technical requirements[34] of the land-based aquaculture facility for Common Cockle species are described and analyzed. In this chapter also functional analyses (including allocations) are integrated[35]. The technical requirements are divided into functional requirements and non-functional requirements. The functional requirements describe what the product (design) must do. The non-functional requirements describe what properties the product must have (Robertson *et al.*, 1999). The functional requirements and the non-functional requirements are partly derived from the design considerations, which are discussed in chapter 3, and relevant literature.

During the functional analysis and allocation seven decomposition levels are identified. The identified decomposition levels, from high abstraction level to a low abstraction level, are: final product, phases, sub-phases, systems, sub-systems, and units. In the first analysis one final product and three phases are identified. The final product is defined as the land-based aquaculture facility for Common Cockle species (0). The three phases are defined as an algal culture phase (AL-0), a Common Cockle culture phase (CC-0), and a general infrastructure phase (GI-0)[36].

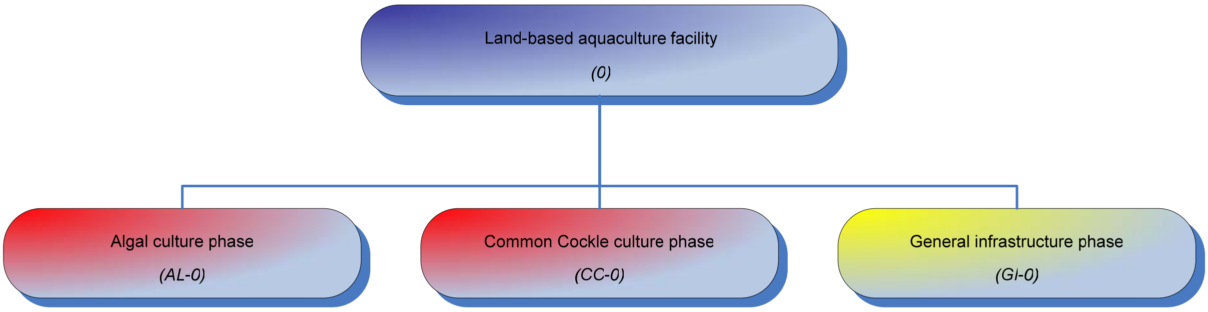


Figure 19: Acquisition of the algal culture phase, Common Cockle culture phase, and the general infrastructure phase, in relation the final product of the land-based aquaculture facility.

In figure 19 the acquisition of the final product and three phases is illustrated. In the acquisition a primary production process and a secondary production process are identified. The primary production process consists of the algal culture phase and the Common Cockle culture phase. These two phases are directly related to the production of the Common Cockle species. The secondary production process consists of the general infrastructure phase. This phase has the function to support the primary production process, so the aquaculture facility can run efficiently and Common Cockle species can be distributed to the market.

[34] The detailed technical requirements are described in appendix IV.
[35] The functional analysis and allocation are described, from final product level to system level. Lower levels are described in appendix V.
[36] The codes which are described behind the defined final product and defined phases are called traceability codes. These traceability codes provide information about the relations between the technical requirements and, the analyzed, functional components in the functional architecture, see also section: 'Systems analysis and control', at page 8.

4.1 Algal culture phase (AL-0)

In the algal culture phase live phytoplankton (uni-algal species)[37] are grown as food for the various sub-phases in the Common Cockle culture phase. The live phytoplankton is produced in the land-based aquaculture facility, because of the critical importance of the live phytoplankton.

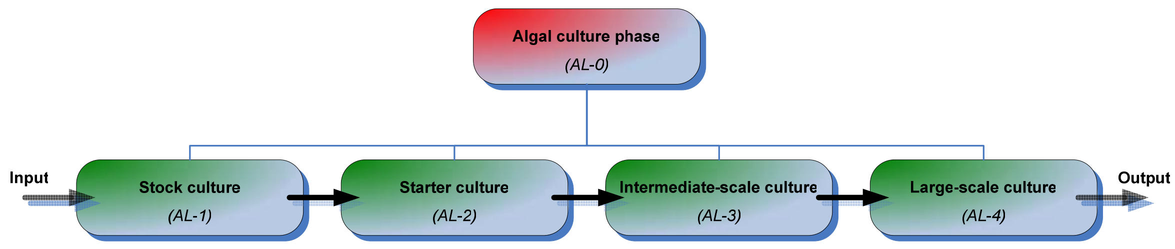


Figure 20: Overview of the acquisition and flow of, respectively, in, the algal culture phase.

The production process in the algal culture phase is divided into four sub-phases. The sub-phases are: the stock culture (AL-1), the starter culture (AL-2), the intermediate-scale culture (AL-3), and the large-scale culture (AL-4). In figure 20 an overview is given of the acquisition of the algal culture phase and its sub-phases. The figure also describes the flow through the sub-phases, which is described according to an input-processing-output-model (paragraph 2.2).

The process in which the uni-algal species are cultured is a combination of a continuous production process and a batch production process. The stock culture, which has the function to inoculate the starter culture, needs to be conditioned. In the other sub-phases of the algal culture phase the uni-algal species are grown in steps. The steps are described in figure 21.

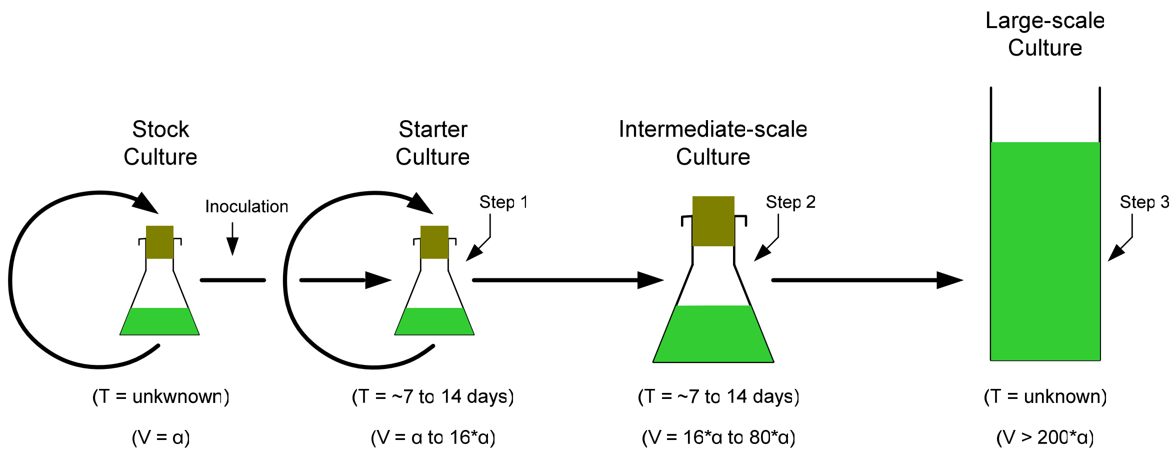


Figure 21: Steps of the production process of uni-algal species in the algal culture phase, including the required volume (V) and characteristic residence time (T).

For the inoculation of the starter culture only a few milliliters are used of stock culture. In the starter culture the uni-algal species are cultured to a larger volume. When the starter culture is ready to be transferred to the intermediate-scale culture approximately 1/16th of the volume is kept in the starter culture. The 15/16th is transferred to the intermediate-scale culture, after which the volume is fully transferred to the large-scale culture (Helm & Bourne, 2004).

[37] Until recently living algae constituted the sole food sources for bivalve larvae, juveniles, spat, and even adult in aquaculture facilities (Helm & Bourne, 2004). At the moment there are also alternative food sources on the market, like pasta and freeze dried powder of algae. Although, the alternative food source has the future, live algae are still considered as best food source for bivalve species (Helm & Bourne, 2004). Therefore, the alternative food sources are not considered in this research.

4.1.1 Identified systems

During the requirements analysis six systems were identified. These six systems are: the culture of algae system (AL-x.1), the seawater treatment system (AL-x.2), the enrichment system (AL-x.3), the environmental control system (AL-x.4), the effluent treatment system (AL-x.5), and the harvest of algae system (AL-x.6)[38]. An overview of the identified systems in the sub-phases in the algal culture phase, including their (non) physical relations (so-called flows) between each other, are given in figure 22.

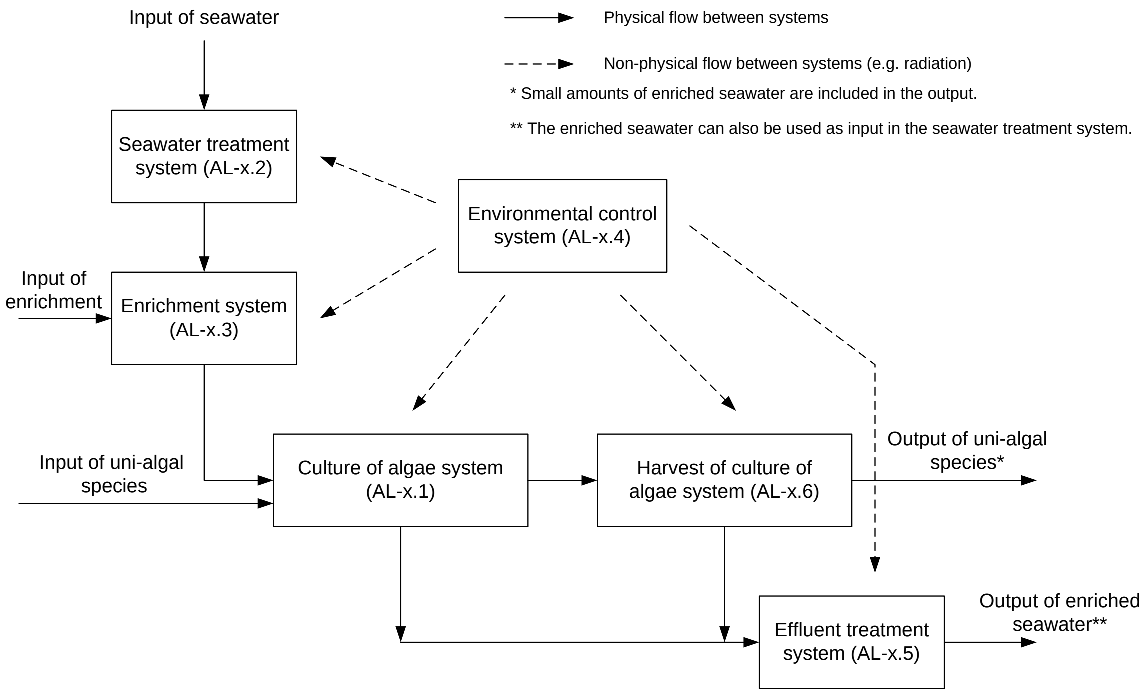


Figure 22: Overview of the identified systems in the sub-phases of the algal culture phase, including the (non) physical flows between each other.

In figure 22 characteristic of an input-processing-output-model can be recognized. The inputs are: the input of seawater, the input of enrichments (e.g. food and building materials), and the input of uni-algal species[39]. The six systems can be identified as the processing part. The outputs are the output of uni-algal species[40], and the output of enriched seawater[41].

Figure 22 also describes the physical- and non-physical flow between systems. It can be concluded that all systems need to be physically contacted[42], except the environmental control system. The environmental control system does not need physical contact, because it uses radiation (e.g. heat and light). This contact is defined as non-physical contact.

[38] The ‘x’ in the traceability codes refers to any sub-phase in the algal culture phase. For example, AL-x.1 can stand for: AL-1.1, AL-2.1, AL-3.1, and AL-4.1.

[39] The uni-algal species can come from culture collection from reputable institutes (e.g. for input of stock culture), or from the harvest of culture of algae systems of previous sub-phases of the algal culture phase.

[40] This output of uni-algal species from the harvest of culture of algae systems is used as input in the culture of algae systems in next sub-phases. In case of the large-scale culture the output is used as input in the first sub-phase of the Common Cockle culture phase.

[41] The output of enriched seawater can be used as input in the seawater treatment system of the same sub-phase, or it needs to go to the effluent treatment system, after which it is discharged to an open water source. During emergencies it should be possible to discharge the enriched seawater directly to an open water source.

[42] Transportation equipment (e.g. load trucks, piping, etc) is defined as physically connected.

4.1.2 Systems analysis

This paragraph describes the technical requirements of the six systems identified during the requirements analysis. The functional components[43] are identified, and the technical requirements are allocated to the functional components. In addition, the relations between the functional components are also described.

Culture of algae system (AL-x.1)

In the culture of algae system uni-algal species (mono-specific) are conditioned or grown, so they can be transferred to the harvest of algae system. The system has one functional component which is called the culture circulation system (AL-x.1.1). In figure 23 a block diagram[44] of the system is illustrated.

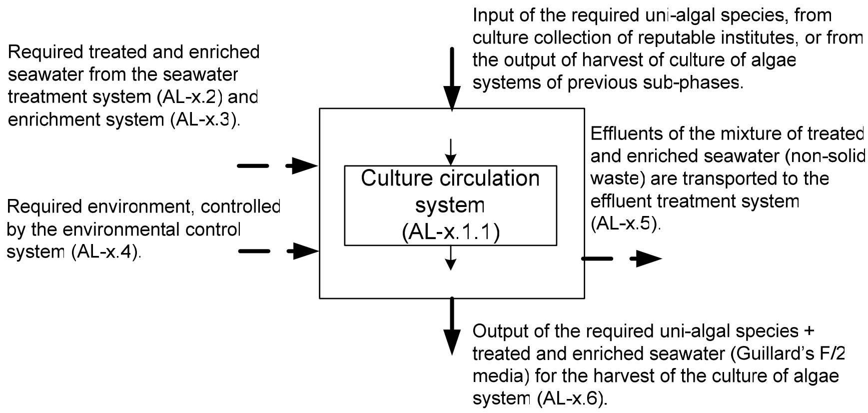


Figure 23: Block diagram of the culture of algae system (AL-x.1).

As can been seen from the block diagram the inputs of the algae system culture are uni-algal species. The uni-algal species are, in case of the stock culture, initially coming from culture collections which are maintained by reputable national institutions or research laboratories. For the starter culture, intermediate-scale culture, and large-scale culture the input of the required uni-algal species come from the harvest of culture of algae system of, respectively, the stock culture, the starter culture, and the intermediate-scale culture. The required quality of the uni-algal species is described in table 1. The uni-algal species are divided in two different groups of diatoms and flagellates.

Uni-algal species	Median cell volume (µm³)	Organic weight (µg 10ˆ6 cells)	Chl. A (%DM)	Lipid (%DM)	Carbohydrate (%DM)	Protein (%DM)
Diatoms:						
Chaetoceros calcitrans	35	7	3.01	16 (17)	6	34
Skeletonema costatum	85	29-52	1.21	8 (13)	4.6 (33)	25 (59)
Flagellates:						
Tahition isochrysis (T-iso)	40-50	14-30	0.98	20 (24)	6	23
Tetraselmis suecica	300	66-292	0.97	6 (10)	12	31

Table 1: Characteristics of the required uni-algal species used in the production process for Common Cockle species (Helm & Bourne, 2004).

[43] The functional component is also referred as sub-system.

[44] The bloc diagram is split in vertical- and horizontal flow. The vertical flow describes the relation of the system in terms of input, process (system itself), and output. The horizontal flow describes the relations of the system in terms of other systems of the same sub-phase.

Diatoms and flagellates are algal species which are both at the base of the marine food chain. They need light for a process called photosynthesis. The uni-algal species described in table 1 have a high value of lipids, protein, and carbohydrates in contrast to other diatoms and flagellates. They are therefore very suitable as food supply for the Common Cockle species in the Common Cockle culture phase.

In table 2 the cumulative quantity of live uni-algal species is described which is required to culture one individual Common Cockle species to a certain length or body weight, in a specific time. The results are the output of a phytoplankton model, which is further described in appendix VI.

Shell length (mm)	Residence time (days)	Cumulative body weight (dry flesh weight) (g)	Cumulative body weight (fresh weight) (g)	Cumulative added live uni-algal species (dry weight) (g)
5	50	0.00	0.06	0.02
10	100	0.03	0.43	0.20
15	150	0.09	1.43	0.92
20	200	0.20	3.35	2.80
25	250	0.39	6.48	6.64
30	300	0.67	11.12	13.49
35	350	1.05	17.54	24.60
40	400	1.56	26.04	41.45

Table 2: Required mass of uni-algal species for the production of an individual Common Cockle per year.

The model is based on the five formulas, which are described in paragraph 3.1.4 and paragraph 3.1.5. Furthermore, the model consists of three parameters, which are defined as: the optimal food concentration[45], the growth factor[46], and the standard residence time[47]. For calculating the results, which are described in table 2, the three parameters are, respectively, set on: an optimal food concentration of 4.8 mg/l, a growth factor of 0.4, and a standard residence time of 10 days.

Utting & Spencer (1991) describe that bivalve species need to have a mix of uni-algal species for optimal growth. Based on this information, mixes of uni-algal species are required for the Common Cockle species in the Common Cockle culture phase. The properties in which the uni-algal species need to be mixed are described in table 3.

Shell length (mm)	***Diatoms:***		***Flagellates:***	
	Chaetoceros calcitrans	Skeletonema costatum	Tahition Isochrysis (T-iso)	Tetraselmis suecica
0.05 / 0.06 - 0.25 / 0.35	27%	--	70%	3%
0.25 / 0.35 - 40	--	50%	--	50%

Table 3: The required proportions of mixes of uni-algal species for two shell length categories of Common Cockle species, expressed in percentages of the required quantity of phytoplankton (Utting & Spencer, 1991).

[45] The defined optimal food concentration is the concentration of phytoplankton (or algae) which Common Cockle species need to feed themselves to achieve optimal growth from the live uni-algal species (paragraph 3.1.5).
[46] The defined growth factor describes an assumed physiological energetic coefficient which describes the absorption of the Common Cockle species due to its body weight (dry weight). By multiplying the growth factor in a time interval, which is equal to the standard residence time, with the cumulative added live uni-algal species, the cumulative body weight (dry weight) of Common Cockle species can be calculated.
[47] The defined standard residence time is the time in which Common Cockle species are assumed to grow 1 mm (in shell length) in the aquaculture facility. The standard residence time has been calculated by fitting the body weight (dry weight) of the Common Cockle species, derived from the added live uni-algal species, with the body weight (dry weight) of Common Cockle species (paragraph 3.1.4).

Seawater treatment system (AL-x.2)

In the seawater treatment system seawater is pre-treated, after which it is transported to the rearing units in the sub-phases of the algal culture phase. For all sub-phases in the algal culture phase a recirculation system, with some net flow-through, is used[48]. The seawater treatment consists of three functional components, which are: the water circulation system (AL-x.2.1), the contamination control system (AL-x.2.2), and the temperature control system (AL-x.2.3). Figure 24 shows a block diagram of the seawater treatment system.

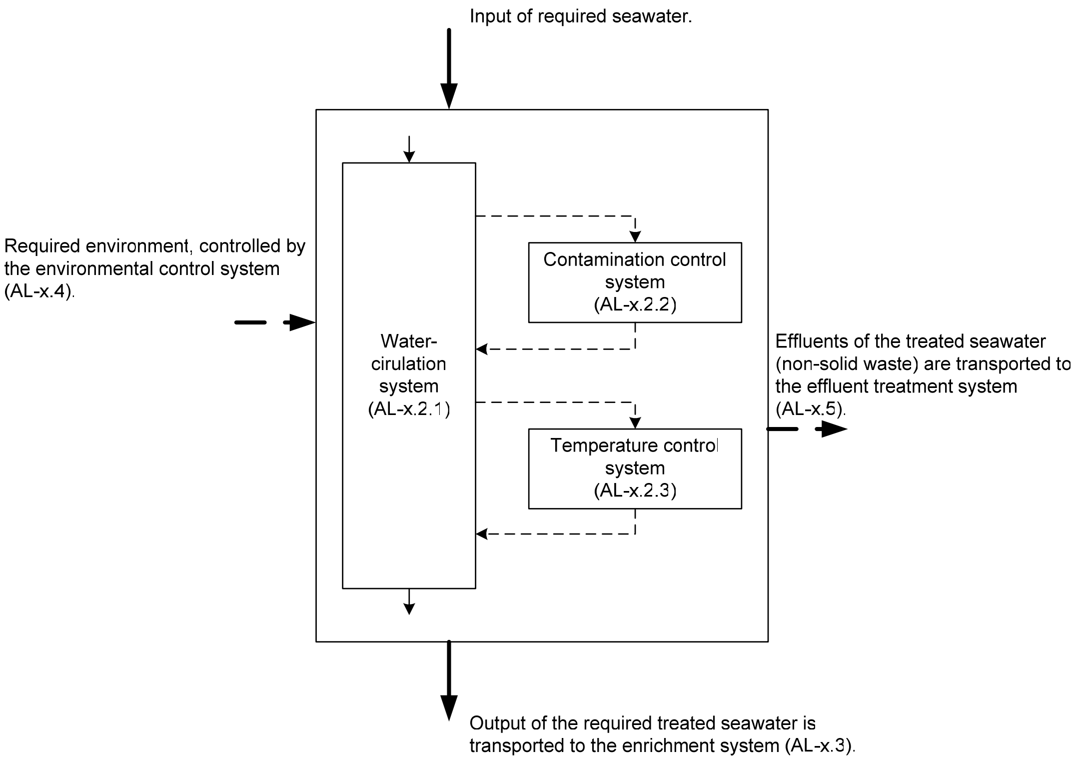


Figure 24: Block diagram of the seawater treatment system (AL-x.2).

The required input of the seawater treatment system is seawater from an open seawater water source. This seawater needs to be treated to a quality which is described in table 4.

Sub-phases / Quality characteristics	Stock culture *(AL-1)*	Starter culture *(AL-2)*	Intermediate-scale culture *(AL-3)*	Large-scale culture *(AL-4)*
Temperature (°C)	4-12	18-22	18-22	18-22
Filtration size (μm)	0*	2	2	2
Disinfection by	ultra-violet	ultra-violet	ultra-violet	ultra-violet
pH	8.0**	7.5-8.2***	7.5-8.2***	7.5-8.2***
Salinity (psu)	20-25	20-25	20-25	20-30****

Remarks:
* distilled water. Does not need to be distilled like seawater from an open water source.
** by adding HCl or NaOH.
*** by adding carbon dioxide (CO2).
**** 20-25 psu for diatom species and 30 psu for flagellates species.

Table 4: Required seawater characteristics of the sub-phases in the algal culture phase (Helm & Bourne, 2004).

[48] As described in figure 19 of paragraph 3.2.1, the characteristic of a recirculation system, with some net flow-through, is that seawater is pre-treated after which it is transported to the rearing units. In this research this characteristic is described in the defined seawater treatment systems. Another characteristic of the recirculation system, with some net flow-through, is that the seawater from the rearing units is transported to post-treatments, or to other water treatments to create a certain recirculation system, with some net flow-through. This characteristic is defined in the effluent treatment systems (AL-x.5).

Besides the required quality of seawater, a certain quantity, or volume (V) of seawater is required, which differs per sub-phase. The required quantity per sub-phase is described in figure 21.

Enrichment system (AL-x.3)

In the enrichment system substances (e.g. food, building materials, etc) are added to the treated seawater to ensure good quality of enriched seawater for the uni-algal species in the algal culture phase. The enrichment system consists of two functional components, the nutrient conditioning system (AL-x.3.1), and the nutrient addition system (AL-x.3.2). The block diagram of the enrichment system is shown in figure 25.

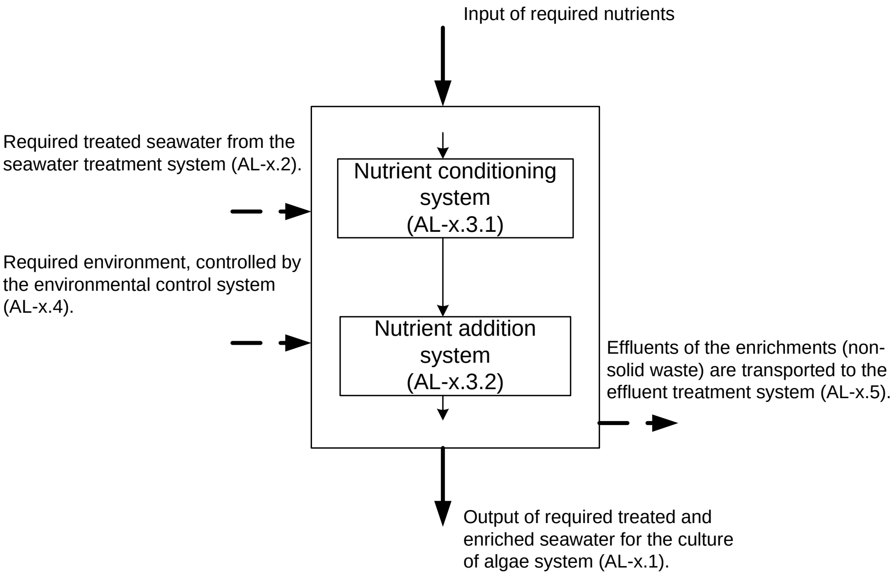


Figure 25: Block diagram of the enrichment system (AL-x.3).

The inputs of the enrichment system are nutrients from reputable chemical production facilities. The nutrients are conditioned in a nutrient conditioning system (AL-x.3.1), after which they are added to the treated seawater in a nutrient addition system (AL-x.3.2).

The types of nutrients which need to be added are based on Guillard's F/2 media (www.ccap.ac.uk, 2005). The Guillard's F/2 media include two recipes for both diatoms and flagellates. Diatoms require an addition of silica for building their hard silica shell. Flagellates do not have such hard silica shells and do not need an addition of silica, see table 5.

(1) trace metals stock solution	**(2) vitamin mix stock solution**	**(3) Sodium metasilicate stock solution**
$EDTANa_2$ - 4.150 g $FeCl_3.6H_2O$ - 3.150 g $CuSO_4.5H_2O$ - 0.010 g $ZnSO_4.7H_2O$ - 0.022 g $CoCl_2.6H_2O$ - 0.010 g $MnCl_2.4H_2O$ - 0.180 g $Na_2MoO_4.2H_2O$ - 0.006 g	Cyanocobalamin - 0.00005 g Thiamine HCl - 0.1 g Biotin - 0.0005 g	$Na_2SiO_3.9H_2O$ - 30.0 g
Medium per liter $NaNO_3$ - 0.075 g $NaH_2PO_4.2H_2O$ - 0.00565 g Trace elements stock solution **(1)** 1.0 ml Vitamin mix stock stock solution **(2)** 1.0 ml Sodium metasilicate stock solution **(3)** 1.0 ml**		
Method Make up to 1 liter with filtered natural seawater and adjust pH to 8.0 with 1 mol NaOH or HCl. Autoclave at 15 psi for 15 minutes.		
* All enrichment needs to be dissolved in 1 liter distilled H_2O of a pH of 8.0 which is adjusted with 1 mol NaOH or HCl. Before enrichment this water needs to autoclave at 15 psi for 15 minutes. ** This enrichment only needs to be used for flagellate uni-algal species.		

Table 5: Required enrichments for Guillard's F/2 media per liter (www.ccap.ac.uk, 2005).

Environmental control system (AL-x.4)

The environmental control system controls the environment in which all systems of the algal culture phase are located. The environmental control system consists of an environmental illumination system (AL-x.4.1), and an environmental temperature system (AL-x.4.2). The functional components are described in the block diagram in figure 26.

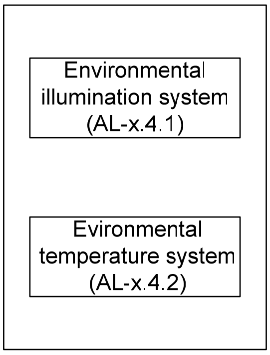


Figure 26: Block diagram of the environmental control system (AL-x.4).

The environmental control system has no vertical- or horizontal relations, because the system has no input or output. The environmental control system has no direct physical relations (or so-called flows) with other systems. However, the environmental control system does have non-physical relations with all other systems.

The required illumination and temperature for systems in each sub-phase in the algal culture phase are described in table 6.

Sub-phases / Quality characteristics	Stock culture *(AL-1)*	Starter culture *(AL-2)*	Intermediate-scale culture *(AL-3)*	Large-scale culture *(AL-4)*
Temperature (°C)*	4-12	18-22	18-22	18-22
Illumination (lux)*	450	4 750-5 250	15 000-25 000	52 000
Remarks: * measured at the culture surface.				

Table 6: Required quality characteristics of the environment which need to be established by the environmental control system.

Effluent treatment system (AL-x.5)

In the effluent treatment systems effluents (non-solid wastes) are treated, so they can be used as input in the seawater treatment systems, or they can be discharged to an open water source. The effluent treatment system consists of three functional components, which are: the water circulation system (AL-x.5.1), the contamination control system (AL-x.5.2), and the temperature control system (AL-x.5.3), see figure 27.

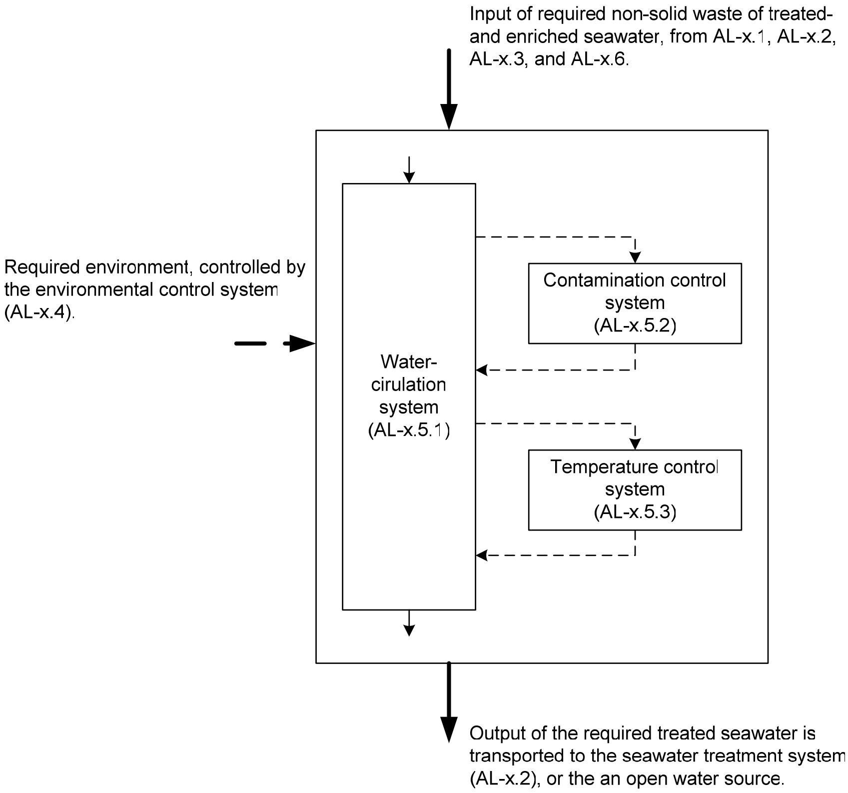


Figure 27: Block diagram of the effluent treatment system (AL-x.5).

The input of the effluent treatment system is treated- and enriched seawater from: the culture of algae system, the seawater treatment system, the enrichment system, and the harvest of culture of algae system. The output of the effluent treatment system needs to be of the same, or close to the, quality of seawater which is used as input in the seawater treatment system.

Harvest of culture of algae system (AL-x.6)

In the harvest of culture of algae system uni-algal species are harvested. The uni-algal species are, after harvesting, transferred to the culture of algae system of the next sub-phase, or to the enrichment systems of the Common Cockle culture phase. The harvest system (AL-x.6.1) is the only functional component in the system, see figure 28. The harvest system needs to buffer and condition the uni-algal species.

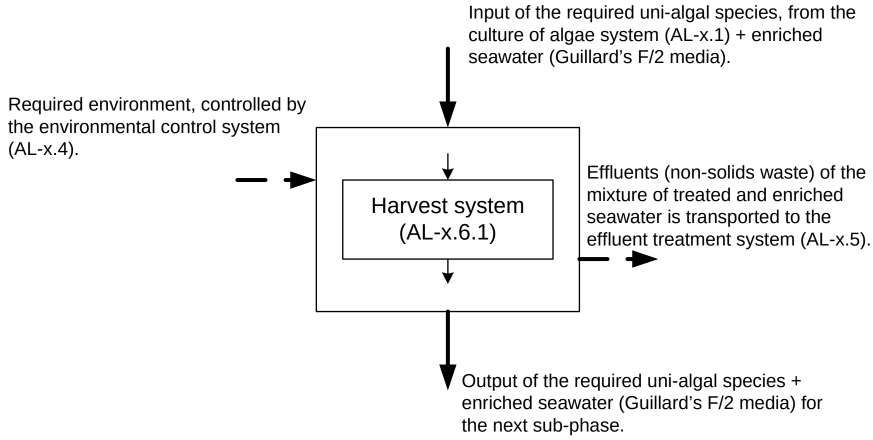


Figure 28: Block diagram of the harvest of culture of algae system (AL-x.6).

The inputs of the harvest of culture of algae system are uni-algal species from the culture of algae system, and the enriched seawater from the seawater treatment system and enrichment system. The output of the system are uni-algal species and enriched seawater for the next sub-phase or sub-phases in the Common Cockle culture phase (in case of the large-scale culture, AL-4)[49].

4.2 Common Cockle culture phase (CC-0)

In the Common Cockle culture phase the Common Cockle species (*Cerastoderma edule* L.) are cultured in a semi-continuous process. This process starts with an inoculation of eggs and sperm from breeders, and ends with the harvest of adult Common Cockle species with a shell length of 30-40 mm. A small amount of the harvest is used to provide fresh breeders. The rest of the harvest is sold to the market.

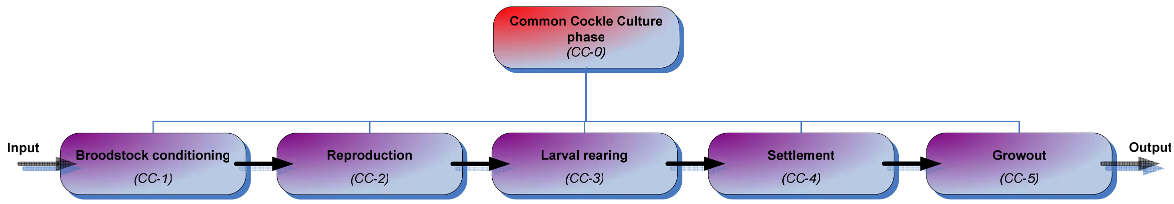


Figure 29: Overview of the acquisition and flow of the Common Cockle culture phase.

In the Common Cockle culture phase Common Cockle species are produced in five sub-phases. The sub-phases are: the broodstock conditioning (CC-1), the reproduction (CC-2), the larval rearing (CC-3), the settlement (CC-4), and the growout (CC-5). In figure 29 an overview is given of the acquisition of the Common Cockle culture phase and its sub-phases. The figure also describes the flow through the sub-phases, which is described according to an input-processing-output-model.

---

49 Although, the input and output of the harvest of culture of algae system (defined in the harvest of culture of algae system) are almost equal, the harvest of culture of algae system allows users to control the output of the harvest, in terms of quality and quantity.

In the broodstock conditioning adult Common Cockle species (so-called breeders) are conditioned. The breeders are used to inoculate the reproduction, by providing eggs and sperm in a process which is called spawning. When the breeders have inoculated the reproduction fertilization takes place. The results of the fertilization are trochophores[50]. The trochophores are grown into D-larva, which already have a shell. In an aquaculture facility it is assumed that this process takes place in two days or less[51] (see figure 30).

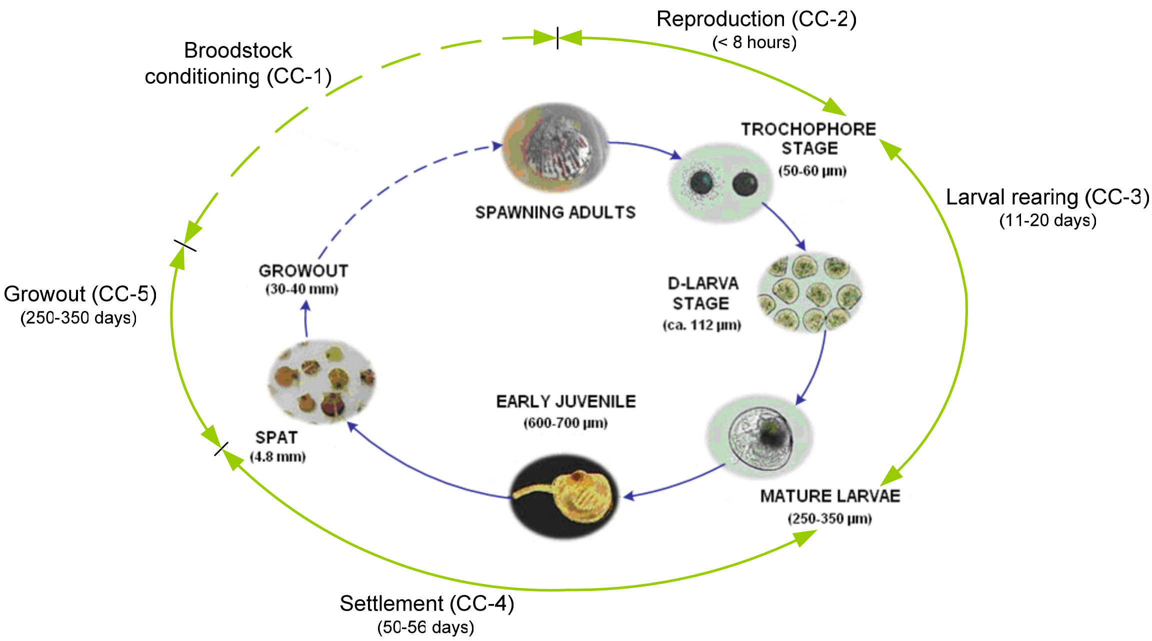


Figure 30: Representation of the sub-phases of the Common Cockle culture phase, including the Common Cockle species' residence time, in combination with the development stages (Helm & Bourne, 2004).

The D-larvae are cultured to mature larvae in the larval rearing, which take approximately 10-18 days (so the complete larval rearing process takes approximately 11-20 days). After the larval rearing the mature larvae, which are living in the water column (pelagic life style) settle to a substrate (benthic life style) in the settlement. In the settlement the mature larvae are metamorphosing to juveniles and spat. The settlement takes approximately 50-56 days. After the settlement the spat is cultured to adults in the growout. The adults are marketable attractive at of shell length of 30-40 mm. Therefore, they are harvested at this size. The growout takes approximately 250-350 days, based on the phytoplankton model (appendix VI). A small amount of the harvest is used as breeders for the broodstock conditioning to inoculate the settlement.

[50] Trochophores are bivalves (Common Cockle species) embryos in a planktonic stage (Helm & Bourne, 2004).
[51] Although, the phytoplankton model (appendix VI) describes the standard residence time of Common Cockle species in the aquaculture facility, certain faults are included in this model (e.g. the model assumes a linear growth which is in fact non-linear). Therefore, the phytoplankton model has been freely interpreted for small (L < 4.8 mm) Common Cockle species.

4.2.1 *Identified systems*

During the requirements analysis of sub-phases of the Common Cockle culture phase six systems are identified. The six systems are almost the same as the identified six systems in the algal culture phase. The six systems are: the culture of Common Cockles system (CC-x.1), the seawater treatment system (CC-x.2), the enrichment system (CC-x.3), the environmental control system (CC-x.4), the effluent treatment system (CC-x.5), and the harvest of culture of Common Cockles system (CC-x.6)[52]. An overview of the identified systems in the sub-phases in the Common Cockle culture phase, including their (non) physical relation (so-called flows) between each other, are described in figure 31.

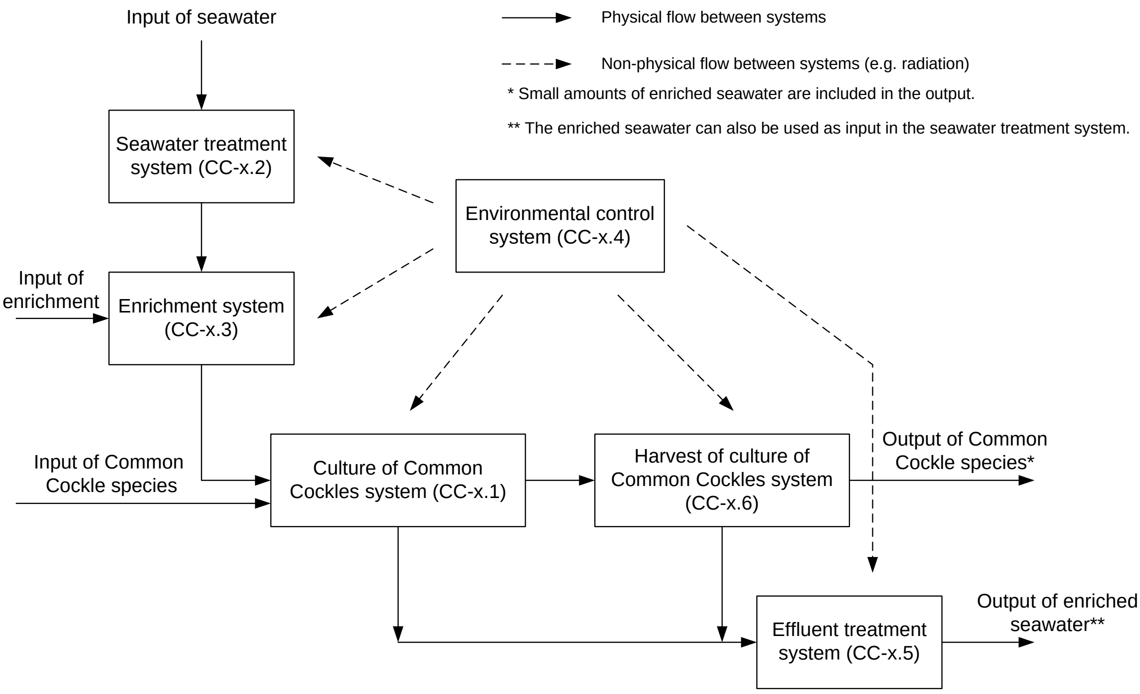


Figure 31: Overview of the identified systems in the sub-phases of the Common Cockle culture phase, including the (non) physical flows between each other.

In figure 31 characteristics of an input-processing-output-model can be identified. The identified inputs are: the input of seawater, the input of enrichments (e.g. food and building materials), and the input of Common Cockle species[53]. The systems can be identified as the processes. The outputs are identified as: the output of Common Cockle species[54], and the output of enriched seawater[55].

[52] The 'x' in the traceability codes refers to any sub-phase in the Common Cockle culture phase. For example, CC-x.1 can stand for: CC-1.1, CC-2.1, CC-3.1, CC-4.1, and CC-5.1.

[53] The Common Cockle species initially come from wild stocks to start the Common Cockle production process. When the Common Cockle production process is running Common Cockle species (breeders) are collected from the growout. These breeders are conditioned in the broodstock conditioning after which they are used to inoculate the reproduction.

[54] The output of the Common Cockle species from the harvest of culture of Common Cockles systems in the Common Cockle culture phase is used as input in the culture of Common Cockles in the next sub-phase, or it is distributed to the market.

[55] The output of enriched seawater can be used as input in the seawater treatment system of the same sub-phase, or it needs to go to the effluent treatment system, after which it is treated and discharged to an open water source. During emergencies it needs to be possible to discharge the enriched seawater directly to an open water source.

Figure 31 also describes the physical- and non-physical flow between systems[56]. It can be concluded that all systems need to physical contacted[57], except the environmental control system. The environmental control system does not need physical contact, because it uses radiation (e.g. heat). This contact is defined as non-physical contact.

4.2.2 Systems analysis

This paragraph describes the technical requirements of the identified six systems. The functional components are identified, and the technical requirements are allocated to the functional components. Furthermore, the relations between the functional components are also described.

Culture of Common Cockles system (CC-x.1)

In the culture of Common Cockles system, Common Cockle species are conditioned and grown, so they can be transferred to the harvest of culture of Common Cockles system. The system has one functional component which is called the culture circulation system (CC-x.1.1). Figure 32 describes the block diagram of the culture of Common Cockles system.

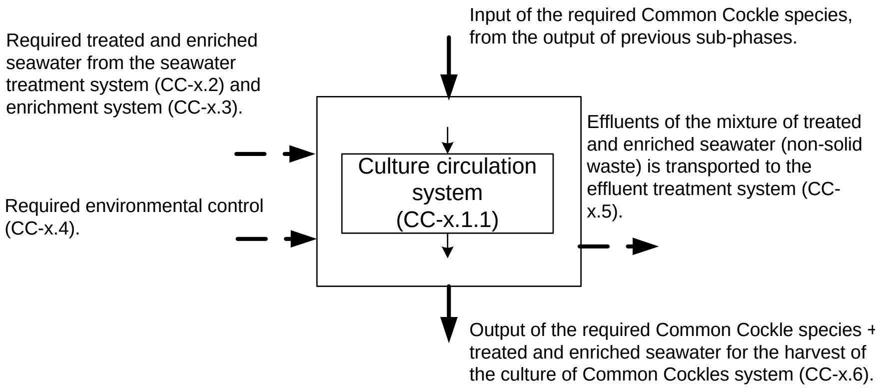


Figure 32: Block diagram of the culture of Common Cockles system (CC-x.1).

As described in the block diagram, which is illustrated in figure 32, the inputs of the culture of Common Cockles system are Common Cockle species. The inputs of the required Common Cockle species come from the outputs (harvest of culture of Common Cockles system) of the previous sub-phase[58]. The required production characteristics of the Common Cockle species in the Common Cockle culture phase are described in table 7.

Required production characteristics	**Broodstock conditioning** ***(CC-1)***	**Reproduction** ***(CC-2)***	**Larval rearing** ***(CC-3)***	**Settlement** ***(CC-4)***	**Growout** ***(CC-5)***
Size (shell length)	30 to 40 mm	-	0.05-0.06 to 0.25-0.35 mm	0.25-0.35 to ~4.8 mm	~4.8 to 30-40 mm
Production quanties	-	-	35 million ind./year*	27 million ind./year*	20 million ind./year*
Type	Conditioning	Conditioning	Growing	Growing	Growing
Residence time	-	< 8 hours**	11-20 days**	50-56 days**	250-300 days***

* based on a mortality loss of 33 % of Common Cockle species per sub-phase.
** the residence time, per sub-phase, is freely interpreted from the phytoplankton model.
*** the residence time, of the growout, is based on the phytoplankton model.

Table 7: Production characteristics of the Common Cockle culture phase. The table provides information about sizes, production quantities, types, and residence times.

[56] In the Common Cockle culture all systems of all sub-phases need to be environmental controlled by the environmental control system, except all systems in the growout. In the growout the environmental control system does not exist.
[57] Transportation equipment, like crane ways, piping, etc, is defined as physical contacted.
[58] For starting the production process for Common Cockle species in the aquaculture facility the input of the Common Cockle species in the broodstock conditioning are initially coming from wild stocks.

In the culture of Common Cockles systems the Common Cockle species need to be held in a required habitat. The required habitat characteristics are described in table 8.

Required habitat characteristics	Broodstock conditioning *(CC-1)*	Reproduction *(CC-2)*	Larval rearing *(CC-3)*	Settlement *(CC-4)*	Growout *(CC-5)*
Quality:					
Substrate required	yes*	no	no	no	yes*
Quantity:					
Required space	20 cm2/ind	-	0.1 cm3/ind	1.5 cm2/ind	10 cm2
Required min. depth	10 cm	-	-	-	30 cm
* The substrate needs to exist of clean sand, mud, or muddy gravel.					

Table 8: Required habitat characteristics (Utting & Spencer, 1991; Helm & Bourne, 2004).

Seawater treatment system (CC-x.2)

In the seawater treatment system seawater is pre-treated, after which it is transported to the rearing units in the sub-phases of the Common Cockle culture phase. For all sub-phases in the Common Cockle culture phase a recirculation system, with some net flow-through, is used[59]. The seawater treatment consists of three functional components, which are: the water circulation system (CC-x.2.1), the contamination control system (CC-x.2.2), and the temperature control system (CC-x.2.3). Figure 33 shows a block diagram of the seawater treatment system.

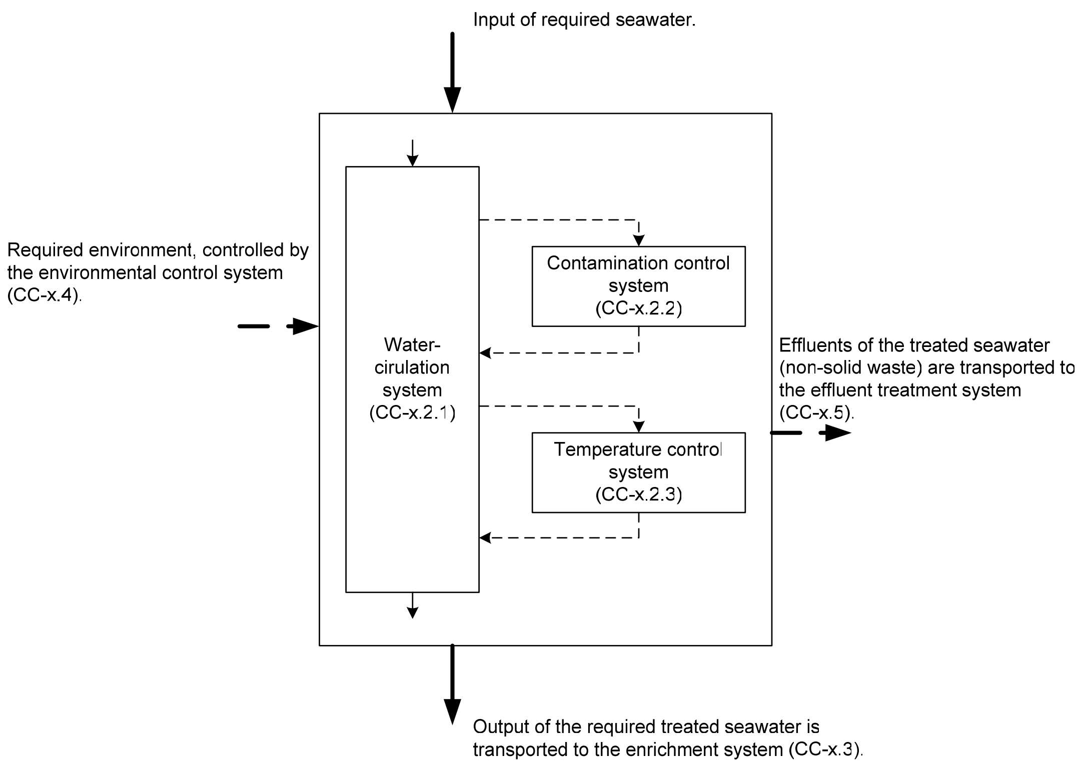


Figure 33: Block diagram of the seawater treatment system (CC-x.2).

[59] As described in figure 19 of paragraph 3.2.1, the characteristic of a recirculation system, with some net flow-through, is that seawater is pre-treated after which it is transported to the rearing units. This characteristic is described in the defined seawater treatment system. Another characteristic of the recirculation system, with some net flow-through, is that the seawater from the rearing units is transported to post-treatments, or to other water treatments to create a certain recirculation (closed system). These characteristics are defined in the effluent treatment system (CC-x.5).

The required input of the seawater treatment system is seawater from an open seawater water source. This seawater needs to be treated to a quality which is described in table 9.

Quality characteristics \ Sub-phases	Broodstock conditioning (CC-*1)*	Reproduction *(CC-2)*	Larval rearing *(CC-3)*	Settlement *(CC-4)*	Growout *(CC-5)*
Temperature (°C)	5-35	15-35	15-35	15-35	5-35
Filtration size (µm)	10 or 20-40	2	2	10	20-40
Disinfection by	no	ultra-violet	ultra-violet	no	no
pH	7.9-8.2*	7.9-8.2*	7.9-8.2*	7.9-8.2*	7.9-8.2*
Salinity (psu)	15-35	15-35	15-35	15-35	15-35
Oxygen (ml/l)	1.5-2.0**	1.5-2.0**	1.5-2.0**	1.5-2.0**	1.5-2.0**

Remarks:
* by adding carbon dioxide (CO_2).
** needs to be filtrated to a size of 45 µm.

Table 9: Required seawater characteristics of the Common Cockle culture phase.

Besides the required quality of seawater, a required quantity, or volume (V) of seawater is required. The required quantity of seawater is described in table 10.

Quantity characteristics \ Sub-phases	Broodstock conditioning (CC-*1)*	Reproduction *(CC-2)*	Larval rearing *(CC-3)*	Settlement *(CC-4)*	Growout *(CC-5)*
Required average volume (V) per 10^6 Common Cockle individuals (l/day)	605.656*	0.004	0.281	15.356	6056.56*

Remarks:
* it is assumed that: 1 liter of seawater is 10 times reused by Common Cockle species, before it is renewed or discharged.

Table 10: Required quantity (or volume) of seawater in the Common Cockle culture phase per million individuals.

The required quantity of seawater is based on the clearance rate, which is described in (paragraph 3.1.5). Furthermore, it has to be noted that Common Cockle species do not need to filter only new (not filtered before) water[60]. In some sub-phases (e.g. the broodstock conditioning, and the growout) the Common Cockle species are required to reuse (enriched) seawater certain times.

Enrichment system (CC-x.3)

In the enrichment system substances (e.g. food, building materials, etc) are added to the treated seawater to ensure good quality of enriched seawater for the Common Cockle species in the Common Cockle culture phase. The enrichment system consists out of two functional components, which are: the nutrient conditioning system (CC-x.3.1), and the nutrient addition system (CC-x.3.2). The block diagram of the enrichment system is described in figure 34.

[60] Fresh water is a definition which means that the seawater is not filtered before, by other Common Cockle species, in the land-based aquaculture facility.

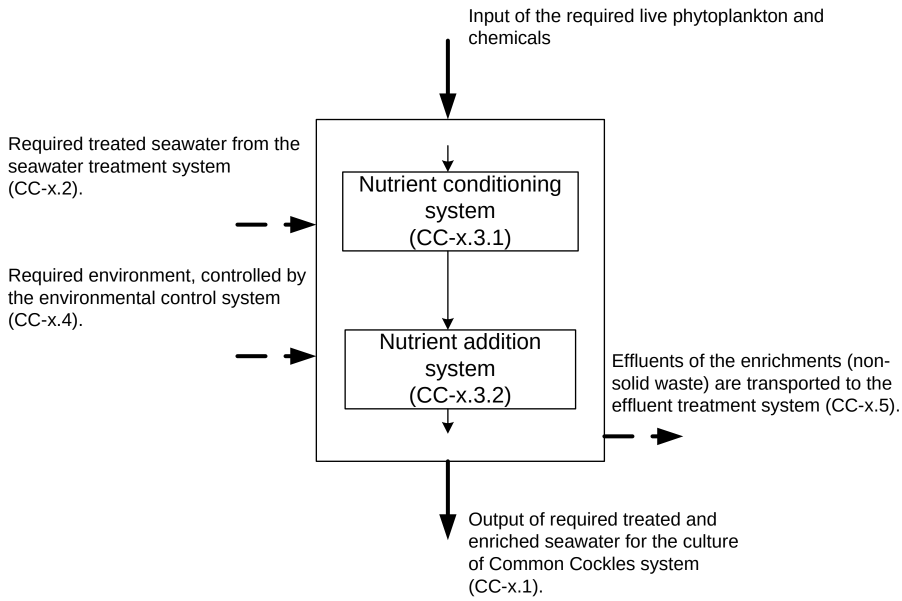


Figure 34: Block diagram of the enrichment system (CC-x.3).

The inputs of the enrichment system are required live phytoplankton (or so-called uni-algal species) which are described in table 1 and table 2. The uni-algal species are coming from the output of the harvest of culture of algae system of the large-scale culture (algal culture phase). The chemicals, which need to be used as input, are: carbon dioxide, oxygen, and sea salt. The characteristics of the chemicals are described in table 9. The chemicals need to come from reputable chemical facilities.

Environmental control system (CC-x.4)

The environmental control system controls the environment in which other all other systems of the Common Cockle culture phase are located. The environmental control system consists only of an environmental temperature system (AL-x.4.1). The block diagram is described in figure 35.

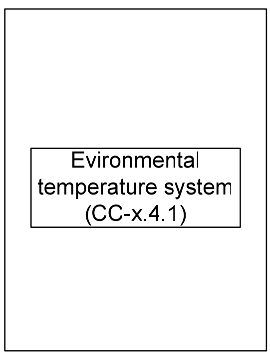


Figure 35: Block diagram of the environmental control system (CC-x.4).

The environmental control system has no vertical- or horizontal relations, because the system has no input or output. The environmental control system also has no direct physical relation (or so-called flow) with other systems. Nevertheless, the environmental control system has non-physical relations with all other systems, except the systems in the growout.

Quality characteristics / Sub-phases	Broodstock conditioning (CC-*1)*	Reproduction *(CC-2)*	Larval rearing *(CC-3)*	Settlement *(CC-4)*	Growout *(CC-5)*
Temperature (°C)*	5-35	15-35	15-35	15-35	5-35**
Remarks: * measured at the culture surface. ** is not controlled by an environmental control system.					

Table 11: Required quality characteristics of the environmental control system.

The required temperature of the environmental temperature system is described in table 11. It has to be noted that the environmental temperature system does not exist in the growout.

Effluent treatment system (CC-x.5)

In the effluent treatment systems effluents (non-solid wastes) are treated, so they can be used as input in the seawater treatment systems, or they can be discharged to an open water source. The effluent treatment system consists out of three functional components, which are: the water circulation system (CC-x.5.1), the contamination control system (CC-x.5.2), and the temperature control system (CC-x.5.3), see figure 36.

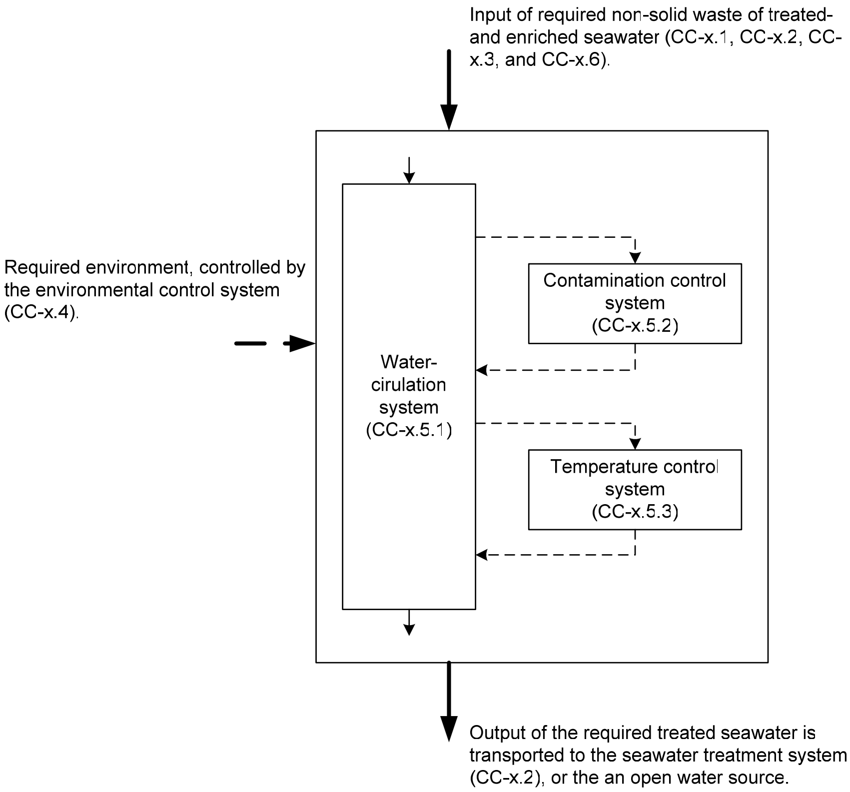


Figure 36: Block diagram of the effluent treatment system (AL-x.5).

The input of the effluent treatment system is treaded- and enriched seawater from: the culture of Common Cockles system, the seawater treatment system, the enrichment system, and the harvest of culture of Common Cockles system. The output of the effluent treatment system needs to be same, or close to the, quality of seawater as which is used as input in the seawater treatment system.

Harvest of culture of Common Cockles system (CC-x.6)

In the harvest of culture of Common Cockles system Common Cockle species are harvested. The Common Cockle species are, after harvesting, transferred to the culture of Common Cockle system of the next sub-phase, or to the distribution system[61] of the general infrastructure phase. The harvest system (CC-x.6.1) is the only functional component in the system, see figure 37. The harvest system needs to buffer and condition the harvested Common Cockle species.

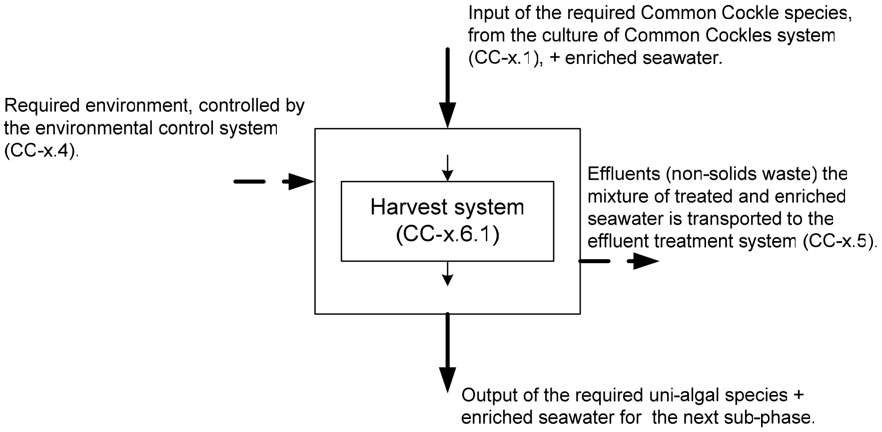


Figure 37: Block diagram of the harvest of culture of algae system (CC-x.6).

The inputs of the harvest of culture of Common Cockles system are the Common Cockle species from the output of the culture of Common Cockles system. Furthermore, enriched seawater is inputted in the system. The enriched seawater comes from the seawater treatment system and the enrichment system. The output of the harvest of Common Cockles system is used as input for the culture of Common Cockles system of the next sub-phase, or, in case of the growout, the Common Cockle species are transferred to the distribution system.

4.3 General infrastructure phase (GI-0)

In the general infrastructure phase functions (or so-called sub-phases) are included which support the primary production process (algal culture phase and Common Cockle culture phase). Sub-phases which are included in the general infrastructure phase are: the general systems (GI-1), the employees/guest facilities (GI-2), and the distribution system (GI-3). In figure 38 an overview is given of the acquisition of the general infrastructure phase.

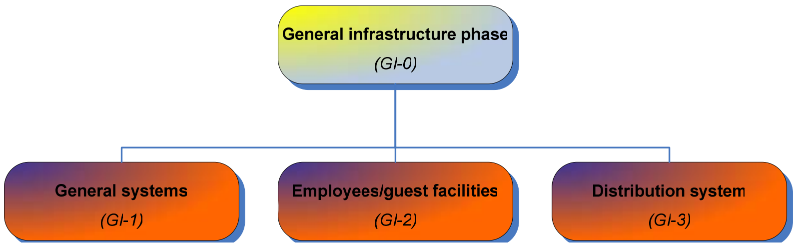


Figure 38: Overview of the acquisition of the general infrastructure phase.

[61] In the distribution system of the general infrastructure phase Common Cockle species (of a shell length of 30-40 mm) are distributed to the market. Within the distribution system uni-algal species and Common Cockle species (shell lengths < 30 mm) are also distributed inside the aquaculture facility.

In the next paragraphs the sub-phases of the general infrastructure phase are further described. It has to be noted that the general infrastructure phase has no systems like the phases in the primary production process. Therefore, the functional components are derived from the sub-phases.

4.3.1 General systems (GI-1)

The general systems include systems which are necessary for a high quality standard of the land-based aquaculture facility. The general systems need to exist out of, at least, four functional components, which are: the power system (GI-1.0.1), the air ventilation system (GI-1.0.2), the emergency system (GI-1.0.3), and the maintenance system (GI-1.0.4)[62].

Power system (GI-1.0.1)

The power system provides electricity to all systems (which need electricity) in the aquaculture facility. The electricity is imported in the facility from local utility companies. The power in the aquaculture facility needs to be controlled from a specific power room. The infrastructure needs to be allocated to all systems which need electricity.

Air ventilation system (GI-1.0.2)

The air ventilation system needs to be located in every building in the aquaculture facility. Its function is to ensure that the air in the aquacultural buildings is refreshed, so a healthy environment is created for the employees (and guests) and the cultured stocks of algae and Common Cockle species. The air needs to be conditioned in a specific air ventilation room. Air ventilation needs to be allocated to all aquacultural buildings, and its sub-phases.

Emergency system (GI-1.0.3)

An emergency system is required to provide safety in the aquaculture facility. The emergency system needs to include: a medical first aid system (in case of accidents), a fire fighting system (in case of fire), and a power generator system (in case of power failure). The emergency system needs to be allocated throughout the whole aquaculture facility, within constraints of governmental laws and regulations.

Maintenance system (GI-1.0.4)

The maintenance system needs to make maintenance of the systems in the aquaculture facility possible. The maintenance system needs to consist of a working chamber (including installed equipment), and a storage room. Furthermore, the systems in the aquaculture facility need to be designed in a way systems are accessible for maintenance.

4.3.2 Employees/guest facilities (GI-2)

The employees/guest facilities are facilities (or so-called functional components) for employees (and possible guests) to do their work. The employees/guest facilities consist of three functional components, which are: working facilities (GI-2.0.1), general facilities (GI-2.0.2), and relaxing facilities (GI-2.0.3).

[62] The ‘0’ in the traceability code is standing for no identified system.

Working facilities (GI-2.0.1)

In the working facilities employees are working. The working facilities are part of the primary production process, as well as in the secondary production process. The working facilities need to be adapted to the environment, so the employees are situated in a healthy environment. Although, many employees will work at the floor of the primary production process, some employees need a specific area. The specific working areas are: the control area[63], administration area[64], and meeting area[65].

General facilities (GI-2.0.2)

The general facilities provide standard facilities for employees, or guests, during breaks. The general facilities consist of: a sanitation area, an area for a kitchen, and an area for a small canteen.

Relaxing facilities (GI-2.0.3)

The relaxing facilities are optional. The relaxing facilities are useful facilities for employees, or guests, who are working in shifts, like production process employees and chauffeurs. The relaxing facilities can provide a bed and sanitation.

4.3.3 Distribution system (GI-3)

In the aquaculture facility the distribution system is defined as the sub-phase in which solid goods[66] are transported to one place to another, within, and outside, the aquaculture facility. Furthermore, the distribution system also distributes non-solid goods from one place to another, but these specific goods are utility related[67]. The distribution system consists out of two functional components, which are: the goods system (GI-3.0.1), and the utility system (GI-3.0.2).

Goods system (GI-3.0.1)

The function of the goods system is to distribute, (canned) uni-algal species of culture collections from reputable institutes, and required chemicals from reputable chemical facilities, from the institutes to the aquaculture facility. Furthermore, the goods system distributes Common Cockle species from the aquaculture facility to the market, but it also distributes the Common Cockle species within the aquaculture facility from one place to another. As described in appendix V, in and between most sub-phases uni-algal species and Common Cockle species are distributed by pipes. Nevertheless, in some cases the uni-algal species and Common Cockle species need to be transferred in solid compounds. This transport can be achieved by vehicles (e.g. load trucks)[68].

Utility system (GI-3.0.2)

The utility system distributes utility related goods, like: electricity, drinking water, gas, and communications (telephone, fax, internet, and internal communications between systems). The utility related goods are in an adequate quantity and quality required.

---

[63] In the control area primary production processes are controlled, by computers.
[64] In the administration room standard administration, or small amount of other paper work, will be done.
[65] In the meeting area meetings can take place.
[66] The solid goods can for example be: (canned) uni-algal species of culture collections from reputable institutes, (packed) chemicals from reputable chemical facilities, and adult (L > 30 mm) Common Cockle species.
[67] Utility related goods are defined as: electricity, drinking water, gas, and communications (telephone, fax, internet, and internal commutations between systems).
[68] This implies that the infrastructure of the aquaculture facility needs to be suitable for these alternative transports.

4.4 Résumé

Looking upon this chapter, it can be concluded that the primary production process and the secondary production process have many technical requirements. These technical requirements are described per phase and per decomposition level (sub-phases, systems, and functional components), in terms of what it must do (functional requirements) and what it must perform (non-functional requirements), in the previous paragraphs. Besides the technical requirements, the previous paragraphs also describe the functions and the relations of functional components at several decomposition levels. This description is called the functional architecture.

From the functional architecture, including the technical requirements, two critical aspects are identified, which could negatively affect the technical feasibility of the aquaculture facility. These critical aspects were found in the primary production process. Besides, these critical aspects other aspects were found which could negatively affect the technical feasibility of the project. The first critical aspect is considered as the large required quantity of treated seawater (table 10) per Common Cockle species. The second critical aspect is considered as the large required quantity of uni-algal species needed (table 2). However, based on the information which is described in the previous chapters it can not be concluded if these large required quantities of treated seawater and the production of uni-algal species do negatively affect the technical feasibility of the project. This conclusion can only be made if an example of a physical architecture, based on 'state-of-the-art' culture techniques, is described. Such an example has been described in chapter 5. After analyses (investment prognosis and verification) of the physical architecture the outputs (conclusions and recommendations) are described in chapter 6.

5 Physical architecture

In this chapter an example of the physical architecture of the land-based aquaculture facility is described. This physical architecture is derived from the technical requirements and functional architecture (chapter 4). In the physical architecture today's 'state-of-the-art' technology has been described for culturing uni-algal species. The technology which is described for the culture process of Common Cockle species is derived from existing 'state-of-the-art' technology which is used for other bivalve species in aquacultures, due to the fact that land-based aquaculture facilities for Common Cockle species have never been developed before. The physical architecture is divided into two dimensions, which are: the aquacultural building, and the aquacultural site. The two dimensions are further described at system level in the next paragraphs.

5.1 Aquacultural building

The aquacultural building is a definition for the dimension of the location of the systems of all sub-phases of the primary production process, which need to be environmental controlled. Because the culture of Common Cockles system (CC-5.1) and the harvest of culture of Common Cockles system (CC-5.6) of the growout, do not need to be environmentally controlled, they are located outdoor. Therefore, these two systems are described in the paragraph of the aquacultural site (paragraph 5.2). Although, the other systems of the growout also do not need to be environmentally controlled, they are located indoor, because of their strong relation with other systems in the aquacultural building.

Figure 39, and appendix VII, describe an example of a floor plan, in which sub-phases and systems are allocated to certain locations. The trade-off of allocating the sub-phases and systems to certain locations has been made according to the functional analysis, which is integrated in chapter 4.

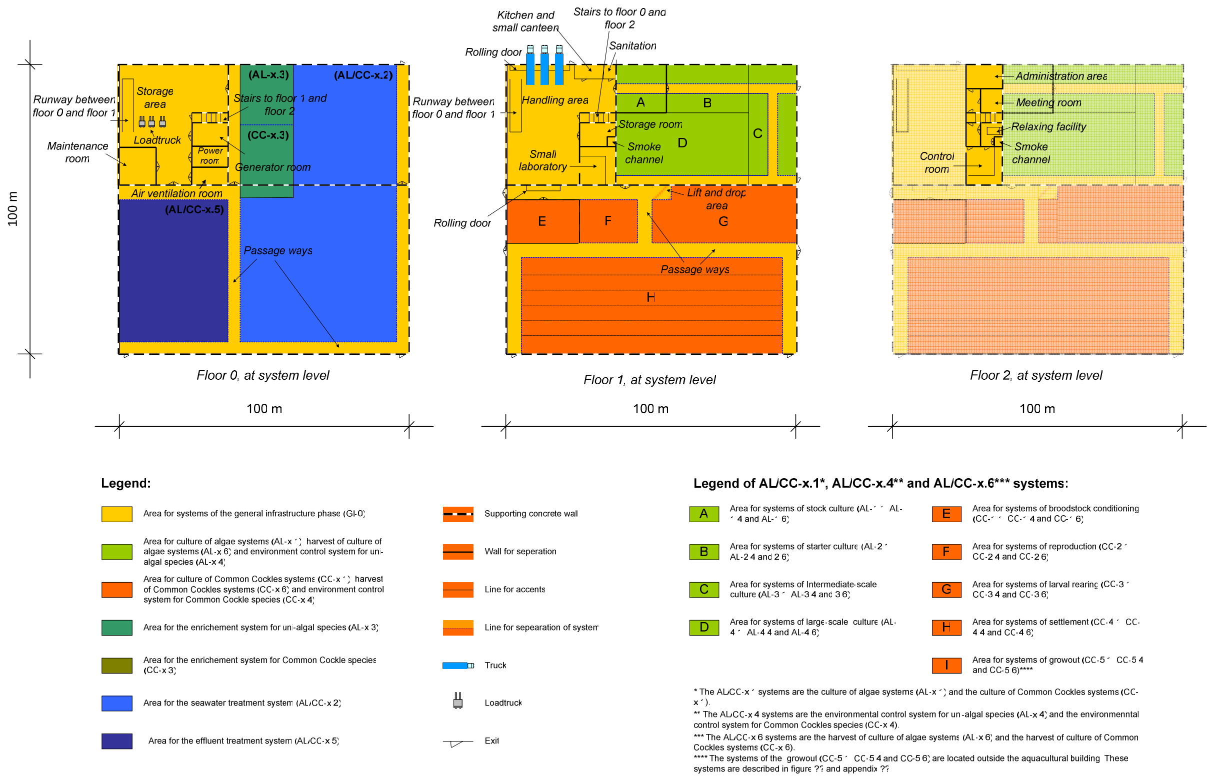


Figure 39: Floor plan of the physical architecture of the aquacultural building at system level.

As described, in the floor plan of the physical architecture of the aquacultural building at system level, the aquacultural building consists of three floor levels. The allocated location of the systems and sub-systems of the three floor levels are described in paragraph 5.1.1. A spatial description of the systems and procedures in the aquaculture building are described in paragraph 5.2.2.

5.1.1 Location of systems and sub-systems

In this paragraph an example has been described of the allocation of the systems and sub-systems in the aquacultural building to certain locations. This allocation is derived from chapter 4 and the "functional architecture: lower levels", which is described in appendix V. The allocation of the locations is described per floor level.

Floor 0

At floor 0 the following systems of the primary production process are located: the seawater treatment system (AL/CC-x.2), the enrichment system (AL/CC-x.3), the environmental control system (AL/CC-x.4), and the effluent treatment systems (AL/CC-x.5)[69]. In behalf of the general infrastructure phase the following functional components are integrated at floor 0: a power room (based on GI-1.0.1), an air ventilation room (based on GI-1.0.2), a generator room (based on GI-1.0.3), a maintenance room (based on GI-1.0.4), a storage area (based on GI-1.0.4), and passage ways (based on GI-3.0.1). Although, they are not explicitly described in the physical architecture, the medical first aid system (based on GI-1.0.3), the fire fighting system (which includes the exits) (based on GI-1.0.3), the working facilities (based on GI-2.0.1), and the utility systems (based on GI-3.0.2) are also integrated at floor 0.

The systems which are allocated to floor 0 have an inter-relationship with the systems at floor 1 (next section). Therefore, these systems need to be allocated to locations nearby each other. Furthermore, it can be noted that the systems, which are allocated to floor 0, can be defined as production systems of, or has a relation with, the production of liquid semi-finish products (e.g. treated seawater, suspension of enrichments) which can be automatically transported by pipes. In this way, these semi-finished products can be easily transferred over small distances to related systems. In the example of the physical architecture, which is shown in figure 39, floor 0 is allocated beneath floor 1, due to the inter-relationship between these systems. In addition, the seawater treatment system (AL/CC-x.2) and the effluent treatment system (AL/CC-x.5) are allocated to this floor. Therefore, it has been considered that, in the aquacultural building these systems need to be located as low as possible (to a certain reference level), due to construction matters (e.g. heavy weight of these systems, the intake and outlet of seawater). Furthermore, the enrichment systems (AL/CC-x.3) are partly located straight beneath the algal culture phase and Common Cockle culture phase, due to transportation aspects (e.g. decrease of transportation distances). Systems of the general infrastructure phase are allocated to this floor to support the systems of the primary production process. However, other alternative locations of the systems of floor 0, in reference to floor 1, may also be possible, but are not considered in this study.

[69] All three systems are both located in all sub-phases in the algal culture phase and in the Common Cockle culture phase. For example, (AL/CC-x.2) describes all seawater treatment systems of all sub-phases of the algal culture phase and Common Cockle culture phase.

Floor 1

At floor 1 the following systems of the primary production process are located: the culture of algae system (AL-x.1), the environmental control system (AL/CC-x.4), the harvest of culture of algae system (AL-x.6), the culture of Common Cockles system (CC-x.1), and the harvest of culture of Common Cockles system (CC-x.6). In behalf of the general infrastructure phase the following functional components are integrated at floor 1: a small laboratory (based on GI-1.0.4), a storage room (based on GI-1.0.4), a kitchen (based on GI-2.0.2), a small canteen (based on GI-2.0.2), sanitation (based on GI-2.2), passage ways (based on GI-3.0.1), and a handling area (based on GI-3.0.1). Although, they are not explicit described in the physical architecture, the medical first aid system (based on GI-1.0.3), the fire fighting system (which includes the exits) (based on GI-1.0.3), the working facilities (based on GI-2.0.1), and the utility systems (based on GI-3.0.2) are also integrated at floor 1.

As described in the previous section the systems, which are allocated at floor 0 and floor 1 are inter-related with each other, which implies that these systems need to be located nearby each other. The systems which are allocated at floor 1 can be defined as production systems which produce, or are related with the production, of uni-algal species and Common Cockle species. The uni-algal species and Common Cockle species have certain characteristics, which imply that they can not be easily transferred from one place to another. On the other hand, technical requirements require easy transport and environmental control. This example shows a stronger inter-relationship of the systems which are allocated at floor 1, in reference to the specific systems at floor 0. The systems of the primary production process are supported by the systems of the general infrastructure at this floor. In addition, the distribution centre at this floor needs to be accessible for trucks. Therefore, it is preferable that this floor is located at surface level.

Floor 2

At floor 2 no systems of the primary production process are located. Nevertheless, a control room (based on GI-2.0.1), an administration room (based on GI-2.0.1), a meeting room (based on GI-2.0.1), a bed (based on GI-2.0.2), and sanitation (based on GI-2.0.2) are located at this floor. Although, they are not explicit described in the physical architecture, the medical first aid system (based on GI-1.3), the fire fighting system (which includes the exits) (based on GI-1.3), the working facilities (based on GI-2.1), and the utility systems (based on GI-3.2) are also integrated at floor 2.

In the physical architecture, which is shown in figure 39, the systems which are allocated to floor 2 are located above floor 1. In this way, employees who are working at the administration area are directly involved at the production processes, because they have sight (through glass windows) on the algal culture phase and at the handling area. Furthermore, employees who are working at the control room need to have sight on the primary production processes (e.g. algal culture phase and Common Cockle culture phase) and the handling area. However, other alternative positions of the systems of floor 2 may be possible, however, these are not considered in this study.

5.1.2 Description of systems and procedures of primary production process

As already described, the primary production process consists of the algal culture phase (AL-0) and the Common Cockle culture phase (CC-0). The algal culture phase consists of: the stock culture (AL-1), the starter culture (AL-2), the intermediate-scale culture (AL-3), and the large-scale culture (AL-4). The Common Cockle culture phase consists of: the broodstock conditioning (CC-1), the reproduction (CC-2), the larval rearing (CC-3), the settlement (CC-4), and the growout (CC-5). All systems and procedures of these sub-phases, expect of the systems of the growout (paragraph 5.2.1), are described in the sections below. Although, some technical requirements are mentioned in this description, it has to be noted that all systems need to meet the technical requirements which are described in chapter 4 and appendix IV. The procedures which are described in this paragraph are mainly derived from information, which is described in Utting & Spencer (1991) and Helm & Bourne (2004).

Stock culture (AL-1)

Stock cultures, otherwise known as master cultures, are the basic foundation of the algal culture phase. The stock cultures consist of uni-algal species, which are required as food supply for the Common Cockle culture phase. The required uni-algal species are split in diatom species and flagellate species, which need to be kept in a required quantity to inoculate the next sub-phase. These required uni-algal species are supplied from reputable culture collections maintained by national institutions or research laboratories. Since the required uni-algal species are valuable, they are kept in a specialized maintenance media (Guillard's F/2 media), under closely controlled conditions of temperature and illumination. A special area or room off the other sub-phases in the algal culture phase is allocated for this purpose.

In the culture of algae system (AL-1.1) the uni-algal species are kept in small, transparent, autoclaveable containers. For example, 500 ml borosilicate glass, flat-bottomed boiling or conical flasks fitted with a cotton wool plug at the neck, suitable for containing 250 ml of sterile, autoclaved maintenance media (Guillard's F/2 media). This maintenance media will be prepared with a required quality of seawater and a required quality of enrichments, from, respectively, the seawater treatment system (AL-1.2) and the enrichment system (AL-1.3).

The culture of algae system (AL-1.1) needs to be environmentally controlled by the environmental control system (AL-1.4). The environmental control system, which needs to control the temperature and light intensity, is achieved, respectively, in a large cooled (step-in) incubator at 4 to 12 ^{o}C and by illumination of two or more 8-watt (W) fluorescent lamps that provide a light intensity of 450 lux measured at the culture surface.

Although, during normal procedures no maintenance media need to be discharged, an effluent treatment system (AL-1.5) needs to be installed in the stock culture. In case of failure of the preparation of the maintenance media, the maintenance media can be discharge by this system. The effluent treatment system can also be used as discharge for water which is used for cleaning. Furthermore, the stock culture has also a harvest of culture of algae system (AL-1.6). This harvest of culture of algae system can be considered as a cabinet that has been sterilized by ultra-violet light to further reduce the risk of contamination (figure 40-A). The uni-algal species which are conditioned in the culture of algae system (AL-1.1) can inoculate the culture of algae system (AL-2.1) of the starter culture, which is the next sub-phase. Before transferring these uni-algal species from one culture of algae system to another, a bunsen burner needs to be used for sterilization of these culture of algae systems (containers or flasks).

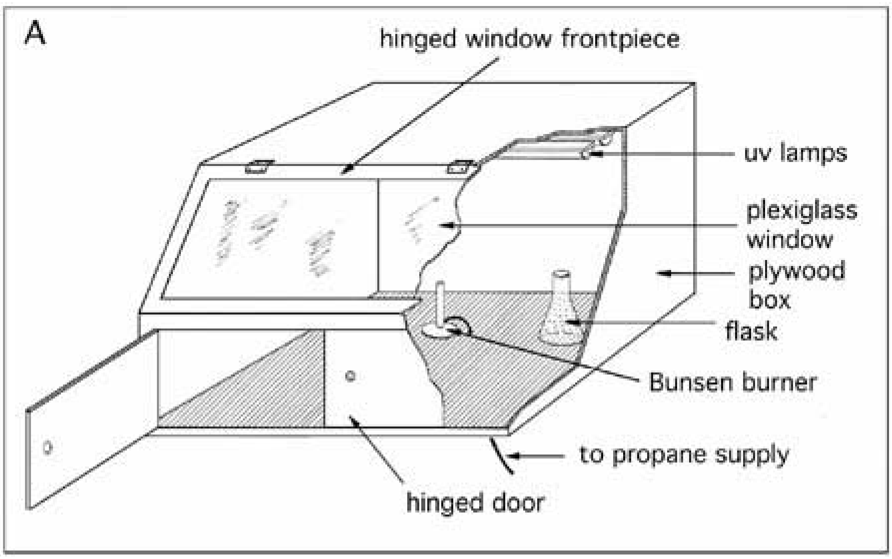


Figure 40: A - schematic diagram of a cabinet (Helm & Bourne, 2004). B - an autoclave suitable for the sterilization of small of maintenance media (Helm & Bourne, 2004).

In figure 40-B an autoclave has been illustrated. In such an autoclave the autoclaveable containers can be put for sterilization of the maintenance media.

Starter culture (AL-2)

After the uni-algal species form the harvest of culture of algae system (AL-1.6) of the stock culture has inoculated the uni-algal species in the culture of algae system (AL-2.1) of the starter culture, the uni-algal species are grown to provide inocula to start larger volumes of the these cultures to produce food for the Common Cockle species in the Common Cockle culture phase. In the culture of algae system (AL-2.1) the uni-algal species are grown in 500 ml boiling flasks in 250 ml of maintenance media. Because the uni-algal species are needed to provide inocula for the intermediate-scale culture it is necessary to grow them quickly. They are grown at 18 to 22 ^{o}C at a distance of 15-20 cm from 65 or 85 W fluorescent lamps, giving a level of illumination at the culture surface of 4 750 to 5 250 lux (figure 41). The uni-algal species need to be aerated with air/carbon dioxide (CO_2) mixture.

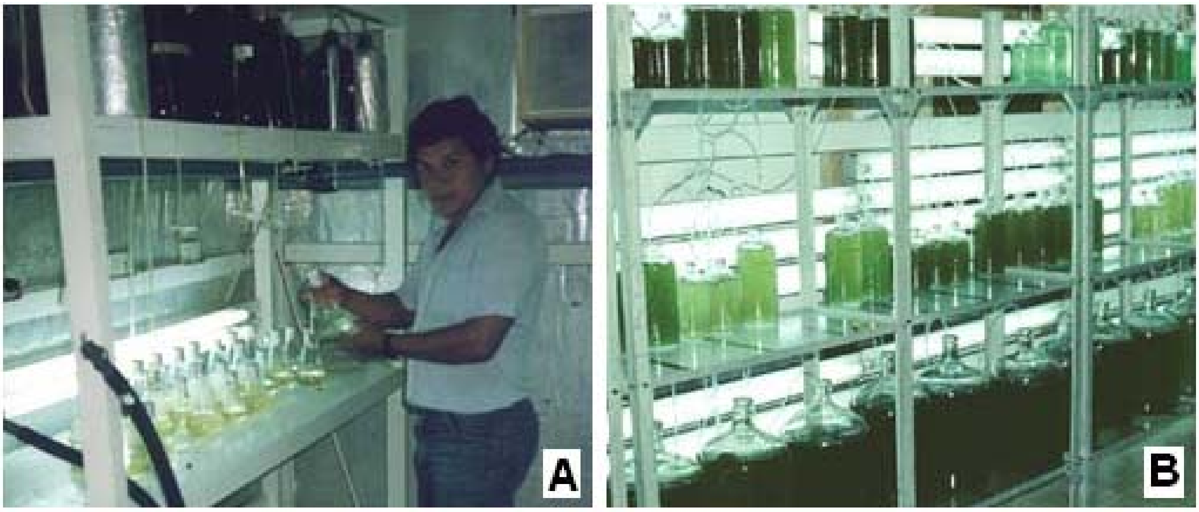


Figure 41: Photographs showing typical facilities for maintenance of starter cultures (Helm & Bourne, 2004).

Starter cultures are grown for variable periods of time prior to use. In case of diatom species, which have short generation times, this period is estimated from 3 to 5 days. For the majority of flagellates it is 7 to 14 days. When ready for use a starter culture is sub-cultured using sterile techniques, as previously described. 20 to 50 ml, depending on species and the density of the culture, is transferred to a fresh 250 ml culture – to maintain the starter culture line. The remainder is used as an inoculum for larger cultures (up to 25 l in volume) in the intermediate-scale culture (AL-3).

The seawater treatment system (AL-2.2), enrichment system (AL-2.3), environmental control system (AL-2.4), effluent treatment system (AL-2.5), and harvest of culture of algae system (AL-2.6) of the starter culture have the same function as the systems of the stock culture, although their parameters may differ. Their specific required parameters and functions are described in chapter 4.

Intermediate-scale culture (AL-3)

The culture of algae system (AL-3.1) of the intermediate-scale culture consists of spherical glass flasks or glass or clear plastic carboys of up to 25 l (figure 42-A), in which small volumes of uni-species are kept in required maintenance media (figure 42-B). The culture of algae systems are harvested in batches, by the harvest of culture of algae system (AL-3.6). Batch culture involves the inoculation of the culture medium with the required species. The culture is then grown rapidly until a further increase in cell density is inhibited by the failure of the light to adequately penetrate the culture. The culture is then completely harvested, the container washed and sterilized and started again with a new culture.

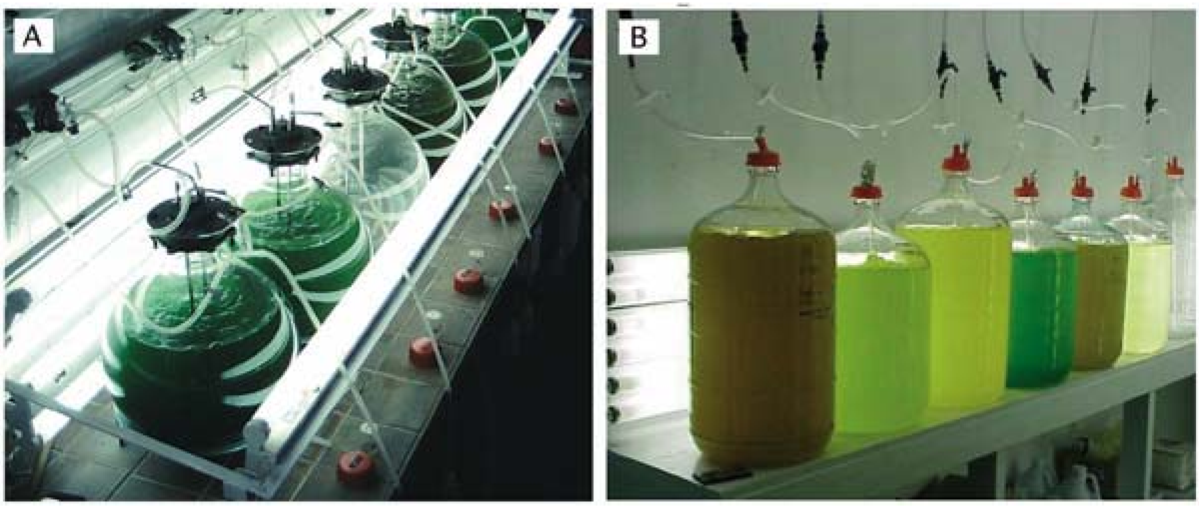


Figure 42: Two different approaches to the intermediate-scale culture of algae: A - 20 l volume round flasks; B - using equally as effective wine making carboys of 15 to 20 l volume (Helm & Bourne, 2004).

The seawater treatment system (AL-3.2), enrichment system (AL-3.3), environmental control system (AL-3.4), and effluent treatment system (AL-3.5) of the intermediate-scale culture have the same function as the systems of the starter culture, although their parameters may differ. Their specific required parameters and functions are described in chapter 4.

Large-scale culture (AL-4)

The uni-algal species in the large-scale culture are cultured continuously, i.e. the uni-algal species are continuously harvested in polyethylene bag cultures of 125 l. This process is feasible due to the electronic control of cell density. A diagram of the automated system, which is developed by the Fisheries Laboratory Conwy, UK is shown in figure 43.

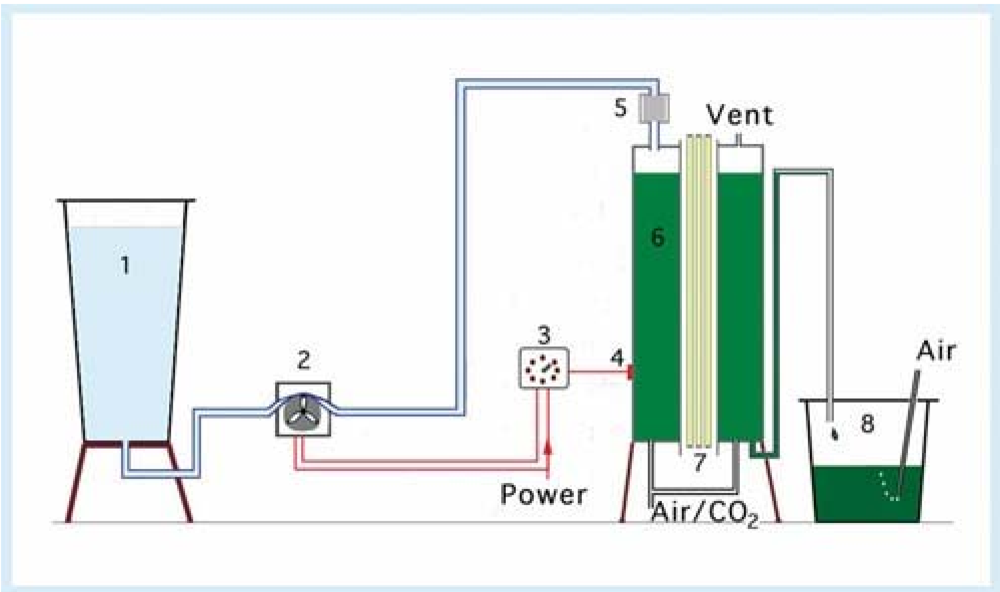


Figure 43: Schematic diagram of a large-scale culture system. Key: 1, reservoir of required maintenance media; 2, peristaltic pump; 3, resistance sensing relay; 4, light dependent resistor; 5, cartridge filter (0.45 µm); 6, culture vessel (125 l volume); 7, six, 80 W fluorescent lamps; 8, harvest of culture of algae system (AL-4.6) to receive the harvest (after Laing & Jones, 1988).

The key component in this system is a Light Dependent Resistor (LDR – no. 4) clamped onto the outer surface of a transparent culture vessel (no. 6). This culture vessel is defined as the culture of algae system (CC-4.1). Light falling on the LDR after penetrating the culture varies depending upon the density of cells in the culture. For internal illumination (no. 7) fluorescent lamps are used. These components are a part of the environmental control system (AL-4.4). As cell density increases the light transmittance through the culture decreases and this increases the resistance value of the LDR. The increase is detected by a Resistance Sensing Relay (RSR – no. 3) which is set to activate a peristaltic pump (no. 2) when a certain pre-set resistance value is reached. The RSR is adjusted to operate at the light intensity at which cell division is at a maximum. When activated, the peristaltic pump supplies fresh maintenance media (no. 1), from the seawater treatment system (AL-4.2) and enrichment system (AL-4.3), to the culture vessel and this displaces an equal volume in a receiving container (no. 8), which is a part of the harvest of culture of algae system (AL-4.6). As the culture in the vessel becomes increasingly diluted, the transmittance of light through the culture, detected by the LDR increases, the resistance of the LDR decreases, and the RSR switches off the peristaltic pump (Laing & Jones, 1988).

Beside, the systems which are described above, the temperature also needs to be controlled by the environmental control system (AL-4.4). Furthermore, an effluent treatment system (AL-4.5) is allocated to this sub-phase.

This device is inexpensive to construct with modern electronics and it is very effective in maintaining cultures at peak productivity. Helm & Bourne (2004) describe a maximum productivity of this device of about 100 liter per day of *Tetraselmis suecica* at 1 000 cells per µl by operating a system of 2 000 cells per µl. For the *Tahitian Isochrysis* a maximum productivity can be achieved of 90 liter per day at 10 000 cells per µl by operating a culture density of 16 000 per µl. Based on these harvested volume and density, which are harvested by the harvest of culture of algae system (AL-4.6), it can be concluded that approximately 20 g (dry weight) of uni-algal species can be harvested per vessel per day. However, the required diatom species are not described above, it is assumed that the weight of 20 g (dry weight) also applies to these species.

Broodstock conditioning (CC-1)

Adult Common Cockle species (breeders) are taken from wild stock or from growout sections. They are placed in a substrate, of coarse sand, in a tank similar to that is shown in figure 44. This tank is called the culture of Common Cockles system (CC-1.1), and has the following dimensions: 80 x 60 x 30 cm.

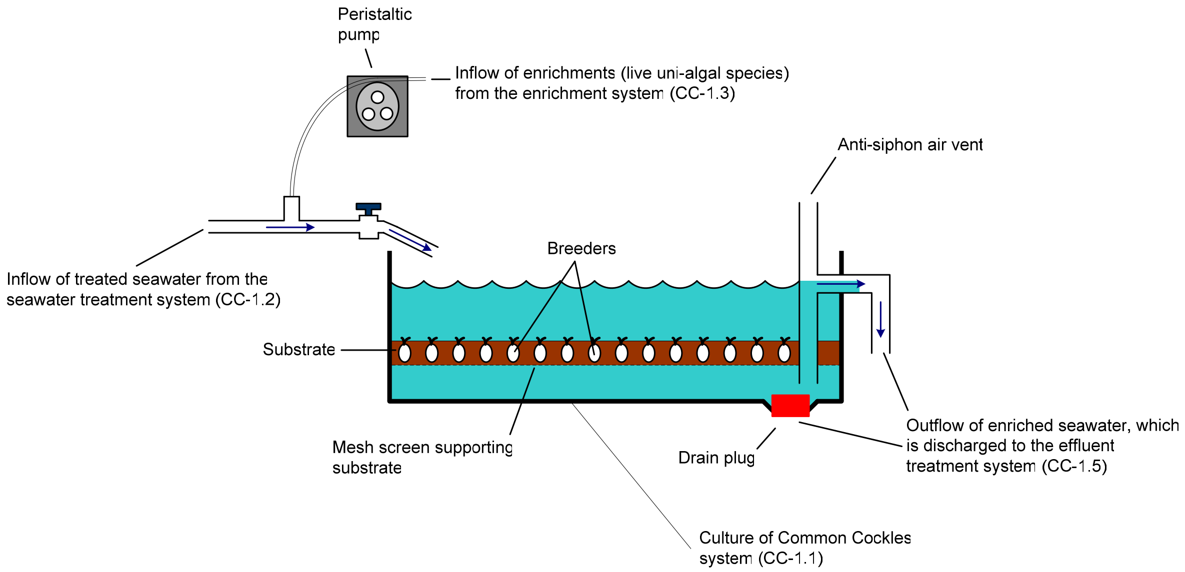


Figure 44: Culture of Common Cockles system (CC-1.1) of the broodstock conditioning (after Utting & Spencer, 1991).

The seawater supply needs to be filtered to a particle size of less than 40 µm in the seawater treatment system (CC-1.2). The enrichment system (CC-1.3) should add enough uni-algal species and salt (salinity of 15-35 PSU). Water flow rate through the tank should exceed 25 ml per minute per breeder and no more than 20 breeders should be held in a tank. The water must run to the effluent treatment system (CC-1.5), after which it is re-used or discharged. The breeders are harvested manually. The equipment which is needed for this harvesting system belongs to the harvest of culture of Common Cockles system (CC-1.6). The environmental control system (CC-1.4) should be able to condition the environmental temperature at a range of 5-35 ^{o}C. However, the assumed average environmental temperature to condition is 18 ^{o}C.

Reproduction (CC-2)

In the reproduction breeders are induced to liberate their gametes (eggs and sperm) in response to applied stimuli, like thermal cycling. During the thermal cycling breeders, taken from the broodstock conditioning tanks, are cleaned externally to remove any adhering debris and are placed in the culture of Common Cockles system (CC-2.1), or so-called spawning tank. These spawning tanks are shallow fibreglass troughs of an approximate size of 150 x 50 x 15 cm. It is fitted with two filtered seawater supplies, one heated to 18-20 ^{o}C and the other 28-35 ^{o}C, from the seawater treatment system (CC-2.2). Both seawater supplies can be enriched (e.g. salt, live uni-algal species) by the enrichment system (CC-2.3). The spawning tanks are also fitted with a stand-pipe drain which distributes the enriched and treated seawater to the effluent treatment system (CC-2.5). The black plastic sheeting, which provide a dark background, so gametes being liberated can be readily seen (figure 45), can be considered as a part of the harvest of culture of Common Cockles system (CC-2.6).

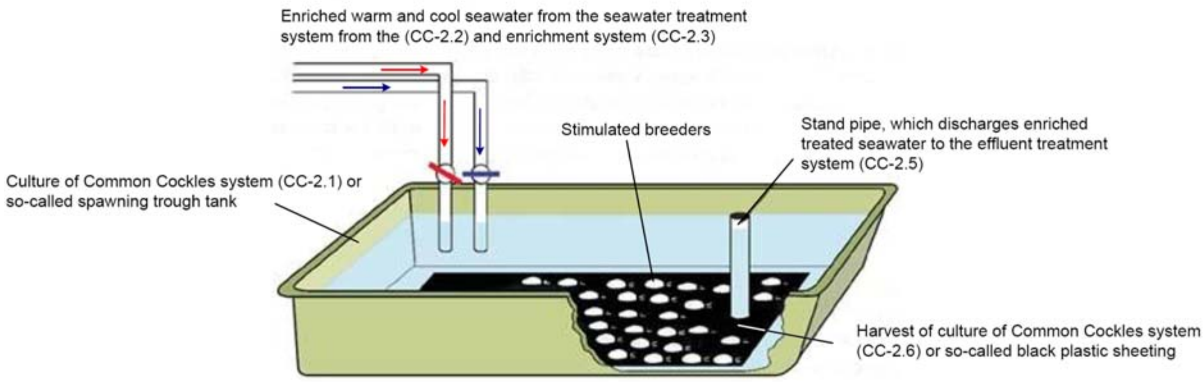


Figure 45: Diagram of a spawning trough tank (after Utting & Spencer, 1991 and Helm & Bourne, 2004).

The trough is fitted with the cooler water to a depth of about 10 cm and a small amount of cultured algae is added (by the enrichment system – CC-2.3) to stimulate the Common Cockle species to extend their siphons and start pumping activity. After 15-30 minutes, the water is drained and replaced with water at 28-30 ^{o}C, again with a small addition of algae. This water is drained after a similar time period and replaced with cooler water and the procedure is repeated. The number of cycles which are necessary to induce spawning depends on the readiness of the breeders to spawn. Normally, the breeders do spawn in less than 8 hours. When the breeders do not respond in within an 8 hour period they are returned to the conditioning tanks in the broodstock conditioning for another week.

When the first breeders to spawn are males, they need to be removed from the trough and kept out of the water until sufficient eggs have been collected from spawning females. The reason for this procedure is that sperm ages rapidly and, if it is more than 1-hour old at the time of fertilization, a low fertilization rate will be obtained.

As each female breeder begins to spawn, it is necessary to transfer it from the spawning trough to an individual spawning dish containing about 400 ml of filtered seawater at 24-26 °C (figure 46). The same procedure applies to spawning males which can be identified as such by the milky appearance of the continuous stream of sperm liberated from the exhalent siphon, as in contrary to the granular clumps of eggs shed by a female.

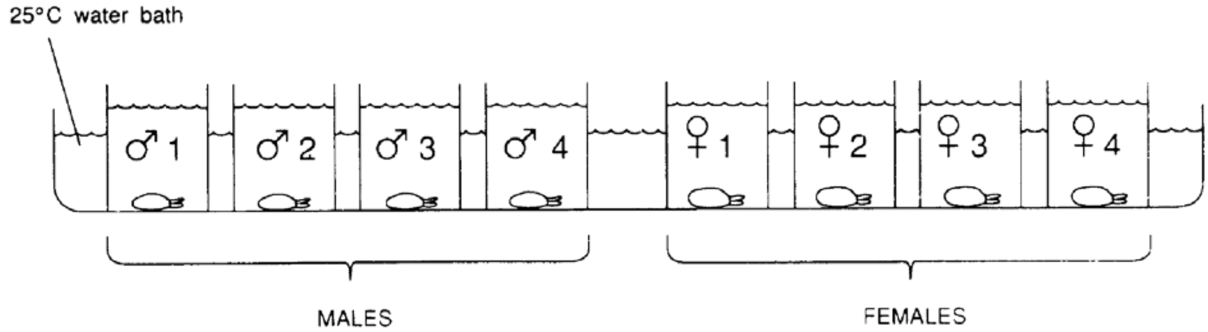


Figure 46: Collection of eggs and sperm in a spawning dish (after Utting & Spencer, 1991).

The time for completion of spawning for an individual breeder is probably variable, but in natural situations gamete liberation rarely lasts for more than 15 minutes. It may, however, be necessary to remove a spawning female from its container, because the pumping activity could be inhibited by the dense concentrations of eggs and the hence expulsion of eggs in the water. Furthermore, the females may also start to filter eggs out of suspension.

The eggs will probably quickly settle to the base of the dish. When spawning has been completed, any clumps of eggs can be separated. The equipment which is needed for this procedure are a part of the harvest of culture of algae system (CC-2.6)[70]. This system also consists of a tank and nylon mesh sieves (15 and 60 µm). By pouring the contents of the dish through 60 µm nylon mesh sieves the separated eggs can be retained on 15 µm mesh sieves (figure 47). The eggs are then gently washed into a clean glass or plastic container with filtered seawater at 25 °C, which comes from the seawater treatment system (CC-2.2).

After separation and examination of the eggs (examination takes places in a small laboratory) are completed, batches of eggs which appear to be in good condition are pooled. Sperm from the various males which spawn are similarly pooled. The eggs of at least six females and sperm from a similar number of males for a production run needs to be used. This ensures a good genetic mix in the offspring (Utting & Spencer, 1991).

After pooling the eggs and sperm in separate containers, it is assumed that fertilization is carried out by adding 2 ml of a dense suspension to each liter of the egg suspension. The sperm should be less than 30 minutes old from the time of spawning and the eggs less than 60 minutes old. After addition of the sperm, the contents of the container should be gently agitated and then allowed to stand for 60-90 minutes. Within this period at 25 °C the fertilized eggs divide into trochophores.

The trochophores are left to develop to the fully-shelled, D-veliger stage in flat-bottomed rearing vessels (figure 47).

[70] The harvest of culture of Common Cockles species (CC-2.6) consists of several parts, which are spread over multiple types of tanks.

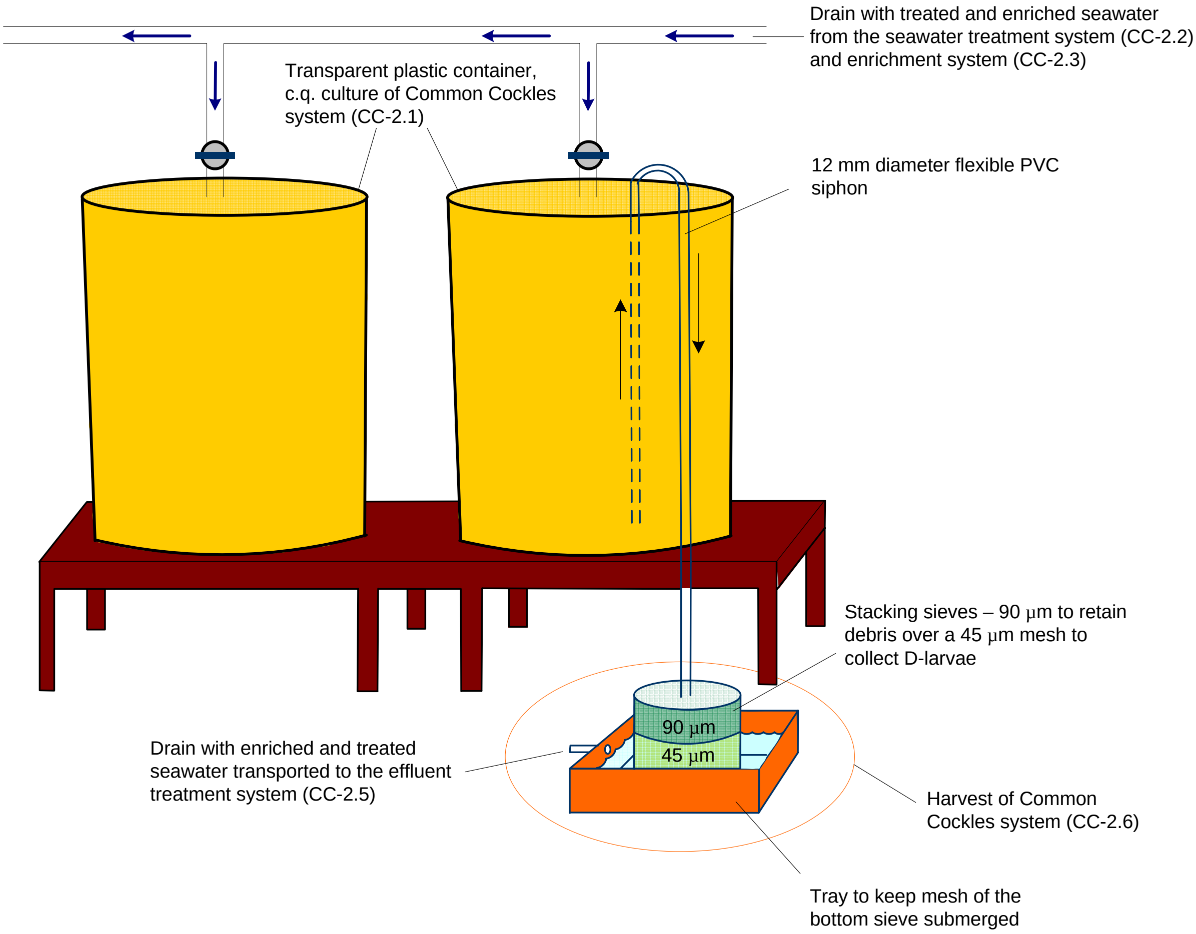


Figure 47: Rearing vessels to retain from trochophores D-larvae (after Utting & Spencer, 1991).

The rearing vessels have a volume of 250 liter, and are made of pigment-free, translucent polyethylene. New vessels must be filled with seawater and allowed to soak, with weekly changes of water, for three months before use. This allows toxic substances (which may be harmful to larvae) to leach from the surface of new plastics. Vessels are filled with seawater, filtered by a rapid sandfilter, cartridge filters and final filtration filters (mesh size of < 2 µm). The water is heated to 15-35 ^{o}C and salinity should be 15-35 PSU. The seawater is then enriched with the required live uni-algal species. The air-flow is switched off during embryonic development (until the D-larva stage).

Embryos are stocked in the vessel about two hours after fertilization at a maximum density of 80 000 per liter and fully developed D-larvae are recovered, by the harvest of culture of algae system (CC-2.6) (figure 47), 24 hours later.

It has to be noted that in this sub-phase the environmental temperature is controlled by the environmental control system (CC-2.4) in a range of 15-35 ^{o}C.

Larval rearing (CC-3)

After the embryonic development the larvae are further grown in the culture of Common Cockles systems (CC-3.1), which are conically-based, fiberglass tanks fitted with bottom drains (figure 48). The tanks have a volume of 5 000 liter and are suitable are most productive at a maximum density of approximately 10 000 larvae per liter.

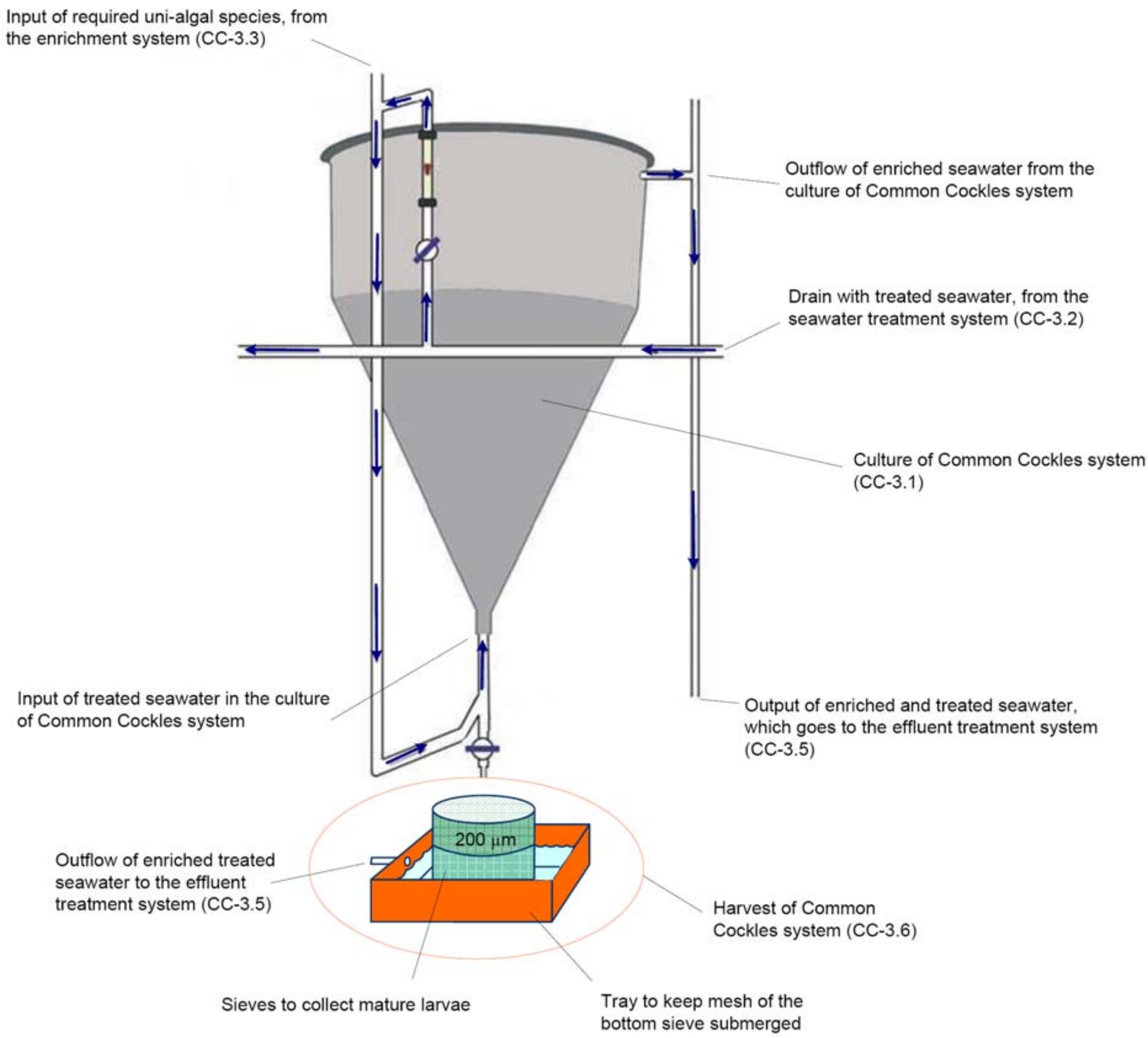


Figure 48: Culture of Common Cockles system (CC-3.1) and the harvest of the culture of Common Cockles system (CC-3.6) (after Utting & Spencer, 1991 and Helm & Bourne, 2004).

Growth is improved by ensuring that the water is sufficiently turbulent to keep the larvae in suspension. Vessels may be aerated by a single central aerator at flow rates of up to 200 liter per hour. The air is filtered to 0.45 µm particle size by a series of cartridge filters of decreasing porosity. This is needed to reduce air-borne contaminants which may include harmful micro-organisms.

Seawater for the larvae is filtered to 2 µm particle size. Besides filtering, the seawater is also heated to 24-26 ^{o}C and sterilized by UV-light. The sterilization is needed to reduce risks of bacterial contamination. The salinity of the seawater should be 15-35 PSU and the seawater should be enriched with the required uni-algal species.

At the end of the culture process the larvae have reached the mature larvae stage. The procedure for harvesting the mature larvae is the same procedure as for the D-larvae in the embryonic development. Therefore, the same harvesting equipment is used. Nevertheless, the mesh of the sieves is dimensioned bigger, with a size of 200 µm.

It has to be noted that in this sub-phase the environmental temperature is controlled by the environmental control system (CC-3.4) in a range of 15-35 ^{o}C.

Settlement (CC-4)

After the mature larvae are harvested they are transferred to the culture of Common Cockles system (CC-4.1) in the settlement. In the settlement two different kind of culture of Common Cockle systems are used. These systems are defined as downwelling systems and upwelling systems. The principles of these systems are described in figure 49-A.

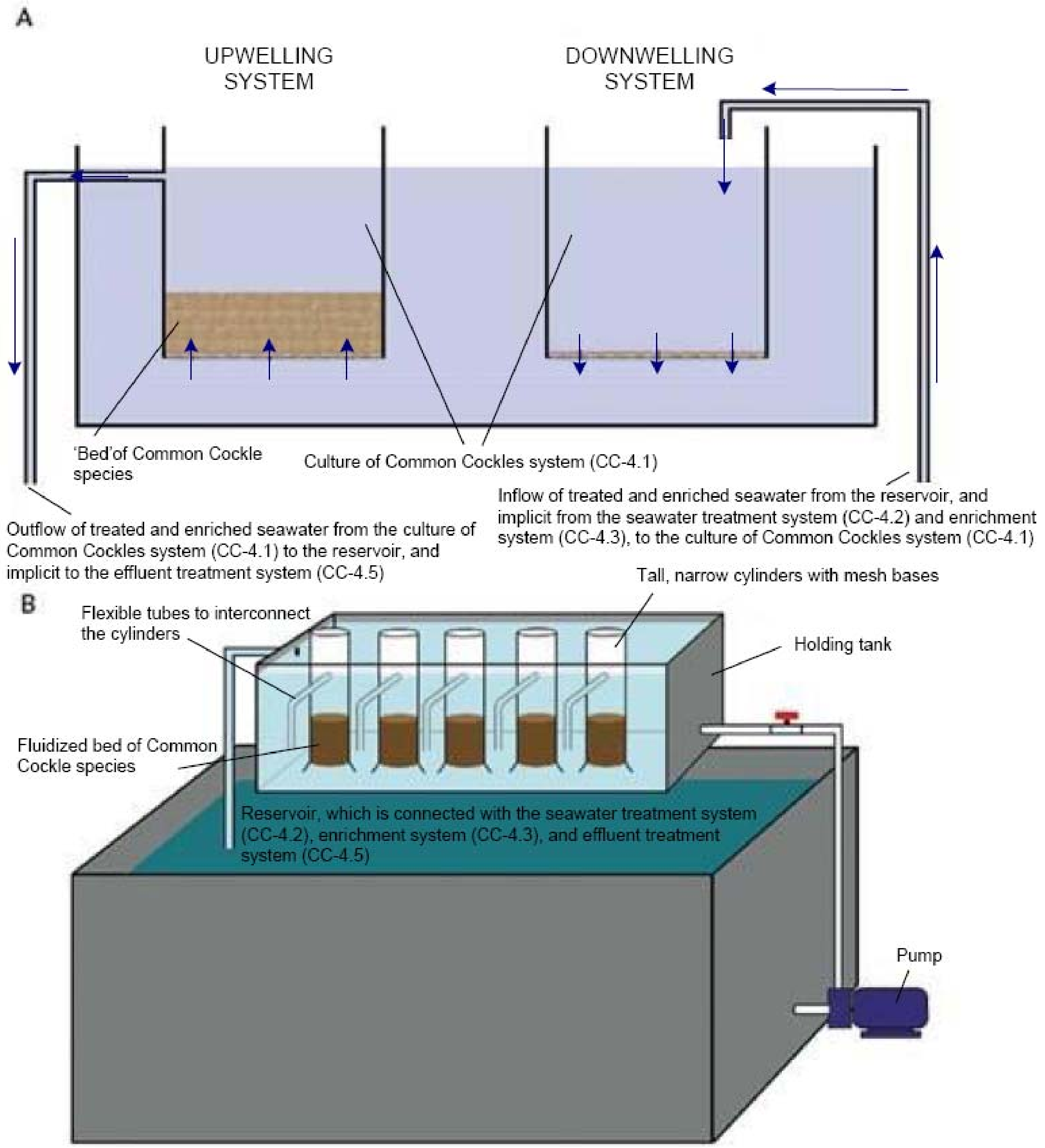


Figure 49: A - principles of the down- and upwelling systems. B - Overview of the systems in the settlement (CC-4).

The downwelling systems are suitable for holding mature larvae during metamorphosis. The husbandry needed for this type of system is similar to that for the in the larvae in the culture of Common Cockle systems (CC-3.1) of the larval rearing.

After the mature larvae are metamorphosed upwelling systems are suitable for the culture of the Common Cockle species. The upwelling systems are considered as a more efficient culture of Common Cockles systems then the downwelling systems (Helm & Bourne, 2004). At an upwelling system the water flow is induced through cylinders, by creating a difference in the head of water. The water may be recycled with an electrically-driven pump (figure 49-B). Valves are fitted to the overflows of the upwelling cylinders, since the growth of the Common Cockle species is strongly influenced by water flow rate. Flow rates of 20-50 ml per minute per gram (fresh weight) should be used.

The seawater is filtered through a set of sandfilters and cartridge filters to a particulate size of 10 µm. The water is kept at 22-25 ^{o}C. The systems are thoroughly cleaned at each water change. The environmental control system (CC-4.4) controls the environmental temperature in a range of 15-35 ^{o}C.

5.2 Aquacultural site

The aquacultural site is the second dimension of the physical architecture. The aquacultural site involves issues, like the growout, distribution channels (passage ways), main infrastructure of (enriched) seawater supply, and space for possible future expansions of the aquacultural site. The floor plan of the physical architecture of the aquacultural site at system level is illustrated in figure 50 (and appendix VIII).

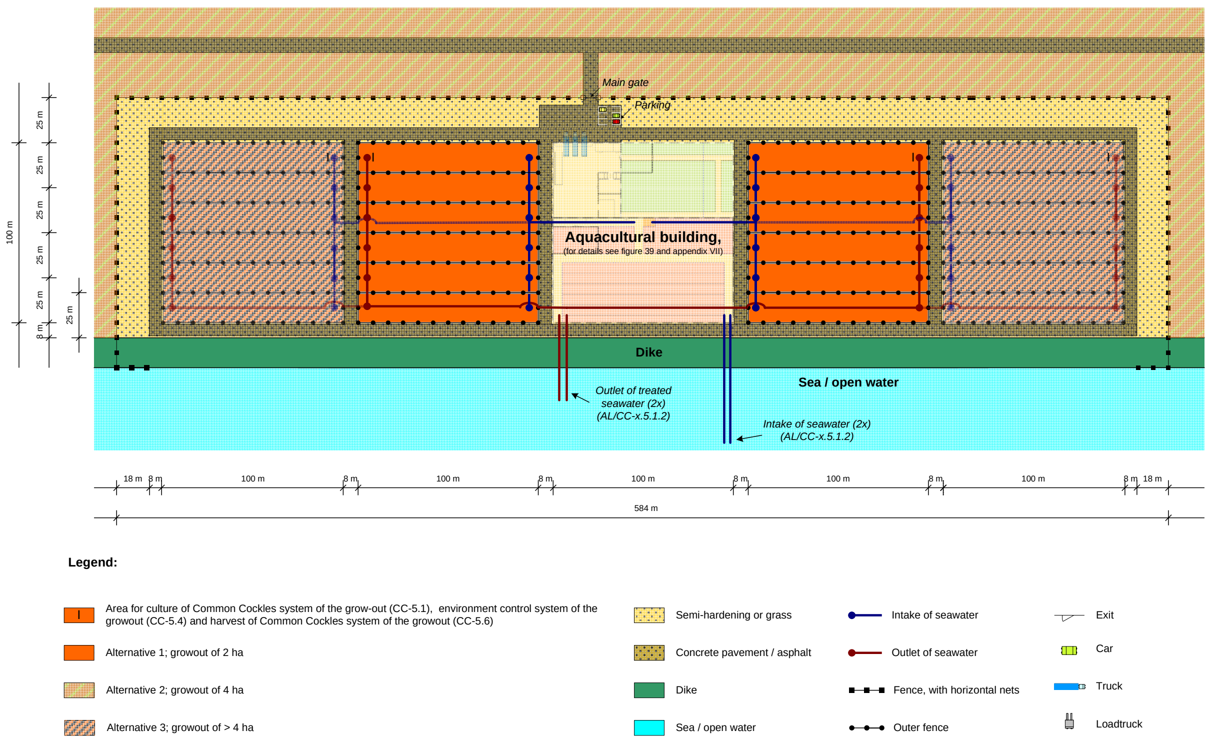


Figure 50: Floor plan of the physical architecture of the aquacultural site at system level.

In the paragraphs below the growout systems and the procedures are described (paragraph 5.2.1). Furthermore, a description has been described of other important technical issues (paragraph 5.2.2).

5.2.1 Description of growout systems and procures

In this example of the physical architecture the growout is the only sub-phase of the primary production process which is partly allocated outside the aquacultural building (figure 51-A). The culture of Common Cockles system (CC-5.1) and the harvest of culture of Common Cockles system (CC-5.6) are completely located outside the aquaculture building. The other systems are partly located outside the aquaculture building. The rest of these systems are located inside the aquacultural building.

The adult Common Cockle species have more resistance against potential hazards (see paragraph 3.1.6) so they do not need to be cultured indoor. However, they still need to be protected against predators, bacteria, and viruses. To protect the species water needs to be treated and constructions need to be build, like fences and nets (figure 51-B). These constructions are mainly built for protection against predators, like birds. The seawater treatment system protected the Common Cockle species mainly against bacteria and viruses.

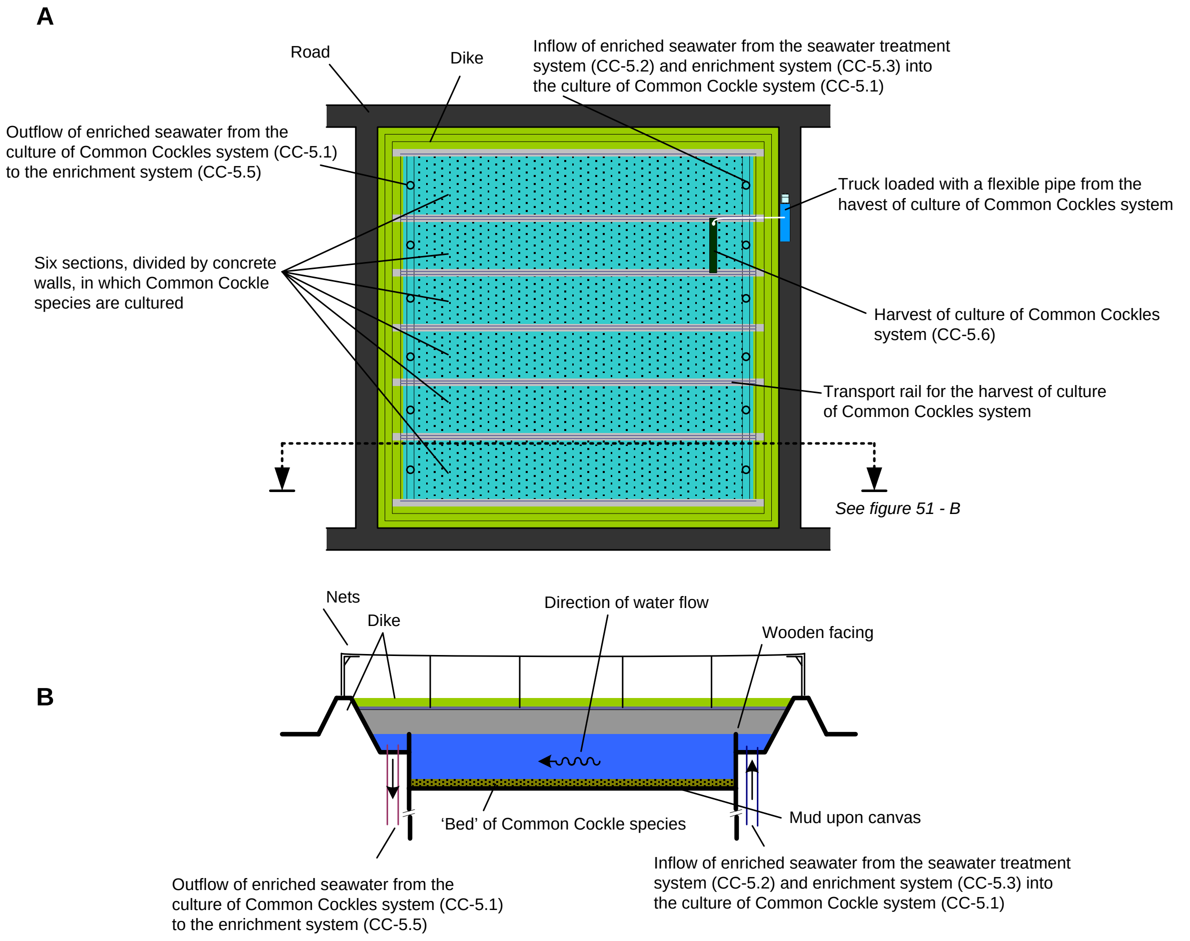


Figure 51: A – Floor plan of the culture of Common Cockles system (CC-5.1) of the growout. B – Side-view of the culture of Common Cockles system (CC-5.1).

The culture of Common Cockles system (CC-5.1) can be considered as a large dimensioned flow-through basin, which is split into six sections. The six sections are totally separated from each other to reduce risk of contamination. Furthermore, these sections make it possible to harvest Common Cockle species as described in SC-4 (paragraph 2.1.2). The harvest of culture of Common Cockles system (CC-5.6) can be considered as mechanical machine, in which is equipped with either suction or elevator dredges. All required properties of the systems of the growout are described in chapter 4.

5.2.2 Other technical issues

In this paragraph other important technical issues are considered. These other important technical issues are the distribution channels and the main infrastructure of (enriched) seawater supply.

Distribution channels

To distribute solid goods from one place to another, roads need to be constructed. The roads need to be dimensioned for vehicles which are used at the aquacultural site. The vehicles can, for example, be: trucks, load truck, cars, etc. To close the aquacultural site, for security reasons, a fence and a main gate are integrated into the design.

Main infrastructure of (enriched) seawater supply

The most complex systems of the primary production process are the seawater treatment system and the effluent treatment system. For most sub-phases of the primary production process these systems are installed within the aquacultural building. A few parts of the seawater treatment system and of the effluent treatment system are located outside the aquacultural building. Only, the parts located outside the aquacultural building, are described in this paragraph. These parts are: the intakes and outlets of (treated and enriched) seawater, and the seawater and effluent treatment system of the growout. It has to be noted that parts which are located inside the aquacultural building are described in paragraph 5.1.2.

Intakes and outlets

The intakes and outlets of the (treated and enriched) seawater are, respectively, the first functional component of all seawater treatment systems and the last functional component of all effluent treatment systems. Because of the importance of these two functional components, they need to function at all times. Therefore, the intakes and outlets of the (treated and enriched) seawater are designed in pairs. Although, the high costs, it ensures that the intakes and outlets will always function properly[71]. When maintenance is needed, always one intake, or, outlet is able to function well.

Seawater -and effluent treatment system of the growout

The main infrastructure for the supply and the outlet of (enriched) seawater of, respectively, the seawater treatment system and the effluent treatment system of the growout is described in the floor plan of the physical architecture of the aquacultural site at system level (see figure 50 and appendix VIII). This main infrastructure starts with an intake of seawater from an open water source, after which the seawater is treated, enriched, and transferred to the culture of Common Cockles system of the growout[72]. In the culture of Common Cockles system the enriched seawater is filtered by the Common Cockle species. When the Common Cockle species are harvested, in the harvest of culture of Common Cockles system, the residue of the enriched seawater (effluents) is transferred to the effluent treatment system. The effluents, which are treated, are used for new input of the seawater treatment system (recirculation), or they are discharged to the open water source (flow-through).

[71] Every intake or outlet needs to supply, or discharge an adequate quantity of (enriched) seawater.
[72] The culture of Common Cockles system of the growout consists of several sections, or so-called raceways. The raceways are not connected with each other, so stock can be split, and spreading of diseases, etc, is prevented. However, the disconnected raceways implicate that the enriched seawater needs to be supplied to several locations.

During the research also other seawater and effluent treatment systems for the growout were considered. One of these considered alternatives was a seawater treatment system and an effluent treatment system which were controlled by nature. This alternative could be achieved by making an inlet and an outlet in the dike, so during high tides (natural enriched) seawater is taken in, and during low tides seawater is discharged. This alternative, which is attractive due to the low (assumed) construction-, maintenance-, and production costs, is not considered in this research, because the alternative does not agree with the required internal rate of return (SC-9).

5.3 Alternatives and future expansion

Here three alternatives of the spatial dimensions are considered of the aquacultural site. Although, all three alternatives consist of equally dimensioned sub-phases, which are allocated in the aquacultural building, the growout differs in dimensions. The three alternatives are selected, because it is assumed that more profit (which implies an increase of the financial feasibility) can be made if the aquacultural facility is dimensioned at a larger scale. However, it is also assumed that large-scale aquaculture facilities decrease in socio-economic feasibility, because of the increasing impact for the involved stakeholders. Due to this contradiction is has been considered to differ the dimensions of aquaculture facility in scale of the growout. The three alternatives are described in the paragraphs below.

5.3.1 Alternative 1

Alternative 1 is an alternative of a growout area of two hectare, with a density of 1 000 Common Cockle individuals per square meter. This alternative is the smallest of the three alternatives. The whole aquaculture facility is located at land properties which are owned. The financial feasibility of this alternative is evaluated in paragraph 5.4.

5.3.2 Alternative 2

The second alternative has a growout area of four hectare, with a density of 1 000 Common Cockle individuals per square meter. All sub-phases of the primary production process has dimensioned for this alternative. All systems are located at land properties which are owned. The financial feasibility of this alternative is evaluated in paragraph 5.4.

5.3.3 Alternative 3

Alternative 3 is the alternative of the largest-scaled facility. This alternative is considered as an option for future expansion. The growout area consists of at least four hectare, with a density of 1 000 Common Cockle individuals per square meter. Four hectares of growout area are located at owned land, the rest still needs to be bought. The area which needs to be bought need to be located nearby the aquacultural building. Although, this alternative is considered in the floor plan of the aquacultural site (figure 50), no financial feasibility is evaluated for this alternative.

5.4 Investment prognoses

This paragraph describes the investment prognosis of alternative 1 and alternative 2. In the investment prognosis factors are considered, like the initial investment budget, exploitation costs, and the financial benefits per alternative. Based on this information the financial feasibility is evaluated.

5.4.1 *Initial investment budget*

In table 12 the initial investment budget for the land-based aquaculture facility is summarized per alternative. The table has been derived from the calculations and assumptions which are described in appendix IX. The initial investment budget consists of systems costs and additive costs. The systems costs are the initial investments for the hardware of the primary and secondary production processes. The additive costs are the initial investments for issues which are not considered in the systems costs. The additive costs consist of land, housing, engineering, and miscellaneous.

The accuracy of the figures of the initial investment budget is not high, due to the limited availability of price indications. Nevertheless, table 12 shows for both alternatives, in contrast to the systems costs high additive costs. These high additive costs are mainly caused by to the high costs of the required area of land.

Systems costs

		ALTERNATIVE 1				ALTERNATIVE 2			
Description	**Traceability code**	**Volume**	**Cost (€)**	**Investment (€)**	**%**	**Volume**	**Cost (€)**	**Investment (€)**	**%**
Algal culture phase	***AL-0***	***2 070 m2***		***2 077 491***	***19.2***	***2 070 m2***		***1 699 808***	***12.8***
Stock culture	AL-1	230 m2	714	164 305	1.5	230 m2	532	122 340	0.9
Starter culture	AL-2	380 m2	815	309 716	2.9	380 m2	633	240 383	1.8
Intermedate-scale culture	AL-3	490 m2	959	469 731	4.3	490 m2	776	380 328	2.9
Large-scale culture	AL-4	970 m2	1 169	1 133 739	10.5	970 m2	986	956 757	7.2
Common Cockle culture phase	***CC-0***	***24 585 m2***		***2 491 628***	***23.0***	***44 585 m2***		***2 868 410***	***21.7***
Broodstock conditioning	CC-1	370 m2	129	47 739	0.4	370 m2	105	38 772	0.3
Reproduction	CC-2	300 m2	120	35 896	0.3	300 m2	95	28 626	0.2
Larval rearing	CC-3	950 m2	108	103 004	1.0	950 m2	84	79 982	0.6
Settlement	CC-4	2 965 m2	128	378 797	3.5	2 965 m2	106	313 029	2.4
Growout	CC-5	20 000 m2	96	1 926 192	17.8	40 000 m2	60	2 408 002	18.2
General infrastructure	***GI-0***	***16 385 m2***		***545 150***	***5.0***	***21 885 m2***		***765 150***	***5.8***
General systems	GI-1	170 m2	1 176	200 000	1.8	170 m2	1 176	200 000	1.5
Employees/guest facilities	GI-2	10 215 m2	10	105 150	1.0	10 215 m2	10	105 150	0.8
Distribution system	GI-3	6 000 m2	40	240 000	2.2	11 500 m2	40	460 000	3.5
			Sub-total:	**5 114 269**	***47.3***		**Sub-total:**	**5 333 368**	***40.3***

Additive costs

Description	**Volume**	**Cost (€)**	**Investment (€)**		**Volume**	**Cost (€)**	**Investment (€)**	**%**
Land	***50 000 m2***	***75***	***3 750 000***	***34.7***	***77 500 m2***	***75***	***5 812 500***	***43.9***
Housing	***1 st.***	***1 500 000***	***1 500 000***	***13.9***	***1 st.***	***1 500 000***	***1 500 000***	***11.3***
Engineering	***1 st.***	***150 000***	***150 000***	***1.4***	***1 st.***	***200 000***	***200 000***	***1.5***
Miscellaneous	***1 st.***	***300 000***	***300 000***	***2.8***	***1 st.***	***400 000***	***400 000***	***3.0***
		Sub-total:	**5 700 000**	**52.7**		**Sub-total:**	**7 912 500**	**59.7**
		Total:	**10 814 269**	**100.0**		**Total:**	**13 245 868**	**100.0**

Table 12: Overview of the estimated initial investment budget per alternative.

5.4.2 *Exploitation costs*

Besides the initial investment budget, exploitation costs do also exist. In the exploitation costs cash outflows are considered, which are related to the exploitation of the facility. Exploitation costs are for example the salary of employees, inputs for the primary production process, distribution of goods, the distribution of utility services, maintenance, etc. For alternative 1 and alternative 2 the exploitation costs are estimated to be, 0.5 million euro per year and 0.8 million euro per year.

5.4.3 *Financial benefits*

The financial benefits are directly related to the area of the growout in the facility, because the growout is assumed as the bottleneck of the production process of Common Cockle species. Furthermore, it is assumed that every growout area can only be harvested once a year. By multiplying the growout area with a density of 1000 adult Common Cockle individuals, a price of € 10,- / per kilogram (fresh weight) adult Common Cockle species and an average fresh weight of an individual adult Common Cockle species of 10 gram (fresh weight), the financial benefits can be estimated. For alternative 1, which has a growout area of 20 000 m^2, the financial benefits are estimated of € 2 million per year. For alternative 2 the estimated financial benefits are € 4 million per year.

5.4.4 *Evaluation of financial feasibility*

Based on the initial investment budget, the annual estimated exploitation costs, and the annual financial benefits, the internal rate of return can be calculated for each alternative after the eighth investment year. For alternative 1 and alternative 2 the internal rate of return are calculated at, respectively, 2.4 % and 17.5 %. By verifying this information with the required internal rate of return (SC-9), alternative 1 needs to be rejected. Alternative 2 is approved, because its internal rate of return exceeds 15.0 % after eight years of the initial investment.

5.5 Risk analysis

The production process of uni-algal species and Common Cockle species is susceptible to several risks. These risks affect the technical and financial feasibility of the aquaculture facility. The risks are categorized into biological risks, technical risks, environmental risks and political risks. These risks are described below.

5.5.1 *Biological risks*

The main biological risk is high mortality due to disease outbreak or infection with parasites. This risk is reduced by the fact that there are six production runs in the aquacultural building per year, between which the systems are cleaned. Also, per production run each batch is kept in separate culture of Common Cockles systems. Management procedures must be put in place regarding hygiene. For example, each separate culture of Common Cockle system must have its own set of tools. There are many ways to kill Common Cockle species, and the main way to prevent problems is to work according to protocols, e.g. to do frequent checks of water quality and health status and to test new actions and procedures on small scale first.

A second risk is the occurrence of frequent phytoplankton crashes, which could result in food shortage. This risk is reduced by maintaining a large number of separate culture of algae systems. In case of periodical over production algae are concentrated and stored, e.g. large-scale culture (AL-4), for use in periods of shortage.

A third risk is that growth of Common Cockle species is slower than expected. Even though, there is a lot known about the biological, chemical, and physical characteristics of Common Cockle species in a natural environment, it is still unknown whether the Common Cockle species will actually grow in an aquaculture facility. Nevertheless, this risk is considered low, because most of the characteristics can be controlled in the aquaculture facility.

5.5.2 *Technical risks*

All machinery, e.g. pumps, can eventually break down or fail. In the same way there can be problems with the power supply, seawater supply, overflowing tanks, etc. This can result in production reduction and increased cost. The main way to reduce those risks includes carrying out preventative routine maintenance, having back-up solutions (e.g. generator), and having spare parts on hand to quickly correct adverse situations. Furthermore, a simple high quality alarm (e.g. monitored from control room) is a must.

5.5.3 *Environmental risks*

Extreme weather (e.g. rainfall, heat waves) can cause problems, as well as for example contamination of the seawater supply. The cultures, which are inside of the aquacultural building, are protected by this building from extreme fluctuations of physical elements (e.g. temperature, light). To prevent problems with the seawater supply large buffer tanks are located in the seawater treatment systems. Furthermore, the seawater intakes and seawater outlets are executed in pairs, so always one intake and one outlet can be closed for maintenance. Dust may pose a problem for the air intakes. Large intake screens that are routinely cleaned are used to minimize this risk. Common Cockle species can survive days without breathing oxygen and therefore a period without aeration can be tolerated. Emergency oxygenation with bottled oxygen can be used to have an extra safety option.

5.5.4 *Socio-economic risks*

Local government, local businesses, and other local stakeholders can cause trouble when they decide “not to like” the project. Good communication with these local stakeholders is a must, as well as the propagation of feasible, innovative and (environmental) durable ideas.

5.6 Verification

This paragraph describes the verification of the physical architecture with the defined technical requirements. The verification of the physical architecture has been analyzed by two methods. The first method is used for the primary production process. The second method is used for the secondary production process. Each of these methods is described in the paragraphs below, including the results.

5.6.1 *Primary production process*

The physical architecture of the primary production process is verified by traceability codes. This method is a part of the systems analysis and control (SAC), which is described in the section at page 8. This method is making use of technical requirements, which are divided in functional requirements and non-functional requirements. All of the functional and non-functional requirements are described in chapter 4. However, these requirements are for the primary production process described in appendix IV in more detail, because of their importance for the technical feasibility of the production of Common Cockle species. In appendix IV every functional component of the physical architecture of the sub-phases of the primary production process has one functional requirement and two functional requirements. The functional requirements described what the functional components must do. The non-functional requirements describe what performance the functional components must have, in terms of required quality and required quantity. The traceability codes of the functional component of in the physical architecture of the sub-phases of the primary production process are, in this way, related with the functional and non-functional requirements. For example, a requirement with a traceability code of FR-AL-2.7 is considered as a functional requirement (FR) and is connected with the enrichment system of the starter culture (AL-2.3). This system has two non-functional requirements (NR), which’s traceability codes are: NR-AL-2.8 and NR-AL-2.9. It has to be noted that the functional and non-functional requirements are numbered consecutively, so each functional requirement of a systems starts with a plural of three.

Based on this method and the systems description of the sub-phases in the aquacultural building (paragraph 5.1.2) and of the grow-out (paragraph 5.2.1) it can be concluded that all identified functional components (phases, sub-phases, systems, and sub-systems) of the primary production process, and therefore all identified functional and non-functional requirements, are allocated in the defined physical architecture. Therefore, it can be concluded that the physical architecture of the primary production process has been verified. However, it has to be noted the physical architecture is not verified with the requirements constraints (chapter 2). Nevertheless, before next development stages are considered, it is recommended that the physical architecture of the primary production process is verified with the requirements constraints (paragraph 6.2).

5.6.2 Secondary production process

The verification of the physical architecture of the secondary production process, or so-called general infrastructure phase, at system level with its technical requirements is described in this paragraph. The method for verification of these systems is to track down all sub-systems, which are described in paragraph 4.3, in the physical architecture. By considering the physical architecture of the aquacultural building (figure 39 and appendix VII) and the physical architecture of the aquacultural site (figure 50 and appendix VIII), it can be concluded that all defined sub-systems are allocated in the physical architecture.

6 Conclusions and recommendations

In this chapter the conclusions and recommendations of the research are described. The conclusions and the recommendation are the output of the research model (paragraph 1.5.1).

6.1 Conclusions

The conclusions of the research are described by answering the research questions. There are five research questions, which are described in paragraph 1.5.2, as translation of the five steps defined in the research model. The defined five steps are: the inputs, the requirements analysis, the functional analysis and allocation, synthesis, and outputs. In this paragraph the central research questions (italic), including their sub-questions (underlined) are repeated, after which the answers will be given.

Step 1: Inputs

What are the inputs of the project?

1. <u>What are the clients´ problems and needs?</u>

The clients' problems are defined by two main problems. The first main problem is identified as the prohibition of mechanical Common Cockle fish activities in the Dutch Wadden Sea (the Netherlands' largest production area) per 1 January 2005. The second main problem is identified as the rise of new demands from the market, which requires a more predictable and controllable production of high quality Common Cockle species. A land-based aquaculture facility for Common Cockle species is able to solve the identified two problems. In the land-based aquaculture facility, Common Cockle species can be cultured under controlled conditions, so the production (quantity) and the quality of the Common Cockle species is more predictable. Furthermore, Common Cockle species can be cultured throughout the whole year.

2. <u>What is the objective of the research?</u>

The objective of the search was to evaluate the technical feasibility of a land-based aquaculture facility for Common Cockle species in the Netherlands. The study provides an analysis of the requirements constraints (chapter 2), an analysis of the most important design considerations (chapter 3), an analysis of the functional architecture, including the defined technical requirements (chapter 4), and an example of a physical architecture (chapter 5). Derived from these products the technical feasibility is evaluated. The results of this evaluation are described in 'step 5: outputs' of this paragraph.

3. <u>Who are the relevant stakeholders in the research?</u>

The most important stakeholders are identified as the clients and the potential customers. The clients are identified as Wageningen IMARES and the University of Twente. The potential customers are defined by the four largest Common Cockle processing and wholesale companies of the Netherlands. These four potential customers are initially represented by the Dutch Commodity Board of the Common Cockle fisheries (PO Kokkels). Other relevant stakeholders are described in appendix I.

4. Which relevant requirements constraints can be identified?

The identified requirements constraints are divided in solution constraints and project constraints.

Solution constraints

The solution constraints are identified by keeping the overall feasibility of the project in mind. There are four solution constraints in the problem domain (chapter 2). The solution constraints in the problem domain are: the cultured infaunal bivalve species need to be Common Cockle species (cultured species); the solution needs to be legal, sustainable, and needs to fit new market demands. There are five solution constraints identified in the solution domain. Within the nine identified solution constraints four solution constraints are identified which have a functional character (SC-1, SC-6, SC-7, and SC-8). The functional solution constraints are translated into the following functional components: the Common Cockle production, the live phytoplankton production, the seawater supply, and the general infrastructure.

Project constraints

There are twenty project constraints identified (chapter 2). The project constraints are described according to the four functional solution constraints and according to an ‘input-processing-output’-model. In the analysis of the project constraints, a primary production process and a secondary production process are identified. The primary production process involves functional components which are directly related to the production of uni-algal species and the production of Common Cockle species. The secondary production process involves functional components which are supporting the primary production process.

5. Which relevant facts and assumptions, or so-called design considerations, can be identified?

In the analysis of relevant facts and assumptions (or so-called design considerations, chapter 3) five components were found which have an influence on the requirements of a commercial (land-based) aquaculture facility. The five components are interrelated, and are identified as: the cultured species (Common Cockle species), the culture methods, the site considerations, the economical (or financial) considerations, and the social environment. Although, all five components need to be considered, in an early[73] development stage, the most important considerations which are described in this research are the cultured species and the culture methods.

Step 2: Requirements analysis

What are the relevant fundamentals of the land-based aquaculture facility for Common Cockle species, in terms of technical requirements?

1. Which relevant technical requirements can be identified?

The technical requirements are divided into functional requirements and non-functional requirements, which are derived from the design considerations. The most critical technical requirements are: the seawater supply, the food supply, growth, and residence time, and the risks of mortalities.

[73] The ‘early’ development stage may also be the next development stage. The next development stage can still be considered as an early development stage.

Seawater supply
Common Cockle species are filter feeders. Therefore, they need enriched seawater to filter out particulate organic matter (e.g. phytoplankton) as food supply. Based on an assumed clearance rate (paragraph 3.1.5), an adult Common Cockle species of a shell length of 30 mm filters 31.60 l/day of seawater, in contrast to, 74.00 l/day for an individual with a shell length of 40 mm. Based on this information, and the information which is described in appendix VI, can be concluded that Common Cockle species require a lot of seawater per unit of time. Furthermore, the required volume of seawater increases exponential in reference to the life stage of the species. Therefore, reuse of seawater has been assumed for certain sub-phases of the Common Cockle culture phase.

By considering the maximum production capacity of the physical architectures of alternative 1 (annual production of 20 million Common Cockle species) and alternative 2 (annual production of 40 million Common Cockle species), it can be concluded that their required quantity of seawater supply is, respectively, 181.7 and 302.8 m^3 per day[74]. Besides, the required quantity of seawater, the seawater also needs to have an adequate quality (table 9). Based on the required quantities of treated seawater per alternative, it can be assumed that existing techniques are able to produce the required quantity and quality for both alternatives. This assumption has been made, due to the fact that existing aquaculture facilities (e.g. aquacultures for fish) are using seawater technology that meets this order of requirements (Huguenin & Colt, 2002).

Food supply, growth, and residence time
The food supply (phytoplankton) for the Common Cockle species is another critical aspect (requirement) of the land-based aquaculture facility for Common Cockle species. In the land-based facility food (live uni-algal species) for the Common Cockle species needs to be produced artificial (based on SC-6) in a land-based phytoplankton culture (or so-called algal culture phase). Based on the phytoplankton model (appendix VI), it has been found that to culture an individual Common Cockle species to a shell length of 30 mm (fresh weight of 11.12 g), it requires 13.49 g (dry weight) phytoplankton, in a residence time of 300 days. This, in contrast to, 41.45 g (dry weight) phytoplankton, in a residence time of 400 days, for Common Cockle species of a shell length of 40 mm (fresh weight of 26.04). Based on these results, there can to be concluded that food supply (uni-algal species) for Common Cockle species is increasing exponential during the (biological) development stages of the Common Cockle species[75]. Furthermore, the weight of the Common Cockle is also increasing exponential. For example, the fresh weight of the Common Cockle species is increasing from 11.12 g (fresh weight) in a residence time of 300 days to a fresh weight of 26.04 g (fresh weight) in a residence time of 400 days.

By considering the maximum production quantities of alternative 1 (annual production of 20 million Common Cockle species) and alternative 2 (annual production of 40 million Common Cockle species), it can be concluded that the required live phytoplankton for these production are 82 ton and 164 ton (dry weight) to culture Common Cockle species to a size of 30 mm. However, the 'state-of the-art' technology for culturing live uni-algal species, which is described in paragraph 5.1.2, is not able to produce such large quantities of the required quality. The maximum production capacity of this technology is approximately 20 g (dry weight) of uni-algal species per day. To make the physical architecture of the two alternatives technical feasible, approximately 11 250 to 22 500 culture vessels are needed in the large-scale culture of the algal culture phase. By keeping in mind that every culture vessel needs an average floor surface of 0.5 m^2 the scale and the costs of the aquaculture facility will

[74] These required seawater quantities are derived from table 10. However, the required quantity of seawater supply for the sub-phase which needs to be located the in aquacultural building has been based on an assumption. This assumption is equal to the quantity of seawater which is needed for one hectare of growout area (full production).
[75] Although, the food supply of Common Cockle species triples, it also has to be noted that the financial benefits (price) of the Common Cockle species will double, or even will be higher, when Common Cockle species' shell lengths are greater.

be far above proportioned. Although, it can be concluded that the required quantity of the aquaculture facility can not be met, the required quality can.

Because of the fact that the algal culture phase is not able to deliver the required quantity of uni-algal to the Common Cockle culture, it can be considered to disconnect the growout of the uni-algal supply from the algal culture phase. The growout then needs to rely on the natural enrichments from the open water, which implies certain risks due to the predictability of the Common Cockle production. This solution conflicts with the solution constraint, for example with SC-4, therefore this alternative is not considered in this study.

Although, the technology which is described in the algal culture phase can not provide an adequate quantity (paragraph 5.1.2), there are new technologies in development. One of these new technologies is the new generations of photobioreactors (PBR's). The expected productivity of these systems is very high and is considered as economically attractive. For example, a production plant, which produces *Chlorella*, has already been established in the year 2000. This plant produces in a glasshouse of an area of 10 000 m^2 an annual production of 130-150 ton (dry weight) (Pulz, 2001). Furthermore, this plant has been considered as economically feasible under Central European conditions. However, the PBR's are still under development for the production of the required uni-algal species which need to be fed to the Common Cockle species. Nevertheless, it has been expected that this technology can be used for the production of food for aquaculture facilities (e.g. for Common Cockle species) in the nearby future (Pulz, 2001).

Risks of mortalities
Another critical aspect is the risks of mortalities of the cultured Common Cockle species. Although, the risks of mortalities are not described in detail in this report, it can be concluded that the risks can be diminished, by avoiding sudden fluctuations of the physical and chemical environment. Furthermore, industrial and domestic pollution, predators, and parasites and diseases need to be avoided. To calculate the required production of Common Cockle species a mortality rate of 0.33 has been assumed per sub-phase[76].

2. <u>Which relevant decomposition levels (until systems) can be identified?</u>
In this report several decomposition levels are identified. These decomposition levels, from a high abstraction level to a low abstraction level, are: final product, phases, sub-phases, systems, sub-systems, and units. In the analysis of the technical requirements the final product has been identified as the land-based aquaculture facility for Common Cockle species. The identified sub-phases are: the algal culture phase, Common Cockle culture phase, and the general infrastructure phase. The algal culture phase and the Common Cockle culture phase are identified as the primary production process, and the general infrastructure phase as the secondary production process. In each phase several sub-phases are identified. For the algal culture phase these sub-phases are: the stock culture, the starter culture, the intermediate-scale culture, and the large-scale culture. For the Common Cockle culture phase the identified sub-phases are: the broodstock conditioning, the reproduction, the larval rearing, the settlement, and the growout. The general infrastructure phase consists of three sub-phases, which are: the general systems, the employees/guest facilities, and the distribution system.

Each sub-phase in the primary production is decomposed into six systems. The identified systems are a set of uniform systems, which are identified as: the culture of algae / Common Cockles system, the seawater treatment system, the enrichment system, the environmental control system, the effluent treatment system, and the harvest of culture of algae / Common Cockles system. In the secondary production process no systems are identified.

[76] The mortality rate is a factor which describes the quantity of Common Cockle species which die during the culturing process of a sub-phase in the Common Cockle culture.

Step 3: Functional analysis and allocation

Which relevant functional components, including relations between the functional components, can be identified?

1. Which relevant functional components can be identified, due to the identified decomposition levels?

The identified decomposition levels are translated into functional components. The identified function of a functional component in a system, which is allocated to a certain phase, is considered as identical to each other in the primary production process, however, their non-functional requirements can differ. For example, the function of a seawater treatment system in the stock culture of the algal culture phase can be considered as identical as that of the seawater treatment system in the starter culture phase. However, it has to be noted their quality of temperature control may differ. The identified functional components of the sub-phases in the primary production process (or so-called sub-systems) are: the culture of circulation system, the water circulation system (of seawater treatment system), the contamination control system (of seawater treatment system), the temperature control system (of seawater treatment system), the nutrient conditioning system, the nutrient addition system, the environmental illumination system, the environmental temperature system, the water circulation system (of effluent treatment system), the contamination control system (of effluent treatment system), the temperature control system (of effluent treatment system), and the harvest system. The identified functional components of the secondary production process, which are derived from the sub-phases, are identified as: the power system, the air ventilation system, the emergency system, the maintenance system, the working facilities, the general facilities, the relaxing facilities, the goods system, and the utility system.

2. Which relevant relations can be identified between the identified functional components?

The relevant relations between the identified functional components of the primary production process are described in the block diagrams in chapter 4. The relations between the functional components of the secondary production process are discussed in paragraph 4.3.

Step 4: Synthesis

How can the land-based aquaculture facility for Common Cockle species be identified, in terms of physical elements, based on the functional architecture?

1. Which relevant considerations, in terms of physical elements, can be identified for the land-based aquaculture facility for Common Cockle species, at building level (until system level)?

In the synthesis, of the functional components, into a physical architecture at building level, it has been found that the 'main' systems of the primary production process are: the culture of algae / Common Cockles system, and the harvest of culture of algae / Common Cockles system. The identified 'main' systems are the systems in which the uni-algal species and Common Cockle species are physically cultured. The main systems need to be supported by 'other' systems to make to production possible. These 'other' systems are identified as: the seawater treatment system, the enrichment system, and the environmental control system. Because the seawater and enrichments can be easily transferred from one place to another they do not need to be located close the 'main' systems.

All[77] systems in the aquacultural building need a certain environmental control. Therefore, they need to be located physically close to environmental control systems. The physical elements which are considered on behalf of the general infrastructure mainly consist of the allocation of functional components into the physical architecture. By allocating the functional components to a specific location, in the physical design, relations of the functional components with the primary production process are considered. Furthermore, some working facilities and relaxing facilities are allocated to a specific floor level (floor 2).

2. <u>Which relevant considerations, in terms of physical elements, can be identified for the land-based aquaculture facility for Common Cockle species at location level (until system level)?</u>
The relevant considerations, in terms of physical elements, which are identified at location level, are: the growout, distribution channels, the main infrastructure of (enriched) seawater supply, and the future expansion of the facility.

Step 5: Outputs

What can be learned from this project?

1. <u>Which relevant conclusions can be identified?</u>
The most relevant conclusion of this project is that it is not technical feasibility with today's 'state-of-the-art' uni-algal production systems. However, this 'state-of the art' algal culture technology can be considered for all sub-phases of the Common Cockle culture phase, except for the growout. Another alternative is to make use of new algal culture technology, for example, new generation photobioreactors. It is expected that these PBR's are able to produce enough uni-algal species to feed the Common Cockle species in the Common Cockle culture of alternative 1 or alternative 2 in the future. Furthermore, it can be concluded that all other critical aspects of the aquaculture facility are technical feasible.

Besides, the technical feasibility of the project, also a small analysis has been made of the financial feasibility (paragraph 5.4). From this financial analysis it can be concluded that the aquaculture facility is more efficient if the scale is larger. Because the aquaculture facility needs to meet all solution constraints only alternative 2, with an annual production of 40 million marketable Common Cockle species, is considered as financial feasible.

2. <u>Which relevant recommendations can be identified?</u>
The most relevant recommendations, which can be derived from the research, are to inspect new technologies which can improve the production capacity of uni-algal species to feed the Common Cockle species. In this way, the land-based aquaculture facility for Common Cockle species could become technical feasible in the future. Besides, the technical feasibility, also the financial and the socio-economical feasibility need to be considered in the future. More detailed recommendations are described in paragraph 6.2.

[77] The enrichment systems of the aquacultural building do not need to be necessarily located in a controlled environment. Nevertheless, they are located inside in the aquacultural building, because they have a close physical relation with the culture of algae / Common Cockles systems, and harvest of algae/ Common Cockles systems, which need environmental control.

6.2 Recommendations

In this paragraph the recommendation are described, which are derived from this research. The recommendations are split into two categories. The first category is identified as the recommendations, due to the product. The second category is identified as the recommendation, due to the process.

6.2.1 Product recommendations

The product recommendations describe the steps, which still need to be successfully accomplished, before it is a good idea to start construction (next development stage) of a land-based aquaculture facility for Common Cockle species, by only considering the technical feasibility of the project. The product recommendations are derived from this report and are described at system level. In behalf of the product's technical feasibility it is recommended that:

- Culture techniques for uni-algal species and Common Cockle species are verified with the defined technical requirements, which are described in chapter 4. It is recommended that this verification is considered at the lowest abstraction level as possible. When the identified functional components can not be met by the technical requirements, other alternatives need to be considered. These other alternatives can, for example, differ in the used technologies, or scale of the aquaculture facility. As mentioned in the conclusion, the example which is described in the physical architecture is not technical feasible, due to the lack of production capacity of the considered technology in the algal culture phase. Therefore, it is recommended to do further research to other technologies, which are suitable to produce the required uni-algal species. Photobioreactors could for example be such a technology in the nearby future. In addition, it is also recommended to optimize the culture techniques. The optimization will increase the financial benefits and will decrease the exploitation costs, which will finally result in an increase of the financial feasibility of the project.

- Seawater treatment systems are further verified and optimized. Although, the seawater treatment systems are assumed to be technical feasible, they are considered as a very important systems. This considered importance is mainly caused by the fact that a good quality of seawater minimizes risks of mortality. Furthermore, uni-algal species and Common Cockle species require an enormous quantity of high-quality seawater per unit of time, which implies that optimization of this system, will probably increase the efficiency of the facility.

- A physical architecture is described, verified, and optimized of an enrichment system for the uni-algal species and Common Cockle species, which is able to (automatically) enrich the treated seawater from the seawater treatment system with the required enrichments. The uni-algal species and Common Cockle species require several enrichments during their production process. These enrichments need to be added to the culture systems of these species. Although, there is a functional architecture described for such a system (appendix V), there is still no physical architecture described.

- Systems which need to control the environment (e.g. light intensity or temperature) are verified and optimized. It is still unknown if the environmental control systems are actually able to control the environment as required. Therefore, verification of these systems is recommended. After verification is accomplished optimization is recommended, because it increases the efficiency of the facility.

- The defined harvesting techniques are verified and optimized. Because no land-based aquaculture facilities for Common Cockle species exist, it is unknown if the harvesting techniques which are described for the Common Cockle species will affect the efficiency of production negatively. Therefore, it is recommended that these defined techniques are verified. When verification is considered as a success, optimization can start. When verification is considered as failure, it is recommended to invest in other harvesting techniques.

6.2.2 Process recommendations

The process recommendations describe the proceeding steps which are recommended for further development (process) of the land-based aquaculture facility. Besides technical factors, these steps also consider financial factors and socio-economic factors. The following process recommendations are identified:

- It is recommended that other examples of physical architectures are derived from the technical requirements and functional architecture. These other examples of physical architectures can provide new information to create a better design, whether it is feasible or not.

- It is also recommended that identical feasibility studies, like this one, are considered for other infaunal bivalve species, which are attractive for the aquaculture sector. These studies can provide new insights, which can be used for optimization of this study. In addition, by considering a few identical studies certain similarities and contradictions can be found, which can be translated into a uniform aquaculture facility for all kinds of infaunal bivalve species.

- In reference to the financial feasibility, it is recommended that after the technical feasibility is established, the financial markets of Common Cockle species are explored. Important issues which are recommended to explore are the actual demand of the market (considered at short-term and long-term) and stakeholders which are able, and want, to invest in the project.

- In reference to the socio-economic feasibility, it is recommended that after the technical feasibility is established, a potential location for the aquaculture facility is found and that potential stakeholders are getting involved, so they are going to "like" the project.

7 Terms and definitions

In this terms and definitions are described which are not fully described in the report.

Adductor muscle	large muscle (muscles) that pull the two shell valves together
Bivalve	mollusk of the Class Pelecypoda, having a shell of two valves that are joined by a hinge
Cerastoderma edule	Latin name of the edule Common Cockle species
Closed system	a seawater system with little or no inflow or outlet of water (also called recirculation system)
Development stage	phase that involves stakeholders in the design process and ensures that the system (so-called design) developed is viable throughout its life
Diatom	a single-celled alga of the Class Bacillariophyceae
D-larva	the early veliger larval stage of bivalves, also known as straight-hinge larva
Embryo	organism in early stage of development; in bivalves, prior to larval stage
Exhalant	area of bivalve where water currents have an outward direction
Fertilization	union of egg and sperm
Flagellate	group of single-celled algae characterized by having a locomotory organ called a flagellum
Flow-through system	a seawater system which has a continuous inflow and outflow
Functional architecture	translation of the requirements, and its analysis, into an architecture in which the functionality, including the relations between the different functionalities, of the preliminary design, are described
Gamete	mature, haploid, functional sex cell capable of uniting with the alternate sex cell to form a zygote
Gametogenesis	process by which eggs and sperm are produced
Hinge	dorsal area of bivalve shell where two valves are joined together
Infaunal bivalve species	benthic bivalve species which live within the seabed
Inhalant	area of bivalve where water currents have an inward direction
Intertidal	area between low and high tides
Ligament	fibrous spring-like material joined two valves of a bivalve at the hinge
Mantle	the soft fold enclosing the body of a bivalve which secretes the shell

Metamorphosis	in bivalves, the period of transformation from the larval to the juvenile stage
Open system	a seawater system that uses large amounts of incoming water to maintain water quality with little or no internal water processing
Physical architecture	translation of the functional architecture, into an architecture in which physical and spatial elements defined
Phytoplankton	floating or weakly swimming aquatic organisms, can be phytoplankton (plants) or zooplankton (animals)
Posterior	the rear, away from the head
Pseudofeaces	false faeces, waste material not taken into the digestive tract
PSU	a measure of salinity, equivalent to part per thousand
Rearing unit	a container in which the organisms are held during the culture
Residence time	average culturing time of cultured species to achieve a certain weight or length
Salinity	the salt content of seawater usually measured in parts per thousand (ppt) or practical salinity units (PSU)
Seed	other definition for spat
Shell length	the straight line distance from the anterior to the posterior margins of the shell
Spat	a newly settled or attached bivalve (also termed post larval or juvenile)
Standard residence time	average culturing time what is assumed in which Common Cockle species will grow 1 mm in shell length.
Systems Engineering process	comprehensive, iterative and recursive problem solving process, applied sequentially top-down
Trochophore	planktonic stage of bivalve embryo
Umbo	beak-like projections at the dorsal part of the shell; it is the oldest part of a bivalve shell
Uni-algal species	mono-specific phytoplankton species
Valve	one of the two parts of a bivalve shell, two valves make up one shell
Veliger Larva	the larval stage of most mollusks, characterized by the presence of a velum
Velum	ciliated locomotory organ of the larva

8 References

André, C., Jonsson, P.R., Lindegarth, M. (1993). Predation on settling bivalve larvae by benthic suspension feeders: the role of hydrodynamics and larval behavior. *Marine Ecology Progress Series,* **97**, 183-192.

Beheshti, M.R. (1999). *Handboek systematisch ontwerpen in de civiele techniek en bouwkunde. Een naslagwerk ten behoeve van systematisch, methodisch en functioneel ontwerpen.* Delft: Delft University Press.

Commissie Schadebepaling Kokkelvisserij (2005). *Financiële vergoeding beëindiging mechanische kokkelvisserij Waddenzee.* Den Haag: Dutch government.

Creek, G.A. (1960). The development of the lamellibranch *Cardium edule* L. *Proceedings of the Zoological Society of London* **135**, 243-260.

Defense Systems Management College Press (1999). *System Engineering Fundamentals.* Fort Belvoir: Department of Defense.

Ens, B.J., Smaal, A.C., Vlas, J. de (2004). *The effects of shellfish fishery in the ecosystems of the Dutch Wadden Sea and Oosterschelde. Final report on the second phase of the scientific evaluation of the Dutch shellfish fishery policy (EVA II).* Wageningen: Alterra.

FAO Inland Water Resources and Aquaculture Service (2003). *Review of the state of world aquaculture.* Rome: FAO, FAO Fisheries Circular. No. 886, Rev. 2.

FAO Inland Water Resources and Aquaculture Service (FIRI) (2005). *National Aquaculture Legislation Overview - Netherlands.* Rome: FAO.

Gosling, E. (2003). *Bivalve Molluscs. Biology, Ecology and Culture.* Oxford: Blackwell Publishing Ltd., Fishing News Books.

Grinter, R.E. (1999). Systems architecture: product designing and social engineering. *International Conference on Work activities Coordination and Collaboration. Proceedings of the international joint conference on Work activities coordination and collaboration*, 11-18.

Hancock, D.A. & Franklin, A. (1972). Seasonal changes in the condition of the edible cockle *Cardium edule* (L.). *Journal of Applied Ecology* **9**, 567-579.

Helm, M.M. & Bourne, N. (2004). *Hatchery culture of bivalves. A practical manual.* Rome: FAO, FAO Fisheries Technical Paper 471.

Huguenin, J.E. & Colt, J. (2002). *Design and Operating Guide for Aquaculture Seawater Systems – Second Edition.* Amsterdam: Elsevier Science B.V., Developments in Aquaculture and Fisheries Science – 33.

Jackson, M.J. & James, R. (1979). The influence of bait digging on cockle *Cerastoderma edule,* populations in north Norfolk. *Journal of Applied Ecology* **16**, 671-679.

Jones, G.G., Sanford, C.L., Jones, B.L. (1993). *Manila clams: Hatchery and Nursery methods.* Skerry Bay: Innovative aquaculture products Ltd.

Kals, J., Schram, E., Mheen, H. van der, Smit, J. (2005). *Potentiële soorten voor de Nederlandse Aquacultuur. Rapportage deelproject 2.* IJmuiden: RIVO.

Kingston, P. (1974). Some observations on the effects of temperature and salinity upon the growth of *Cardium edule* and *Cardium glaucum* larvae in the laboratory. *Journal of the Marine Biological Association of the United Kingdom* **54**, 309-317.

Laing, I. & Jones, E. (1988). A turbidoostat vessel for the continuous culture of marine microalgae. *Aquaculture Engineering* **7**, 89-96.

Lebour, M.V. (1938). Notes on the breeding of some lamellibranchs from Plymouth and their larvae. *Journal of the Marine Biological Association of the United Kingdom* **23**, 119-144.

Lucas, J.S. & Southgate, P.C. (2003). *Aquaculture. Farming Aquatic Animals and Plants.* Oxford: Blackwell Publishing Ltd, Fishing News Books.

LNV (Ministerie van Landbouw, Natuur en Voedselkwaliteit) (2004). *Ruimte voor een zilte oogst. Naar een omslag in de Nederlandse schelpdiercultuur. Beleidsbesluit Schelpdiervisserij 2005-2020.* Den Haag: Dutch government.

Luiten, E (2004). *Zee in zicht. Zilte warden duurzaam benut.* Den Haag: STT/Beweton.

Montaudouin de X. (1996). Factors involved in growth plasticity of cockles *Cerastoderma edule* (L.), identified by field survey and transplant experiments. *Journal of Sea Research* **36**, 251-265.

Montaudouin de X. & Bachelet, G. (1996). Experimental evidence of complex interactions between biotic and abiotic factors in the dynamics of an intertidal population of the bivalve *Cerastoderma edule*. *Oceanologica Acta* **19,** 449-463.

Navarro, J.M. & Widdows, J. (1997). Feeding physiology of *Cerastoderma edule* in response to a wide range of seston concentrations. *Marine Ecology Progress Series* **152,** 175-186.

Newell, R.I.E. & Bayne, B.L. (1980). Seasonal changes in the physiology, reproductive condition and carbohydrate content of the cockle *Cardium* (=*Cerastoderma*) *edule* (Bivalvia: Cardidae). *Marine Biology* **56**, 11-19.

Orton, J.H. (1926). On the growth rate of *Cardium edule*, part 1. Experimental observations. *Journal of the Marine Biological Association of the United Kingdom* **14**, 239-280.

Pillay, T.V.R. (1992). *Aquaculture and the Environment.* Oxford: Blackwell Publishing Ltd., Fishing News Books.

Pulz, O. (2001). Photobioreactors: production systems for phototrophic microorganisms. *Applied Microbiology and Biotechnology* **57**, 287-293.

Robertson, J. & Robertson, S. (1999). *Mastering the requirements process.* London: Addison-Wesley.

Rueda, J.L., Smaal, A.C., Scholten, H. (2005). A growth model of the cockle (*Cerastoderma edule* L.) tested in the Oosterschelde estuary (The Netherlands). *Journal of Sea Research* **Article in Press**.

Russell, P.J.C. & Petersen, G.H. (1973). The use of ecological data in the elucidation of some shallow water European *Cardium* species. *Malacologia* **14**, 223-232.

Salz, P., Wijk, M.O. van, Smit, J.G.P., Taal, C. (2001). *De Nederlandse schelpdiersector.* Den Haag: LEI.

Seed, R. & Brown, R.A. (1977). A comparison of the reproductive cycles of *Modiolus modiolus* (L.), *Cerastoderma* (=*Cardium*) *edule* (L.), and *Mytilus edulis* L. in Strangford Lough, Northern Ireland. *Oecologia* **30**, 173-188.

Smaal, A.C., Vonck, A.P.M.A., Bakker, M. (1997). Seasonal variation in physiological energetics of Mytilus edulis and Cerastoderma edule of different size classes. Journal of the Marine Biological Association of the United Kingdom **77**, 817-838.

Stralen, M.R. van (1990). Het kokkelbestand in de Oosterschelde en de Waddenzee in 1990. Yerseke: RIVO. Rapport AQ 90-03.

Systems Engineering College (2001). *System Engineering Fundamentals.* Fort Belvoir: Defense Acquisition University Press, Department of Defense.

Utting, S.D. & Spencer, B.E. (1991). *Laboratory leaflet number 68. The hatchery culture of bivalve mollusc larvae and juveniles.*Lowestoft: Ministry of agriculture, fisheries and food directorate of fisheries research.

Vooys, C.G.N. de (y.u.). De biologie van de kokkel, Cerastoderma edule L., in het bijzonder met betrekking tot de plaats in de voedselketen. Een literatuuronderzoek. Texel: Nederlands Instituut voor Onderzoek der Zee.

Websites:

Website: www.ccap.ac.uk [accessed June 2006].

Website: (FAO, 2006) http://www.fao.org/figis/... [accessed June 2006].

Website: www.marlin.ac.uk [accessed June 2006].

Website: www.seckenberg.de [accessed June 2006].

Appendix I: Stakeholders analysis

In this appendix relevant stakeholders of the project are described and analyzed. The stakeholders in the project can be divided in the clients, potential customer, potential users and other potential stakeholders.

I.1 Clients

As pointed out in the colophon, the University of Twente, represented by Dr. ir. D.M.C. Augustijn, and Wageningen IMARES, represented by Dr. A.C. Smaal, are considered as the clients of the research. These clients are interested in the development of a land-based aquaculture facility of Common Cockles in the Netherlands and have also given the assignment to generate requirements, a functional architecture, and a physical architecture of such a facility.

I.2 Potential customers

Potential customers of the land-based aquaculture facility for Common Cockle species in the Netherlands are ventures which have interest in farming, processing and wholesale of Common Cockle species in the world. In the past, Dutch ventures always have had a very strong market share in traditional Common Cockle fish activities, therefore they are identified as most important potential customers.

The Dutch Common Cockle fish sector is very strong concentrated (Commissie Schadebepaling Kokkelvisserij, 2005). The sector exists out of eleven ventures, of which four of them are integrated farming, processing and wholesale ventures Before the 1st of January 2005 all these ventures had permits for traditional Common Cockle fish activities in the Dutch Wadden Sea. These four ventures are:

- Heiploeg Shellfish International (recently, called: Holland Shellfish International);
- Roem van Yerseke;
- Prins & Dingemanse;
- Landa Conserven.

Although, the recent prohibition of mechanical Common Cockle fish activities in the Dutch Wadden Sea, these ventures still have permits for traditional mechanical Common Cockle fish activities in: the Voordelta, the Oosterschelde estuary, and the Westerschelde estuary (Commissie Schadebepaling Kokkelvisserij, 2005). Furthermore, these ventures are also active in the processing and wholesale of other marine invertebrates, like shrimps, mussels and oysters.

Before the prohibition, of the mechanical Common Cockle fish activities in the Dutch Wadden Sea, these four ventures had a total market share of 34, of the 37 permits, in the Dutch Wadden Sea (Commissie Schadebepaling Kokkelvisserij, 2005). Heiploeg Shellfish International was the biggest venture of these four which had a market share of 21 permits, plus the processing of the supply of three independent ventures (which are only specialized in fishing). Furthermore, Heiploeg Shellfish International is the biggest supplier of shrimps and shellfishes in Europe (Commissie Schadebepaling Kokkelvisserij, 2005).

In this project, the four relevant potential customers, which are described above, are represented by the Mr. ir. J. Holstein, of the Commodity Board of the Common Cockle fisheries (PO Kokkels). This man will take care for any communications between the project designers and the potential customers.

I.3 Potential users

The potential users of the aquaculture facility are the people who working in, out, and with the facility. These people can be defined as employees, and eventual guest. The employees can be divided in:

- Employees/guest, who are working/looking in the algal culture phase (AL-0) and Common Cockle culture phase (CC-0) (primary production process) at the aquaculture facility.
- Employees/guests, who are working/looking at functions which supports the primary production process (secondary production process), including the distribution and sale the Common Cockle species.

It has to be noted that these potential users need to have facilities in which they can do their work. These facilities need to include employees/guest facilities and distribution facilities/systems, which have good general systems, like a power system, an air ventilation system, an emergency system and a maintenance system. The employees/guest facilities need to include functions like working facilities, general facilities and relaxing facilities. Furthermore, the distribution system needs to include a goods system, and a utility system. All these facilities (so-called sub-systems) of in the general infrastructure phase are further described in paragraph 4.3.

I.4 Other stakeholders

Other stakeholders which have a potential interest in the project are for example project- and product managers, business subject matter experts, technical experts, system developers, marketing people, safety inspectors, lawyers, usability experts, governmental bodies, and professional bodies of the industry.

In this development stage of the project the most important other stakeholders, which have a reasonable effect on the feasibility of the project is the Dutch national government, including their lower level agencies. Furthermore, research organizations, universities, Dutch companies with aquaculture experience, and organizations which are stimulating innovation of aquaculture, also have a major role in the gathering of (reliable) requirements.

I.4.1 Dutch (national) government

The most important other stakeholder in this project is the Dutch national government, including their lower level agencies, like provinces, communities and Local Water Boards. These stakeholders can provide restrictions, which are based on governmental laws and regulations (or so-called legislation). An overview of the national aquaculture legislation, including the agencies, is described at the website of the FAO[1]. Lower level governmental agencies, like the provinces, communities and Local Water Boards, are represented by drs. J. Broodman of the Province of Zeeland.

---

[1] http://www.fao.org/figis/servlet/static?dom=legalframework&xml=nalo_netherlands.xml [Accessed June 2006].

I.4.2 Research organizations

Research organizations can provide (reliable) requirements for the land-based aquaculture facility of Common Cockle species in the Netherlands. Research organizations which can provide these (reliable) requirements, because they have an overlapping with the matter, are defined as:

- Wageningen IMARES;
- NIOO (Dutch research institute for ecology);
- RIKZ (Governmental institute for coast en sea);
- WL Delft (Water laboratory).

The contacts at these research organizations are:

- IMARES, repr. by dr. A.C. Smaal (interviewed) and dr. P. Kamermans (interviewed);
- NIOO, repr. by dr. T. Ysebaert (interviewed);
- RIKZ, no contact;
- WL Delft, repr. by ir. M.B. de Vries (interviewed).

I.4.3 Universities

Universities can also provide (reliable) requirements, according to subject matter issues. The following two universities are defined as relevant stakeholders:

- University of Twente, and;
- Wageningen University and Research center.

The University of Twente has relevant knowledge of water engineering and- management (repr. by dr. ir. D.C.M. Augustijn - interviewed), design processes (repr. ir. K.T. Veenvliet - interviewed), and financing and marketing (repr. drs. P. Bliek - interviewed). The Wageningen University and Research center has relevant knowledge of aquaculture (repr. prof. dr. Verreth) and culture techniques of phytoplankton species (repr. prof. dr. ir. Wijffels - interviewed).

I.4.4 Companies with aquaculture experiences

Although, there are not many marine aquaculture facilities in the Netherlands, there is one in Zeeland, which cultures ragworms for the sport fishing industry (www.topsybaits.nl). To studying other aquaculture ventures can provide new insights and requirements. The aquaculture facility for culturing ragworms is represented by B. Meyering (interviewed).

I.4.5 Organizations for innovation of aquaculture

In the last recent years the innovation of aquaculture facilities has become a hot issue. Several organizations are working to innovating the world’s aquaculture sector and several innovation platforms have been raised. The most relevant organizations which are stimulating the innovation of aquaculture facilities are described below:

- Food and Agriculture Organization of the United Nations (FAO);
- FIOV of the European Union (provides European financial grants);
- Innovation Network of ‘Groene Ruimte en Agrocluster’.

Appendix II: Solution constraints

In this appendix detailed information is provided of the solution constraints. The solution constraints are divided in solution constraints in the problem domain and solution constraints in the solution domain.

The solution constraints are described according to, so-called, Volere cards. For every solution constraint certain issues are described. These issues are explained in figure II-1.

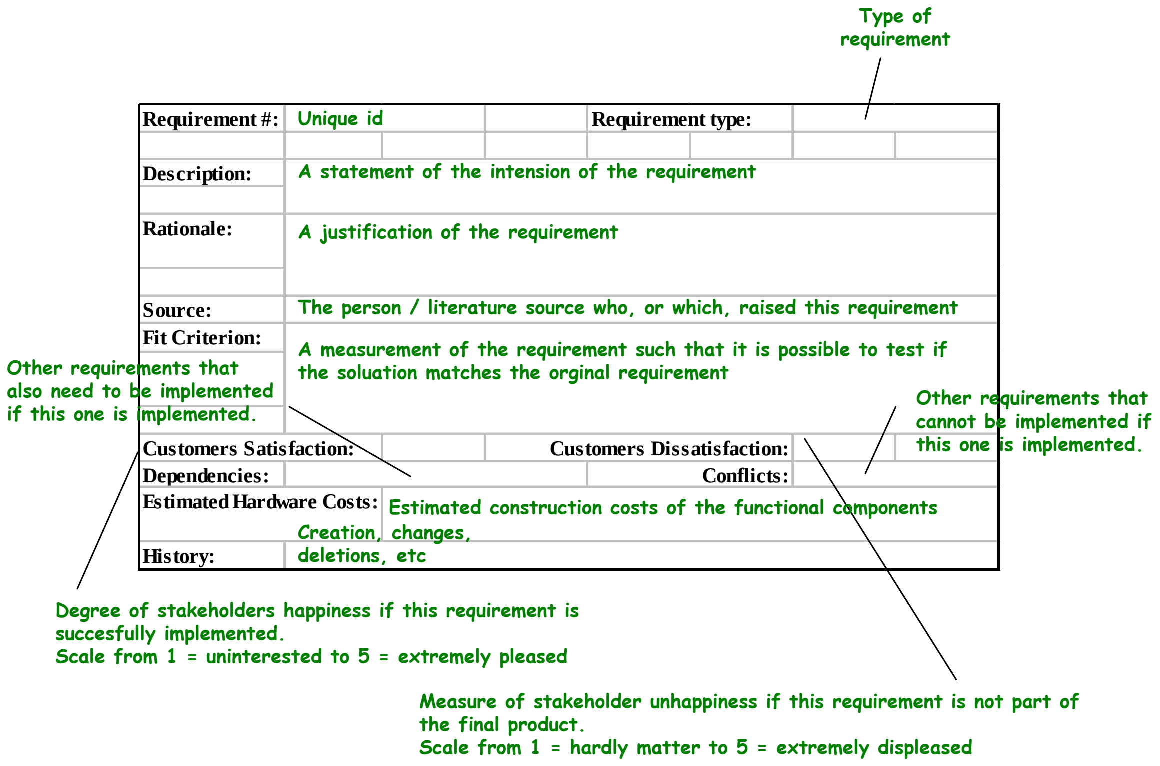


Figure II-1: Overview of the definitions in the Volere-card.

Not all definitions, which are described in figure II-1, are worked out in this appendix. However, it is recommended that definitions which are not worked out this appendix are described in next development levels. Therefore, these definitions are still integrated in the Volere cards. Furthermore, there is also a spreadsheet available which can calculate the estimated hardware costs, but because no data is available for the input of this spreadsheet the estimated hardware costs are not calculated.

II.1 Problem domain

Requirement #:	SC-1	**Requirement type:**	Solution Constraint
Description:	The innovative solution needs to produce Common Cockle species (Cerastoderma edule).		
Rationale:	The Dutch Common Cockle fish sector is looking for innovative solutions for extending their national production of Common Cockle species.		
Source:	A.C. Smaal, October 2005.		
Fit Criterion:	The Common Cockle species which need to be produced need to be of the 'edule' family and of the genus 'Cerastoderma'.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	SC-2	**Requirement type:**	Solution Constraint
Description:	The innovative solution needs to be legal.		
Rationale:	If the solution is not legal the overall feasibility of the project can be considered as not feasible.		
Source:	A.C. Smaal, October 2005; D.C.M. Augustijn, October 2005.		
Fit Criterion:	The innovative solution needs to be legal according to Dutch governmental laws and regulations.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	SC-3	**Requirement type:**	Solution Constraint
Description:	The innovative solution needs to be sustainable.		
Rationale:	If the innovative solution is sustainable the socio-economic feasibility will be high.		
Source:	A.C. Smaal, October 2005; D.C.M. Augustijn, October 2005.		
Fit Criterion:	The production methods of the new innovative solution must not pollute or damage habitats as defined by European and national laws and regulations.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #: SC-4 **Requirement type:** Solution Constraint

Description: The innovative solution needs to fit new market demands.

Rationale: New market demands need to be fulfilled to keep good relations with the clients/consumers of the product.
Source: A.C. Smaal, October 2005; D.C.M. Augustijn, October 2005.
Fit Criterion: The innovative solution needs to have a production of an adequate quality and quantity. Furthermore, the innovative solution needs to be able to deliver Common Cockle species of a size of 30-40 mm to the market every two months.
Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, October 2005.

II.2 Solution domain

Requirement #: SC-5 **Requirement type:** Solution Constraint

Description: The aquaculture facility for Common Cockle species needs to be located onshore.

Rationale: If the aquaculture facility is located onshore governmental laws and regulations, which are the cause the legal conflicts, have no effect on the production of Common Cockle species anymore.
Source: A.C. Smaal, October 2005.
Fit Criterion: At least 90% of all constructions of the aquaculture facility need to be located onshore.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, October 2005.

Requirement #: SC-6 **Requirement type:** Solution Constraint

Description: The aquaculture facility needs to have its own live phytoplankton supply.

Rationale: Phytoplankton (also called algae) is the main food source of Common Cockle species. Live phytoplankton always needs to be available to feed the Common Cockle species in the Common Cockle culture.
Source: A.C. Smaal, October 2005.
Fit Criterion: Adequate quantity of uni-algal (mono-specific) species of an adequate quality needs to be produced, at a specific location (algal culture) at the site, for the production process of the Common Cockle species (Common Cockle culture).
Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, October 2005.

Requirement #:	SC-7	**Requirement type:**	Solution Constraint
Description:	The aquaculture facility needs to have its own seawater supply.		
Rationale:	An own seawater supply minimizes the risk of no-supply, contamination, etc.		
Source:	A.C. Smaal, October 2005.		
Fit Criterion:	The primary production processes (algal culture and Common Cockle culture) in the aquaculture facility needs to have its own seawater supply.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	SC-8	**Requirement type:**	Solution Constraint
Description:	The aquaculture facility needs to have its own general infrastructure.		
Rationale:	General infrastructure (or the so-called secondary production process) is needed for supporting the primary production processes (algal culture and Common Cockle culture) like production, distribution and sale of the products.		
Source:	A.C. Smaal, October 2005.		
Fit Criterion:	The general infrastructure needs to have functions for general systems (power system, air ventilation systems, emergency systems, and maintenance systems), employees/guest facilities (working facilities, general facilities, and relaxing facilities), and the distribution systems (goods systems, and utility systems).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	SC-9	**Requirement type:**	Solution Constraint
Description:	The aquaculture facility needs to be financial profitable.		
Rationale:	The aquaculture facility for Common Cockle species needs to be a commercial venture, which needs to make profit to survive.		
Source:	A.C. Smaal, October 2005.		
Fit Criterion:	The aquaculture facility needs to have a financial break-even point in less than 8 years, and it needs to have an annual internal rate of return (IRR) of 15.0 % or more. Furthermore, the financial risks of the facility need to be kept to a minimum.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Appendix III: Project constraints

In this appendix detailed information is given of the project constraints. The project constraints are described according the four functional solution constraints and the ‘input-processing-output-model’.

The project constraints are described according to, so-called, Volere cards. For every project constraint certain issues are described. These issues are explained in figure III-1.

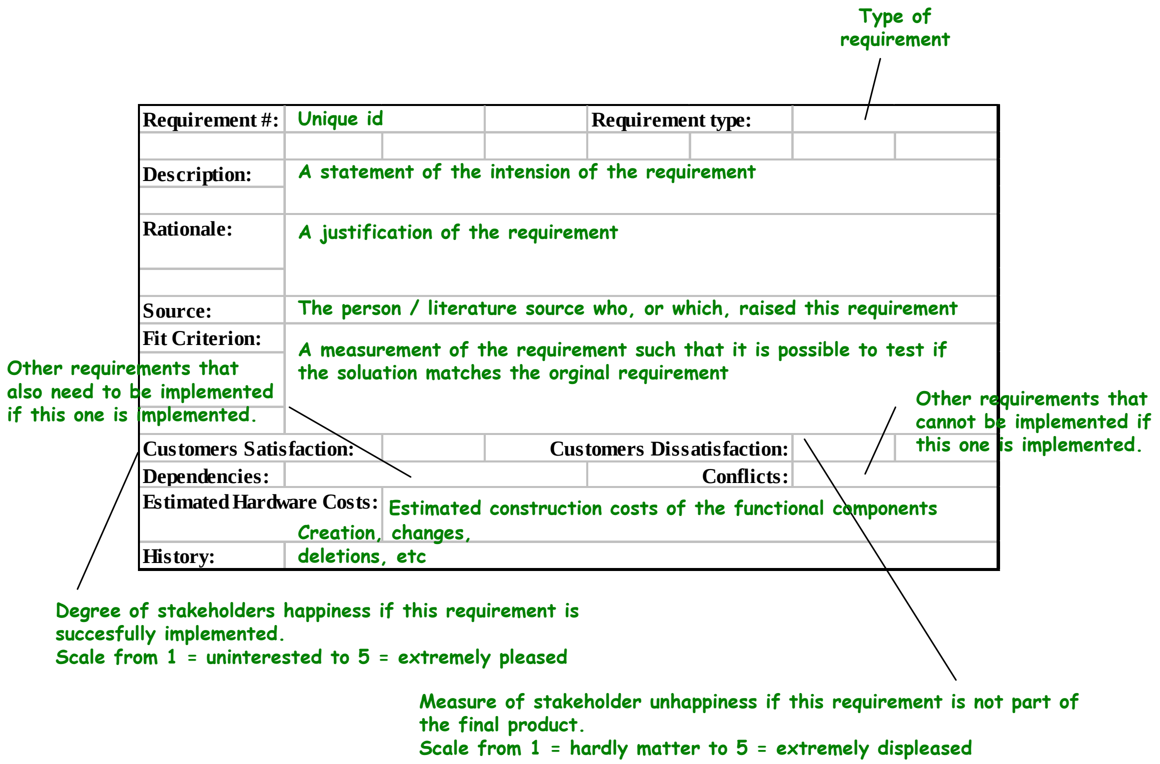


Figure III-1: Overview of the definitions in the Volere-card.

Not all definitions, which are described in figure III-1, are worked out in this appendix. However, it is recommended that definitions which are not worked out this appendix are described in next development levels. Therefore, these definitions are still integrated in the Volere cards. Furthermore, there is also a spreadsheet available which can calculate the estimated hardware costs, but because no data is available for the input of this spreadsheet the estimated hardware costs are not calculated.

III.1 ‘Common Cockle production’, based at SC-1

III.1.1 Input

Requirement #:	PC-1	**Requirement type:**	Project Constraint
Description:	The intake (input) of the Common Cockle species, in the primary production process (Common Cockle culture), needs to be of an adequate quality.		
Rationale:	The intake of the Common Cockle species needs to be of an adequate quality, to ensure an adequate quality of production at the end of the production process.		
Source:	No source (assumption).		
Fit Criterion:	The Common Cockle individuals (breeders) need to have a size of 30-40 mm, they need to be able to spawn, and males, as well as females, need to be used.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	PC-2	**Requirement type:**	Project Constraint
Description:	The intake (input) of the Common Cockle species in the primary production process (Common Cockle culture) needs to be of an adequate quantity.		
Rationale:	The intake needs to be of an adequate quantity to ensure adequate quantity of production at the end of the production process.		
Source:	No source (assumption).		
Fit Criterion:	The quantity of the intake of the Common Cockle species needs to be 20 Common Cockle individuals (breeders) to provide life of 10 000 Common Cockle individuals (measured at the harvest (output) of the Common Cockle culture) per year.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

III.1.2 Processing

Requirement #:	PC-3	**Requirement type:**	Project Constraint
Description:	The production (processing) of the Common Cockle species (in the Common Cockle culture) needs to have an adequate quality.		
Rationale:	If the production is of an adequate quality the Common Cockle species are also of an adequate quality, after which they are supplied to the market.		
Source:	No source (assumption).		
Fit Criterion:	The quality of the production process of Common Cockle species needs to approve market demands and Dutch/European legal demands. For example, the production process of the Common Cockle species and the Common Cockle species itself need to approve the demands of the Dutch Food and Consumer's Product Safety Authority (VWA).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	PC-4	**Requirement type:**	Project Constraint
Description:	The production (processing) of the Common Cockle species (in the Common Cockle culture) needs to supply an adequate quantity.		
Rationale:	Enough Common Cockle species need to be produced to supply the market and to make profit.		
Source:	No source (assumption).		
Fit Criterion:	The quantity of the annual production of Common Cockle species need to be at least 200 ± 50 ton (fresh weight). This weight is based on 0.7% of the average annual wild production of Dutch Common Cockle species over the period 1986-2003 (Commissie Schadebepaling Kokkelvisserij, 2005).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

III.1.3 Output

Requirement #:	PC-5	**Requirement type:**	Project Constraint
Description:	The harvest (output) of the production process of Common Cockle species (in the Common Cockle culture) needs to have an adequate quality.		
Rationale:	The Common Cockle species are sold to the market, therefore they need to have an adequate quality.		
Source:	No source (assumption).		
Fit Criterion:	The quality of the production process of Common Cockle species needs to approve market demands and Dutch/European legal demands. For example, the production process of the Common Cockle species and the Common Cockle species itself need to approve the demands of the Dutch Food and Consumer's Product Safety Authority (VWA).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	PC-6	**Requirement type:**	Project Constraint
Description:	The harvest (output) of the production process of Common Cockle species (in the Common Cockle culture phase) needs to have an adequate quantity.		
Rationale:	Enough Common Cockle species need to be harvested to supply the market and to make profit.		
Source:	No source (assumption).		
Fit Criterion:	Every two months 1/6th of the annual production of Common Cockle species need to be harvested.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

III.2 'Live phytoplankton production', based at SC-6

III.2.1 Inputs

Requirement #:	PC-7	**Requirement type:**	Project Constraint
Description:	The intake (input) of live phytoplankton into the production process of the Common Cockle species needs to be of an adequate quality.		
Rationale:	For optimal growth of the Common Cockle species good quality of food (live phytoplankton) is needed.		
Source:	Utting & Spencer, 1991; Helm & Bourne, 2004.		
Fit Criterion:	The live phytoplankton needs to consist of a mix of uni-algal species. Furthermore, the uni-algal species need to be of the right size to ensure optimal feeding behavior of Common Cockle species.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	PC-8	**Requirement type:**	Project Constraint
Description:	The intake (input) of live phytoplankton into the production process of the Common Cockle species needs to be of an adequate quantity.		
Rationale:	For optimization of the growth of the Common Cockle species an adequate quantity of food (live phytoplankton) is needed.		
Source:	Utting & Spencer, 1991; Helm & Bourne, 2004.		
Fit Criterion:	The quantity of live phytoplankton (or uni-algal species) needs to be of an adequate quantity per life stage of the Common Cockle species.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

III.2.2 Processing

Requirement #:	PC-9	**Requirement type:**	Project Constraint
Description:	The production (processing) of live phytoplankton (or uni-algal species), in the algal culture, needs to have an adequate quality.		
Rationale:	For optimal growth of the Common Cockle species good quality of food (live phytoplankton) is needed.		
Source:	Utting & Spencer, 1991; Helm & Bourne, 2004.		
Fit Criterion:	The live phytoplankton needs to consist of a mix of uni-algal species. Furthermore, the uni-algal species need to be of the right size to ensure optimal feeding behavior of Common Cockle species.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	PC-10	**Requirement type:**	Project Constraint
Description:	The production (processing) of live phytoplankton (or uni-algal species), in the algal culture, needs to have an adequate quantity.		
Rationale:	For optimization of the growth of the Common Cockle species an adequate quantity of food (live phytoplankton) is needed.		
Source:	Utting & Spencer, 1991; Helm & Bourne, 2004.		
Fit Criterion:	The quantity of live phytoplankton (or uni-algal species) needs to be of an adequate quantity per life stage of the Common Cockle species.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

III.2.3 Outputs

Requirement #:	PC-11	**Requirement type:**	Project Constraint
Description:	The harvest (output) of live phytoplankton (or uni-algal species) needs to have an adequate quality.		
Rationale:	The output of the live phytoplankton (or uni-algal species) is used as a food source for the Common Cockle species. Furthermore, the effluents need to fit governmental laws and regulations, and may not harm the surrounded marine habitats and ecosystems.		
Source:	Utting & Spencer, 1991; Helm & Bourne, 2004.		
Fit Criterion:	Live phytoplankton needs to consist a mix of uni-algal species of an adequate size. Furthermore, the effluents need to be treated to an acceptable quality, before the seawater can be discharged.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	PC-12	**Requirement type:**	Project Constraint
Description:	The harvest (output) of live phytoplankton (or uni-algal species) needs to have an adequate quantity.		
Rationale:	The output of the live phytoplankton (or uni-algal species) is used as a food source for the Common Cockle species. Furthermore, the effluents need to fit governmental laws and regulations, and may not harm the surrounded marine habitats and ecosystems.		
Source:	Helm & Bourne, 2004.		
Fit Criterion:	The quantity of live phytoplankton (or uni-algal species) needs to be of an adequate quantity per life stage of the Common Cockle species. Furthermore, the volume of effluents need to fit governmental laws and regulations, and do not need to harm the surrounded marine habitats and ecosystems.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

III.3 ‘Seawater supply’, based at SC-7

III.3.1 Inputs

Requirement #:	PC-13	**Requirement type:**	Project Constraint
Description:	The intake (input) of seawater in the algal culture, as in the Common Cockle culture, needs to have an adequate quality.		
Rationale:	For optimization of the growth of the Common Cockle species (in Common Cockle culture), and the uni-algal species (in algal culture), good quality seawater is needed.		
Source:	Helm & Bourne, 2004.		
Fit Criterion:	The seawater needs to be brought to a level of quality which is achievable with 'state of the art' water treatment equipment.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	PC-14	**Requirement type:**	Project Constraint
Description:	The intake (input) of seawater in the algal culture, as in the Common Cockle culture, needs to have an adequate quantity.		
Rationale:	For optimization of the growth of the Common Cockle species (in Common Cockle culture), and the uni-algal species (in algal culture) adequate quantity seawater is needed.		
Source:	Huguenin & Colt, 2002; Helm & Bourne, 2004		
Fit Criterion:	Common Cockle species and uni-algal species need to be cultured at (assumed) optimal quantity of seawater.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

III.3.2 Processing

Requirement #:	PC-15	**Requirement type:**	Project Constraint
Description:	The production (processing) of seawater in the algal culture, as in the Common Cockle culture, needs to have an adequate quality.		
Rationale:	For optimization of the growth of the Common Cockle species (in Common Cockle culture), and the uni-algal species (in algal culture), good quality seawater is needed.		
Source:	Helm & Bourne, 2004.		
Fit Criterion:	The seawater needs to be brought to a level of quality which is achievable with 'state of the art' water treatment equipment.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	PC-16	**Requirement type:**	Project Constraint
Description:	The production (processing) of seawater in the algal culture, as in the Common Cockle culture, needs to have an adequate quantity.		
Rationale:	For optimization of the growth of the Common Cockle species (in Common Cockle culture), and the uni-algal species (in algal culture) adequate quantity seawater is needed.		
Source:	Helm & Bourne, 2004.		
Fit Criterion:	Common Cockle species and uni-algal species need to be cultured at (assumed) optimal quantity of seawater.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

III.3.3 Outputs

Requirement #:	PC-17	**Requirement type:**	Project Constraint
Description:	The output of seawater in the algal culture, as in the Common Cockle culture, needs to have an adequate quality.		
Rationale:	The output of the seawater supply is used as input for the production process of live uni algal species (algal culture) and for the production process of Common Cockle species (Common Cockle culture). Furthermore, the effluents need to fit governmental laws and regulations, and do not need to harm the surrounded marine habitats and ecosystems.		
Source:	Helm & Bourne, 2004.		
Fit Criterion:	The seawater needs to be of a level of quality which is achievable with 'state of the art' water treatment equipment. Furthermore, the effluents need to be treated to an acceptable quality, before the seawater can be discharged.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	PC-18	**Requirement type:**	Project Constraint
Description:	The output of seawater in the algal culture, as in the Common Cockle culture, needs to have an acceptable quantity.		
Rationale:	The output of the seawater supply is used as input for the production process of live uni algal species (algal culture) and for the production process of Common Cockle species (Common Cockle culture). Furthermore, the effluents need to fit governmental laws and regulations, and do not need to harm the surrounded marine habitats and ecosystems.		
Source:	Helm & Bourne, 2004.		
Fit Criterion:	The seawater needs to be of a level of quantity which is achievable with 'state of the art' water treatment equipment. Furthermore, the quantity of the effluents need to be of an acceptable quantity.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

III.4 ‘General infrastructure’, based at SC-8

Requirement #:	PC-19	**Requirement type:**	Project Constraint
Description:	The general infrastructure (or so-called secondary production process), which supports the primary production processes of the Common Cockle species (Common Cockle culture) and uni-algal species (algal culture), needs to be of an adequate quality.		
Rationale:	The secondary production process, like accounting, distribution, etc, has also have its effects on the quality and quantity of the final product (adult Common Cockle species of a marketable size).		
Source:	Helm & Bourne, 2004.		
Fit Criterion:	Accounting and distribution need to be of a quality, so that the final products (Common Cockle species) are not, or very slow (within VWA-constraints), decreasing, after the harvest of the products at the end of the primary production process (implies conditioning).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Requirement #:	PC-20	**Requirement type:**	Project Constraint
Description:	The general infrastructure (or so-called secondary production process), which supports the primary production processes of the Common Cockle species (Common Cockle culture) and uni-algal species (algal culture) needs to be of an adequate quantity.		
Rationale:	The secondary production process, like accounting, distribution, etc, has also have its effects on the quality and quantity of the final product (adult Common Cockle species of a marketable size).		
Source:	Helm & Bourne, 2004.		
Fit Criterion:	Accounting and distribution need to be of a quality, so that the final products (Common Cockle species) are not, or very slow (within VWA-constraints), decreasing, after the harvest of the products at the end of the primary production process (implies conditioning).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, October 2005.		

Appendix IV: Technical requirements

In this appendix detailed information is given of the technical requirements. The technical requirements are divided into functional and non-functional requirements

The technical requirements project constraints are described according to, so-called, Volere cards. For every technical requirement certain issues are described. These issues are explained in figure IV-1.

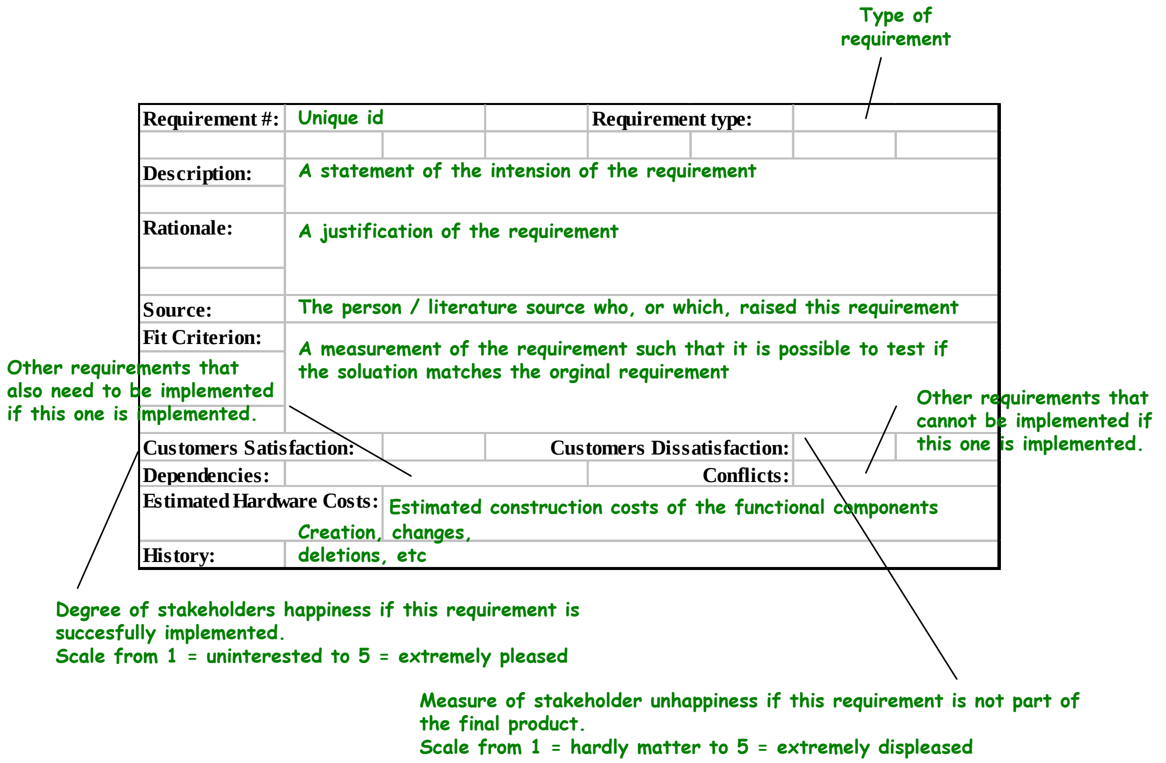


Figure IV-1: Overview of the definitions in the Volere-card.

Not all definitions, which are described in figure VI-1, are worked out in this appendix. However, it is recommended that definitions which are not worked out this appendix are described in next development levels. Therefore, these definitions are still integrated in the Volere cards. Furthermore, there is also a spreadsheet available which can calculate the estimated hardware costs, but because no data is available for the input of this spreadsheet the estimated hardware costs are not calculated.

IV.1 Algal culture phase (AL-0)

Input

Culture of algae system (AL-0.1)

Requirement #: FR-AL-0.1 **Requirement type:** Functional

Description: The input of the algal culture phase (AL-0) needs to be good uni-algal (mono-specific) species for the production process for Common Cockle species.
Rationale: The required uni-algal species need to have good culture characteristics to ensure adequate quantity of production. Furthermore, the uni-algal species need to have an adequate quality, so they can be used in the production process of uni-algal species in the algal culture.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The input of the uni-algal species in the algal culture phase needs to be the uni-algal species which are described in table 1 and they needs to come from reputable collections (which are approved by the clients).
Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-AL-0.2 **Requirement type:** Non-functional

Description: The input of the algal culture phase (AL-0) needs to be the required uni-algal species which need to have an adequate quality.
Rationale: Common Cockle species' growth is optimized by a food supply of live uni-algal species, which have a adequate size (or volume), organic weight, and a high food value (lipid %, carbohydrate %, protein %). Furthermore, the growth rate (or production rate) of the uni-algal species depends on the Chl. A % of the cultured species.

Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quality of the required uni-algal species of the input of the algal culture is described in table 1.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-AL-0.3 **Requirement type:** Non-functional

Description: The input of the algal culture phase (AL-0) needs to be the required uni-algal species which need to have an adequate quantity
Rationale: To ensure an adequate quantity of the output of the algal culture phase an adequate quantity of the input is required.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quantity of the required uni-algal species of the input of the algal culture are the quantities which are described in table 2.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Processing

Seawater treatment system (AL-0.2)

Requirement #:	FR-AL-0.4	**Requirement type:**	Functional
Description:	The required uni-algal species in the algal culture phase (AL-0) needs to be kept in (treated) seawater.		
Rationale:	The required uni-algal species are marine algal species which need seawater for good conditioning or growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required uni-algal species need to be kept in seawater which is available in a range of 50 meter of the coast of Yerseke, the Netherlands.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-0.5	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the algal culture phase (AL-0) need to be kept in an adequate quality of seawater.		
Rationale:	The required uni-algal species need to be kept in an adequate quality of seawater to obtain good conditioning or growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of seawater needs to have a optimal temperature, filtration, disinfecting, a good pH, and a good salinity concentration for suitable conditioning or growth of the uni-algal species (see table 4).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-0.6	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the algal culture phase (AL-0) need to be kept in an adequate quantity of seawater.		
Rationale:	The required uni-algal species need to be kept in an adequate quantity of seawater to obtain good conditioning or growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of seawater, which is described in figure 21, needs to be suitable to condition or grow the uni-algal species, according to the objective.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Enrichment system (AL-0.3)

Requirement #:	FR-AL-0.7	**Requirement type:**	Functional
Description:	The required uni-algal species in the algal culture phase (AL-0) need to be enriched with specialized maintenance media.		
Rationale:	The required uni-algal species need to be enriched with specialized maintenance media, which consist of nitrates, phosates, essential trace elements, vitamins and carbon dioxide, to ensure good conditioning or growth of the uni-algal species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The enriched maintenance media for the uni-algal species need to be F/2 media, or a similar media.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-0.8	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the algal culture phase (AL-0) need to be enriched with a required quality of maintenance media.		
Rationale:	The required uni-algal species need to be enriched with a required quality of maintenance media to ensure good conditioning or growth of the uni-algal species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the maintenance media for the required uni-algal species is described in table 5.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-0.9	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the algal culture phase (AL-0) need to be enriched with a required quantity of maintenance media.		
Rationale:	The required uni-algal species need to be enriched with a required quantity of maintenance media to ensure good conditioning or growth of the uni-algal species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of maintenance media, which is described in figure 31, needs to be suitable to condition or grow the uni-algal species, according to the objective.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Environmental control system (AL-0.4)

Requirement #:	FR-AL-0.10	**Requirement type:**	Functional
Description:	The environment in which the uni-algal species, seawater, and specialized maintenance media are kept in the algal culture phase (AL-0) needs to be conditioned.		
Rationale:	For good conditioning or growth of the uni-algal species the environment, in which the uni-algal species are conditioned or grown, needs to be conditioned at an adequate illumination and an adequate temperature.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environmental illumination and temperature need to be conditioned for good conditioning or growth of the uni-algal species.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-0.11	**Requirement type:**	Non-functional
Description:	The environment in which the uni-algal species, seawater, and specialized maintenance media are kept in the algal culture phase (AL-0) needs to have an adequate quality of conditioning.		
Rationale:	For good conditioning or growth of the uni-algal species the environment, in which the uni-algal species are conditioned or grown, needs to be conditioned at an adequate quality of illumination and an adequate quality of temperature.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environmental illumination and temperature need to have good dispersion for good conditioning or growth of the uni-algal species.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-0.12	**Requirement type:**	Non-functional
Description:	The environment in which the uni-algal species, seawater, and specialized maintenance media are kept in the algal culture phase (AL-0) needs to have an adequate quantity of conditioning.		
Rationale:	For good conditioning or growth of the uni-algal species the environment, in which the uni-algal species are conditioned or grown, needs to be conditioned at an adequate quantity (or intensity) of illumination and an adequate quantity of temperature.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environmental illumination and temperature need to have a good intensity for good conditioning or growth of the uni-algal species (see table 6).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Effluent treatment system (AL-0.5)

Requirement #:	FR-AL-0.13	**Requirement type:**	Functional
Description:	The effluents of the uni-algal species, seawater, and specialized maintenance media in the algal culture phase (AL-0) need to be treated (cleaned).		
Rationale:	To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated before discharging.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The effluents of the uni-algal species, seawater, and specialized maintenance media need to treated for discharging these effluents to an open water source.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-0.14	**Requirement type:**	Non-functional
Description:	The effluents of the uni-algal species, seawater, and specialized maintenance media in the algal culture phase (AL-0) need to be treated to an adequate quality.		
Rationale:	To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated to an adequate quality before discharging.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The adequate quality of the effluents of the uni-algal species, seawater, and specialized maintenance media from the algal culture phase needs to have the same, or close to, quality of the seawater which is used as input for the Common Cockle production process.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-0.15	**Requirement type:**	Non-functional
Description:	The effluents of the uni-algal species, seawater, and specialized maintenance media in the algal culture phase (AL-0) need to be treated to have an adequate quantity.		
Rationale:	To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated to an adequate quantity before discharging.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the treated and discharge effluents of uni-algal species, seawater, and specialized maintenance media from the algal culture phase need to be an adequate quantity.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Output

Harvest of culture of algae system (AL-0.6)

Requirement #:	FR-AL-0.16	**Requirement type:**	Functional
Description:	The output of the algal culture phase (AL-0) needs to be the required uni-algal (mono-specific) species for the production process of Common Cockle species.		
Rationale:	The required uni-algal species need be of an adequate quantity to supply the Common Cockle culture. Furthermore, the uni-algal species need to have an adequate quality, so they can be used for food supply for the Common Cockle species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required uni-algal species which need to be the output of the algal culture are described in table 1.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-0.17	**Requirement type:**	Non-functional
Description:	The output of the algal culture phase (AL-0) needs to be the required uni-algal species which need to have an adequate quality.		
Rationale:	Common Cockle species' growth is optimized by a food supply of live uni-algal species, which have a adequate size (or volume), organic weight, and a high food value (lipid %, carbohydrate %, protein %). Furthermore, the growth rate (or production rate) of the uni-algal species depends on the Chl. A % of the cultured species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the required uni-algal species of the output of the algal culture are described in table 1.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-0.18	**Requirement type:**	Non-functional
Description:	The output of the algal culture phase (AL-0) needs to be the required uni-algal species which need to have an adequate quantity.		
Rationale:	The output (required uni-algal species) of the algal culture phase needs to be of an adequate quantity, so it is enough to provide the Common Cockle culture of food (live uni-algal species).		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the required uni-algal species of the output of the algal culture are described in figure 21.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Stock culture (AL-1)

Input

Culture of algae system (AL-1.1)

Requirement #: FR-AL-1.1	**Requirement type:** Functional
Description:	The input of the stock culture (AL-1) needs to be good uni-algal (mono-specific) species to inoculate the starter culture (AL-2).
Rationale:	The required uni-algal species need to have good culture characteristics to ensure adequate quantity of production. Furthermore, the uni-algal species need to have an adequate quality, so they can be used in the production process of uni-algal species in the algal culture.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The input of the uni-algal species in the stock culture needs to be the uni-algal species, which are described in table 1, and they need to come from reputable collections (which are approved by the clients) .
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-AL-1.2	**Requirement type:** Non-functional
Description:	The input of the required uni-algal species in the stock culture (AL-1) needs to be of an adequate quality.
Rationale:	Common Cockle species' growth is optimized by a food supply of live uni-algal species, which have a adequate size (or volume), organic weight, and a high food value (lipid %, carbohydrate %, protein %). Furthermore, the growth rate (or production rate) of the uni-algal species depends on the Chl. A % of the cultured species.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quality of the required uni-algal species of the input of the stock culture are described in table 1.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-AL-1.3	**Requirement type:** Non-functional
Description:	The input of the stock culture (AL-1) needs to be the required uni-algal species, which needs to have an adequate quantity.
Rationale:	To ensure an adequate quantity of the output of the algal culture phase an adequate quantity of the input is required.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quantity of the required uni-algal species of the input of the algal culture are the quantities which are described in figure 21.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Processing

Seawater treatment system (AL-1.2)

Requirement #:	FR-AL-1.4	**Requirement type:**	Functional
Description:	The required uni-algal species in the stock culture (AL-1) need to be kept in seawater.		
Rationale:	The required uni-algal species are marine algal species which need seawater for good conditioning.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required uni-algal species need to be kept in seawater which have, or almost have, the original characteristics.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-1.5	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the stock culture (AL-1) need to be kept in an adequate quality of seawater.		
Rationale:	The required uni-algal species need to be kept in an adequate quality of seawater to obtain good conditioning or growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The seawater in the stock culture needs to have a (water) temperature of 4-12 oC, filtration of 0 µm, ultra-violet (uv) disinfection, a pH of 8.0, and a salinity concentration of 0 PSU (practical salinity units, equivalent to parts per thousand).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-1.6	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the stock culture (AL-1) need to be cultured in an adequate quantity of seawater.		
Rationale:	The required uni-algal species need to be kept in an adequate quantity of seawater to obtain good conditioning or growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of seawater, which is described in figure 21, needs to be suitable to condition the uni-algal species, according to the objective.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Enrichment system (AL-1.3)

Requirement #:	FR-AL-1.7	**Requirement type:**	Functional
Description:	The required uni-algal species in the stock culture (AL-1) need to be enriched with specialized maintenance media (seawater plus enrichments).		
Rationale:	The required uni-algal species need to be enriched with specialized maintenance media, which consist of nitrates, phosates, essential trace elements, vitamins and carbon dioxide, to ensure good conditioning of the uni-algal species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The enriched maintenance media for the uni-algal species in the stock culture need enrichments which are described in table 5.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-1.8	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the stock culture (AL-1) need to be enriched with a required quality of maintenance media (seawater plus enrichments).		
Rationale:	The required uni-algal species need to be enriched with a required quality of maintenance media to ensure good conditioning of the uni-algal species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the maintenance media for the required uni-algal species is described in table 5.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-1.9	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the stock culture (AL-1) need to be enriched with a required quantity of maintenance media (seawater plus enrichments).		
Rationale:	The required uni-algal species need to be enriched with a required quantity of maintenance media to ensure good conditioning of the uni-algal species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of maintenance media, which is described in figure 21, needs to be suitable to condition the uni-algal species, according to the objective.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Environmental control system (AL-1.4)

Requirement #: FR-AL-1.10	**Requirement type:** Functional
Description:	The environment in the stock culture (AL-1) in which the uni-algal species, seawater, and specialized maintenance media are kept needs to be conditioned.
Rationale:	For good conditioning of the uni-algal species the environment, in which the uni-algal species are conditioned or grown, needs to be conditioned at an adequate illumination and an adequate temperature.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The environmental illumination and temperature need to have good dispersion for good conditioning of the uni-algal species.
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-AL-1.11	**Requirement type:** Non-functional
Description:	The environment in the stock culture (AL-1) in which the uni-algal species, seawater, and specialized maintenance media are kept needs to have an adequate quality of conditioning.
Rationale:	For good conditioning of the uni-algal species the environment, in which the uni-algal species are conditioned, needs to be conditioned at an adequate quality of illumination and an adequate quality of temperature.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The dispersion of the light intensity and temperature need to meet the requirements on the culture surface.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-AL-1.12	**Requirement type:** Non-functional
Description:	The environment in the stock culture (AL-1) in which the uni-algal species, seawater, and specialized maintenance media are kept needs to have an adequate quantity of conditioning.
Rationale:	For good conditioning of the uni-algal species the environment, in which the uni-algal species are conditioned, needs to be conditioned at an adequate quantity (or intensity) of illumination and an adequate quantity of temperature.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The light intensity of the illumination and the adequate temperature are described in table 6.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Effluent treatment system (AL-1.5)

Requirement #:	FR-AL-1.13	**Requirement type:**	Functional
Description:	The effluents of the uni-algal species, seawater, and specialized maintenance media of the stock culture (AL-1) need to be treated (cleaned).		
Rationale:	To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated before discharging.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The effluents of the uni-algal species, seawater, and specialized maintenance media of the stock culture (AL-1) need to be treated (cleaned).		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-1.14	**Requirement type:**	Non-functional
Description:	The effluents of the uni-algal species, seawater, and specialized maintenance media from the stock culture (AL-1) need to be treated to have an adequate quality.		
Rationale:	To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated to an adequate quality before discharging.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The adequate quality of the effluents of the uni-algal species, seawater, and specialized maintenance media need to have the same quality, or close to, of the seawater which is used as input for the Common Cockle production process.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-1.15	**Requirement type:**	Non-functional
Description:	The effluents of the uni-algal species, seawater, and specialized maintenance media from the stock culture (AL-1) need to be treated to have an adequate quantity.		
Rationale:	To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated to an adequate quantity before discharging.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the treated and discharge effluents of uni-algal species, seawater, and specialized maintenance media need to be adequate.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Output

Harvest of culture of algae system (AL-1.6)

Requirement #: FR-AL-1.16 **Requirement type:** Functional

Description: The output of the stock culture (AL-1) needs to be the required uni-algal (mono-specific) species to inoculate the starter culture (AL-2).

Rationale: The required uni-algal species need be of an adequate quantity, so they can be grown in the starter culture. Furthermore, the uni-algal species need to have an adequate quality, so they can be used for inoculation of the starter culture.

Source: Derived from literature sources (for reference, see report).

Fit Criterion: The required uni-algal species which needs to be the output of the stock culture are described in table 1.

Customers Satisfaction: x1 **Customers Dissatisfaction:** x2

Dependencies: x3 **Conflicts:** x4

Estimated Hardware Costs: --

History: S. Deen, April 2006.

Requirement #: NR-AL-1.17 **Requirement type:** Non-functional

Description: The output of the stock culture (AL-1) needs to be the required uni-algal species which need to have an adequate quality.

Rationale: The required uni-algal species need be of an adequate quantity, so they can be grown in the starter culture. Furthermore, the uni-algal species need to have an adequate quality, so they can be used for inoculation of the starter culture.

Source: Derived from literature sources (for reference, see report).

Fit Criterion: The quality of the required uni-algal species of the output of the stock culture are described in table 1.

Customers Satisfaction: -- **Customers Dissatisfaction:** --

Dependencies: -- **Conflicts:** --

Estimated Hardware Costs: --

History: S. Deen, April 2006.

Requirement #: NR-AL-1.18 **Requirement type:** Non-functional

Description: The output of the algal culture (AL-1) needs to be the required uni-algal species which need to have an adequate quantity.

Rationale: The required uni-algal species need be of an adequate quantity, so they can be grown in the starter culture. Furthermore, the uni-algal species need to have an adequate quality, so they can be used for inoculation of the starter culture.

Source: Derived from literature sources (for reference, see report).

Fit Criterion: The quantity of the required uni-algal species of the output of the stock culture are the quantities described in figure 21.

Customers Satisfaction: -- **Customers Dissatisfaction:** --

Dependencies: -- **Conflicts:** --

Estimated Hardware Costs: --

History: S. Deen, April 2006.

IV.1.1 Starter culture (AL-2)

Input

Culture of algae system (AL-2.1)

Requirement #:	FR-AL-2.1	**Requirement type:**	Functional
Description:	The input of the starter culture (AL-2) needs to be good uni-algal (mono-specific) species to inoculate the intermediate-scale culture (AL-3).		
Rationale:	The required uni-algal species need to have good culture characteristics to ensure adequate quantity of production. Furthermore, the uni-algal species need to have an adequate quality, so they can be used in the production process of uni-algal species in the algal culture.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The input of the uni-algal species in the starter culture (AL-2) needs to be the uni-algal species which are described in table 1 and they need to come from the output of the stock culture (AL-1).		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-2.2	**Requirement type:**	Non-functional
Description:	The input of the required uni-algal species in the starter culture (AL-2) needs to be of an adequate quality.		
Rationale:	Common Cockle species' growth is optimized by a food supply of live uni-algal species, which have a adequate size (or volume), organic weight, and a high food value (lipid %, carbohydrate %, protein %). Furthermore, the growth rate (or production rate) of the uni-algal species depends on the Chl. A % of the cultured species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the required uni-algal species of the input of the stock culture are described in table 1.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-2.3	**Requirement type:**	Non-functional
Description:	The input of the starter culture (AL-2) needs to be the required uni-algal species which needs to have an adequate quantity.		
Rationale:	To ensure an adequate quantity of the output of the algal culture phase an adequate quantity of the input is required.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the required uni-algal species of the input of the algal culture are the quantities which are described in figure 21.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Processing

Seawater treatment system (AL-2.2)

Requirement #:	FR-AL-2.4	**Requirement type:**	Functional
Description:	The required uni-algal species in the starter culture (AL-2) needs to be kept in seawater.		
Rationale:	The required uni-algal species are marine algal species which need seawater for good growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required uni-algal species need to be kept in seawater which have, or almost have, the original characteristics.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-2.5	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the starter culture (AL-2) need to be kept in an adequate quality of seawater.		
Rationale:	The required uni-algal species need to be kept in an adequate quality of seawater to obtain good growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The seawater in the starter culture needs to have a temperature of 18-22 oC, a filtration of 2 µm, uv disinfection, a pH of 7.5-8.2, and a salinity concentration of 20-25 PSU (practical salinity units, equivalent to parts per thousand).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-2.6	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the starter culture (AL-2) need to be cultured in an adequate quantity of seawater.		
Rationale:	The required uni-algal species need to be kept in an adequate quantity of seawater to obtain good growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of seawater, which is described in figure 21, needs to be suitable to grow the uni-algal species, according to the objective.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Enrichment system (AL-2.3)

Requirement #: FR-AL-2.7 **Requirement type:** Functional

Description: The required uni-algal species in the starter culture (AL-2) need to be enriched with specialized maintenance media (seawater plus enrichments).

Rationale: The required uni-algal species need to be enriched with specialized maintenance media, which consist of nitrates, phosates, essential trace elements, vitamins and carbon dioxide, to ensure good growth of the uni-algal species.

Source: Derived from literature sources (for reference, see report).

Fit Criterion: The enriched maintenance media for the uni-algal species in the starter culture need to have enrichments which are described in table 5, plus air/carbon dioxide (CO2) mixture and salt.

Customers Satisfaction: x1 **Customers Dissatisfaction:** x2

Dependencies: x3 **Conflicts:** x4

Estimated Hardware Costs: --

History: S. Deen, April 2006.

Requirement #: NR-AL-2.8 **Requirement type:** Non-functional

Description: The required uni-algal species in the starter culture (AL-2) need to be enriched with a required quality of maintenance media (seawater plus enrichments).

Rationale: The required uni-algal species need to be kept in an adequate quantity of seawater to obtain good growth.

Source: Derived from literature sources (for reference, see report).

Fit Criterion: The quality of the maintenance media for the required uni-algal species is described in table 5, plus an adequate air/carbon dioxide (CO2) mixture and an adequate aadition of salt.

Customers Satisfaction: -- **Customers Dissatisfaction:** --

Dependencies: -- **Conflicts:** --

Estimated Hardware Costs: --

History: S. Deen, April 2006.

Requirement #: NR-AL-2.9 **Requirement type:** Non-functional

Description: The required uni-algal species in the starter culture (AL-2) need to be enriched with a required quantity of maintenance media.

Rationale: The required uni-algal species need to be enriched with a required quantity of maintenance media to ensure good growth of the uni-algal species.

Source: Derived from literature sources (for reference, see report).

Fit Criterion: The required quantity of maintenance media, which is described in figure 21, needs to be suitable to grow the uni-algal species, according to the objective.

Customers Satisfaction: -- **Customers Dissatisfaction:** --

Dependencies: -- **Conflicts:** --

Estimated Hardware Costs: --

History: S. Deen, April 2006.

Environmental control system (AL-0.4)

Requirement #:	FR-AL-2.10	**Requirement type:**	Functional
Description:	The environment in the starter culture (AL-2) in which the uni-algal species, seawater, and specialized maintenance media are kept, needs to be conditioned.		
Rationale:	For good growth of the uni-algal species the environment, in which the uni-algal species are grown, needs to be conditioned at an adequate illumination and an adequate temperature.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environmental illumination and temperature need to have good dispersion for good growth of the uni-algal species.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-2.11	**Requirement type:**	Non-functional
Description:	The environment in the starter culture (AL-2) in which the uni-algal species, seawater, and specialized maintenance media are kept, need to have an adequate quality of conditioning.		
Rationale:	For good growth of the uni-algal species the environment, in which the uni-algal species are grown, needs to be conditioned at an adequate quality of illumination and an adequate quality of temperature.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The dispersion of the light intensity and temperature need to meet the requirements on the culture surface.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-2.12	**Requirement type:**	Non-functional
Description:	The environment in the starter culture (AL-2) in which the uni-algal species, seawater, and specialized maintenance media are kept, needs to have an adequate quantity of conditioning.		
Rationale:	For good growth of the uni-algal species the environment, in which the uni-algal species are grown, needs to be conditioned at an adequate quantity (or intensity) of illumination and an adequate quantity of temperature.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environment in the starter culture needs to be kept in a temperature range of 18-22 oC and needs to be kept illuminated, with a light intensity of 4750-5250 lux. (measured at the culture surface).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Harware Costs:	--		
History:	S. Deen, April 2006.		

Effluent treatment system (AL-2.5)

Requirement #: FR-AL-2.13	**Requirement type:** Functional
Description:	The effluents of the uni-algal species, seawater, and specialized maintenance media of the starter culture (AL-2) need to be treated (cleaned).
Rationale:	To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated before discharging.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The effluents of the uni-algal species, seawater, and specialized maintenance media need to treated for discharging these effluents to an open water source.
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Harware Costs: --	
History: S. Deen, April 2006.	

Requirement #: NR-AL-2.14	**Requirement type:** Non-functional
Description:	The effluents of the uni-algal species, seawater, and specialized maintenance media from the starter culture (AL-2) need to be treated to have an adequate quality.
Rationale:	To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated to an adequate quality before discharging.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The adequate quality of the effluents of the uni-algal species, seawater, and specialized maintenance media need to have the same quality, or close to, of the seawater which is used as input for the Common Cockle production process.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Harware Costs: --	
History: S. Deen, April 2006.	

Requirement #: NR-AL-2.15	**Requirement type:** Non-functional
Description:	The effluents of the uni-algal species, seawater, and specialized maintenance media from the starter culture (AL-2) need to be treated to have an adequate quantity.
Rationale:	To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated to an adequate quantity before discharging.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quantity of the treated and discharge effluents of uni-algal species, seawater, and specialized maintenance media need to be adequate.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Harware Costs: --	
History: S. Deen, April 2006.	

Output

Harvest of culture of algae system (AL-2.6)

Requirement #:	FR-AL-2.16	**Requirement type:**	Functional
Description:	The output of the starter culture (AL-2) needs to be the required uni-algal (mono-specific) species to inoculate the intermediate-scale culture.		
Rationale:	The required uni-algal species need be of an adequate quantity to supply the Common Cockle culture. Furthermore, the uni-algal species need to have an adequate quality, so they can be used for food supply for the Common Cockle species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required uni-algal species which need to be the output of the starter culture are described in table 1.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Harware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-2.17	**Requirement type:**	Non-functional
Description:	The output of the starter culture (AL-2) needs to be the required uni-algal species which need to have an adequate quality.		
Rationale:	Common Cockle species' growth is optimized by a food supply of live uni-algal species, which have a adequate size (or volume), organic weight, and a high food value (lipid %, carbohydrate %, protein %). Furthermore, the growth rate (or production rate) of the uni-algal species depends on the Chl. A % of the cultured species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the required uni-algal species of the output of the starter culture are described in table 1.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Harware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-2.18	**Requirement type:**	Non-functional
Description:	The output of the starter culture (AL-2) needs to be the required uni-algal species which need to have an adequate quantity.		
Rationale:	The output (required uni-algal species) of the algal culture phase needs to be of an adequate quantity, so it is enough to provide the Common Cockle culture of food (live uni-algal species).		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the required uni-algal species of the output of the starter culture are the quantities described in figure 21.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Harware Costs:	--		
History:	S. Deen, April 2006.		

IV.1.2 Intermediate-scale culture (AL-3)

Input

Culture of algae system (AL-3.1)

Requirement #:	FR-AL-3.1	**Requirement type:**	Functional
Description:	The input of the intermediate-scale culture (AL-3) needs to be good uni-algal (mono-specific) species to inoculate the large-scale culture (AL-4).		
Rationale:	The required uni-algal species need to have good culture characteristics to ensure adequate quantity of production. Furthermore, the uni-algal species need to have an adequate quality, so they can be used in the production process of uni-algal species in the algal culture.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The input of the uni-algal species in the intermediate-scale culture (AL-3) needs to be the uni-algal species which are described in table 2 and they needs to come from the output of the starter culture (AL-2).		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-3.2	**Requirement type:**	Non-functional
Description:	The input of the required uni-algal species in the intermediate-scale culture (AL-3) needs to be of an adequate quality.		
Rationale:	Common Cockle species' growth is optimized by a food supply of live uni-algal species, which have a adequate size (or volume), organic weight, and a high food value (lipid %, carbohydrate %, protein %). Furthermore, the growth rate (or production rate) of the uni-algal species depends on the Chl. A % of the cultured species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the required uni-algal species of the input of the intermediate-scale culture are the qualities described in table 1.		
Customers Satisfaction:		**Customers Dissatisfaction:**	
Dependencies:		**Conflicts:**	
Estimated Hardware Costs:			
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-3.3	**Requirement type:**	Non-functional
Description:	The input of the intermediate-scale culture (AL-3) needs to be the required uni-algal species which need to have an adequate quantity.		
Rationale:	To ensure an adequate quantity of the output of the algal culture phase an adequate quantity of the input is required.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the required uni-algal species of the input of the algal culture are the quantities which are described in figure 21.		
Customers Satisfaction:		**Customers Dissatisfaction:**	
Dependencies:		**Conflicts:**	
Estimated Hardware Costs:			
History:	S. Deen, April 2006.		

Processing

Seawater treatment system (AL-3.2)

Requirement #:	FR-AL-3.4	**Requirement type:**	Functional
Description:	The required uni-algal species in the intermediate-scale culture (AL-3) need to be kept in seawater.		
Rationale:	The required uni-algal species are marine algal species which need seawater for good growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required uni-algal species need to be kept in seawater which have, or almost have, the original characteristics.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-3.5	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the intermediate-scale culture (AL-3) need to be kept in an adequate quality of seawater.		
Rationale:	The required uni-algal species need to be kept in an adequate quality of seawater to obtain good growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The seawater in the intermediate-scale culture needs to have a temperature of 18-22 oC,a filtration of 2 µm, ultra-violet (uv) disinfection, a pH of 7.5-8.2, and a salinity concentration of 20-25 PSU (practical salinity units, equivalent to parts per thousand).		
Customers Satisfaction:		**Customers Dissatisfaction:**	
Dependencies:		**Conflicts:**	
Estimated Hardware Costs:			
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-3.6	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the intermediate-scale culture (AL-3) need to be cultured in an adequate quantity of seawater.		
Rationale:	The required uni-algal species need to be kept in an adequate quantity of seawater to obtain good growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of seawater, which is described in figure 21, needs to be suitable to grow the uni-algal species, according to the objective.		
Customers Satisfaction:		**Customers Dissatisfaction:**	
Dependencies:		**Conflicts:**	
Estimated Hardware Costs:			
History:	S. Deen, April 2006.		

Enrichment system (AL-3.3)

Requirement #:	FR-AL-3.7	**Requirement type:**	Functional
Description:	The required uni-algal species in the intermediate-scale culture (AL-3) need to be enriched with specialized maintenance media.		
Rationale:	The required uni-algal species need to be enriched with specialized maintenance media, which consist of nitrates, phosates, essential trace elements, vitamins and carbon dioxide, to ensure good growth of the uni-algal species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The enriched maintenance media for the uni-algal species in the intermediate-scale culture needs to have enrichments which are described in table 5, plus air/carbon dioxide (CO2) mixture and salt.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-3.8	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the intermediate-scale culture (AL-3) need to be enriched with a required quality of maintenance media.		
Rationale:	The required uni-algal species need to be kept in an adequate quantity of seawater to obtain good growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the maintenance media for the required uni-algal species is described in table 5, plus an adequate air/carbon dioxide (CO2) mixture and an adequate aadition of salt.		
Customers Satisfaction:		**Customers Dissatisfaction:**	
Dependencies:		**Conflicts:**	
Estimated Hardware Costs:			
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-3.9	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the intermediate-scale culture (AL-3) need to be enriched with a required quantity of maintenance media.		
Rationale:	The required uni-algal species need to be enriched with a required quantity of maintenance media to ensure good growth of the uni-algal species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of maintenance media, which is described in figure 21, needs to be suitable to grow the uni-algal species, according to the objective.		
Customers Satisfaction:		**Customers Dissatisfaction:**	
Dependencies:		**Conflicts:**	
Estimated Hardware Costs:			
History:	S. Deen, April 2006.		

Environmental control system (AL-3.4)

Requirement #:	FR-AL-3.10	**Requirement type:**	Functional
Description:	The environment in the intermediate-scale culture (AL-3) in which the uni-algal species, seawater, and specialized maintenance media are kept, needs to be conditioned.		
Rationale:	For good growth of the uni-algal species the environment, in which the uni-algal species are grown, needs to be conditioned at an adequate illumination and an adequate temperature.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environmental illumination and temperature need to have good dispersion for good conditioning or growth of the uni-algal species.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-3.11	**Requirement type:**	Non-functional
Description:	The environment in the intermediate-scale culture (AL-3) in which the uni-algal species, seawater, and specialized maintenance media are kept, needs to have an adequate quality of conditioning.		
Rationale:	For good growth of the uni-algal species the environment, in which the uni-algal species are grown, needs to be conditioned at an adequate quality of illumination and an adequate quality of temperature.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The dispersion of the light intensity and temperature need to meet the requirements on the culture surface.		
Customers Satisfaction:		**Customers Dissatisfaction:**	
Dependencies:		**Conflicts:**	
Estimated Hardware Costs:			
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-3.12	**Requirement type:**	Non-functional
Description:	The environment in the intermediate-scale culture (AL-3) in which the uni-algal species, seawater, and specialized maintenance media are kept, needs to have an adequate quantity of conditioning.		
Rationale:	For good growth of the uni-algal species the environment, in which the uni-algal species are grown, needs to be conditioned at an adequate quantity (or intensity) of illumination and an adequate quantity of temperature.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environment in the intermediate-scale culture needs to be kept in a temperature range of 18-22 oC and needs to be kept illuminated, with a light intensity of 15000-25000 lux. (measured at the culture surface).		
Customers Satisfaction:		**Customers Dissatisfaction:**	
Dependencies:		**Conflicts:**	
Estimated Hardware Costs:			
History:	S. Deen, April 2006.		

Effluent treatment system (AL-3.5)

Requirement #: FR-AL-3.13 **Requirement type:** Functional

Description: The effluents of the uni-algal species, seawater, and specialized maintenance media of the intermediate-scale culture (AL-3) need to be treated (cleaned).
Rationale: To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated before discharging.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The effluents of the uni-algal species, seawater, and specialized maintenance media need to treated for discharging these effluents to an open water source.

Customers Satisfaction: x1 **Customers Dissatisfaction:** x2
Dependencies: x3 **Conflicts:** x4
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-AL-3.14 **Requirement type:** Non-functional

Description: The effluents of the uni-algal species, seawater, and specialized maintenance media from the intermediate-scale culture (AL-3) need to be treated to have an adequate quality.
Rationale: To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated to an adequate quality before discharging.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The adequate quality of the effluents of the uni-algal species, seawater, and specialized maintenance media need to have the same quality, or close to, of the seawater which is used as input for the Common Cockle production process.

Customers Satisfaction: **Customers Dissatisfaction:**
Dependencies: **Conflicts:**
Estimated Hardware Costs:
History: S. Deen, April 2006.

Requirement #: NR-AL-3.15 **Requirement type:** Non-functional

Description: The effluents of the uni-algal species, seawater, and specialized maintenance media from the intermediate-scale culture (AL-3) need to be treated to have an adequate quantity.
Rationale: To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated to an adequate quantity before discharging.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quantity of the treated and discharge effluents of uni-algal species, seawater, and specialized maintenance media need to be adequate.

Customers Satisfaction: **Customers Dissatisfaction:**
Dependencies: **Conflicts:**
Estimated Hardware Costs:
History: S. Deen, April 2006.

Output

Harvest of culture of algae system (AL-3.6)

Requirement #: FR-AL-3.16	**Requirement type:** Functional
Description:	The output of the intermediate-scale culture (AL-3) needs to be the required uni-algal (mono-specific) species to inoculate the large-scale culture.
Rationale:	The required uni-algal species need be of an adequate quantity to supply the Common Cockle culture. Furthermore, the uni-algal species need to have an adequate quality, so they can be used for food supply for the Common Cockle species.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The required uni-algal species which need to be the output of the intermediate-scale culture are described in table 1.
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-AL-3.17	**Requirement type:** Non-functional
Description:	The output of the intermediate-scale culture (AL-3) needs to be the required uni-algal species which need to have an adequate quality.
Rationale:	Common Cockle species' growth is optimized by a food supply of live uni-algal species, which have a adequate size (or volume), organic weight, and a high food value (lipid %, carbohydrate %, protein %). Furthermore, the growth rate (or production rate) of the uni-algal species depends on the Chl. A % of the cultured species.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quality of the required uni-algal species of the output of the intermediate-scale culture are described in table 1.
Customers Satisfaction:	**Customers Dissatisfaction:**
Dependencies:	**Conflicts:**
Estimated Hardware Costs:	
History:	S. Deen, April 2006.

Requirement #: NR-AL-3.18	**Requirement type:** Non-functional
Description:	The output of the intermediate-scale culture (AL-3) needs to be the required uni-algal species which need to have an adequate quantity.
Rationale:	The output (required uni-algal species) of the algal culture phase needs to be of an adequate quantity, so it is enough to provide the Common Cockle culture of food (live uni-algal species).
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quantity of the required uni-algal species of the output of the intermediate-scale culture are the quantities described in figure 21.
Customers Satisfaction:	**Customers Dissatisfaction:**
Dependencies:	**Conflicts:**
Estimated Hardware Costs:	
History:	S. Deen, April 2006.

IV.1.3 Large-scale culture (AL-4)

Input

Culture of algae system (AL-4.1)

Requirement #: FR-AL-4.1	**Requirement type:** Functional
Description:	The input of the large-scale culture (AL-4) needs to be good uni-algal (mono-specific) species for growing them for the input of the Common Cockle production process (Common Cockle culture - CC-0).
Rationale:	The required uni-algal species need to have good culture characteristics to ensure adequate quantity of production. Furthermore, the uni-algal species need to have an adequate quality, so they can be used in the production process of uni-algal species in the algal culture.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The input of the uni-algal species in the large-scale culture (AL-4) needs to be the uni-algal species which are described in table 1 and they needs to come from the output of the intermediate-scale culture (AL-3).
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-AL-4.2	**Requirement type:** Non-functional
Description:	The input of the required uni-algal species in the large-scale culture (AL-4) needs to be of an adequate quality.
Rationale:	Common Cockle species' growth is optimized by a food supply of live uni-algal species, which have a adequate size (or volume), organic weight, and a high food value (lipid %, carbohydrate %, protein %). Furthermore, the growth rate (or production rate) of the uni-algal species depends on the Chl. A % of the cultured species.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quality of the required uni-algal species of the input of the large-scale culture are the qualities described in table 1.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-AL-4.3	**Requirement type:** Non-functional
Description:	The input of the large-scale culture (AL-4) needs to be the required uni-algal species which need to have an adequate quantity.
Rationale:	To ensure an adequate quantity of the output of the algal culture phase an adequate quantity of the input is required.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quantity of the required uni-algal species of the input of the algal culture are the quantities which are described figure 21.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Processing

Seawater treatment system (AL-4.2)

Requirement #: FR-AL-4.4	**Requirement type:** Functional
Description:	The required uni-algal species in the large-scale culture (AL-4) need to be kept in seawater.
Rationale:	The required uni-algal species are marine algal species which need seawater for good growth.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The required uni-algal species need to be kept in seawater which have, or almost have, the original characteristics.
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-AL-4.5	**Requirement type:** Non-functional
Description:	The required uni-algal species in the large-scale culture (AL-4) need to be kept in an adequate quality of seawater.
Rationale:	The required uni-algal species need to be kept in an adequate quality of seawater to obtain good growth.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The seawater in the large-scale culture needs to have a temperature of 18-22 oC, a filtration of 2 µm, ultra-violet (uv) disinfection, a pH of 7.5-8.2, and a salinity concentration of 20-25 PSU (practical salinity units, equivalent to parts per thousand) for diatoms, and 30 PSU for flagellates.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-AL-4.6	**Requirement type:** Non-functional
Description:	The required uni-algal species in the large-scale culture (AL-4) need to be cultured in an adequate quantity of seawater.
Rationale:	The required uni-algal species need to be kept in an adequate quantity of seawater to obtain good growth.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The required quantity of seawater, which is described in figure 21, needs to be suitable to grow the uni-algal species, according to the objective.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Enrichment system (AL-4.3)

Requirement #:	FR-AL-4.7	**Requirement type:**	Functional
Description:	The required uni-algal species in the large-scale culture (AL-4) need to be enriched with specialized maintenance media.		
Rationale:	The required uni-algal species need to be enriched with specialized maintenance media, which consist of nitrates, phosates, essential trace elements, vitamins and carbon dioxide, to ensure good conditioning or growth of the uni-algal species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The enriched maintenance media for the uni-algal species in the large-scale culture need to have enrichments which are described in table 5, plus air/carbon dioxide (CO2) mixture and salt.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-4.8	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the large-scale culture (AL-4) need to be enriched with a required quality of maintenance media.		
Rationale:	The required uni-algal species need to be kept in an adequate quantity of seawater to obtain good growth.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the maintenance media for the required uni-algal species is described in table 5, plus an adequate air/carbon dioxide (CO2) mixture and an adequate aadition of salt.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-4.9	**Requirement type:**	Non-functional
Description:	The required uni-algal species in the large-scale culture (AL-4) need to be enriched with a required quantity of maintenance media.		
Rationale:	The required uni-algal species need to be enriched with a required quantity of maintenance media to ensure good growth of the uni-algal species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of maintenance media, which is described in figure 21, needs to be suitable to condition or grow the uni-algal species, according to the objective.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Environmental control system (AL-4.4)

Requirement #:	FR-AL-4.10	**Requirement type:**	Functional
Description:	The environment in the large-scale culture (AL-4) in which the uni-algal species, seawater, and specialized maintenance media are kept, needs to be conditioned.		
Rationale:	For good growth of the uni-algal species the environment, in which the uni-algal species are grown, needs to be conditioned at an adequate illumination and an adequate temperature.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environmental illumination and temperature needs to have good dispersion for good growth of the uni-algal species.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-4.11	**Requirement type:**	Non-functional
Description:	The environment in the large-scale culture (AL-4) in which the uni-algal species, seawater, and specialized maintenance media are kept, needs to have an adequate quality of conditioning.		
Rationale:	For good growth of the uni-algal species the environment, in which the uni-algal species are grown, needs to be conditioned at an adequate quality of illumination and an adequate quality of temperature.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The dispersion of the light intensity and temperature need to meet the requirements on the culture surface.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-4.12	**Requirement type:**	Non-functional
Description:	The environment in the large-scale culture (AL-4) in which the uni-algal species, seawater, and specialized maintenance media are kept, needs to have an adequate quantity of conditioning.		
Rationale:	For good growth of the uni-algal species the environment, in which the uni-algal species are grown, needs to be conditioned at an adequate quantity (or intensity) of illumination and an adequate quantity of temperature.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environment in the large-scale culture needs to be kept in a temperature range of 18-22 oC and needs to be kept illuminated, with a light intensity of 52000 lux. (measured at the culture surface).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Effluent treatment system (Al-4.5)

Requirement #:	FR-AL-4.13	**Requirement type:**	Functional
Description:	The effluents of the uni-algal species, seawater, and specialized maintenance media of the large-scale culture (AL-4) need to be treated (cleaned).		
Rationale:	To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated before discharging.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The effluents of the uni-algal species, seawater, and specialized maintenance media needs to treated for discharging these effluents to an open water source.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-4.14	**Requirement type:**	Non-functional
Description:	The effluents of the uni-algal species, seawater, and specialized maintenance media from the large-scale culture (AL-4) need to be treated to have an adequate quality.		
Rationale:	To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated to an adequate quality before discharging.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The adequate quality of the effluents of the uni-algal species, seawater, and specialized maintenance media need to have the same quality, or close to, of the seawater which is used as input for the Common Cockle production process.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-4.15	**Requirement type:**	Non-functional
Description:	The effluents of the uni-algal species, seawater, and specialized maintenance media from the large-scale culture (AL-4) need to be treated to have an adequate quantity.		
Rationale:	To not pollute the marine habitats or marine ecosystems the effluents of the algal culture phase need to be treated to an adequate quantity before discharging.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the treated and discharge effluents of uni-algal species, seawater, and specialized maintenance media need to be adequate.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Output

Harvest of culture of algae system (AL-4.6)

Requirement #:	FR-AL-4.16	**Requirement type:**	Functional
Description:	The output of the large-scale culture (AL-4) needs to be the required uni-algal (mono-specific) species to inoculate the large-scale culture.		
Rationale:	The required uni-algal species need be of an adequate quantity to supply the Common Cockle culture. Furthermore, the uni-algal species need to have an adequate quality, so they can be used for food supply for the Common Cockle species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required uni-algal species which needs to be the output of the large-scale culture are described in table 1.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-4.17	**Requirement type:**	Non-functional
Description:	The output of the large-scale culture (AL-4) needs to be the required uni-algal species which needs to have an adequate quality.		
Rationale:	Common Cockle species' growth is optimized by a food supply of live uni-algal species, which have a adequate size (or volume), organic weight, and a high food value (lipid %, carbohydrate %, protein %). Furthermore, the growth rate (or production rate) of the uni-algal species depends on the Chl. A % of the cultured species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the required uni-algal species of the output of the large-scale culture are described in table 1.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-AL-4.18	**Requirement type:**	Non-functional
Description:	The output of the large-scale culture (AL-4) needs to be the required uni-algal species which need to have an adequate quantity.		
Rationale:	The output (required uni-algal species) of the algal culture phase needs to be of an adequate quantity, so it is enough to provide the Common Cockle culture of food (live uni-algal species).		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the required uni-algal species of the output of the large-scale culture are the quantities described in table 2.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

IV.2 Common Cockle culture phase (CC-0)

Input

Culture of Common Cockles system (CC-0.1)

Requirement #:	FR-CC-0.1	**Requirement type:**	Functional
Description:	The input of the Common Cockle Culture phase (CC-0) needs to be good adult Common Cockle species which are able to produce new (or young) Common Cockle larvae (so-called 'breeders').		
Rationale:	To ensure that the Common Cockle production process is inoculated, 'breeders' are used which are coming from the 'growout' sub-phase. (Initially these 'breeders' are coming from wild stocks).		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The 'breeders' needs to have a male:female ratio of 50:50.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-0.2	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the Common Cockle Culture phase (CC-0) need to have an adequate quality.		
Rationale:	To ensure an output of good quality of Common Cockle species an input of good quality of Common Cockle species is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the Common Cockle species in the Common Cockle Culture phase is described in table 7.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-0.3	**Requirement type:**	Non-functional
Description:	The Common Cockles species in the Common Cockle Culture phase (CC-0) need to have an adequate quantity.		
Rationale:	To ensure an adequate quantity of Common Cockle species as output an adequate quantity of Common Cockle species is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the Common Cockle species in the Common Cockle Culture phase is described in table 7.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #: FR-CC-0.4 **Requirement type:** Functional

Description: The Common Cockles species in the Common Cockle Culture phase (CC-0) needs to have a good habitat.
Rationale: For good conditioning or growth of the Common Cockle species a good habitat is needed.

Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quality of the habitat which the Common Cockle species need is described in table 8.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-0.5 **Requirement type:** Non-functional

Description: The habitat of the Common Cockle species in the Common Cockle Culture phase (CC-0) needs to have an adequate quality.
Rationale: For a good conditioning or growth of the Common Cockle species an adequate quality of the habitat is needed.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The required quality of the habitat of the Common Cockle species is described in table 8.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-0.6 **Requirement type:** Non-functional

Description: The habitat of the Common Cockle species in the Common Cockle Culture phase (CC-0) needs to have an adequate quantity.
Rationale: For a good conditioning or growth of the Common Cockle species an adequate quantity of the habitat is needed.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The required quantity of the habitat of the Common Cockle species in the Common Cockle Culture is described in table 8.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Processing

Seawater treatment system (CC-0.2)

Requirement #:	FR-CC-0.7	**Requirement type:**	Functional
Description:	The Common Cockle species in the Common Cockle Culture phase (CC-0) need to be kept in seawater.		
Rationale:	For a good conditioning or growth of the Common Cockle species they need to be kept in seawater.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The Common Cockle species in the Common Cockle Culture phase need to be kept in seawater which is available in a range of 50 meter of the coast.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-0.8	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the Common Cockle Culture phase (CC-0) need to be kept in an adequate quality of seawater.		
Rationale:	For a good conditioning or growth of the Common Cockle species they need to be kept in seawater of an adequate quality.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of seawater needs to have an optimal temperature, filtration, disinfecting, a good pH, a good oxygen concentration, and a good salinity concentration for suitable conditioning or growth of the uni-algal species (see table 9).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-0.9	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the Common Cockle Culture phase (CC-0) need to be kept in an adequate quantity of seawater.		
Rationale:	For a good conditioning or growth of the Common Cockle species they need to be kept in seawater of an adequate quantity.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of seawater needs to be suitable to condition or grow the Common Cockle species of the Common Cockle Culture phase (see table 9), according to the objective.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Enrichment system (CC-0.3)

Requirement #: FR-CC-0.10 **Requirement type:** Functional

Description: The Common Cockle species in the Common Cockle Culture phase (CC-0) need to be enriched with live phytoplankton from the algal culture phase (AL-0).
Rationale: For good conditioning or growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The phytoplankton which is needs to be enriched to the Common Cockle species is described in table 1.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-0.11 **Requirement type:** Non-functional

Description: The Common Cockle species in the Common Cockle culture phase (CC-0) need to be enriched with an adequate quality of live phytoplankton.
Rationale: For good conditioning or growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species of an adequate quality.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The required quality of live phytoplankton which needs to be enriched is described in table 1.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-0.12 **Requirement type:** Non-functional

Description: The Common Cockle species in the Common Cockle culture phase (CC-0) need to be enriched with an adequate quantity of live phytoplankton.
Rationale: For good conditioning or growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species of an adequate quantity.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quantity of live phytoplankton which needs to be enriched is described in table 2.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Environmental control system (CC-0.4)

Requirement #:	FR-CC-0.13	**Requirement type:**	Functional
Description:	The environment in the Common Cockle culture phase (CC-0) in which the Common Cockle species, seawater, and enrichments are kept, needs to be conditioned.		
Rationale:	For good conditioning or growth the Common Cockle species need to be kept in a conditioned environment.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environmental temperature needs to be conditioned.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-0.14	**Requirement type:**	Non-functional
Description:	The environment in the Common Cockle culture phase (CC-0) in which the Common Cockle species, seawater, and enrichments are kept, needs to have an adequate quality of conditioning.		
Rationale:	For good conditioning or growth the Common Cockle species need to be kept in a conditioned environment of an adequate quality.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environmental temperature needs to have a good dispersion.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-0.15	**Requirement type:**	Non-functional
Description:	The environment in the Common Cockle Culture phase (CC-0) in which the Common Cockle species, seawater, and enrichments are kept, needs to have an adequate quantity of conditioning.		
Rationale:	For good conditioning or growth the Common Cockle species need to be kept in a conditioned environment of an adequate quantity.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environmental temperature needs to have of good intensity (see table 11).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Effluent treatment system (CC-0.5)

Requirement #:	FR-CC-0.16	**Requirement type:**	Functional
Description:	The effluents of the Common Cockle species, seawater, and enrichments in the Common Cockle culture phase (CC-0) needs to be treated (cleaned).		
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated before discharging to an open water source.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The effluents of the Common Cockle species, seawater, and enrichments in the Common Cockle Culture phase need to be treated for discharging these effluents to an open water source.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-0.17	**Requirement type:**	Non-functional
Description:	The effluents of the Common Cockle species, seawater, and phytoplankton in the Common Cockle Culture phase (CC-0) need to be treated to have an adequate quality.		
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated to an adequate quality before discharging to an open water source.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The adequate quality of the effluents of the Common Cockle species, seawater, and phytoplankton from the Common Cockle Culture phase needs to have the same, or close to the, quality of the seawater which is used as input for the Common Cockle production process.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-0.18	**Requirement type:**	Non-functional
Description:	The effluents of the Common Cockle species, seawater, and phytoplankton in the Common Cockle Culture phase (CC-0) need to be treated to have an adequate quantity.		
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated to an adequate quantity before discharging to an open water source.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the treated and discharge effluents of Common Cockle species, seawater, and phytoplankton from the Common Cockle Culture phase need to be of a proportioned quantity.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Output

Harvest of culture of Common Cockles system (CC-0.6)

Requirement #: FR-CC-0.19	**Requirement type:** Functional
Description:	The output of the Common Cockle Culture phase (CC-0) need to be Common Cockle species which have adequate characteristics.
Rationale:	The output in the Common Cockle culture needs to be Common Cockle species which can be distributed and sold to the market.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The required output of the Common Cockle Culture phase needs to be adult Common Cockle species, which are strong enough for the distribution and sale to the market.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-0.20	**Requirement type:** Non-functional
Description:	The output of the Common Cockle Culture phase (CC-0) needs to be Common Cockle species which needs to have an adequate quality.
Rationale:	The output in the Common Cockle culture needs to be Common Cockle species which have an adequate quality, so they can be distributed and sold to the market.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quality of the output of the Common Cockle Culture phase needs to be Common Cockle species of a size of 30-40 mm.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-0.21	**Requirement type:** Non-functional
Description:	The output of the Common Cockle Culture phase (CC-0) needs to be the required Common Cockle species which needs to have an adequate quantity.
Rationale:	The output in the Common Cockle culture needs to be Common Cockle species which have an adequate quantity, so they can be distributed and sold to the market.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quantity of the required Common Cockle species of the output of the Common Cockle Culture need to be of an adequate quanity of species / month.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

IV.2.1 Broodstock conditioning (CC-1)

Input

Culture of Common Cockles system (CC-1.1)

Requirement #: FR-CC-1.1 **Requirement type:** Functional

Description: The input of the broodstock conditioning (CC-1) needs to be good adult Common Cockle species which are able to spawn.
Rationale: To ensure that the Common Cockle production process is inoculated, 'breeders' are used which are coming from the 'growout' sub-phase. (Initially these 'breeders' are coming from wild stocks).
Source: Derived from literature sources (for reference, see report).
Fit Criterion: During spawning, the males need to release approximately 15 million cells sperm / second and females need to release approximate 1900 eggs/second.

Customers Satisfaction: x1 **Customers Dissatisfaction:** x2
Dependencies: x3 **Conflicts:** x4
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-1.2 **Requirement type:** Non-functional

Description: The Common Cockle species in the broodstock conditioning (CC-1) need to have an adequate quality.
Rationale: To ensure an output of good quality of Common Cockle species an input of good quality of Common Cockle species is needed.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quality of the Common Cockle species in the broodstock conditioning is described in table 7.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-1.3 **Requirement type:** Non-functional

Description: The Common Cockles species in the broodstock conditioning (CC-1) need to have an adequate quantity.
Rationale: To ensure an adequate quantity of Common Cockle species as output an adequate quantity of Common Cockle species is needed.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quantity of the Common Cockle species in the broodstock conditioning needs to be adequate.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #:	FR-CC-1.4	**Requirement type:**	Functional
Description:	The Common Cockles species in the broodstock conditioning (CC-1) need to have a good habitat.		
Rationale:	For good conditioning of the Common Cockle species a good habitat is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the habitat which the Common Cockle species needs is described in table 8.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-1.5	**Requirement type:**	Non-functional
Description:	The habitat of the Common Cockle species in the broodstock conditioning (CC-1) needs to have an adequate quality.		
Rationale:	For a good conditioning of the Common Cockle species an adequate quality of the habitat is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of the habitat of the Common Cockle species is described in table 8.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-1.6	**Requirement type:**	Non-functional
Description:	The habitat of the Common Cockle species in the broodstock conditioning (CC-1) needs to have an adequate quality.		
Rationale:	For a good conditioning of the Common Cockle species an adequate quantity of the habitat is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of the habitat of the Common Cockle species in the Common Cockle Culture is described in table 8.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Processing

Seawater treatment system (CC-1.2)

Requirement #: FR-CC-1.7	**Requirement type:** Functional
Description:	The Common Cockle species in the broodstock conditioning (CC-1) need to be kept in seawater.
Rationale:	For a good conditioning of the Common Cockle species they need to be kept in seawater.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The Common Cockle species in the broodstock conditioning need to be kept in seawater which have, almost, the original characteristics of the seawater of the open water source.
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-1.8	**Requirement type:** Non-functional
Description:	The Common Cockle species in the broodstock conditioning (CC-1) need to be kept in an adequate quality of seawater.
Rationale:	For a good conditioning of the Common Cockle species they need to be kept in seawater of an adequate quality.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The required quality of seawater in the broodstock conditioning needs to have a temperature of 15-20 oC , filtration of 10 µm, or 20-40 µm, no disinfecting, a pH of 7.9-8.2, oxygen concentration of 1.5-2.0 ml/l, and a salinity concentration of 15-35 PSU for suitable conditioning of the Common Cockle species (see table 9).
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-1.9	**Requirement type:** Non-functional
Description:	The Common Cockle species in the broodstock conditioning (CC-1) need to be kept in an adequate quantity of seawater.
Rationale:	For a good conditioning of the Common Cockle species they need to be kept in seawater of an adequate quantity.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The required quantity of seawater is described in appendix VI.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Enrichment system (CC-1.3)

Requirement #: FR-CC-1.10	**Requirement type:** Functional
Description:	The Common Cockle species in the broodstock conditioning (CC-1) need to be enriched with live phytoplankton for the algal culture phase (AL-0).
Rationale:	For good conditioning the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The phytoplankton which needs to be enriched to the Common Cockle species is described in table 1.
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-1.11	**Requirement type:** Non-functional
Description:	The Common Cockle species in the broodstock conditioning (CC-1) need to be enriched with an adequate quality of live phytoplankton.
Rationale:	For good conditioning the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species of an adequate quality.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The required quality of live phytoplankton which needs to be enriched is described in table 1.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-1.12	**Requirement type:** Non-functional
Description:	The Common Cockle species in the broodstock conditioning (CC-1) need to be enriched with an adequate quantity of live phytoplankton.
Rationale:	For good conditioning the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species of an adequate quantity.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quantity of live phytoplankton which needs to be enriched to the Common Cockle species is described in table 2.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Environmental control system (CC-1.4)

Requirement #:	FR-CC-1.13	**Requirement type:**	Functional
Description:	The environment in the broodstock conditioning (CC-1) in which the Common Cockle species, seawater, and enrichments are kept needs to be conditioned.		
Rationale:	For good conditioning the Common Cockle species need to be kept in a conditioned environment.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environmental temperature needs to be conditioned.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-1.14	**Requirement type:**	Non-functional
Description:	The environment in the broodstock conditioning (CC-1) in which the Common Cockle species, seawater, and enrichments are kept needs to have an adequate quality of conditioning.		
Rationale:	For good conditioning the Common Cockle species need to be kept in a conditioned environment of an adequate quality.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The dispersion of the temperature needs to meet the requirements on the culture surface.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-1.15	**Requirement type:**	Non-functional
Description:	The environment in the broodstock conditioning (CC-1) in which the Common Cockle species, seawater, and enrichments are kept needs to have an adequate quantity of conditioning.		
Rationale:	For good conditioning the Common Cockle species need to be kept in a conditioned environment of an adequate quantity.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environment in the broodstock conditioning needs to be kept in a temperature range of 5-25 oC.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Effluent treatment system (CC-1.5)

Requirement #:	FR-CC-1.16	**Requirement type:**	Functional
Description:	The effluents of the Common Cockle species, seawater, and enrichments in the broodstock conditioning (CC-1) need to be treated (cleaned).		
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated before discharging to an open water source.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The effluents of the Common Cockle species, seawater, and enrichments in the broodstock conditioning need to be treated for discharging these effluents to an open water source.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-1.17	**Requirement type:**	Non-functional
Description:	The effluents of the Common Cockle species, seawater, and phytoplankton in the broodstock conditioning (CC-1) need to be treated to have an adequate quality.		
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated to an adequate quality before discharging to an open water source.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The adequate quality of the effluents of the Common Cockle species, seawater, and phytoplankton from the Common Cockle Culture phase needs to have the same, or close to the, quality of the seawater which is used as input for the Common Cockle production process.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-1.18	**Requirement type:**	Non-functional
Description:	The effluents of the Common Cockle species, seawater, and phytoplankton in the broodstock conditioning (CC-1) need to be treated to have an adequate quantity.		
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated to an adequate quantity before discharging to an open water source.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the treated and discharge effluents of Common Cockle species, seawater, and phytoplankton from the Common Cockle Culture phase need to be of a proportioned quantity.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Output

Harvest of culture of Common Cockles system (CC-1.6)

Requirement #: FR-CC-1.19	**Requirement type:** Functional
Description:	The output of the broodstock conditioning (CC-1) needs to be breeders, and the sperm and eggs of Common Cockle species from the breeders.
Rationale:	The output in the Common Cockle culture needs to be Common Cockle species which can be distributed and sold to the market.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The required output of the broodstock conditioning needs to be the breeders which were also the input, and which need to be used as input again. Furthermore, the output need to be the eggs and sperm of the Common Cockle species from the breeders which are able to transfer into a trochophore (early larvae).
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-1.20	**Requirement type:** Non-functional
Description:	The output of the broodstock conditioning (CC-1) needs to be Common Cockle species which needs to have an adequate quality.
Rationale:	The output in the Common Cockle culture needs to be Common Cockle species which have an adequate quality, so they can be distributed and sold to the market.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The size of the breeder from the output must have a size of 30-40 mm, and the size of the eggs needs to be 50-60 µm. Size of the sperm is not defined.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-1.21	**Requirement type:** Non-functional
Description:	The output of the broodstock conditioning (CC-1) needs to be the required Common Cockle species which need to have an adequate quantity.
Rationale:	The output in the Common Cockle culture needs to be Common Cockle species which have an adequate quantity, so they can be distributed and sold to the market.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quantity of the required Common Cockle species of the output of the broodstock conditioning needs to be the same quantity of breeders in reference to the quantity which are required to keep the facility running.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

IV.2.2 Reproduction

Input

Culture of Common Cockles system (CC-2.1)

Requirement #: FR-CC-2.1	**Requirement type:** Functional
Description:	The input of the reproduction (CC-2) needs to be good adult Common Cockle species which are able to spawn in a short period.
Rationale:	To ensure that the Common Cockle production process is inoculated 'breeder' from the 'broodstock conditioning' are used for the reproduction.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The input of the reproduction needs to be eggs and sperm which needs to be able to transfer into D-larvae (or trochophores).
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-2.2	**Requirement type:** Non-functional
Description:	The Common Cockle species in the reproduction (CC-2) need to have an adequate quality.
Rationale:	To ensure good sperm and eggs, and after this good D-larva, the 'breeders' need to be of good quality
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quality of the Common Cockle species in the reproduction is described in table 7.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-2.3	**Requirement type:** Non-functional
Description:	The Common Cockles species in the reproduction (CC-2) need to have an adequate quantity.
Rationale:	To ensure good sperm and eggs, and after this good D-larva, the 'breeders' need to be of good quantity
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quantity of the Common Cockle species in the reproduction is described in table 7.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #:	FR-CC-2.4	**Requirement type:**	Functional
Description:	The Common Cockles species in the reproduction (CC-2) need to have a good habitat.		
Rationale:	For good growth of the Common Cockle species a good habitat is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the habitat in which the Common Cockle species needs to live is a pelagic habitat (only water) (see table 8).		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-2.5	**Requirement type:**	Non-functional
Description:	The habitat of the Common Cockle species in the reproduction (CC-2) needs to have an adequate quality.		
Rationale:	For a good growth of the Common Cockle species an adequate quality of the habitat is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of the pelagic habitat of the Common Cockle species are the same as the seawater properties which are described in requirement NR-CC-2.8.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-2.6	**Requirement type:**	Non-functional
Description:	The habitat of the Common Cockle species in the reproduction (CC-2) needs to have an adequate quality.		
Rationale:	For a good growth of the Common Cockle species an adequate quantity of the habitat is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of the pelagic habitat of the Common Cockle species are the same as the seawater properties which are described in requirement NR-CC-2.9.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Processing

Seawater treatment system (CC-2.2)

Requirement #:	FR-CC-2.7	**Requirement type:**	Functional
Description:	The Common Cockle species in the reproduction (CC-2) need to be kept in seawater.		
Rationale:	For a good growth of the Common Cockle species they need to be kept in seawater.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The Common Cockle species in the broodstock conditioning need to be kept in seawater which have, almost, the original characteristics of the seawater of the open water source.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-2.8	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the reproduction (CC-2) need to be kept in an adequate quality of seawater.		
Rationale:	For a good growth of the Common Cockle species they need to be kept in seawater of an adequate quality.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of seawater in the reproduction needs to have a temperature of 15-35 oC , filtration of 2 µm, uv disinfecting, a pH of 7.9-8.2 , oxygen concentration of 1.5-2.0 ml/l, and a salinity concentration of 15-35 PSU for suitable conditioning of the Common Cockle species (see table 9).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-2.9	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the reproduction (CC-2) need to be kept in an adequate quantity of seawater.		
Rationale:	For a good growth of the Common Cockle species they need to be kept in seawater of an adequate quantity.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of seawater is described in appendix VI.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Enrichment system (CC-2.3)

Requirement #:	FR-CC-2.10	**Requirement type:**	Functional
Description:	The Common Cockle species in the reproduction (CC-2) need to be enriched with live phytoplankton for the algal culture phase (AL-0).		
Rationale:	For good growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The phytoplankton which needs to be enriched to the Common Cockle species is described in table 1.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-2.11	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the reproduction (CC-2) need to be enriched with an adequate quality of live phytoplankton.		
Rationale:	For good growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species of an adequate quality.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of live phytoplankton which needs to be enriched is described in table 1.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-2.12	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the reproduction (CC-2) need to be enriched with an adequate quantity of live phytoplankton.		
Rationale:	For good growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species of an adequate quantity.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of live phytoplankton which needs to be enriched to the Common Cockle species is described in table 2.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Environmental control system (CC-2.4)

Requirement #:	FR-CC-2.13	**Requirement type:**	Functional
Description:	The environment in the reproduction (CC-2) in which the Common Cockle species, seawater, and enrichments are kept needs to be conditioned.		
Rationale:	For good growth the Common Cockle species need to be kept in a conditioned environment.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environmental temperature needs to be conditioned.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-2.14	**Requirement type:**	Non-functional
Description:	The environment in the reproduction (CC-2) in which the Common Cockle species, seawater, and enrichments are kept needs to have an adequate quality of conditioning.		
Rationale:	For good growth the Common Cockle species need to be kept in a conditioned environment of an adequate quality.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The dispersion of the temperature need to meet the requirements on the culture surface.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-2.15	**Requirement type:**	Non-functional
Description:	The environment in the reproduction (CC-2) in which the Common Cockle species, seawater, and enrichments are kept needs to have an adequate quantity of conditioning.		
Rationale:	For good growth the Common Cockle species need to be kept in a conditioned environment of an adequate quantity.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environment in the reproduction needs to be kept in a temperature range of 15-25 oC.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Effluent treatment system (CC-2.5)

Requirement #: FR-CC-2.16 **Requirement type:** Functional

Description: The effluents of the Common Cockle species, seawater, and enrichments in the reproduction (CC-2) need to be treated (cleaned).

Rationale: For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated before discharging to an open water source.

Source: Derived from literature sources (for reference, see report).

Fit Criterion: The effluents of the Common Cockle species, seawater, and enrichments in the reproduction need to be treated for discharging these effluents to an open water source.

Customers Satisfaction: x1 **Customers Dissatisfaction:** x2

Dependencies: x3 **Conflicts:** x4

Estimated Hardware Costs: --

History: S. Deen, April 2006.

Requirement #: NR-CC-2.17 **Requirement type:** Non-functional

Description: The effluents of the Common Cockle species, seawater, and phytoplankton in the reproduction (CC-2) need to be treated to have an adequate quality.

Rationale: For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated to an adequate quality before discharging to an open water source.

Source: Derived from literature sources (for reference, see report).

Fit Criterion: The adequate quality of the effluents of the Common Cockle species, seawater, and phytoplankton from the Common Cockle Culture phase needs to have the same, or close to the, quality of the seawater which is used as input for the Common Cockle production process.

Customers Satisfaction: -- **Customers Dissatisfaction:** --

Dependencies: -- **Conflicts:** --

Estimated Hardware Costs: --

History: S. Deen, April 2006.

Requirement #: NR-CC-2.18 **Requirement type:** Non-functional

Description: The effluents of the Common Cockle species, seawater, and phytoplankton in the reproduction (CC-2) need to be treated to have an adequate quantity.

Rationale: For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated to an adequate quantity before discharging to an open water source.

Source: Derived from literature sources (for reference, see report).

Fit Criterion: The quantity of the treated and discharge effluents of Common Cockle species, seawater, and phytoplankton from the Common Cockle Culture phase need to be of a proportioned quantity.

Customers Satisfaction: -- **Customers Dissatisfaction:** --

Dependencies: -- **Conflicts:** --

Estimated Hardware Costs: --

History: S. Deen, April 2006.

Output

Harvest of culture of Common Cockles system (CC-2.6)

Requirement #:	FR-CC-2.19	**Requirement type:**	Functional
Description:	The output of the reproduction (CC-2) needs to be 'breeders', and the sperm and eggs of the breeders.		
Rationale:	The output of the reproduction (CC-2) is used as input for the larval rearing (CC-3).		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required output of the reproduction are Common Cockle trochophores and the breeders (early larvae).		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-2.20	**Requirement type:**	Non-functional
Description:	The output of the reproduction (CC-2) needs to be Common Cockle species which needs to have an adequate quality.		
Rationale:	The output of the reproduction (CC-2) is used as input for the larval rearing (CC-3).		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The size of the trochophores from the output must have a approximate size of 50-60 µm.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-2.21	**Requirement type:**	Non-functional
Description:	The output of the reproduction (CC-2) needs to be the required Common Cockle species which needs to have an adequate quantity.		
Rationale:	The output of the reproduction (CC-2) is used as input for the larval rearing (CC-3).		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the required Common Cockle species of the output of the reproduction needs to be the same quantity of larvae in reference to the quantity which are required to keep the facility running.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

IV.2.3 Larval rearing (CC-3)

Input

Culture of Common Cockles system (CC-3.1)

Requirement #: FR-CC-3.1 **Requirement type:** Functional

Description: The input of the larval rearing (CC-3) needs to be good adult Common Cockle species.

Rationale: To ensure that the Common Cockle production process is inoculated the D-larva of the output of the reproduction are used as input in the larval rearing.

Source: Derived from literature sources (for reference, see report).
Fit Criterion: The input of the larval rearing needs to be D-larvae which are able to transfer into mature larvae.

Customers Satisfaction: x1 **Customers Dissatisfaction:** x2
Dependencies: x3 **Conflicts:** x4
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-3.2 **Requirement type:** Non-functional

Description: The Common Cockle species in the larval rearing (CC-3) need to have an adequate quality.
Rationale: To ensure an output of good quality of Common Cockle species an input of good quality of Common Cockle species is needed.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quality of the Common Cockle species in the larval rearing is described in table 7

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-3.3 **Requirement type:** Non-functional

Description: The Common Cockles species in the larval rearing (CC-3) need to have an adequate quantity.
Rationale: To ensure an adequate quantity of Common Cockle species as output an adequate quantity of Common Cockle species is needed.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quantity of the Common Cockle species in the larval rearing is described in table 7.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #:	FR-CC-3.4	**Requirement type:**	Functional

Description: The Common Cockles species in the larval rearing (CC-3) need to have a good habitat.

Rationale: For good growth of the Common Cockle species a good habitat is needed.

Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quality of the habitat in which the Common Cockle species need to live is a pelagic habitat (only water).

Customers Satisfaction: x1 **Customers Dissatisfaction:** x2
Dependencies: x3 **Conflicts:** x4
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #:	NR-CC-3.5	**Requirement type:**	Non-functional

Description: The habitat of the Common Cockle species in the larval rearing (CC-3) needs to have an adequate quality.
Rationale: For a good growth of the Common Cockle species an adequate quality of the habitat is needed.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The required quality of the pelagic habitat of the Common Cockle species are the same as the seawater properties which are described in requirement NR-CC-3.8.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #:	NR-CC-3.6	**Requirement type:**	Non-functional

Description: The habitat of the Common Cockle species in the larval rearing (CC-3) needs to have an adequate quality.
Rationale: For a good growth of the Common Cockle species an adequate quantity of the habitat is needed.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The required quantity of the pelagic habitat of the Common Cockle species are the same as the seawater properties which are described in requirement NR-CC-3.9.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Processing

Seawater treatment system (CC-3.2)

Requirement #:	FR-CC-3.7	**Requirement type:**	Functional
Description:	The Common Cockle species in the larval rearing (CC-3) need to be kept in seawater.		
Rationale:	For a good growth of the Common Cockle species they need to be kept in seawater.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The Common Cockle species in the broodstock conditioning need to be kept in seawater which have, almost, the original characteristics of the seawater of the open water source.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-3.8	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the larval rearing (CC-3) need to be kept in an adequate quality of seawater.		
Rationale:	For a good growth of the Common Cockle species they need to be kept in seawater of an adequate quality.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of seawater in the larval rearing needs to have a temperature of 15 35 oC , filtration of 2 µm, uv disinfecting, a pH of 7.9-8.2 , oxygen concentration of 1.5-2.0 ml/l (filtrated to 45 µm), and a salinity concentration of 15-35 PSU for suitable conditioning of the Common Cockle species.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-3.9	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the larval rearing (CC-3) need to be kept in an adequate quantity of seawater.		
Rationale:	For a good growth of the Common Cockle species they need to be kept in seawater of an adequate quantity.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of seawater is described in appendix VI.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Enrichment system (CC-3.3)

Requirement #:	FR-CC-3.10	**Requirement type:**	Functional
Description:	The Common Cockle species in the larval rearing (CC-3) need to be enriched with live phytoplankton for the algal culture phase (AL-0).		
Rationale:	For good growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The phytoplankton which is needed to be enriched to the Common Cockle species is described in table 1.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-3.11	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the larval rearing (CC-3) need to be enriched with an adequate quality of live phytoplankton.		
Rationale:	For good growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species of an adequate quality.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of live phytoplankton which needs to be enriched is described in table 1.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-3.12	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the larval rearing (CC-3) need to be enriched with an adequate quantity of live phytoplankton.		
Rationale:	For good growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species of an adequate quantity.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of live phytoplankton which needs to be enriched to the Common Cockle species is described in table 2.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Environmental control system (CC-3.4)

Requirement #:	FR-CC-3.13	**Requirement type:**	Functional
Description:	The environment in the larval rearing (CC-3) in which the Common Cockle species, seawater, and enrichments are kept needs to be conditioned.		
Rationale:	For good growth the Common Cockle species need to be kept in a conditioned environment.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environmental temperature needs to be conditioned.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-3.14	**Requirement type:**	Non-functional
Description:	The environment in the larval rearing (CC-3) in which the Common Cockle species, seawater, and enrichments are kept needs to have an adequate quality of conditioning.		
Rationale:	For good growth the Common Cockle species need to be kept in a conditioned environment of an adequate quality.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The dispersion of the temperature need to meet the requirements on the culture surface.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-3.15	**Requirement type:**	Non-functional
Description:	The environment in the larval rearing (CC-3) in which the Common Cockle species, seawater, and enrichments are kept needs to have an adequate quantity of conditioning.		
Rationale:	For good growth the Common Cockle species need to be kept in a conditioned environment of an adequate quantity.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The environment in the larval rearing needs to be kept in a temperature range of 15-25 oC.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Effluent treatment system (CC-3.5)

Requirement #: FR-CC-3.16	**Requirement type:** Functional
Description:	The effluents of the Common Cockle species, seawater, and enrichments in the larval rearing (CC-3) need to be treated (cleaned).
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated before discharging to an open water source.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The effluents of the Common Cockle species, seawater, and enrichments in the larval rearing need to be treated for discharging these effluents to an open water source.
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-3.17	**Requirement type:** Non-functional
Description:	The effluents of the Common Cockle species, seawater, and phytoplankton in the larval rearing (CC-3) need to be treated to have an adequate quality.
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated to an adequate quality before discharging to an open water source.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The adequate quality of the effluents of the Common Cockle species, seawater, and phytoplankton from the Common Cockle Culture phase needs to have the same, or close to the, quality of the seawater which is used as input for the Common Cockle production process.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-3.18	**Requirement type:** Non-functional
Description:	The effluents of the Common Cockle species, seawater, and phytoplankton in the larval rearing (CC-3) need to be treated to have an adequate quantity.
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated to an adequate quantity before discharging to an open water source.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quantity of the treated and discharge effluents of Common Cockle species, seawater, and phytoplankton from the larval rearing need to be adequate.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Output

Harvest of culture of Common Cockles system (CC-3.6)

Requirement #: FR-CC-3.19 **Requirement type:** Functional

Description: The output of the larval rearing (CC-3) needs to be mature larvae.

Rationale: The output of the larval rearing (CC-3) is used as input in the settlement (CC-4).

Source: Derived from literature sources (for reference, see report).
Fit Criterion: The required output of the larval rearing needs to be un-settled Common Cockle mature larvae.

Customers Satisfaction: x1 **Customers Dissatisfaction:** x2
Dependencies: x3 **Conflicts:** x4
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-3.20 **Requirement type:** Non-functional

Description: The output of the larval rearing (CC-3) needs to be Common Cockle species which needs to have an adequate quality.
Rationale: The output of the larval rearing (CC-3) is used as input in the settlement (CC-4).

Source: Derived from literature sources (for reference, see report).
Fit Criterion: The size of the mature larvae from the output must have a approximate size of 250-350 μm.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-3.21 **Requirement type:** Non-functional

Description: The output of the larval rearing (CC-3) needs to be the required Common Cockle species which needs to have an adequate quantity.
Rationale: The output of the larval rearing (CC-3) is used as input in the settlement (CC-4).

Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quantity of the required Common Cockle species of the output of the larval rearing needs to be the same quantity of larvae in reference to the quantity which are required to keep the facility running.
Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

IV.2.4 Settlement (CC-4)

Input

Culture of Common Cockles system (CC-4.1)

Requirement #: FR-CC-4.1 **Requirement type:** Functional

Description: The input of the settlement (CC-4) needs to be good adult Common Cockle species.

Rationale: To ensure that the Common Cockle production process is inoculated the mature larvae of the output of the larval rearing are used as input in the settlement.

Source: Derived from literature sources (for reference, see report).
Fit Criterion: The input of the settlement needs to be mature larvae which are able to transfer into settled spat (or juveniles).

Customers Satisfaction: x1 **Customers Dissatisfaction:** x2
Dependencies: x3 **Conflicts:** x4
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-4.2 **Requirement type:** Non-functional

Description: The Common Cockle species in the settlement (CC-4) need to have an adequate quality.
Rationale: To ensure an output of good quality of Common Cockle species an input of good quality of Common Cockle species is needed.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quality of the Common Cockle species in the settlement is described in table 7.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-4.3 **Requirement type:** Non-functional

Description: The Common Cockles species in the settlement (CC-4) need to have an adequate quantity.
Rationale: To ensure an adequate quantity of Common Cockle species as output an adequate quantity of Common Cockle species is needed.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quantity of the Common Cockle species in the settlement is described in table 7.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #:	FR-CC-4.4	**Requirement type:**	Functional
Description:	The Common Cockles species in the settlement (CC-4) need to have a good habitat.		
Rationale:	For good growth of the Common Cockle species a good habitat is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the habitat in which the Common Cockle species needs to live is a pelagic habitat (only water).		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-4.5	**Requirement type:**	Non-functional
Description:	The habitat of the Common Cockle species in the settlement (CC-4) needs to have an adequate quality.		
Rationale:	For a good growth of the Common Cockle species an adequate quality of the habitat is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of the pelagic habitat of the Common Cockle species are the same as the seawater properties which are described in requirement NR-CC-4.8.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-4.6	**Requirement type:**	Non-functional
Description:	The habitat of the Common Cockle species in the settlement (CC-4) needs to have an adequate quality.		
Rationale:	For a good growth of the Common Cockle species an adequate quantity of the habitat is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of the pelagic habitat of the Common Cockle species are the same as the seawater properties which are described in requirement NR-CC-4.9.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Processing

Seawater treatment system (CC-4.2)

Requirement #:	FR-CC-4.7	**Requirement type:**	Functional
Description:	The Common Cockle species in the settlement (CC-4) need to be kept in seawater.		
Rationale:	For a good growth of the Common Cockle species they need to be kept in seawater.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The Common Cockle species in the broodstock conditioning need to be kept in seawater which have, almost, the original characteristics of the seawater of the open water source.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-4.8	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the settlement (CC-4) need to be kept in an adequate quality of seawater.		
Rationale:	For a good growth of the Common Cockle species they need to be kept in seawater of an adequate quality.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of seawater in the settlement needs to have a temperature of 15-35 oC , filtration of 10 µm, no disinfecting, a pH of 7.9-8.2 , oxygen concentration of 1.5-2.0 ml/l, and a salinity concentration of 15-35 PSU for suitable conditioning of the Common Cockle species.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-4.9	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the settlement (CC-4) need to be kept in an adequate quantity of seawater.		
Rationale:	For a good growth of the Common Cockle species they need to be kept in seawater of an adequate quantity.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of seawater is described in appendix VI.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Enrichment system (CC-4.3)

Requirement #:	FR-CC-4.10	**Requirement type:**	Functional
Description:	The Common Cockle species in the settlement (CC-4) need to be enriched with live phytoplankton for the algal culture phase (AL-0).		
Rationale:	For good growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The phytoplankton which is needs to be enriched to the Common Cockle species is described in table 1.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-4.11	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the settlement (CC-4) need to be enriched with an adequate quality of live phytoplankton.		
Rationale:	For good growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species of an adequate quality.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of live phytoplankton which needs to be enriched is described in table 1.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-4.12	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the settlement (CC-4) need to be enriched with an adequate quantity of live phytoplankton.		
Rationale:	For good growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species of an adequate quantity.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of live phytoplankton which needs to be enriched to the Common Cockle species is described in table 2.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Environmental control system (CC-4.4)

Requirement #: FR-CC-4.13 **Requirement type:** Functional

Description: The environment in the settlement (CC-4) in which the Common Cockle species, seawater, and enrichments are kept needs to be conditioned.
Rationale: For good growth the Common Cockle species need to be kept in a conditioned environment.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The environmental temperature needs to be conditioned.

Customers Satisfaction: x1 **Customers Dissatisfaction:** x2
Dependencies: x3 **Conflicts:** x4
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-4.14 **Requirement type:** Non-functional

Description: The environment in the settlement (CC-4) in which the Common Cockle species, seawater, and enrichments are kept needs to have an adequate quality of conditioning.

Rationale: For good growth the Common Cockle species need to be kept in a conditioned environment of an adequate quality.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The dispersion of the temperature needs to meet the requirements on the culture surface.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-4.15 **Requirement type:** Non-functional

Description: The environment in the settlement (CC-4) in which the Common Cockle species, seawater, and enrichments are kept needs to have an adequate quantity of conditioning.

Rationale: For good growth the Common Cockle species need to be kept in a conditioned environment of an adequate quantity.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The environment in the settlement needs to be kept in a temperature range of 15-25 oC.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Effluent treatment system (CC-4.5)

Requirement #:	FR-CC-4.16	**Requirement type:**	Functional
Description:	The effluents of the Common Cockle species, seawater, and enrichments in the settlement (CC-4) need to be treated (cleaned).		
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated before discharging to an open water source.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The effluents of the Common Cockle species, seawater, and enrichments in the settlement need to be treated for discharging these effluents to an open water source.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-4.17	**Requirement type:**	Non-functional
Description:	The effluents of the Common Cockle species, seawater, and phytoplankton in the settlement (CC-4) need to be treated to have an adequate quality.		
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated to an adequate quality before discharging to an open water source.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The adequate quality of the effluents of the Common Cockle species, seawater, and phytoplankton from the settlement need to have the same quality of the seawater which is used as input for the Common Cockle production process (see appendix).		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-4.18	**Requirement type:**	Non-functional
Description:	The effluents of the Common Cockle species, seawater, and phytoplankton in the settlement (CC-4) need to be treated to have an adequate quantity.		
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated to an adequate quantity before discharging to an open water source.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the treated and discharge effluents of Common Cockle species, seawater, and phytoplankton from the settlement need to be .. per year or less.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Output

Harvest of culture of Common Cockles system

Requirement #: FR-CC-4.19	**Requirement type:** Functional
Description:	The output of the settlement (CC-4) needs to be spat (or juveniles).
Rationale:	The output of the settlement (CC-4) is used as input of the growout (CC-5).
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The required output of the settlement needs to be settled Common Cockle spat.
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-4.20	**Requirement type:** Non-functional
Description:	The output of the settlement (CC-4) needs to be Common Cockle species which needs to have an adequate quality.
Rationale:	The output of the settlement (CC-4) is used as input of the growout (CC-5).
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The size of the mature larvae from the output must have a approximate size of approximately 4.8 mm.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-4.21	**Requirement type:** Non-functional
Description:	The output of the settlement (CC-4) needs to be the required Common Cockle species which needs to have an adequate quantity.
Rationale:	The output of the settlement (CC-4) is used as input of the growout (CC-5).
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quantity of the required Common Cockle species of the output of the settlement needs to be the same quantity of Common Cockle species in reference to the quantity which are required to keep the facility running.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

IV.2.5 Growout (CC-5)

Input

Culture of Common Cockles system (CC-5.1)

Requirement #:	FR-CC-5.1	**Requirement type:**	Functional
Description:	The input of the growout (CC-5) needs to be good adult Common Cockle species.		
Rationale:	To ensure the the Common Cockle production process is inoculated early juveniles are used as input in the growout.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The input of the growout needs to be spat which are able to transfer into adult Common Cockle species.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-5.2	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the growout (CC-5) need to have an adequate quality.		
Rationale:	To ensure an output of good quality of Common Cockle species an input of good quality of Common Cockle species is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the Common Cockle species in the growout is described in table 7.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-5.3	**Requirement type:**	Non-functional
Description:	The Common Cockles species in the growout (CC-5) need to have an adequate quantity.		
Rationale:	To ensure an adequate quantity of Common Cockle species as output an adequate quantity of Common Cockle species is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the Common Cockle species in the growout is described in table 7.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	FR-CC-5.4	**Requirement type:**	Functional
Description:	The Common Cockles species in the growout (CC-5) need to have a good habitat.		
Rationale:	For good growth of the Common Cockle species a good habitat is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quality of the habitat in which the Common Cockle species needs to live is described in table 8.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-5.5	**Requirement type:**	Non-functional
Description:	The habitat of the Common Cockle species in the growout (CC-5) needs to have an adequate quality.		
Rationale:	For a good growth of the Common Cockle species an adequate quality of the habitat is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of the pelagic habitat of the Common Cockle species is described in table 8.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-5.6	**Requirement type:**	Non-functional
Description:	The habitat of the Common Cockle species in the growout (CC-5) needs to have an adequate quality.		
Rationale:	For a good growth of the Common Cockle species an adequate quantity of the habitat is needed.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of the pelagic habitat of the Common Cockle species s described in table 8.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Processing

Seawater treatment system (CC-5.2)

Requirement #:	FR-CC-5.7	**Requirement type:**	Functional
Description:	The Common Cockle species in the growout (CC-5) need to be kept in seawater.		
Rationale:	For a good growth of the Common Cockle species they need to be kept in seawater.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The Common Cockle species in the broodstock conditioning need to be kept in seawater which have, almost, the original characteristics of the seawater of the open water source.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-5.8	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the growout (CC-5) need to be kept in an adequate quality of seawater.		
Rationale:	For a good growth of the Common Cockle species they need to be kept in seawater of an adequate quality.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quality of seawater in the settlement needs to have a temperature of 5-35 oC , filtration of 20-40 µm, no disinfecting, a pH of 7.9-8.2 , oxygen concentration of 1.5-2.0 ml/l, and a salinity concentration of 15-35 PSU for suitable conditioning of the Common Cockle species.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-5.9	**Requirement type:**	Non-functional
Description:	The Common Cockle species in the growout (CC-5) need to be kept in an adequate quantity of seawater.		
Rationale:	For a good growth of the Common Cockle species they need to be kept in seawater of an adequate quantity.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The required quantity of seawater is described in appendix VI.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Enrichment system (CC-5.3)

Requirement #: FR-CC-5.10 **Requirement type:** Functional

Description: The Common Cockle species in the growout (CC-5) need to be enriched with live phytoplankton for the algal culture phase (AL-0).
Rationale: For good growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The phytoplankton which is needs to be enriched to the Common Cockle species is described in table 1.

Customers Satisfaction: x1 **Customers Dissatisfaction:** x2
Dependencies: x3 **Conflicts:** x4
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-5.11 **Requirement type:** Non-functional

Description: The Common Cockle species in the growout (CC-5) need to be enriched with an adequate quality of live phytoplankton.
Rationale: For good growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species of an adequate quality.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The required quality of live phytoplankton which needs to be enriched is described in table 1.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-5.12 **Requirement type:** Non-functional

Description: The Common Cockle species in the growout (CC-5) need to be enriched with an adequate quantity of live phytoplankton.
Rationale: For good growth the Common Cockle species need to be enriched with the required live uni-algal (phytoplankton) species of an adequate quantity.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The quantity of live phytoplankton which needs to be enriched to the Common Cockle species is described in table 2.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Environmental control system (CC-5.4)

Requirement #: FR-CC-5.13 **Requirement type:** Functional

Description: The environment in the growout (CC-5) in which the Common Cockle species, seawater, and enrichments are kept needs to be protected by predators.
Rationale: For good growth the Common Cockle species need to be kept in a conditioned environment.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The environment (area) needs to be secured.

Customers Satisfaction: x1 **Customers Dissatisfaction:** x2
Dependencies: x3 **Conflicts:** x4
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-5.14 **Requirement type:** Non-functional

Description: The environment in the growout (CC-5) in which the Common Cockle species, seawater, and enrichments are kept needs to have adequate quality of protection.

Rationale: For good growth the Common Cockle species need to be kept in a conditioned environment of an adequate quality.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: The protecting needs to stable and needs to be located on spots, so mortality by predation will not exceed 5 % of the yearly production.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Requirement #: NR-CC-5.15 **Requirement type:** Non-functional

Description: The environment in the growout (CC-5) in which the Common Cockle species, seawater, and enrichments are kept needs to have adequate quantity of protection.

Rationale: For good growth the Common Cockle species need to be kept in a conditioned environment of an adequate quantity.
Source: Derived from literature sources (for reference, see report).
Fit Criterion: There needs to be enough protection, so mortality by predation will not exceed 5 % of the yearly production.

Customers Satisfaction: -- **Customers Dissatisfaction:** --
Dependencies: -- **Conflicts:** --
Estimated Hardware Costs: --
History: S. Deen, April 2006.

Effluent treatment system (CC-5.5)

Requirement #:	FR-CC-5.16	**Requirement type:**	Functional
Description:	The effluents of the Common Cockle species, seawater, and enrichments in the growout (CC-5) need to be treated (cleaned).		
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated before discharging to an open water source.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The effluents of the Common Cockle species, seawater, and enrichments in the growout need to be treated for discharging these effluents to an open water source.		
Customers Satisfaction:	x1	**Customers Dissatisfaction:**	x2
Dependencies:	x3	**Conflicts:**	x4
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-5.17	**Requirement type:**	Non-functional
Description:	The effluents of the Common Cockle species, seawater, and phytoplankton in the growout (CC-5) need to be treated to have an adequate quality.		
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated to an adequate quality before discharging to an open water source.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the required Common Cockle species of the output of the settlement needs to be the same quantity of Common Cockle species in reference to the quantity which are required to keep the facility running.		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Requirement #:	NR-CC-5.18	**Requirement type:**	Non-functional
Description:	The effluents of the Common Cockle species, seawater, and phytoplankton in the growout (CC-5) need to be treated to have an adequate quantity.		
Rationale:	For legality and sustainability the effluents of the Common Cockle species, seawater, and enrichments need to be treated to an adequate quantity before discharging to an open water source.		
Source:	Derived from literature sources (for reference, see report).		
Fit Criterion:	The quantity of the treated and discharge effluents of Common Cockle species, seawater, and phytoplankton from the growout needs to be adequate		
Customers Satisfaction:	--	**Customers Dissatisfaction:**	--
Dependencies:	--	**Conflicts:**	--
Estimated Hardware Costs:	--		
History:	S. Deen, April 2006.		

Output

Harvest of culture of Common Cockles system (CC-5.6)

Requirement #: FR-CC-5.19	**Requirement type:** Functional
Description:	The output of the growout (CC-5) needs to be spat (or juveniles).
Rationale:	The output of the growout (CC-5) will be distributed and sold.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The required output of the growout needs to be settled Common Cockle spat.
Customers Satisfaction: x1	**Customers Dissatisfaction:** x2
Dependencies: x3	**Conflicts:** x4
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-5.20	**Requirement type:** Non-functional
Description:	The output of the growout (CC-5) needs to be Common Cockle species which needs to have an adequate quality.
Rationale:	The output of the growout (CC-5) will be distributed and sold.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The size of the mature larvae from the output must have a approximate size of approximately 30-40 mm.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Requirement #: NR-CC-5.21	**Requirement type:** Non-functional
Description:	The output of the growout (CC-5) needs to be the required Common Cockle species which needs to have an adequate quantity.
Rationale:	The output of the growout (CC-5) will be distributed and sold.
Source:	Derived from literature sources (for reference, see report).
Fit Criterion:	The quantity of the required Common Cockle species of the output of the larval growout needs to be the same quantity which be achieved by an growout production of a density of 1 000 Common Cockle species / m2.
Customers Satisfaction: --	**Customers Dissatisfaction:** --
Dependencies: --	**Conflicts:** --
Estimated Hardware Costs: --	
History:	S. Deen, April 2006.

Appendix V: Functional architecture: lowers levels

As already described, the aquaculture facility is divided in a primary production process and a secondary production process. In the primary production process, which include the algal culture phase (AL-0) and the Common Cockle culture phase (CC-0), products (uni-algal species and Common Cockle species) are cultured. The secondary production process, which exists out of the general infrastructure (GI-0), provides ancillary functions to support the primary production process.

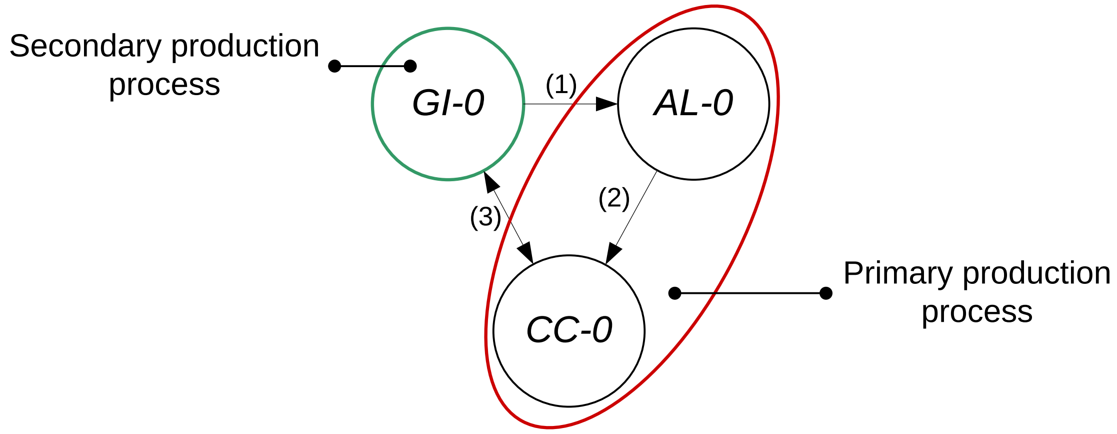


Figure V-1: Interrelated relations in the aquaculture facility

In the aquaculture facility the primary and secondary production processes are interrelated with each other (see figure V-1). (1) Describes a relation of the general infrastructure phase (GI-0) with the algal culture phase (AL-0). This relation can be seen as the distribution of uni-algal species, from culture collections of reputable research institutes, which is used as input in the algal culture phase. Furthermore, this relation includes the use of the algal culture phase of the ancillary functions of the secondary production process. Relation (2) describes the food supply of the uni-algal species from the algal culture phase to the Common Cockle culture phase. Relation (3) describes the output of Common Cockle species which are distributed to the secondary production process, after which they are distributed to the market. Furthermore, relation (3) also describes the input of breeders in the Common Cockle culture phase from the secondary production process, and the use of the ancillary functions.

V.1 Primary production process

The algal culture phase and the Common Cockle culture phase are forming the primary production process. In chapter 4 the requirements and the functional architecture of the decomposition levels: phases, sub-phases, and systems are described. In addition they identified functional components are identified and analysed. In this paragraph the functional components are identified for lower level decomposition levels (systems, sub-systems, and units), after which they are analyzed. The analyses are presented in flow diagrams, which are interrelated with each other. The interrelationship of the six flow diagrams can be seen as the functional architecture of the land-based aquaculture facility for Common Cockle species of lower decomposition levels (from systems to units). Furthermore, this paragraph also describes the function and rationale of every sub-system and unit of the functional architecture.

V.1.1 Culture of algae / Common Cockles system (AL/CC-x.1)

The culture of algae / Common Cockles system which is used for culturing the required uni-algal species or Common Cockle species is described in figure V-2.

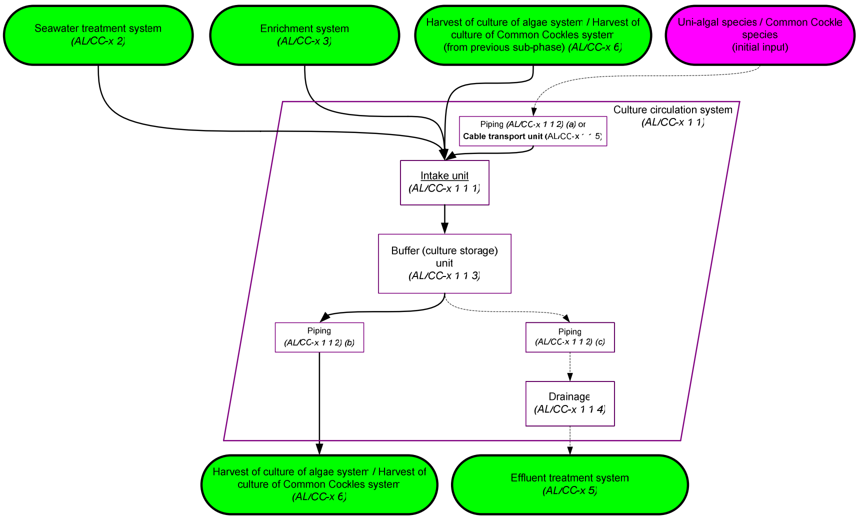


Figure V-2: Culture of algae / Common Cockle species (AL/CC-x.1)

This system is the hart of the culture operation, because in this system the cultured species are conditioned or grown. The system has one input ingredient, which are the uni-algal species (for the algal culture phase) and Common Cockle species (for the Common Cockle culture phase). Furthermore, the system is related with four input/output systems (see table V-1).

Related input/output ingredients (products): Uni-algal species (for the algal culture phase) / Common Cockle species (for the Common Cockle culture pha **Input related systems:** Seawater treatment system (AL/CC-x.2) Enrichment system (AL/CC-x.3) Harvest of culture of algae system / Harvest of culture of Common Cockles system (from previous sub-phase **Output related systems:** Effluent treatment system (AL/CC-x.5) Harvest of culture of algae system / Harvest of culture of Common Cockles system (AL/CC-x.6)

Table V-1: Functional relations of the Culture of algae system / Culture of Common Cockles system (AL/CC-x.1).

Culture circulation system (AL/CC-x.1.1)

The culture circulation system is the only sub-system in the culture of algae system / culture of Common Cockles system. This system has a function to culture (conditioning or growing) uni-algal species or Common Cockle species by circulating (enriched) seawater in a tank (a so-called buffer (culture storage) unit).

The culture circulation system exists out of several unit categories. These unit categories are defined in table V-2.

Algal culture phase (AL-0)		**Common Cockle culture phase (CC-0)**	
Traceability code:	***Unit categories:***	***Traceability code:***	***Unit categories:***
AL-x.1.1.1	Intake unit	*CC-x.1.1.1*	Intake unit
AL-x.1.1.2	Piping	*CC-x.1.1.2*	Piping
AL-x.1.1.3	Buffer (culture storage) unit	*CC-x.1.1.3*	Buffer (culture storage) unit
AL-x.1.1.4	Drainage	*CC-x.1.1.4*	Drainage
AL-x.1.1.5	**Cable transport unit**	*CC-x.1.1.5*	**Cable transport unit**

Table V-2: Unit categories of the culture circulation system (AL/CC-x.1.1).

Intake unit (AL/CC-x.1.1.1)

The intake unit[1] is the unit in which the seawater, enrichment and uni-algal species / Common Cockle species are mixed.

Piping (AL/CC-x.1.1.2)

As described in figure V-2 there are three piping units needed in the culture circulation system. The functions of these three piping units are described in table V-3.

Code:	***Function:***
(AL/CC-x.1.1.2) (a)	Transporting uni-algal species or Common Cockle species, which have a pelegic life style, with (enriched) seawater from the distibution centre or from the harvest of algae system / harvest of Common Cockles system (of a previous sub-phase) to the intake unit (AL/CC-x.1.1.1).
(AL/CC-x.1.1.2) (b)	Transporting uni-algal species or Common Cockle species, which have a pelegic life style, from the buffer unit (AL/CC-x.1.1.3) to the harvest of culture of algae system / harvest of culture of Common Cockles system.
(AL/CC-x.1.1.2) (c)	Transporting (enriched) seawater from the buffer unit (AL/CC-x.1.1.3) to the drainage (AL/CC-x.1.1.4).

Table V-3: Functions of piping units of the culture circulation system (AL/CC-x.1).

Buffer (culture storage) unit (AL/CC-x.1.1.3)

In the buffer (culture storage) unit the uni-algal species or Common Cockle species are kept for conditioning of growing. In the buffer (culture storage) unit the uni-algal species or Common Cockle species are kept in enriched seawater.

Drainage (AL/CC-1.1.4)

For minimizing the risks of pollution of the local environment (algal culture phase and Common Cockle culture phase), for example caused by leakage or maintenance activities of the buffer (culture storage) unit, drainage is used. This drainage is also used for deliberately discharging of effluents of (enriched) seawater from the buffer (culture storage) unit to the effluent treatment system.

Cable transport unit (CC-1.1.5)

To transport Common Cockle species, which have a benthic life style, from one unit to another, a cable transport unit is used. The cable transport unit can be seen as a crane way which is helping the employees by lifting and transporting the Common Cockle species.

[1] Every unit category which has to function to take something in is underlined.

V.1.2 *Seawater treatment system (AL/CC-x.2)*

The seawater treatment system is the most complex system in the aquaculture facility. This system needs to pre-treat seawater to required quality for the production of uni-algal species and Common Cockle species per sub-phase. The system, which is described in figure V-3, consists out of three sub-systems. These sub-systems are the water circulation system, contamination control system and the temperature control system.

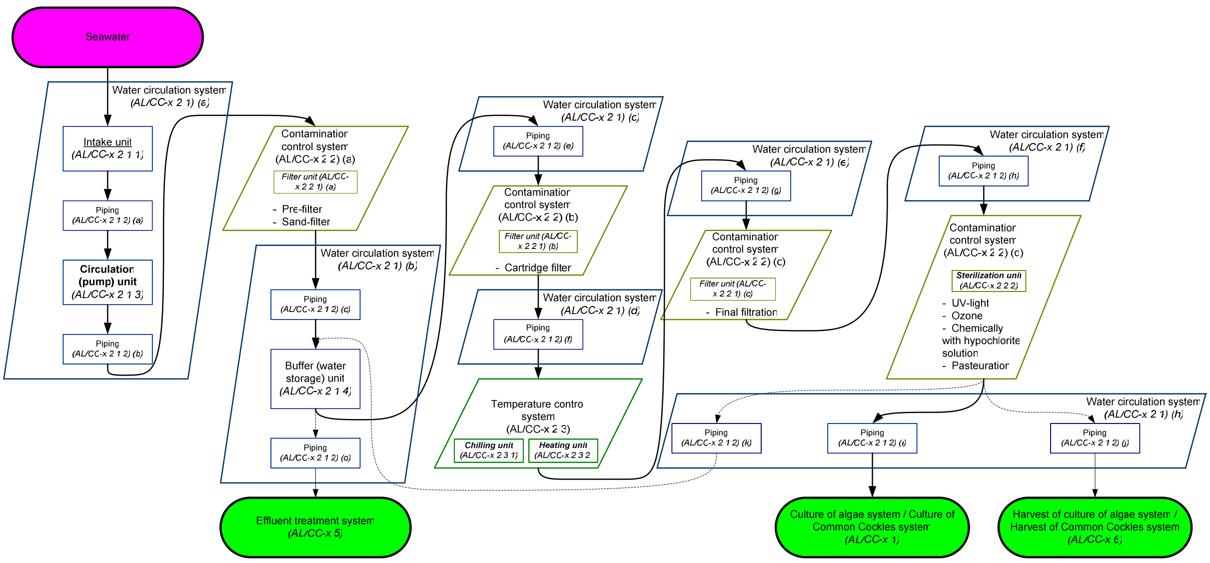


Figure V-3: Seawater treatment system (AL/CC-x.2).

Furthermore, the seawater treatment system is related with one input ingredient which is seawater from an open seawater source. The system is also related with three output systems, see table V-4.

Related input/output ingredients (products):
Seawater (input)
Input related systems:
--
Output related systems:
Culture of algae system / Culture of Common Cockles system (AL/CC-x.1)
Effluent treatment system (AL/CC-x.5)
Harvest of culture of algae system / Harvest of culture of Common Cockles system (AL/CC-x.6)

Table V-4: Functional relations of the seawater treatment system (AL/CC-x.2).

Water circulation system (AL/CC-x.2.1)

The function of the water circulation system, which is one of the three sub-systems in the seawater treatment system, is to circulate seawater through the primary production process (algal culture phase and Common Cockle culture phase). To establish this function the water circulation system needs to exist out of four unit categories, which are described in table V-5.

Algal culture phase (AL-0) / Common Cockle culture phase (CC-0)			
Traceability code:	***Unit categories:***	***Traceability code:***	***Unit categories:***
AL-x.2.1.1	Intake unit	*CC-x.2.1.1*	Intake unit
AL-x.2.1.2	Piping	*CC-x.2.1.2*	Piping
AL-x.2.1.3	**Circulation (pump) unit**	*CC-x.2.1.3*	**Circulation (pump) unit**
AL-x.2.1.4	Buffer (water storage) unit	*CC-x.2.1.4*	Buffer (water storage) unit

Table V-5: Unit categories of the water circulation system (AL/CC-x.2.1).

Intake unit (AL/CC-x.2.1.1)

The intake unit is the unit in which the seawater is taken in the system from an open water source. The intake unit needs to be located at an adequate depth to minimize contaminated seawater. In the intake unit is also a pre-filter installed to avoid damages of the seawater treatment system. This pre-filter filters the seawater to a size of less than 100 µm.

Piping (AL/CC-x.2.1.2)

The seawater is transported by diverse piping through the system. The functions of each of these piping are described in table V-6.

Code:	***Function:***
(AL/CC-x.2.1.2)(a)	Transporting seawater from the intake unit (AL/CC-x.2.1.1) to the circulation (pump) unit (AL/CC-x.2.1.3).
(AL/CC-x.2.1.2)(b)	Transporting seawater from the circulation (pump) unit (AL/CC-x.2.1.3) to the filter unit (AL/CC-x.2.2.1)(a).
(AL/CC-x.2.1.2)(c)	Transporting seawater from the filter unit (AL/CC-x.2.1.3) to the buffer unit (AL/CC-x.2.2.4).
(AL/CC-x.2.1.2)(d)	Transporting seawater from the buffer unit (AL/CC-x.2.1.3) to the effluent treatment system (AL/CC-x.5).
(AL/CC-x.2.1.2)(e)	Transporting seawater from the buffer unit (AL/CC-x.2.1.3) to the filter unit (AL/CC-x.2.2.1)(b).
(AL/CC-x.2.1.2)(f)	Transporting seawater from the filter unit (AL/CC-x.2.2.1)(b) to the chilling unit (AL/CC-x.2.3.1) and heating unit (AL/CC-x.2.3.2).
(AL/CC-x.2.1.2)(g)	Transporting seawater from the chilling unit (AL/CC-x.2.3.1) and heating unit (AL/CC-x.2.3.2) to the filter unit (AL/CC-x.2.2.1)(c).
(AL/CC-x.2.1.2)(h)	Transporting seawater from the filter unit (AL/CC-x.2.2.1)(c) to the sterilization unit (AL/CC-x.2.2.2).
(AL/CC-x.2.1.2)(i)	Transporting seawater from the sterilization unit (AL/CC-x.2.2.2) to the culture of algae system / culture of Common Cockles system (AL/CC-x.1).
(AL/CC-x.2.1.2)(j)	Transporting seawater from the sterilization unit (AL/CC-x.2.2.2) to the harvest of culture of algae system / harvest of culture of Common Cockles system (AL/CC-x.6).
(AL/CC-x.2.1.2)(k)	Transporting seawater from the sterilization unit (AL/CC-x.2.2.2) to the buffer unit (AL/CC-x.2.1.4).

Table V-6: Functions of piping units of the water circulation system (AL/CC-x.2.1).

Circulation (pump) unit (AL/CC-2.1.3)

The circulation (pump) unit is providing energy to the seawater so it can flow through the primary production system. This unit needs properly electricity[2].

Buffer (water storage) unit (AL/CC-2.1.4)

To ensure a continuous water circulation through the primary production system a buffer (water storage) unit is needed.

Contamination control system (AL/CC-x.2.2)

The function of the contamination control system is to improve the quality of the seawater so it can be used in the primary production process. The improvement of the quality of seawater is done by different filter units and a sterilization unit, see table V-7.

Algal culture phase (AL-0) / Common Cockle culture phase (CC-0)			
Traceability code:	***Unit categories:***	***Traceability code:***	***Unit categories:***
AL-x.2.2.1	Filter unit	*CC-x.2.2.1*	Filter unit
AL-x.2.2.2	**Sterilization unit**	*CC-x.2.2.2*	**Sterilization unit**

Table V-7: Unit categories of the contamination control system (AL/CC-x.2.2).

[2] Unit categories which need properly electricity are described in bold.

Filter unit (AL/CC-x.2.2.1)

To make to seawater of a better quality three types of filters (pre-filter not included) can be used. These three filters are defined as sand-filter (to 20-40 µm), cartridge filters (to < 10 µm) and final filtration filters (to < 2 µm). Furthermore, these filters need to be used in this specific order. If a bigger filtration size of 2 µm in required the final filtration filters and eventually the cartridge filters can be skipped. In figure V-3 three filter units are described. In table V-8 the functions of these three filter units are described.

Code:	***Function:***
(AL/CC-x.2.2.1) (a)	This filter unit is located between the circulation (pump) unit (AL/CC-x.2.1.3) and the buffer (water storage) unit (AL/CC-x.2.1.4). The filter unit is sand-filtering the seawater to a size of 20-40 µm.
(AL/CC-x.2.2.1) (b)	This cartridge filter is filtering the seawater to a size of 10 µm. The filter is located between the buffer (water storage) unit (AL/CC-x.2.1.4) and the chilling unit (AL/CC-x.2.3.1) and heating unit (AL/CC-x.2.3.2).
(AL/CC-x.2.2.1) (c)	The third filter unit is the final filtration filter, which filters seawater to a size of 2 µm. This filter unit is located between the chilling unit (AL/CC-x.2.3.1) and heating unit (AL/CC-x.2.3.2), and the sterilization unit.

Table V-8: Functions of filter units of the contamination control system (AL/CC-x.2.2).

Sterilization unit (AL/CC-x.2.2.2)

Bacteria and other organic material which is dissolved in seawater can cause major problems in aquaculture facilities. To minimize this contamination the seawater needs to be disinfected for different sub-phases in the primary production process. The disinfection of the seawater is taken place in the sterilization unit. Because the disinfection process do not need to be harmful for the production of uni-algal species or Common Cockle species UV-light is used for disinfection[3]. It has to be noted that disinfection of seawater by UV-light a particle size is required of less than 2 µm (Utting & Spencer, 1991; Helm & Bourne, 2004).

Temperature control system (AL/CC-x.2.3)

The third sub-system in the seawater treatment system is the temperature control system. The function of the temperature control system is to control the temperature of the seawater. This is done by making use of a chilling unit and a heating unit.

Algal culture phase (AL-0) / Common Cockle culture phase (CC-0)			
Traceability code:	***Unit categories:***	***Traceability code:***	***Unit categories:***
AL-x.2.3.1	**Chilling unit**	*CC-x.2.3.1*	**Chilling unit**
AL-x.2.3.2	**Heating unit**	*CC-x.2.3.2*	**Heating unit**

Table V-9: Unit categories of the contamination control system (AL/CC-x.2.2).

Chilling unit (AL/CC-x.2.3.1)

The chilling unit is decreasing the temperature of the seawater to a required temperature level. This unit needs electricity.

Heating unit (AL/CC-x.2.3.2)

The heating unit is increasing the temperature of the seawater to a required temperature level. This unit needs electricity.

[3] Other options for disinfection of seawater are ozone, hypochlorite solution and pasteuration. These options are not considered for the disinfection process in the sterilization unit, because they are harmful for the production of uni-algal species or Common Cockle species or because they are unpractical is use. Nevertheless, hypochlorite solution can be used for disinfection of the equipment in the primary production process during maintenance operations when production is stopped.

V.1.3 Enrichment system (AL-x.3)[4]

To ensure good conditioning and growth of uni-algal species in the aquaculture facility the seawater needs to exist out of an adequate quantity and quality of nutrients. The nutrients need to be added to the seawater in the facility because a great amount is removed or died during the contamination process in the seawater treatment system. In figure V-4 the enrichment system for the uni-algal species has been described.

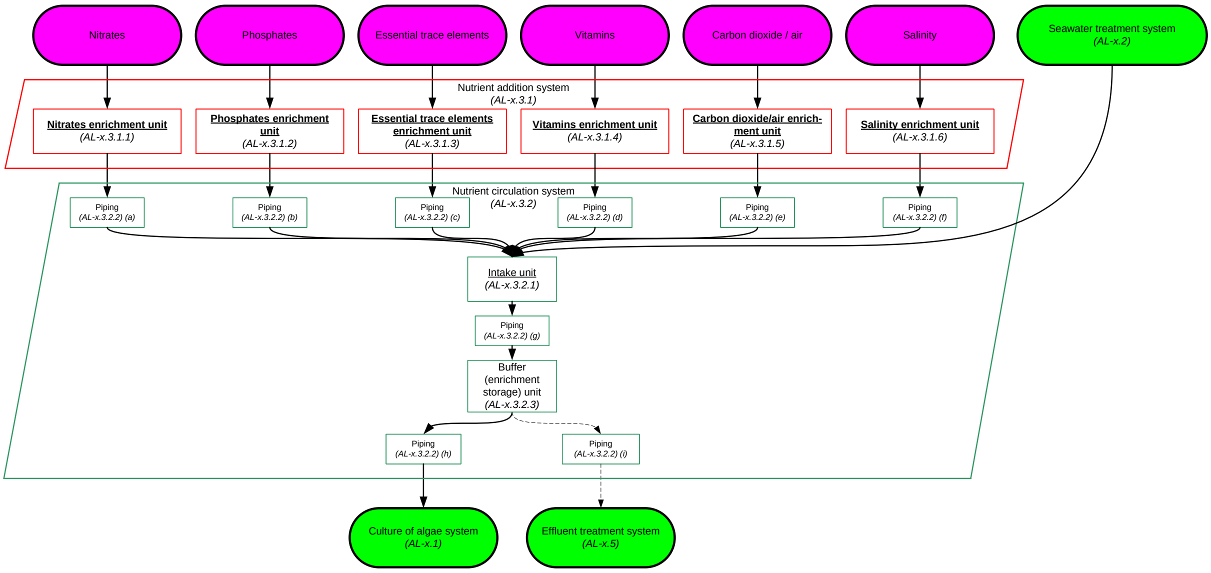


Figure V-4: Enrichment system (AL-x.3).

As described in figure V-10 the enrichment system for uni-algal species consists out of two sub-systems. These sub-systems are the nutrient addition system and the nutrient circulation system. Moreover, the enrichment system for uni-algal species has six input ingredients, one input related systems and two output related systems. These input ingredients input- and output systems are described in table V-10.

Related input/output ingredients (products):
Nitrates (input)
Phoshates (input)
Essential trace elements (input)
Vitamins (input)
Carbon dioxide / air (input)
Salinity (input)
Input related systems:
Seawater treatment system (AL-x.2)
Output related systems:
Culture of algae system (AL-x.1)
Effluent treatment system (AL-x.5)

Table V-10: Functional relations of the enrichment system (for the algal culture phase) (AL-x.3).

[4] Because the differences between the enrichment system of the uni-algal species and the enrichment system of the Common Cockle species are very different they are described in two different paragraphs.

Nutrient addition system (AL-x.3.1)

The nutrient addition system is the sub-system in which six different nutrient groups are taken in and buffered. This buffering of the nutrients is to ensure the continuity of the enrichment process. The nutrients addition system is divided into six enrichment units which are described below.

Algal culture phase (AL-0)	
Traceability code:	*Unit categories:*
AL-x.3.1.1	Nitrates enrichment unit
AL-x.3.1.2	Phosphates enrichment unit
AL-x.3.1.3	Essential trace elements unit
AL-x.3.1.4	Vitamins enrichment unit
AL-x.3.1.5	Carbon dioxide / air enrichment unit
AL-x.3.1.6	Salinity enrichment unit

Table V-11: Unit categories of the nutrient addition system (for algal culture phase) (AL-x.3.1).

It have to be noted the enrichments which are described in table V-11, except the carbon dioxide / air, are taken in, buffered and added to the system in a liquid (dissolved) form. This is to prevent corrosion of the system. The carbon dioxide /air are taken in, buffered and added to the system in a form of gas.

Nitrates enrichment unit (AL-x.3.1.1)

The nitrates enrichment unit is taken in and buffers nitrates in a liquid form (dissolved in distilled water). This liquid form provides better mixing in the intake unit (AL-x.3.2.1). The nitrates enrichment unit needs to have its own mixing element to condition the nitrates. This unit needs electricity.

Phosphates enrichment unit (AL-x.3.1.2)

The phosphates enrichment unit is taken in and buffers phosphates in a liquid form (dissolved in distilled water). This liquid form provides better mixing in the intake unit (AL-x.3.2.1). The phosphates enrichment unit needs to have an own mixing element to condition the phosphates. This unit needs electricity.

Essential trace elements enrichment unit (AL-x.3.1.3)

The essential trace elements enrichment unit is taken in and buffers essential trace elements in a liquid form (dissolved in distilled water). This liquid form provides better mixing in the intake unit (AL-x.3.2.1). The essential trace elements enrichment unit needs to have an own mixing element to condition the essential trace elements. This unit needs electricity.

Vitamins enrichment unit (AL-x.3.1.4)

The vitamins enrichment unit is taken in and buffers vitamins in a liquid form (dissolved in distilled water). This liquid form provides better mixing in the intake unit (AL-x.3.2.1). The vitamins enrichment unit needs to have an own mixing element to condition the vitamins. This unit needs electricity.

Carbon dioxide / air enrichment unit (AL-x.3.1.5)

The carbon dioxide / air enrichment unit is taken in and buffers carbon dioxide / air in a form of gas. This form provides better mixing in the intake unit (AL-x.3.2.1).

Salinity enrichment unit (AL-x.3.1.6)

The salinity enrichment unit is taken in and buffers salt water in a concentrated and liquid form (dissolved in distilled water). This liquid form provides better mixing in the intake unit (AL-x.3.2.1). The salinity enrichment unit needs to have its own mixing element to condition the salt water. This unit needs electricity.

Nutrient circulation system (AL-x.3.2)

The nutrient circulation system is the second sub-system in the enrichment system for uni-algae. The function of this system is to mix the different enrichments into the seawater. In this way enriched seawater is made, which can be used to feed the uni-algal species in the algal culture phase. The nutrient circulation system for algae (AL-x.3.2) consists out of three unit categories which are described in table V-12.

Algal culture phase (AL-0)	
Traceability code:	***Unit categories:***
AL-x.3.2.1	Intake unit
AL-x.3.2.2	Piping
AL-x.3.2.3	Buffer (enrichment storage) unit

Table V-12: Unit categories of nutrient circulation system (for the algal culture phase) (AL-x.3.2).

Intake unit (AL-x.3.2.1)

The intake unit is the unit which is mixing the different enrichments into treated seawater in the right proportion, so the enriched seawater can be used for conditioning and growing of the uni-algal species.

Piping (AL-x.3.2.2)

Different piping is used in the nutrient circulation system. The piping is described in table V-13.

Code:	***Function:***
(AL-x.3.2.2) (a)	Transporting dissolved nitrates from the nitrates enrichment unit (AL-x.3.1.1) to the intake unit (AL-x.3.2.1).
(AL-x.3.2.2) (b)	Transporting dissolved phosphates from the phosphates enrichment unit (AL-x.3.1.2) to the intake unit (AL-x.3.2.1).
(AL-x.3.2.2) (c)	Transporting dissolved essential trace elements from the essential trace elements enrichment unit (AL-x.3.1.3) to the intake unit (AL-x.3.2.1).
(AL-x.3.2.2) (d)	Transporting dissolved vitamins from the vitamins enrichment unit (AL-x.3.1.4) to the intake unit (AL-x.3.2.1).
(AL-x.3.2.2) (e)	Transporting carbon dioxide / air from the carbon dioxide / air enrichment unit (AL-x.3.1.5) to the intake unit (AL-x.3.2.1).
(AL-x.3.2.2) (f)	Transporting dissolved salinity concentration from the salinity enrichment unit (AL-x.3.1.6) to the intake unit (AL-x.3.2.1).
(AL-x.3.2.2) (g)	Transporting enriched seawater which can can be used for conditioning and growing uni-algal species to the buffer (enrichment storage) unit (AL-x.3.2.3).
(AL-x.3.2.2) (h)	Transporting enriched seawater for conditioning and growing uni-algal species to the culture of algae system (AL-x.1).
(AL-x.3.2.2) (i)	Transporting enriched seawater to the effluent treatment system (AL-x.5).

Table V-13: Functions of piping units of the nutrient circulation system (of the algal culture phase) (AL-x.3.2).

Buffer (enrichment storage) unit (AL-x.3.2.3)

In the nutrient enrichment system includes also a buffer (enrichment storage) unit. This unit guarantees a continuous flow of enriched seawater for the uni-algal species in the algal culture phase.

V.1.4 Enrichment system (CC-x.3)

Common Cockle species need like uni-algal species also enrichment in their seawater for good conditioning and growth. This enrichment consists mainly out of uni-algal species. The enrichment system for Common Cockles is described in figure V-5.

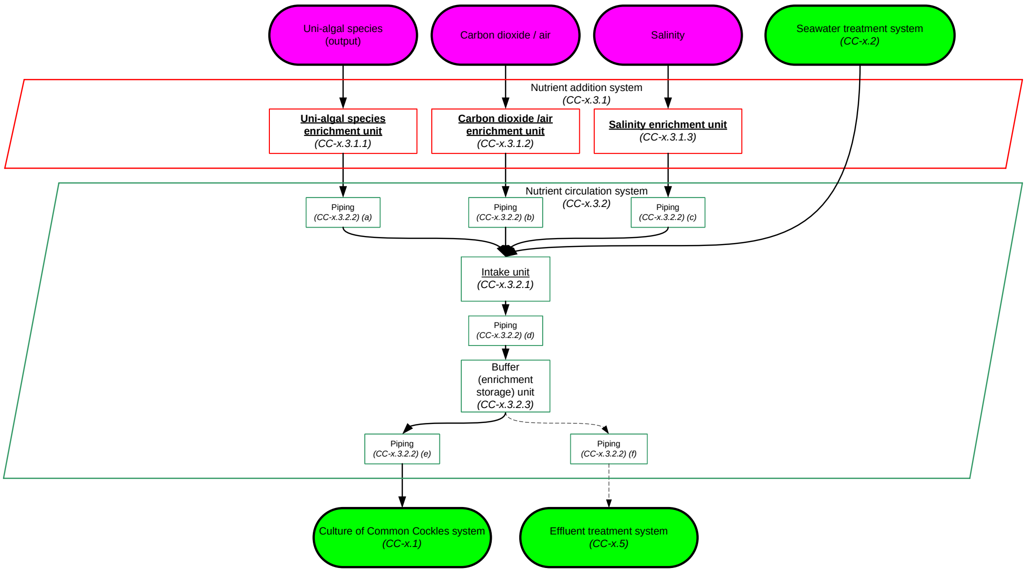


Figure V-5: Enrichment system (CC-x.3).

Figure V-5 shows the same structure for Common Cockle species as the enrichment system for uni-algal species (see figure V-5). The enrichment system for Common Cockle species also consist out of two sub-systems. These sub-systems are the nutrient addition system and the nutrient circulation system. The system has three input ingredients, which are the enrichments of uni-algal species from the algal culture, the carbon dioxide / air enrichment and the enrichments of a salinity concentration. The system has one input related system and two output related systems, see table V-14.

Related input/output ingredients (products): Uni-algal species (input) Carbon dioxide / air (input) Salinity (input) **Input related systems:** Seawater treatment system (CC-x.2) **Output related systems:** Culture of Common Cockles system (CC-x.1) Effluent treatment system (CC-x.5)

Table V-14: Functional relations of the enrichment system (for the Common Cockle culture phase) (CC-x.3).

Nutrient addition system (CC-x.3.1)

In the nutrient addition system three nutrient groups are taken in and buffered. This buffering of the nutrients is to ensure the continuity of the enrichment process. The nutrients addition system is divided into three enrichment units which are described in table V-15.

Common Cockle culture phase (CC-0)	
Traceability code:	*Unit categories:*
CC-x.3.1.1	Uni-algal species enrichment unit
CC-x.3.1.2	Carbon dioxide / air enrichment unit
CC-x.3.1.3	Salinity enrichment unit

Table V-15: Unit categories of the nutrient addition system (for Common Cockle culture phase) (CC-x.3.1).

Uni-algal species enrichment unit (CC-x.3.1.1)

The uni-algal species are the uni-algal species which are cultured in the algal culture phase. They are imported into the Common Cockle Culture phase from the large-scale culture (AL-4) sub-phase. It has to be noted that the uni-algal species are dissolved in enriched and treated seawater.

Carbon dioxide/air enrichment unit (CC-3.1.2)

The carbon dioxide / air enrichment unit is taken in and buffers carbon dioxide / air in a form of gas. This form provides better mixing in the intake unit (CC-x.3.2.1).

Salinity enrichment unit (CC-3.1.3)

The salinity enrichment unit is taken in and buffers salt water in a concentrated and liquid form (dissolved in distilled water). This liquid form provides better mixing in the intake unit (CC-x.3.2.1). The salinity enrichment unit needs to have its own mixing element to condition the salt water. This unit needs electricity.

Nutrient circulation system (CC-x.3.2)

The nutrient circulation system for Common Cockle species has the same function and structure as the enrichment system for the uni-algal species. The unit categories are described in table V-16.

Common Cockle culture phase (CC-0)	
Traceability code:	*Unit categories:*
CC-x.3.2.1	Intake unit
CC-x.3.2.2	Piping
CC-x.3.2.3	Buffer (enrichment storage) unit

Table V-16: Unit categories of the nutrient circulation system (for Common Cockle culture phase) (CC-x.3.2).

Intake unit (CC-x.3.2.1)

The intake unit is the unit which is mixing the different enrichments into treated seawater in the right proportion, so the enriched seawater can be used for conditioning and growing of the Common Cockle species.

Piping (CC-x.3.2.2)

Different piping is used in the nutrient circulation system. The piping is described in table V-17.

Code:	***Function:***
(CC-x.3.2.2) (a)	Transporting dissolved uni-algal species from the uni-algal species enrichment unit (CC-x.3.1.1) to the intake unit (CC-x.3.2.1).
(CC-x.3.2.2) (b)	Transporting carbon dioxide / air from the carbon dioxide / air enrichment unit (CC-x.3.1.5) to the intake unit (CC-x.3.2.1).
(CC-x.3.2.2) (c)	Transporting dissolved salinity concentration from the salinity enrichment unit (CC-x.3.1.6) to the intake unit (CC-x.3.2.1).
(CC-x.3.2.2) (d)	Transporting enriched seawater which can can be used for conditioning and growingCommon Cockle species to the buffer (enrichment storage) unit (CC-x.3.2.3).
(CC-x.3.2.2) (e)	Transporting enriched seawater for conditioning and growing Common Cockle species to the culture of Common Cockles system (CC-x.1).
(CC-x.3.2.2) (f)	Transporting enriched seawater to the effluent treatment system (CC-x.5).

Table V-17: Functions of piping units of the nutrient circulation system (of the Common Cockle culture phase) (CC-x.3.2).

Buffer (enrichment storage) unit (CC-x.3.2.3)

In the nutrient enrichment system includes also a buffer (enrichment storage) unit. This unit guarantees a continuous flow of enriched seawater for the Common Cockle species in the Common Cockle Culture phase.

V.1.5 *Environmental control system (AL/CC-x.4)*

The environmental control system controls the illumination in the algal culture phase and the temperature in the algal culture phase and the Common Cockle culture phase (except in the growout). This is necessary for good conditioning and growth of the uni-algal species and Common Cockle species.

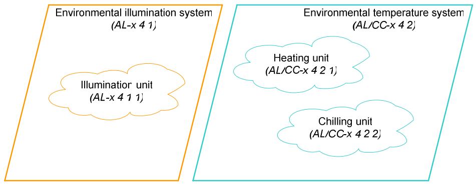


Figure V-6: Environmental control system (AL/CC-x.4).

The environmental control system, which is described in figure V-6, has two sub-systems. These sub-systems are the environmental illumination system and the environmental temperature system. Furthermore, the system is not related with input/output ingredients, or input/output related systems, see table V-18.

Related input/output ingredients (products): -- **Input related systems:** -- **Output related systems:** --

Table V-18: Functional relations of the environmental control system (AL/CC-x.4).

Environmental illumination system (AL-x.4.1)

The environmental illumination system is only used in the algal culture phase to provide the uni-algal species energy in a form of light. The environmental illumination system consist out of one illumination unit, see table V-19.

Algal culture phase (AL-0)	
Traceability code:	***Unit categories:***
AL-x.4.1.1	**Illumination unit**

Table V-19: Unit categories of the environmental illumination system (AL-x.4.1).

Illumination unit (AL-x.4.1.1)

To illuminate the uni-algal species as efficient as possible the illumination unit is in the culture of algae system (AL-x.1), see figure V-19.

Environmental temperature system (AL/CC-x.4.2)

For good conditioning and growth the environmental temperature system is controlling the temperature in the algal culture phase and Common Cockle culture phase. For this activity the sub-system is making use of a heating and chilling unit, see table V-20

Algal culture phase (AL-0) / Common Cockle culture phase (CC-0)			
Traceability code:	*Unit categories:*	*Traceability code:*	*Unit categories:*
AL-x.4.2.1	**Heating unit**	*CC-x.4.2.1*	**Heating unit**
AL-x.4.2.2	**Chilling unit**	*CC-x.4.2.2*	**Chilling unit**

Table V-20: Unit categories of the environmental temperature system (AL/CC-x.4.2).

Heating unit (AL/CC-x.4.2.1)

The heating unit's function is to warm up the environment in the algal culture phase and Common Cockle culture phase.

Chilling unit (AL/CC-x.4.2.2)

The chilling unit's function is to chill down the environment in the algal culture phase and Common Cockle culture phase.

V.1.6 Effluent treatment system (AL/CC-x.5)

An effluent treatment system is integrated in the aquaculture facility to avoid wastes from the facility in the surrounding environment. The function of this effluent treatment system is to treatment all effluents of the facility to a level of which they were at the time of intake.

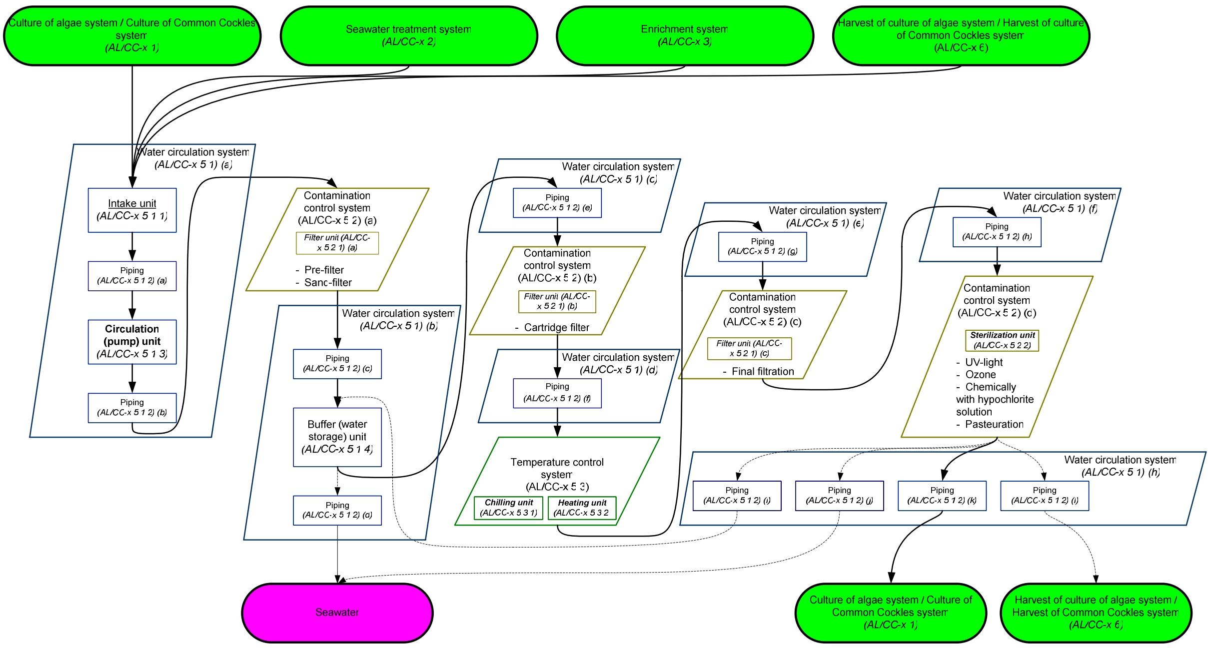


Figure V-7: Effluent treatment system (AL/CC-x.5).

The effluent treatment system is described in figure V-7. The system has one output related ingredient, which is the seawater. After treatment all effluents are discharged to an open seawater source. The system has also four input related systems and one output related system, which are described in table V-21.

Related input/output ingredients (products): Seawater (ouput) **Input related systems:** Culture of algae system / Culture of Common Cockles system (AL/CC-x.1) Seawater treatment system (AL/CC-x.2) Enrichment system (AL/CC-x.3) Harvest of culture of algae system / Harvest of culture of Common Cockles system (AL/CC-x.6) **Output related systems:** Culture of algae system / Culture of Common Cockles system (AL/CC-x.1)

Table V-21: Functional relations of the effluent treatment system (AL/CC-x.5).

Water circulation system (AL/CC-x.5.1)

The function of the water circulation system, which is one of the four sub-systems in the effluent treatment system, is to circulate seawater through the system. To establish this function the water circulation system needs to exist out of four unit categories, which are described in table V-22.

Algal culture phase (AL-0) / Common Cockle culture phase (CC-0)			
Traceability code:	*Unit categories:*	*Traceability code:*	*Unit categories:*
AL-x.5.1.1	Intake unit	*CC-x.5.1.1*	Intake unit
AL-x.5.1.2	Piping	*CC-x.5.1.2*	Piping
AL-x.5.1.3	**Circulation (pump) unit**	*CC-x.5.1.3*	**Circulation (pump) unit**
AL-x.5.1.4	Buffer (water storage) unit	*CC-x.5.1.4*	Buffer (water storage) unit

Table V-22: Unit categories of the water circulation system (AL/CC-x.5.1).

Intake unit (AL/CC-x.5.1.1)

The intake unit is the unit in which the effluents are taken in the system from the algal culture phase and Common Cockle culture phase. In the intake unit is also a pre-filter installed to avoid damages of the effluent treatment system. This pre-filter filters the effluents to a size of less than 100 µm.

Piping (AL/CC-x.5.1.2)

The effluents are transported by diverse piping through the system. The functions of each of these piping is described in table V-23.

Code:	*Function:*
(AL/CC-x.5.1.2)(a)	Transporting effluents from the intake unit (AL/CC-x.5.1.1) to the circulation (pump) unit (AL/CC-x.5.1.3).
(AL/CC-x.5.1.2)(b)	Transporting effluents from the circulation (pump) unit (AL/CC-x.5.1.3) to the filter unit (AL/CC-x.5.2.1)(a).
(AL/CC-x.5.1.2)(c)	Transporting effluents from the filter unit (AL/CC-x.5.1.3) to the buffer unit (AL/CC-x.5.2.4).
(AL/CC-x.5.1.2)(d)	Transporting effluents from the buffer unit (AL/CC-x.5.1.3) to the open seawater source (spill over).
(AL/CC-x.5.1.2)(e)	Transporting effluents from the buffer unit (AL/CC-x.5.1.3) to the filter unit (AL/CC-x.5.2.1)(b).
(AL/CC-x.5.1.2)(f)	Transporting effluents from the filter unit (AL/CC-x.5.2.1)(b) to the chilling unit (AL/CC-x.5.3.1) and heating unit (AL/CC-x.5.3.2).
(AL/CC-x.5.1.2)(g)	Transporting effluents from the chilling unit (AL/CC-x.5.3.1) and heating unit (AL/CC-x.5.3.2) to the filter unit (AL/CC-x.5.2.1)(c).
(AL/CC-x.5.1.2)(h)	Transporting effluents from the filter unit (AL/CC-x.5.2.1)(c) to the sterilization unit (AL/CC-x.5.2.2).
(AL/CC-x.5.1.2)(i)	Transporting effluents from the sterilization unit (AL/CC-x.5.2.2) to the buffer unit (AL/CC-x.5.1.4).
(AL/CC-x.5.1.2)(j)	Transporting effluents from the sterilization unit (AL/CC-x.5.2.2) to the open seawater source.
(AL/CC-x.5.1.2)(k)	Transporting efflunets from the sterilization unit (AL/CC-x.5.2.2) to the culture of algae system / culture of Common Cockles system (AL/CC-x.1).
(AL/CC-x.5.1.2)(l)	Transporting effluents from the sterilization unit (AL/CC-x.5.2.2) to the harvest of culture of algae system / harvest of culture of Common Cockles system (AL/CC-x.6).

Table V-23: Functions of piping units of the water circulation system (AL/CC-x.5.1).

Circulation (pump) unit (AL/CC-5.1.3)

The circulation (pump) unit is providing energy to the effluents so it can flow through the system. This unit needs electricity.

Buffer (water storage) unit (AL/CC-5.1.4)

To ensure a continuous water circulation through the system a buffer (water storage) unit is needed.

Contamination control system (AL/CC-x.5.2)

The function of the contamination control system is to improve the quality of the seawater so it can be used in the primary production process. The improvement of the quality of seawater is done by different filter units and a sterilization unit, see table V-24.

Algal culture phase (AL-0) / Common Cockle culture phase (CC-0)			
Traceability code:	*Unit categories:*	*Traceability code:*	*Unit categories:*
AL-x.5.2.1	Filter unit	*CC-x.5.2.1*	Filter unit
AL-x.5.2.2	**Sterilization unit**	*CC-x.5.2.2*	**Sterilization unit**

Table V-24: Unit categories of the contamination control system (AL/CC-x.5.2).

Filter unit (AL/CC-x.5.2.1)

To make to seawater of a better quality three types of filters (pre-filter not included) can be used. These three filters are defined as sand-filter (to 20-40 µm), cartridge filters (to < 10 µm) and final filtration filters (to < 2 µm). Furthermore, these filters need to be used in this specific order. If a bigger filtration size of 2 µm in required the final filtration filters and eventually the cartridge filters can be skipped. In figure V-7 three filter units are described. In table V-25 the functions of these three filter units are described.

Code:	***Function:***
(AL/CC-x.5.2.1) (a)	This filter unit is located between the circulation (pump) unit (AL/CC-x.5.1.3) and the buffer (water storage) unit (AL/CC-x.5.1.4). The filter unit is sand-filtering the seawater to a size of 20-40 µm.
(AL/CC-x.5.2.1) (b)	This cartridge filter is filtering the seawater to a size of 10 µm. The filter is located between the buffer (water storage) unit (AL/CC-x.5.1.4) and the chilling unit (AL/CC-x.5.3.1) and heating unit (AL/CC-x.5.3.2).
(AL/CC-x.5.2.1) (c)	The third filter unit is the final filtration filter, which filters seawater to a size of 2 µm. This filter unit is located between the chilling unit (AL/CC-x.5.3.1) and heating unit (AL/CC-x.5.3.2), and the sterilization unit.

Table V-25: Functions of filter unit of the contamination control system (AL/CC-x.5.2).

Sterilization unit (AL/CC-x.5.2.2)

Bacteria and other organic material which is dissolved in seawater can cause major problems in aquaculture facilities. To minimize this contamination the seawater needs to be disinfected for different sub-phases in the primary production process. The disinfection of the seawater is taken place in the sterilization unit. Because the disinfection process do not need to be harmful for the production of uni-algal species or Common Cockle species UV-light is used for disinfection[5]. It has to be noted that disinfection of seawater by UV-light a particle size is required of less than 2 µm (Utting & Spencer, 1991; Helm & Bourne, 2004).

Temperature control system (AL/CC-x.5.3)

The third sub-system in the seawater treatment system is the temperature control system. The function of the temperature control system is to control the temperature of the seawater. This is done by making use of a chilling unit and a heating unit.

Algal culture phase (AL-0) / Common Cockle culture phase (CC-0)			
Traceability code:	***Unit categories:***	***Traceability code:***	***Unit categories:***
AL-x.5.3.1	**Chilling unit**	*CC-x.5.3.1*	**Chilling unit**
AL-x.5.3.2	**Heating unit**	*CC-x.5.3.2*	**Heating unit**

Table V-26: Unit categories of the temperature control system (AL/CC-x.5.2.3).

Chilling unit (AL/CC-x.5.3.1)

The chilling unit is decreasing the temperature of the seawater to a required temperature level. This unit needs electricity.

Heating unit (AL/CC-x.5.3.2)

The heating unit is increasing the temperature of the seawater to a required temperature level. This unit needs electricity.

[5] Other options for disinfection of seawater are ozone, hypochlorite solution and pasteuration. These options are not considered for the disinfection process in the sterilization unit, because they are harmful for the production of uni-algal species or Common Cockle species or because they are unpractical is use. Nevertheless, hypochlorite solution can be used for disinfection of the equipment in the primary production process during maintenance operations when production is stopped.

V.1.7 Harvest of culture of algae system / Harvest of culture of Common Cockles system (AL/CC-x.6)

The harvest of culture of algae system / harvest of culture of Common Cockles system are the systems in which the species harvested. The system is described in figure V-8.

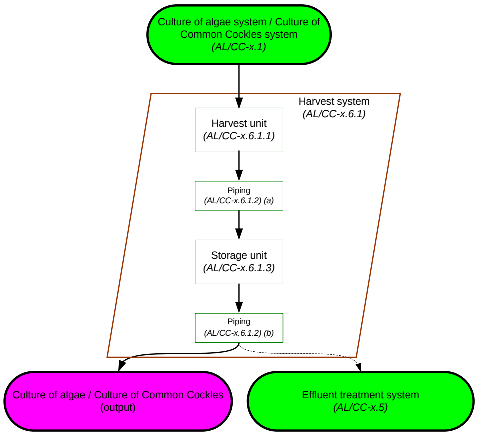


Figure V-8: Harvest of culture of algae system / harvest of culture of Common Cockles system (AL/CC-x.6).

The system has one sub-system, which consist out of one output related ingredient, one input related system and one output related system., see table V-27.

Related input/output ingredients (products):
Uni-algal species (from the algal culture phase) / Common Cockle species (from the Common Cockle culture

Input related systems:
Culture of algae system / Culture of Common Cockles system (AL/CC-x.1)

Output related systems:
Effluent treatment system (AL/CC-x.5)

Table V-27: Functional relations of the harvest of culture of algae / harvest of culture of Common Cockles (AL/CC-x.6).

Harvest system (AL/CC-x.6.1)

The harvest system consists out of three unit categories, see table V-28. These unit categories are described below.

Algal culture phase (AL-0) / Common Cockle culture phase (CC-0)			
Traceability code:	***Unit categories:***	***Traceability code:***	***Unit categories:***
AL-x.6.1.1	Intake unit	*CC-x.6.1.1*	Intake unit
AL-x.6.1.2	Piping	*CC-x.6.1.2*	Piping
AL-x.6.1.3	Storage unit	*CC-x.6.1.3*	Storage unit

Table V-28: Unit categories of the harvest system (AL/CC-x.6.1).

Harvest unit (AL/CC-6.1.1)

The harvest unit is the unit which is harvest the uni-algal species or Common Cockle species. This harvesting can be achieved by nets, suction, etc.

Piping (AL/CC-6.1.2)

The harvest is transported by diverse piping through the system. The functions of each of these piping are described in table V-29.

Code:	***Function:***
(AL/CC-x.6.1.2)(a)	Transporting harvest from the harvest unit (AL/CC-x.6.1.1) to the storage unit (AL/CC-x.6.1.3).
(AL/CC-x.6.1.2)(b)	Transporting harvest from the storage unit (AL/CC-x.6.1.3) to the culture of algae / culture of Common Cockles (AL/CC-x.1) (next sub-phase) or to the distribution centre (only AL-4.6 and CC-5.6).

Table V-29: Functions of piping units of the harvest system (AL/CC-x.6.1).

Storage unit (AL/CC-x.6.1.3)

To minimize the loss of energy the harvest is stored in a storage unit, after which the harvest is transported in batches.

V.2 Secondary production process

As described in figure V-1 the secondary production process, or so-called general infrastructure, consist out of three sub-phases. These three sub-phases are the general systems (GI-1), employees/guest facilities (GI-2) and distribution system (GI-3). These systems are needed to support the primary production system in each of their specific way. These functions of these sub-phases are described in the next paragraphs.

V.2.1 General systems (GI-1)

The general systems involve systems which are necessary for a high quality of production of uni-algal species or Common Cockle species and which are not included in the primary production system. The general systems include a power system (GI-1.1), an air ventilation system (GI-1.2), emergency system (GI-1.3) and maintenance system (GI-1.4). It has to be noted the system do not necessarily be located at one location, but they can also be integrated through the whole design.

Power system (GI-1.0.1)

The power system provides electricity to all systems in the aquaculture facility. The electricity is imported into the aquaculture facility from local nuts companies. If there is no power available for a moment a generator system is needed, see emergency system (GI-1.3).

Air ventilation system (GI-1.0.2)

The air ventilation system is located in every building in the aquaculture facility. Its function is to ensure that the air in the facility is refreshed every unit of time, so a healthy environment is created for employees and stocks of algae or Common Cockle species.

Emergency system (GI-1.0.3)

The emergency system is located and working in every sub-phase of the primary production process, including the distribution centre. The emergency system is a integrated system of a medical first aid system, firefighting system and a generator system. The function of the emergence system is creating safety in the aquaculture facility.

Maintenance system (GI-1.0.4)

The maintenance system is a system which is meant the make maintenance in the aquaculture facility more accessible. The maintenance system exists out of a working chamber (including installed equipment) and a storage room. Furthermore, the aquaculture facility is also designed in a way that the setup can be easily transformed, for example, by making use of non-permanent walls.

V.2.2 Employees/guest facilities (GI-2)

The function of the sub-phase employees/guest facilities is to provide facilities for employees, and eventually guest, to do their work. In the sub-phase a difference can be made between working facilities (GI-2.1), general facilities (GI-2.2) and relaxing facilities (GI-2.3).

Working facilities (GI-2.0.1)

In the working facilities employees are doing their work in the primary and secondary production processes. These working facilities need to be adapted to the environment in which these employees are working. It has to be noted that the primary production process needs to be operated from the floor, but also from a production process control area (area in which the production process have been electronically controlled). Furthermore, for administration and meeting activities an administration room and a meeting room need to be located in the aquaculture facility.

General facilities (GI-2.0.2)

The general facilities provide standard facilities for the employees, or eventually guest, during breaks. The general facilities consist out of sanitation, a kitchen, canteen, washing area. These facilities are useful for the employees / guest and they contribute to a better working environment.

Relaxing facilities (GI-2.0.3)

Relaxing facilities are optional facilities. These facilities are very useful when employees are working in shifts. These faculties are also very useful for chauffeurs who are returning from long travels and who want to rest. The relaxing facility provides a bed and sanitation.

V.2.3 Distribution centre (GI-3)

The third sub-phase of the general infrastructure is the distribution centre. The distribution can be seen as the start and finish of the production of the aquaculture facility, because inputs (stock culture of uni-algae species and initial breeders) and output (harvests of Common Cockle species) of the primary production process are transported in, respectively, out by this sub-phase. Besides installment of infrastructure for transporting goods, like the uni-algal species and Common Cockles species, also infrastructure of transporting energy, drinking water and communications needs to be installed.

Appendix VI: Phytoplankton model

This appendix describes the results of the phytoplankton model, including its critical factors. This model calculates the required quantity of phytoplankton needed for food supply for the Common Cockle species. The phytoplankton model is derived from five formulas which are described in paragraph 3.1.4 and paragraph 3.1.5. The five formulas are:

- Converting the shell length of Common Cockle species to a certain fresh weight[1];
- Converting fresh weight to a certain dry flesh weight (DFW)*;*
- To calculate the clearance rate, as a function of the dry flesh weight of Common Cockle species*;*
- Calculating the clearance rate, as a function of the shell length of Common Cockle species*;*
- Calculating the feeding rate, as a function of the shell length of Common Cockle species.

VI.1 Defined formulas

The five formulas are defined as:

Length-versus-fresh-weight-correlation

$W_{fr} = 0.6162 * L^{2.9582}$ (Van Stralen, 1990)

Where W_{fr} = Total fresh weight of the Common Cockle species in mg, and;
L = Shell length of the Common Cockle species in mm.

Equation 2: Conversion of fresh weight to dry flesh weight

$$W_{DFW} = 0.06 * W_{fr}$$

Where W_{DFW} = Total dry weight of the Common Cockle species in mg.

For converting fresh weight to dry weight a factor of 0.06 is used. This factor is derived by multiplying a fresh weight-dry weight correlation of 0.4 (Utting & Spencer, 1991) with 1/7, which is the correlation of dry weight to dry flesh weight (DFW).

Equation 3: Clearance rate, as a function of W_{DFW}

$Cl = 1.52 * (W_{DFW} / 1000)$ (Smaal *et al.*, 1997)

Where Cl = Clearance rate of the Common Cockle species in l/hr, and;
W_{DFW} = Total dry flesh weight of the Common Cockle species in mg.

[1] 'Fresh weight' and 'dry weight' are defined including their shell.

Equation 4: Clearance rate, as a function of L

$$Cl = 0.1340 * 10^{-5} * L^{2.9582}$$

Where Cl = Clearance rate in m^3/day, and;
L = Shell length of the Common Cockle species in mm.

Equation 5: Feeding rate, based on an optimal food (phytoplankton) concentration of 4.8 mg/l

$$Fr = 0.6433 * 10^{-2} * L^{2.9582}$$

Where Fr = Optimal feeding rate in mg phytoplankton/day per individual Common Cockle species, and;
L = Shell length of the Common Cockle species in mm.

VI.2 Results of five formulas

The following results are derived from the five equations. The results are described per individual Common Cockle species.

Shell length (mm)	Length-vs.-fresh-weight-ratio (mg)	Convertion of fresh weight into dry flesh weight (DFW) (mg)	Clearance rate (l/day)	Feeding rate (mg algae / day)
L	Wfr = 0.6162*L^2.9582	Wdfw = 0.06*Wfr	Cl = 0.1349*10^-2*(L^2.9582)	Fr =0.6474*10^-2*L^2.9582
0	0.00	0.00	0.00	0.00
0.05	**0.00**	**0.00**	**0.00**	**0.00**
0.06	**0.00**	**0.00**	**0.00**	**0.00**
0.25	**0.01**	**0.00**	**0.00**	**0.00**
0.35	**0.03**	**0.00**	**0.00**	**0.00**
1	0.62	0.04	0.00	0.01
2	4.79	0.29	0.01	0.05
3	15.89	0.95	0.03	0.17
4	37.22	2.23	0.08	0.39
4.8	**63.82**	**3.83**	**0.14**	**0.67**
5	72.01	4.32	0.16	0.76
6	123.49	7.41	0.27	1.30
7	194.85	11.69	0.43	2.05
8	289.23	17.35	0.63	3.04
9	409.79	24.59	0.90	4.31
10	559.66	33.58	1.23	5.88
11	741.94	44.52	1.62	7.80
12	959.74	57.58	2.10	10.08
13	1216.15	72.97	2.66	12.78
14	1514.25	90.86	3.32	15.91
15	1857.10	111.43	4.07	19.51
16	2247.76	134.87	4.92	23.62
17	2689.28	161.36	5.89	28.25
18	3184.70	191.08	6.97	33.46
19	3737.06	224.22	8.18	39.26
20	4349.39	260.96	9.52	45.70
21	5024.71	301.48	11.00	52.79
22	5766.02	345.96	12.62	60.58
23	6576.35	394.58	14.40	69.09
24	7458.69	447.52	16.33	78.36
25	8416.04	504.96	18.42	88.42
26	9451.39	567.08	20.69	99.30
27	10567.74	634.06	23.14	111.03
28	11768.05	706.08	25.76	123.64
29	13055.32	783.32	28.58	137.16
30	**14432.51**	**865.95**	**31.60**	**151.63**
31	15902.59	954.16	34.81	167.08
32	17468.53	1048.11	38.24	183.53
33	19133.29	1148.00	41.89	201.02
34	20899.82	1253.99	45.75	219.58
35	22771.09	1366.27	49.85	239.24
36	24750.03	1485.00	54.18	260.03
37	26839.60	1610.38	58.76	281.99
38	29042.74	1742.56	63.58	305.13
39	31362.38	1881.74	68.66	329.50
40	**33801.47**	**2028.09**	**74.00**	**355.13**
41	36362.93	2181.78	79.61	382.04
42	39049.70	2342.98	85.49	410.27
43	41864.71	2511.88	91.65	439.84
44	44810.87	2688.65	98.10	470.80
45	47891.12	2873.47	104.84	503.16
46	51108.36	3066.50	111.89	536.96
47	54465.51	3267.93	119.24	572.23
48	57965.49	3477.93	126.90	609.00
49	61611.21	3696.67	134.88	647.31
50	65405.57	3924.33	143.19	687.17
51	69351.49	4161.09	151.83	728.63
52	73451.86	4407.11	160.80	771.71
53	77709.58	4662.57	170.12	816.44
54	82127.56	4927.65	179.80	862.86
55	86708.69	5202.52	189.82	910.99
56	91455.86	5487.35	200.22	960.87
57	96371.96	5782.32	210.98	1012.52
58	101459.89	6087.59	222.12	1065.97
59	106722.53	6403.35	233.64	1121.26
60	112162.77	6729.77	245.55	1178.42

Table VI-1: Results, derived from the five formulas.

VI.3 Results, as function of time

In table VI-1 the results are described, which are derived from the five formulas, of the required phytoplankton. Nevertheless, these results do not describe the required phytoplankton as a function of time. To calculate the required phytoplankton as a function of time certain assumptions need to be made. In this model three assumptions are made, which are identified as:

- The optimal food (phytoplankton) concentration (so-called ‘factor feeding rate’). It is assumed that this food concentration will be conditioned at a level of 4.8 mg phytoplankton per litre seawater.
- The standard residence time. This is the time needed to culture one individual Common Cockle species 1 mm. The growth rate has been assumed as a linear process. It is assumed that the standard residence time is 10.
- The growth factor. The growth factor is the quotient which describes the net transformation of food into body weight of the Common Cockle species. The growth factor has been assumed as 0.4.

Based on the assumptions the results, as a function of time, are found. The results are described in table VI-2. The results are described for individual Common Cockle species.

Standard residence time	growth factor	factor feeding rate
10	*0.4*	*4.8*

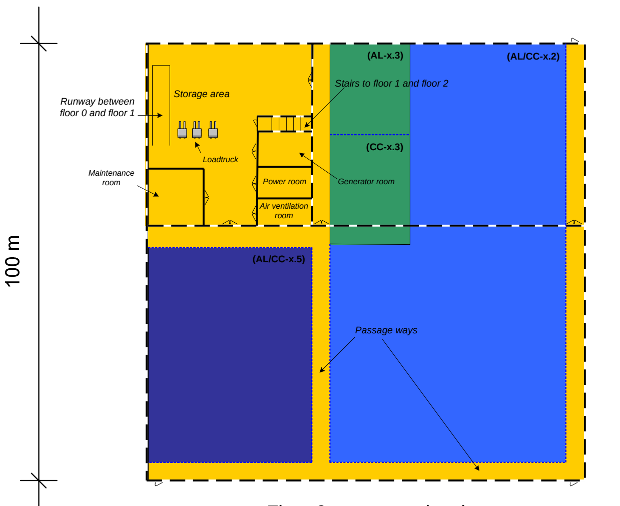
Shell length (mm)	Residence time (days)	Cumulative body weight (dry flesh weight) (g)	Cumulative body weight (fresh weight) (g)	Uni-algal species needed per standard residence time (dry weight) (g)	Cumulative added live uni-algal species (dry weight) (g)
0	0	0.00	0.00	0.0	0.00
1	10	0.00	0.00	0.0	0.00
2	20	0.00	0.00	0.0	0.00
3	30	0.00	0.01	0.0	0.00
4	40	0.00	0.03	0.0	0.01
5	50	0.00	0.06	0.0	0.02
6	60	0.01	0.10	0.0	0.03
7	70	0.01	0.15	0.0	0.05
8	80	0.01	0.22	0.0	0.09
9	90	0.02	0.32	0.0	0.13
10	100	0.03	0.43	0.1	0.20
11	110	0.03	0.57	0.1	0.28
12	120	0.04	0.74	0.1	0.39
13	130	0.06	0.94	0.1	0.53
14	140	0.07	1.17	0.2	0.71
15	150	0.09	1.43	0.2	0.92
16	160	0.10	1.73	0.3	1.18
17	170	0.12	2.07	0.3	1.49
18	180	0.15	2.45	0.4	1.86
19	190	0.17	2.88	0.4	2.29
20	200	0.20	3.35	0.5	2.80
21	210	0.23	3.87	0.6	3.38
22	220	0.27	4.44	0.7	4.04
23	230	0.30	5.07	0.8	4.80
24	240	0.34	5.75	0.9	5.67

25	250	0.39	6.48	1.0	6.64
26	260	0.44	7.28	1.1	7.73
27	270	0.49	8.14	1.2	8.95
28	280	0.54	9.07	1.4	10.31
29	290	0.60	10.06	1.5	11.82
30	300	0.67	11.12	1.7	13.49
31	310	0.74	12.25	1.8	15.33
32	320	0.81	13.46	2.0	17.35
33	330	0.88	14.74	2.2	19.56
34	340	0.97	16.10	2.4	21.97
35	350	1.05	17.54	2.6	24.60
36	360	1.14	19.07	2.9	27.46
37	370	1.24	20.68	3.1	30.57
38	380	1.34	22.38	3.4	33.92
39	390	1.45	24.16	3.6	37.55
40	400	1.56	26.04	3.9	41.45
41	410	1.68	28.02	4.2	45.66
42	420	1.81	30.09	4.5	50.17
43	430	1.94	32.26	4.8	55.01
44	440	2.07	34.53	5.2	60.19
45	450	2.21	36.90	5.5	65.72
46	460	2.36	39.38	5.9	71.63
47	470	2.52	41.96	6.3	77.92
48	480	2.68	44.66	6.7	84.62
49	490	2.85	47.47	7.1	91.74
50	500	3.02	50.39	7.6	99.30
51	510	3.21	53.43	8.0	107.32
52	520	3.40	56.59	8.5	115.80
53	530	3.59	59.87	9.0	124.79
54	540	3.80	63.28	9.5	134.28
55	550	4.01	66.81	10.0	144.30
56	560	4.23	70.46	10.6	154.87
57	570	4.46	74.25	11.1	166.00
58	580	4.69	78.17	11.7	177.73
59	590	4.93	82.23	12.3	190.06

Table VI-2: Results, as a function of time.

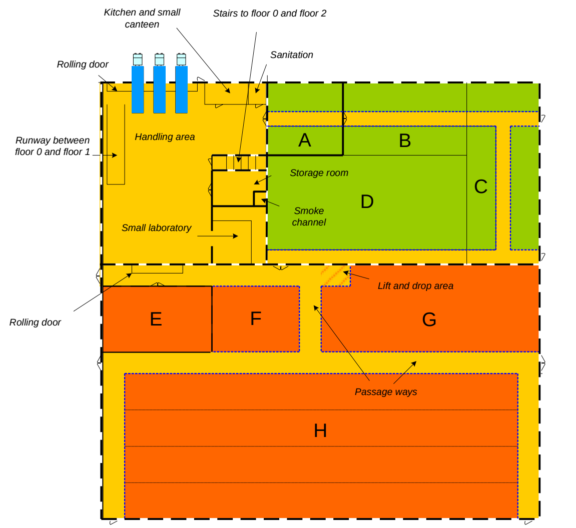
Appendix VII: Physical architecture

Aquacultural building at system level



Floor 0, at system level

100 m



Floor 1, at system level

100 m

Floor 2, at system level

100 m

Legend:

- Area for systems of the general infrastructure phase (GI-0)
- Area for culture of algae systems (AL-x.1), harvest of culture of algae systems (AL-x.6) and environment control system for uni-algal species (AL-x.4)
- Area for culture of Common Cockles systems (CC-x.1), harvest of Common Cockles systems (CC-x.6) and environment control system for Common Cockle species (CC-x.4)
- Area for the enrichement system for uni-algal species (AL-x.3)
- Area for the enrichement system for Common Cockle species (CC-x.3)
- Area for the seawater treatment system (AL/CC-x.2)
- Area for the effluent treatment system (AL/CC-x.5)
- Supporting concrete wall
- Wall for seperation
- Line for accents
- Line for sepearation of system
- Truck
- Loadtruck
- Exit

Legend of AL/CC-x.1*, AL/CC-x.4 and AL/CC-x.6*** systems:**

- A — Area for systems of stock culture (AL-1.1, AL-1.4 and AL-1.6)
- B — Area for systems of starter culture (AL-2.1, AL-2.4 and 2.6)
- C — Area for systems of Intermediate-scale culture (AL-3.1, AL-3.4 and 3.6)
- D — Area for systems of large-scale culture (AL-4.1, AL-4.4 and AL-4.6)
- E — Area for systems of broodstock conditioning (CC-1.1, CC-1.4 and CC-1.6)
- F — Area for systems of reproduction (CC-2.1, CC-2.4 and CC-2.6)
- G — Area for systems of larval rearing (CC-3.1, CC-3.4 and CC-3.6)
- H — Area for systems of settlement (CC-4.1, CC-4.4 and CC-4.6)
- I — Area for systems of growout (CC-5.1, CC-5.4 and CC-5.6)****

* The AL/CC-x.1 systems are the culture of algae systems (AL-x.1) and the culture of Common Cockles systems (CC-x.1).

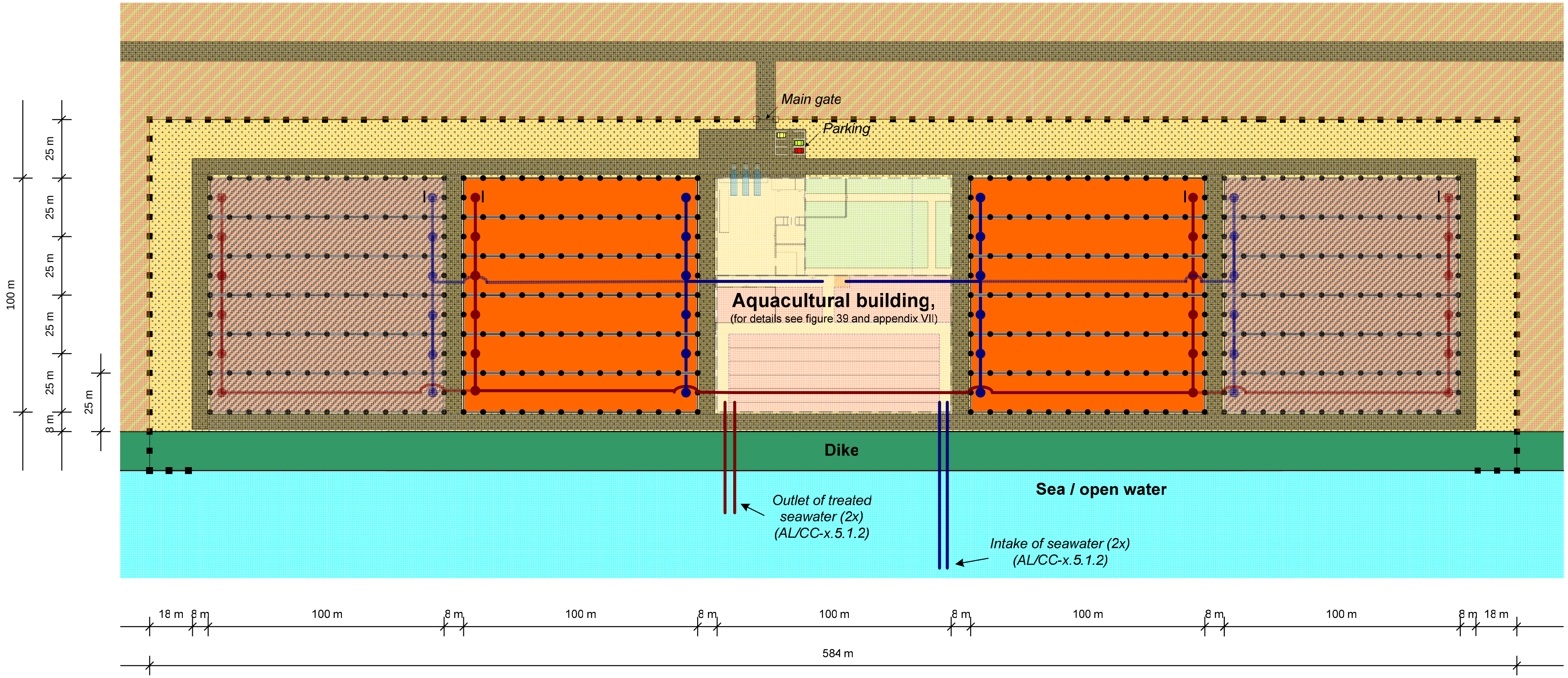
** The AL/CC-x.4 systems are the environmental control system for uni-algal species (AL-x.4) and the environmennntal control system for Common Cockles species (CC-x.4).

*** The AL/CC-x.6 systems are the harvest of culture of algae systems (AL-x.6) and the harvest of culture of Common Cockles systems (CC-x.6).

**** The systems of the growout (CC-5.1, CC-5.4 and CC-5.6) are located outside the aquacultural building. These systems are described in figure ?? and appendix ??

Appendix VIII: Physical architecture

Aquacultural site at system level, including three alternatives



Legend:

Area for culture of Common Cockles system of the grow-out (CC-5.1), environment control system of the growout (CC-5.4) and harvest of Common Cockles system of the growout (CC-5.6)	Semi-hardening or grass	Intake of seawater	Exit
Alternative 1; growout of 2 ha	Concrete pavement / asphalt	Outlet of seawater	Car
Alternative 2; growout of 4 ha	Dike	Fence, with horizontal nets	Truck
Alternative 3; growout of > 4 ha	Sea / open water	Outer fence	Loadtruck

IX Specification of the estimated costs

In this appendix the specification of the estimated costs of alternative is described. In table IX-1 an overview has been presented of the systems costs and additive costs at phase and sub-phase level of alternative 1 and alternative 2.

Specification of the estimated costs
Overview

Systems costs		**ALTERNATIVE 1**				**ALTERNATIVE 2**			
Description	**Traceability code**	**Volume**	**Cost (€)**	**Investment (€)**	**%**	**Volume**	**Cost (€)**	**Investment (€)**	**%**
Algal culture phase	***AL-0***	***2 070 m2***		***2 077 491***	***19.2***	***2 070 m2***		***1 699 808***	***12.8***
Stock culture	AL-1	230 m2	714	164 305	1.5	230 m2	532	122 340	0.9
Starter culture	AL-2	380 m2	815	309 716	2.9	380 m2	633	240 383	1.8
Intermedate-scale culture	AL-3	490 m2	959	469 731	4.3	490 m2	776	380 328	2.9
Large-scale culture	AL-4	970 m2	1 169	1 133 739	10.5	970 m2	986	956 757	7.2
Common Cockle culture phase	***CC-0***	***24 585 m2***		***2 491 628***	***23.0***	***44 585 m2***		***2 868 410***	***21.7***
Broodstock conditioning	CC-1	370 m2	129	47 739	0.4	370 m2	105	38 772	0.3
Reproduction	CC-2	300 m2	120	35 896	0.3	300 m2	95	28 626	0.2
Larval rearing	CC-3	950 m2	108	103 004	1.0	950 m2	84	79 982	0.6
Settlement	CC-4	2 965 m2	128	378 797	3.5	2 965 m2	106	313 029	2.4
Growout	CC-5	20 000 m2	96	1 926 192	17.8	40 000 m2	60	2 408 002	18.2
General infrastructure	***GI-0***	***16 385 m2***		***545 150***	***5.0***	***21 885 m2***		***765 150***	***5.8***
General systems	GI-1	170 m2	1 176	200 000	1.8	170 m2	1 176	200 000	1.5
Employees/guest facilities	GI-2	10 215 m2	10	105 150	1.0	10 215 m2	10	105 150	0.8
Distribution system	GI-3	6 000 m2	40	240 000	2.2	11 500 m2	40	460 000	3.5
			Sub-total:	**5 114 269**	***47.3***		**Sub-total:**	**5 333 368**	***40.3***
Additive costs									
Description		**Volume**	**Cost (€)**	**Investment (€)**		**Volume**	**Cost (€)**	**Investment (€)**	
Land		***50 000 m2***	***75***	***3 750 000***	***34.7***	***77 500 m2***	***75***	***5 812 500***	***43.9***
Housing		***1 st.***	***1 500 000***	***1 500 000***	***13.9***	***1 st.***	***1 500 000***	***1 500 000***	***11.3***
Engineering		***1 st.***	***150 000***	***150 000***	***1.4***	***1 st.***	***200 000***	***200 000***	***1.5***
Miscellaneous		***1 st.***	***300 000***	***300 000***	***2.8***	***1 st.***	***400 000***	***400 000***	***3.0***
			Sub-total:	**5 700 000**	**52.7**		**Sub-total:**	**7 912 500**	**59.7**
			Total:	**10 814 269**	**100.0**		**Total:**	**13 245 868**	**100.0**

Table IX-1: Overview of the estimated costs at phase and sub-phase level of alternative 1 and 2.

In table IX-2, IX-3, and IX-4 the estimated costs of the Common Cockle culture phase, algal culture phase, and general infrastructure phase are described at system level.

Specification of the estimated costs
of the algal culture phase

Description	Traceability code	ALTERNATIVE 1				ALTERNATIVE 2			
		Volume	Cost (€)	Investment (€)	%	Volume	Cost (€)	Investment (€)	%
Stock culture	***AL-1***	***230 m2***		***164 305***	***100.0***	***230 m2***		***122 340***	***100.0***
Culture of algae system	AL-1.1	207 m2	100	20 700	12.6	207 m2	100	20 700	16.9
Seawater treatment system	AL-1.2	37 m2	2 000	74 207	45.2	21 m2	2 000	42 396	34.7
Enrichment system	AL-1.3	42 m2	500	21 111	12.8	42 m2	500	21 111	17.3
Environmental control system	AL-1.4	23 m2	200	4 600	2.8	23 m2	200	4 600	3.8
Effluent treatment system	AL-1.5	16 m2	1 500	23 686	14.4	9 m2	1 500	13 532	11.1
Harvest of culture system	AL-1.6	4 st.	5 000	20 000	12.2	4 st.	5 000	20 000	16.3
Starter culture	***AL-2***	***380 m2***		***309 716***	***100.0***	***380 m2***		***240 383***	***100.0***
Culture of algae system	AL-2.1	342 m2	250	85 500	27.6	342 m2	250	85 500	35.6
Seawater treatment system	AL-2.2	61 m2	2 000	122 604	39.6	35 m2	2 000	70 046	29.1
Enrichment system	AL-2.3	70 m2	500	34 879	11.3	70 m2	500	34 879	14.5
Environmental control system	AL-2.4	38 m2	200	7 600	2.5	38 m2	200	7 600	3.2
Effluent treatment system	AL-2.5	26 m2	1 500	39 133	12.6	15 m2	1 500	22 358	9.3
Harvest of culture system	AL-2.6	4 st.	5 000	20 000	6.5	4 st.	5 000	20 000	8.3
Intermediate-scale culture	***AL-3***	***490 m2***		***469 731***	***100.0***	***490 m2***		***380 328***	***100.0***
Culture of algae system	AL-3.1	441 m2	400	176 400	37.6	441 m2	400	176 400	46.4
Seawater treatment system	AL-3.2	79 m2	2 000	158 094	33.7	45 m2	2 000	90 323	23.7
Enrichment system	AL-3.3	90 m2	500	44 976	9.6	90 m2	500	44 976	11.8
Environmental control system	AL-3.4	49 m2	200	9 800	2.1	49 m2	200	9 800	2.6
Effluent treatment system	AL-3.5	34 m2	1 500	50 461	10.7	19 m2	1 500	28 830	7.6
Harvest of culture system	AL-3.6	6 m2	5 000	30 000	6.4	6 m2	5 000	30 000	7.9
Large-scale culture	***AL-4***	***970 m2***		***1 133 739***	***100.0***	***970 m2***		***956 757***	***100.0***
Culture of algae system	AL-4.1	873 m2	650	567 450	50.1	873 m2	650	567 450	59.3
Seawater treatment system	AL-4.2	156 m2	2 000	312 962	27.6	89 m2	2 000	178 802	18.7
Enrichment system	AL-4.3	178 m2	500	89 034	7.9	178 m2	500	89 034	9.3
Environmental control system	AL-4.4	97 m2	200	19 400	1.7	97 m2	200	19 400	2.0
Effluent treatment system	AL-4.5	67 m2	1 500	99 893	8.8	38 m2	1 500	57 071	6.0
Harvest of culture system	AL-4.6	6 st.	7 500	45 000	4.0	6 st.	7 500	45 000	4.7

Table IX-2: Estimated costs at system level of the algal culture phase of alternative 1 and 2.

Specification of the estimated costs
of the Common Cockle culture phase

Description	Traceability code	ALTERNATIVE 1				ALTERNATIVE 2			
		Volume	Cost (€)	Investment (€)	%	Volume	Cost (€)	Investment (€)	%
Broodstock conditioning	***CC-1***	***370 m2***		***47 739***	***100.0***	***370 m2***		***38 772***	***100.0***
Culture of Common Cockles system	CC-1.1	333 m2	50	16 650	34.9	333 m2	50	16 650	42.9
Seawater treatment system	CC-1.2	54 m2	250	13 430	28.1	31 m2	250	7 673	19.8
Enrichment system	CC-1.3	7 m2	250	1 693	3.5	4 m2	250	934	2.4
Environmental control system	CC-1.4	37 m2	250	9 250	19.4	37 m2	250	9 250	23.9
Effluent treatment system	CC-1.5	23 m2	250	5 716	12.0	13 m2	250	3 265	8.4
Harvest of culture system	CC-1.6	2 st.	500	1 000	2.1	2 st.	500	1 000	2.6
Reproduction	***CC-2***	***300 m2***		***35 896***	***100.0***	***300 m2***		***28 626***	***100.0***
Culture of Common Cockles system	CC-2.1	270 m2	50	13 500	37.6	270 m2	50	13 500	47.2
Seawater treatment system	CC-2.2	44 m2	250	10 889	30.3	25 m2	250	6 221	21.7
Enrichment system	CC-2.3	5 m2	250	1 373	3.8	3 m2	250	757	2.6
Environmental control system	CC-2.4	30 m2	150	4 500	12.5	30 m2	150	4 500	15.7
Effluent treatment system	CC-2.5	19 m2	250	4 634	12.9	11 m2	250	2 648	9.2
Harvest of culture system	CC-2.6	2 st.	500	1 000	2.8	2 st.	500	1 000	3.5
Larval rearing	***CC-3***	***950 m2***		***103 004***	***100.0***	***950 m2***		***79 982***	***100.0***
Culture of Common Cockles system	CC-3.1	855 m2	50	42 750	41.5	855 m2	50	42 750	53.4
Seawater treatment system	CC-3.2	138 m2	250	34 482	33.5	79 m2	250	19 700	24.6
Enrichment system	CC-3.3	17 m2	250	4 347	4.2	10 m2	250	2 397	3.0
Environmental control system	CC-3.4	95 m2	50	4 750	4.6	95 m2	50	4 750	5.9
Effluent treatment system	CC-3.5	59 m2	250	14 675	14.2	34 m2	250	8 384	10.5
Harvest of culture system	CC-3.6	2 st	1 000	2 000	1.9	2 st	1 000	2 000	2.5
Settlement	***CC-4***	***2 965 m2***		***378 797***	***100.0***	***2 965 m2***		***313 029***	***100.0***
Culture of Common Cockles system	CC-4.1	2 669 m2	50	133 425	35.2	2 669 m2	50	133 425	42.6
Seawater treatment system	CC-4.2	430 m2	250	107 621	28.4	246 m2	250	61 486	19.6
Enrichment system	CC-4.3	297 m2	250	74 125	19.6	297 m2	250	74 125	23.7
Environmental control system	CC-4.4	297 m2	50	14 825	3.9	297 m2	50	14 825	4.7
Effluent treatment system	CC-4.5	183 m2	250	45 801	12.1	105 m2	250	26 167	8.4
Harvest of culture system	CC-4.6	2 st	1 500	3 000	0.8	2 st	1 500	3 000	1.0
Growout	***CC-5***	***20 000 m2***		***1 926 192***	***100.0***	***40 000 m2***		***2 408 002***	***100.0***
Culture of Common Cockles system	CC-5.1	20 000 m2	10	200 000	10.4	40 000 m2	10	400 000	16.6
Seawater treatment system	CC-5.2	3 226 m2	250	806 603	41.9	3 687 m2	250	921 659	38.3
Enrichment system	CC-5.3	366 m2	500	183 038	9.5	404 m2	500	201 862	8.4
Environmental control system	CC-5.4	0 m2	0	0	0.0	0 m2	0	0	0.0
Effluent treatment system	CC-5.5	1 373 m2	500	686 550	35.6	1 569 m2	500	784 482	32.6
Harvest of culture system	CC-5.6	2 m2	25 000	50 000	2.6	4 m2	25 000	100 000	4.2

Table IX-3: Estimated costs at system level of the Common Cockle culture phase of alternative 1 and 2.

Specification of the estimated costs
of the general infrastructure phase

Description	System Code	ALTERNATIVE 1 Volume	ALTERNATIVE 1 Cost (€)	ALTERNATIVE 1 Investment (€)	ALTERNATIVE 1 %	ALTERNATIVE 2 Volume	ALTERNATIVE 2 Cost (€)	ALTERNATIVE 2 Investment (€)	ALTERNATIVE 2 %
General systems	***GI-1***	***170 m2***		***200 000***	***100.0***	170 m2		200 000	100.0
Power system	GI-1.0.1	90 m2	1 000	90 000	45.0	90 m2	1 000	90 000	45.0
Air ventilation system	GI-1.0.2	80 m2	1 000	80 000	40.0	80 m2	1 000	80 000	40.0
Emergency system	GI-1.0.3	n/a	n/a	10 000	5.0	n/a	n/a	10 000	5.0
Maintenance system	GI-1.0.4	n/a	n/a	20 000	10.0	n/a	n/a	20 000	10.0
Employees/guest facilities	***GI-2***	***10 215 m2***		***105 150***	***100.0***	***10 215 m2***		***105 150***	***100.0***
Working facilities	GI-2.0.1	10 000 m2	10	100 000	95.1	10 000 m2	10	100 000	95.1
General facilities	GI-2.0.2	75 m2	50	3 750	3.6	75 m2	50	3 750	3.6
Relaxing facilities	GI-2.0.3	140 m2	10	1 400	1.3	140 m2	10	1 400	1.3
Distribution system	***GI-3***	***6 000 m2***		***240 000***	***100.0***	***11 500 m2***		***460 000***	***100.0***
Goods system	GI-3.0.1	6 000 m2	20	120 000	50.0	11 500 m2	20	230 000	50.0
Utility system	GI-3.0.2	n/a	n/a	120 000	50.0	n/a	n/a	230 000	50.0

Table 4: Estimated costs at system level of the general infrastructure phase of alternative 1 and 2.