Common factors behind success or failure of innovations

Algae farming in the port of Rotterdam

Master's Thesis

Students
Ewa Paluszkiewicz, 326507
Wilfred Mak, 323940

Supervisor
Dr. Wouter Jacobs

Erasmus School of Economics
Erasmus University Rotterdam

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1. Introduction

Sustainability has been recognized by the international community as a fundamental principle for economic development. The need to balance economical, societal and environmental requirements, sets out the new context in which business operate. This view is shared by some economists, Freeman and Louca pointed out that renewable energy could be the main constellation of innovations for the next Kondratieff wave (Freeman, 1996b, Freeman and Louca, 2001).[1]

There are reasons why ports should be concerned about sustainability. Ports are sources of pollution; they contribute greatly to the environmental degradation of the area, which affects the welfare of the local stakeholders and the image of the port cities. The signing of agreements and regulations such as the Kyoto Protocol and the American Clean Energy and Security Act suggest that the need to achieve sustainability will only grow through time. If ports want to continue to grow, they must resolve a range of issues derived from port activities, namely air pollution, water contamination, extensive land use, industrial wastes and congestion to name but a few.

New initiatives aiming to reduce the negative impact of ports on the environment have arisen recently. Hans Smits, CEO of the Port of Rotterdam Authority, said that "Investment in sustainability is essential, because the port of the future is green and clean."[2] Innovativeness and creativity in sustainability initiatives benefit the environment and contributes to the port's long term competitive position. The ability of a port cluster to generate or adopt sustainable innovations will therefore be the key to achieve these initiatives. There are, however, many factors behind the successful generation or adoption of innovations. The quality of the learning process is one example, and it is determined by the quality of the cluster's knowledge flow such as pipelines and local buzz (Maskell, Bathelt and Malmberg, 2004). Past experience is another factor, as it leads to path-dependence and cognitive lock-in (Hudson, 2005; Maskell & Malmberg, 1999).

The pursuit of sustainability is stimulating technological innovations across the society. This includes the use of alternative energy such as biofuels. What gained a lot of public interest in the last few years is algae. Like other biomass, algae could generate energy and has many other applications. Although the commercial scale has not yet been reached, the concept of algae as a biofuel continues to attract investments. In theory, port makes a good location for algae energy generation activities as its pollution (e.g. CO_2, sewage) can be used as fertilisers for algae. In practise, however, amongst European ports only the seaport of Venice is openly looking into algae as an energy source.

According to the academic literature, there is a number of factors influencing the success of the adoption of innovations. Our thesis aims to assess these factors and evaluate the potential of algae technology in the port of Rotterdam. We also aim to provide policy recommendations on the adoption of the algae technology based on our research.

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[1] Malecki and Moriset (2008), The Digital Economy: Business Organisation, Production Processes and Regional Developments, Routledge, pp.26

[2] *Working together towards a sustainable port*, DCMR Rijnmond Environmental Protection Agency, Rotterdam department, Port of Rotterdam Authority, Corporate Development department; Rotterdam, December 2007; *http://www.portofrotterdam.com/mmfiles/sustainable_port_tcm26-50118.pdf*

1.1 Research Aim

The goal of our thesis is to gain insights in the factors influencing successful adaptation of innovations in order to evaluate the potential of algae farming in the port of Rotterdam.

1.2 Research Questions

1. What are the common factors behind success and failure of sustainable innovations?
2. Why are sustainable innovations important for ports?
3. What is the role of the port cluster in the innovation process?
4. What are the outstanding obstacles for algae farming in the port of Rotterdam?

1.3 Research Methodology

First, a literature review is conducted to understand what factors are important to the success of an innovation. This is combined with a series of exploratory in-depth interviews with representatives of algae industry in the Netherlands, universities, local and national government representatives, consultants, energy companies, port of Rotterdam and port industry association. The face-to-face interviews last about an hour, and we conducted the interviews with fourteen organisations. The collection period went from June 2009 to July 2009.

1.4 Structure of the Thesis

In chapter two we introduce the innovation theory, the concept of sustainability and its importance for ports (port clusters). Next, we present the literature review on factors influencing success and failure of innovations. Chapter three provides background information about algae. Policy background on renewable energy is given in chapter four. In chapter five results from the empirical study are discussed – we analyze success and failure factors with regard to algae technology in the Netherlands. We end the thesis with conclusions and policy recommendations (chapter six).

2. Innovations and sustainability

The first step to understand what factors may influence the success or failure of algae as a renewable energy source in the port of Rotterdam is the literature review. There are three aspects relevant for our research.

The starting point is defining what the innovation is and what is its role in the economic development, so why do we need innovations. Then we look closer at the concept of sustainability, as it is a driver for innovations such as algae. It leads us to **sustainable innovations**, which are at the heart of this thesis.

Second, we are interested in a specific environment for innovations which is a **seaport**. Ports are clusters of maritime and industrial activities with significant impact on their surroundings. They play an important role in the regional and national economy, but at the same time generate negative externalities which are a cost to society. In order to facilitate further growth, ports are actively looking for ways to reduce that negative impact, hence the importance of sustainable innovations.

We also go back to the definition of a cluster and its role in the innovation process to find the characteristics that may be useful in empirical analysis.

Having gained the background information on sustainable innovations, we explore the **factors behind their success or failure**. Renewable energy technologies are the focal point here.

Comprehensive literature review allowed us to come up with the list of most common factors which served as a framework for the empirical analysis.

2.1 The role of innovations in sustainable development

We start our discussion about the importance of sustainable innovations with introducting the innovation theory and the origins of the sustainability concept. Having done that, we will define sustainable innovations and describe their role in the economic system.

2.1.1 Innovations – short introduction

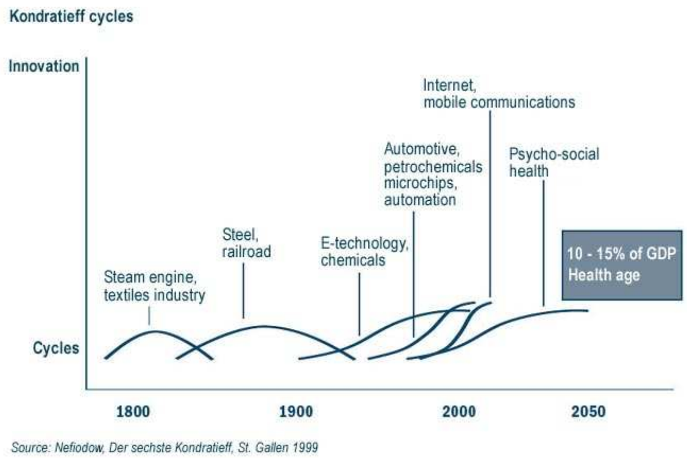
It is argued that a society's economic structure is not static. From time to time the economy adjusts itself in terms of the type of output and the production method. In other words, the economy tends to 'evolve', and the question is what causes these adjustments.

Evolutionary economics suggest that the cause is innovation. It is argued that the main reason behind the change of economic structure is not the population, social environment, or even war. Rather, it is the new markets, new consumers' goods, new production method and new organisational development created by the enterprises, and they can only be created through a process of qualitative change. As Schumpeter said, "*add successively as many mail coaches as you please, you will never get a railway thereby*" (Schumpeter, 1961). He then describes the innovation process as "*a process of industrial mutation that incessantly revolutionises the economic structure from within, incessantly destroying the old one, incessantly creating a new one."* The innovation process is therefore what Schumpeter would call the process of Creative Destruction (Schumpeter, 1950).

In another piece, Schumpeter argues that technological innovation is behind the Kondratieff waves – long waves of accelerated and decelerated economic growth that last around fifty years. Named after the economist Nikolai Kondratieff, these waves are longer than a normal business cycle that generally means seven to eleven years (Kondratieff, 1935). Schumpeter believes innovations ‘carry a Kondratieff’, but through time the innovation loses its stimulating character and ceases to drive the economy, bringing the wave to a downgrade.

There are different views on what the next Kondratieff innovation is going to be. In the diagram below, on top of illustrating the Kondratieff waves in the past two centuries, Niefiodow (1999) considers the psycho-social health technology as the next Kondratieff innovation. Some economists, however, believe that given the right conditions, renewable energy could be the main constellation of the next Kondratieff wave (Freeman, 1996, Freeman & Louca, 2001).

Figure 1.Kondratieff cycles



Source: Niefodow, 1999

There is not a fixed definition for an innovation (Burgelman and Sayles, 1986). Many agree that whatever innovation is, it is not invention. Schumpeter suggests that the making of invention and the carrying out of the corresponding innovation are two entirely different things, requiring different aptitudes. His definition boils down to “doing things differently in the realm of economic life.”

The Organisation for Economic Co-operation and Development (OECD) definition is popularly cited (The Economist, 2007; Garcia & Calantone, 2002; Rogers, 1998). The latest OECD definition covers four areas: product, process, marketing and organisation. It says that ‘*an innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations”* (OECD, 2005). It is clear that an innovation is only considered so if it leads to significant improvements. Application is therefore a criterion in defining an innovation. The ability to add economic value therefore distinguishes an innovation from an invention (Garcia & Calantone, 2002). Roberts (2007) further simplifies the definition to the following equation:

Innovation = Invention + Exploitation

Although the OECD defines innovation as a process, there is another view that innovation is a discrete event. However, the two views do not necessarily clash. Those who consider innovation as an event focus on the point when the innovation is put to use within an organisation (Cooper, 1998). This implies the application stage of the innovation process, or the ‘exploitation’ part of

Roberts' equation. It is argued that treating innovation as a discrete event is more suitable for assessing an organisation's ability to adopt an innovation. Given that firms tend to imitate other organisations (fashion setters) regarding which technology to adopt or reject (Abrahamson, 1991), the discrete event approach allow firms to better understand who to imitate.

2.1.2 Sustainability – short introduction

The idea of sustainability was first introduced in the report "The Limits to Growth" in 1972. The report, commissioned by a group of professionals called the Club of Rome, highlights the contradiction between the exponential growth of resource consumption and planet's capacity to support such growth. It says that the limits to growth on this planet will be reached within a hundred years (Meadows et al., 1972).

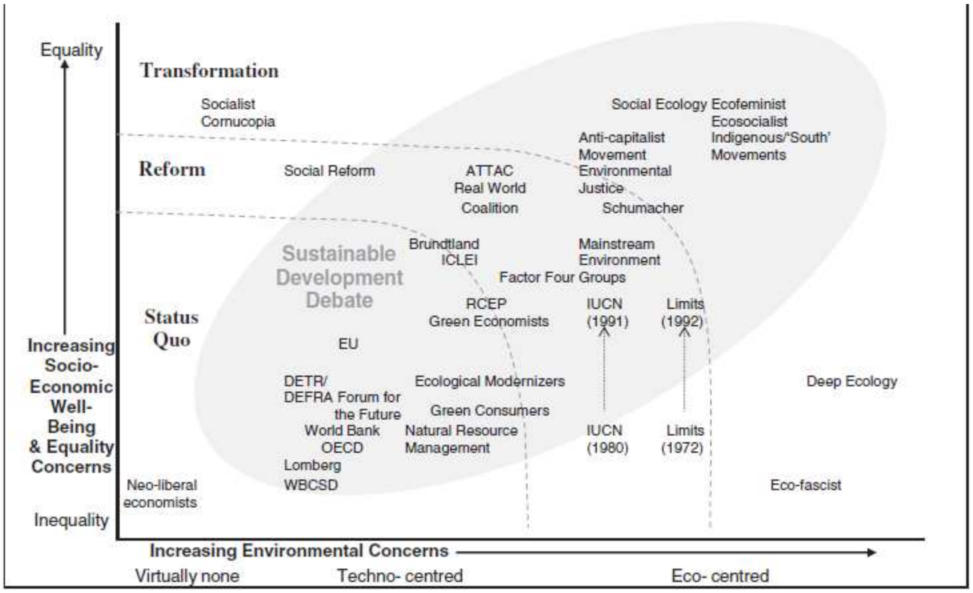
The term *sustainable development* is first coined in 1987 when the United Nations (UN) released the Report of the World Commission on Environment and Development, also known as the Brundtland Report. The report defines sustainable development as *"meeting the needs of the present without compromising the ability of future generations to meet their own needs"* (UN, 1987). This is followed by an action plan for sustainable development called Agenda 21, often referred to as the Blueprint for Sustainable Development (UNEP website). The plan was adopted by more than 178 governments at the 'Earth Summit' conference in Rio de Janeiro in 1992 (UN, 1993) and subsequently reaffirmed in 2002. Participants are required to meet various objectives set by the agenda; they range from enhancing the understanding of the Earth's carrying capacity, to providing new and predictable financial resources.

During the Earth Summit the United Nations Framework convention on Climate Change (UNFCCC) was also adopted. The convention encourages intergovernmental efforts to deal with climate change. The focus, however, goes to the Kyoto Protocol – an additional treaty that has more stringent greenhouse gases binding targets and requires commitment (UNFCC website). Participants of the Kyoto Protocol are given mechanisms to achieve their targets, one of them being 'emissions trading', also known as the 'carbon market' (UNFCC website). This mechanism allows countries to trade emission capacities, putting a price on emissions and therefore allow emitting parties to optimise their production process. The American Clean Energy and Security Act, a recently proposed bill, embodies a similar cap-and-trade system (New York Times, 2009).

Environment issues are central to sustainability. Scientific evidence suggests that there is discernible human influence on global climate (IPCC, 2007), and climate change has been linked to melting icecaps, land loss, water shortage rising sea level across the world (The Guardian, 2008), and even the shrinking size of the sheep (Coulson et al., 2009). Greenhouse gases such as Carbon Dioxide (CO_2) and Nitrous Oxide (N2O) have been cited as a central cause of climate change. They are the by-product of economic activities such as transport and energy supply, and their emission is increasing in an alarming rate. The global CO_2 emission, for example, has grown by 80% from 1970 to 2004 (IPCC, 2007). In Europe, transport has been the only economic sector seeing its greenhouse gas emissions increase between 1990 - 2004, this has led to the discussion of 'decoupling' – de-linking economic growth from increasing environmental problems (Mingardo et al., 2008). The attitude towards decoupling is that "just slowing the growth in emissions of greenhouse gases from transport is not enough" (EEA, 2007), this view encapsulates the spirit of sustainability in general.

Sustainability, however, is not only about the environment. There is a socioeconomic aspect which covers poverty, inequality and health. Recall that the definition in the Brundtland report is about future generation meeting their needs; such need is clearly not confined to just a clean environment. The following diagram summarises the environmental view, the socio-economic view and the position of the players (Hopwood et al., 2005):

Figure 2. Mapping of views on sustainable development



Source: Hopwood et al., 2005

An example of the socio-economic aspect is the Grameen bank. Muhammad Yunus, the founder and 2006 Nobel Peace prize winner, argues that one cannot sustain peace in a society if poverty is not eliminated (Yunus, 2006). The Grameen bank achieves sustainability not only by reducing poverty and all the issues that entail, it is also a loan providing model that lives on its own results – loans are conditional to the entrepreneurs meeting their repayment schedule. The model provides strong incentives for loan demanders to share knowledge and repay on time. At a loan recovery rate of 98% (Hal Varian, 1996), the bank is in a better position to continue lending and continue to help the development of the region. The model is therefore sustained only by its own success.

2.1.3 Importance of sustainable innovations

Before reviewing the existing definitions of sustainable innovations, it is possible to crudely define sustainable innovations by combining the definitions of innovations and sustainability in 2.1.1 and 2.1.2 That would be *"the implementation of a new or significantly improved product (good or service), or process, a new marketing method or a new organisational method in business practices, workplace organisation or external relations, that meets the need of the present without compromising the ability of the future generations to meet their own needs."*

This definition is not too far off compare to the existing definitions. In general, sustainable innovations are defined as innovations that lead to more sustainable technological and institutional systems and processes, taking into account environmental limits, social acceptance and social justice (Foxon & Pearson, 2008; Foxon et al., 2004). Sometimes the name *'sustainability-driven innovations'* is adopted, defined as the creation of new market space, products and services driven by sustainability issues (Keeble et al., 2005).

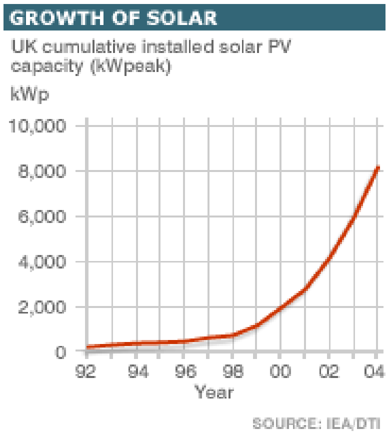
Some definitions find a corporate, rather than general, angle. Sustainable innovation could be a process where sustainability is incorporated into various areas of the business (Clark & Charter, 2007). Approaches such as the sustainable innovation design diamond are developed to help companies integrate sustainability in daily business practice (Hallenga-Brink & Brezet, 2005). The need of connecting with stakeholders is explicitly mentioned, since they are not part of the firms. It is worth noting that some interprets 'sustainable innovations' differently. They see sustainable innovation as an innovation that continues to produce economic benefit for the organisation in the long run – the opposite of temporary innovation. Rather than focusing on the environmental or social aspect, it looks at the innovation's ability to generate the 'second successful venture', especially for small and medium enterprises (Yang, 2008).

The connection between sustainable innovation and sustainability lies in how much we are prepared to sacrifice our economic growth. Pollution, a major obstacle to sustainability, is a by-product of economic activity. Reducing economic activity will reduce pollution, but this also implies giving up economic growth. This is clearly unrealistic. Many governments have economic growth as their top priority. China, for example, is aiming to grow by 8% in 2009 and more than 9% in 2011. It only considers its economy to have recovered from the current recession when it achieves an annual growth higher than 9% (Bloomberg News, 2009). Since reducing economic activities is not an option, the focus must shift to promote innovation in clean technology in economic activities such as energy supply (Carrillo-Hermosilla, 2006; EnergieTransitie, 2008). This is particularly important for countries adopting the Kyoto Protocol since emissions will bring extra costs, and sustainable innovations could provide savings. The extra cost of adopting such innovations may be offset by the savings in the carbon market, leading to net savings.

Some researchers have taken the importance of sustainable innovation as a given and focus their research on the choice of innovation. They argue that incremental innovations along established paths are not enough to achieve environmental sustainability, and a more radical approach is required (Nill & Kemp, 2009). Sustainable innovation therefore helps to achieve sustainability while minimising the sacrifice of economic growth.

Sustainable innovation has another role in the economy: it is itself an industry. The market for sustainable products is growing fast, presenting firms and entrepreneurs, big or small, with opportunities to make profits. Between 2003 and 2008, the volume of biofuels consumption for road transport went from 4 million litres to 526 million litres (CBS, 2009); Solar Photovoltaic (Solar PV), a domestic device that converts sunlight into electricity (Energy Saving Trust, 2009), has seen its installation increased substantially during 1992 to 2004 (BBC, 2006). With business opportunities come jobs. In the UK, the environmental industries are estimated to provide an extra 400,000 jobs by 2015 (BBC, 2009).

Figure 3. UK cumulative installed solar PV capacity



Source: BBC, 2006

The size of the enterprises does not seem to be a factor here. In presenting the sustainable innovation design diamond, Hallenga-Brink and Brezet stated that theoretically it is possible to adapt innovation models meant for large organisations to micro-sized enterprises (Hallenga-Brink & Brezet, 2005). Echoing section 2.1.1, sustainable innovation can therefore be understood as the new wave of Schumpeter's 'creative-destruction' that firms of all size can participate in. These innovations fulfil the sustainability criteria while producing profits – a win-win situation for all, and they could help firms to 'migrate toward a long term stable carrying capacity' (Larson, 2000).

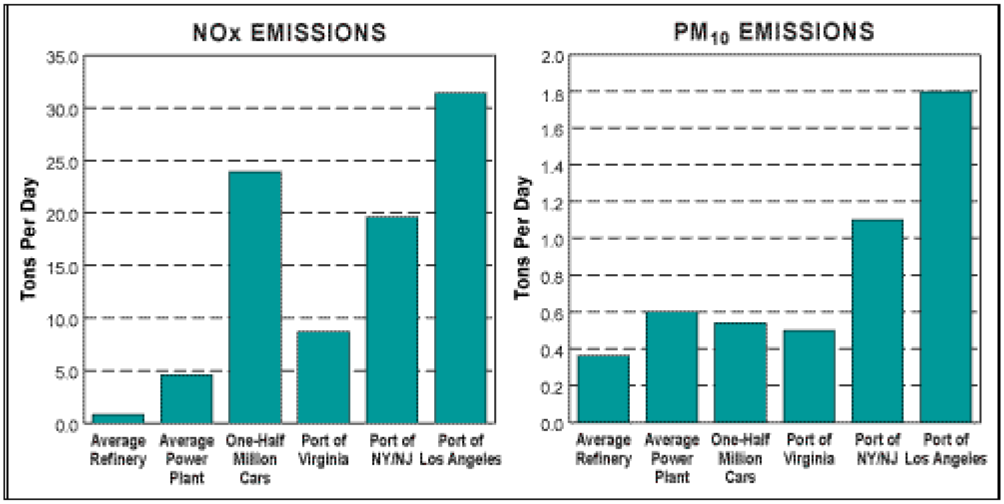
2.2Sustainability in ports

2.2.1 Why are sustainable innovations important for ports?

Ports are hubs of maritime transport and economic activities. However, such a concentration of activities generates pollution – a *negative production externality* which is a cost to society. Hal Varian used the reduction of fishery catch due to the pollution produced by a nearby steel mill as an example (Hal Varian, 1996).

Ports are therefore sources of pollutions, and Rotterdam and Antwerp are prime examples. 25% of the carbon dioxide production in the Netherlands is related to the port of Rotterdam, while the ports of Rotterdam and Antwerp produce the highest concentration of nitrogen dioxide in Europe together with the Ruhr Area and Northern Italy (Kuipers, 2008). The environmental impact of ports has also been noted in other parts of the world. The nitrous oxide and particulate matter pollution from port of Los Angeles and the port of New York/New Jersey are substantially higher than an average refinery or an average power plant (Bailey et al., 2004).

Figure 4. Nitrous Oxide (Nox) and Particulate Matter (PM10) Pollution from Ports Compared to Refineries, Power Plants and Cars



Source: Bailey et al., 2004

Ports generate a substantial amount of pollution because they are not just about cargo handling and stevedoring. Being a transport hub, the port is an attractive location for industrial activities such as refinery. The port of Rotterdam houses five oil refineries and forty three chemical & petrochemical companies amongst its industry (Port of Rotterdam, 2008). The port of Antwerp boasts the largest and most diversified petrochemical centre in Europe (Port of Antwerp, 2008). The industrial activities add to the existing air pollution, water contamination, extensive land use, industrial wastes and traffic congestion. In other words, ports are sources of negative externalities, and it affects the welfare of the stakeholders of the ports, which do not only include its employees, but also the residents in the port areas for example.

The ports' heavy generation of externalities has made sustainability a major port issue worldwide. Hans Smits, the CEO of the Port of Rotterdam Authority, said that "*Investment in sustainability is essential, because the port of the future is green and clean*." Jacques Barrot, vice president of the European Commission in charge of Transport, said "*Environmental protection and port development need to go hand in hand*" (Barrot, 2007). Many ports understand that sustainability is important to their continuity and profitability, and this has led to ports participating in climate initiatives. The port of Rotterdam is one of the initiators of the Rotterdam Climate Initiative (RCI); the port aims to help the city reduce its CO_2 emission by 50% (1990 level) by 2025 and turn Rotterdam into the 'world capital of CO2-free energy' (RCI, 2007). Ports also cooperate to achieve sustainability. In July 2008, fifty-five ports adopted The C40 World Ports Climate Declaration regarding greenhouse gas emission (WPCC, 2008). This is followed by the launch of The World Ports Climate Initiative, a global platform for ports to tackle climate change (IAPH, 2008).

The best way to minimise pollution is to shut down port operations altogether, but like we mentioned in 2.1.2, it is clearly unrealistic. Sustainable innovations therefore help ports to fulfil these initiatives by reducing the amount of pollution produced by port operations. An example is 'Distrivaart'. Distrivaart is a project that develops a network in the Netherlands to transport goods on barges between distribution centres and supermarkets (Wiegmans, 2005). This innovation aims to increase the use of barges, a more environmentally friendly transport mode than road transport – the dominant inland transport mode in the European Union (European Road Statistics, 2008). Algae, a type of organisms that could be converted into oil amongst other commercial applications, are capable of absorbing CO2 and industrial waste during their growth. Studies suggest that producing 1kg of algae require between 1.8kg to 3kg of CO_2 (Becker, 1994; BBC, 2008).

Despite the financial crisis, studies have shown that the world economy, as well as world trade volume, should resume its growth starting 2010 (World Bank, 2009; IMF, 2009). This means activities in the ports – both the transport and industrial activities – are unlikely to slow down and ports will be actively looking for ways to grow in a cleaner fashion. Sustainable innovations will play a key role in helping ports to reduce the environmental impact of their growth.

2.2.2 Port as a cluster – innovations in clusters

Before zooming into port clusters, it is worth understanding what a cluster is. Porter defined a cluster as *"a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities"* (Porter, 2000). Most cluster participants do not compete with each other, but they share common needs and opportunities. An example cited by Porter is the California wine cluster (Porter, 1998). The cluster consists of vineyards (direct competitors) as well as research institutes and bottlers. Another example is the Italian leather fashion cluster. Shoe companies such as Ferragamo and Gucci may be direct competitors, but the cluster also consists of suppliers for molds and design services. Porter concludes that it is the close linkages with other cluster participants and the resulting knowledge spill-over that improve efficiency and rate of innovation in a cluster. The geographical proximity amplifies these linkages and spillover.

Industrial clusters have existed for a long time. Jingdezhen in China has a pottery and porcelain production cluster with a history of more than 1,400 years (Li & Fung Research Centre, 2006), while Seto city in Japan has a ceramics cluster that dates back to the 1100s (Yamawaki, 2002). In the 18th century, Adam Smith touched the subject of geographical proximity and specialisation, although he seems to question their benefits by saying that *"People of the same trade seldom meet together, even for merriment and diversion, but the conversation ends in a conspiracy against the public, or in some contrivances to raise the prices"* (Smith, 1776).

However, it was Alfred Marshall who first put forward the concept of geographical agglomeration. He observed that specialised firms tend to concentrate to form industrial districts – a cluster of companies that concentrates expertise and economic activities. To the firms, especially the small ones, clustering (and therefore proximity) provide three types of external economies of scale. First, economies resulting from access to a common labour pool and shared public goods such as infrastructure; second, economies from saved transport cost and transactions costs; third, the economies from spill-overs of industry knowledge (Marshall, 1890). Marshall's concept of localisation economies is verified by two other economists Arrow and Romer, hence the concept is sometimes known as the MAR (Marshall, Arrow and Romer) scale economies (Polese, 2005; Feldman & Audretsch, 1999). Clusters have been widely recognised as having the potential to aggregate more than the sum of their parts (Begg, 1999). Clusters are not confined to large cities or favoured regions (Porter, 1996), as a result clusters have formed a key part of local economic policies (Bartik, 2003; H.M.Treasury, 2001).

Many experts draw on the first and the third Marshallian external economies of scale to explain the link between clustering and innovation. With the first Marshallian external economies of scale, some economists believe that firms cluster to draw from a pool of talented people. Proximity to this pool means quicker mobilisation of the talent, and resulting in innovation and economic growth (Florida, 2003). This view also helps explain the purpose of locating in a city rather than the peripheral and is centre to Jane Jacobs' work. As Lucas asked, *"what can people be paying Manhattan or downtown Chicago rents for, if not for being near other people?"*(Lucas Jr, 1988).

Many literatures have stated the link between knowledge-spillovers and innovation (Lambooy, 2002; Malmberg & Maskell, 2006), which brings us to the third Marshallian external economies of scale. E-mail and video conferences may have reduced the transmission cost of information, but some knowledge is expensive to acquire, transfer and use in a new location *(sticky)*, and is further complicated by the attributes of the information seekers themselves. It is better to communicate such knowledge face-to-face and this highlights the advantage of proximity (von Hippel, 1994). Indeed, the relationship between proximity and knowledge spill-overs has been verified by several studies (Jaffe et al., 1993; Feldman & Audretsch, 1996).

It is worth noting that neither group disputes the importance of the external economies of scale stressed by the other group, the difference merely lies in their focus. Not all economists agree on the benefit of clusters. Some evidence suggests that the significance of clusters may have been exaggerated (Turok, 2004). A closed cluster may struggle to interpret new and external information, leading to poor decision making and prevent the much needed renewal of best business practises (Visser, 1999).

A port cluster could be defined as *"the set of interdependent firms engaged in port related activities, located within the same port region and possibly with similar strategies leading to a competitive advantage and characterised by a joint competitive position vis-à-vis the environment external to the cluster"* (Haezendonck, 2001). In the port cluster of Rotterdam, the port-related activities include transport, production, logistics, stevedoring and trade, with the first two dominating the total port employment (de Langen, 2008). It is argued that the presence of trust, leader firms, intermediaries and especially collective action regimes all contribute to the innovation in the port cluster. The port of Rotterdam is described as not an "innovation prone environment" precisely because of the inability to build such regimes, with trust being cited as one of the main reason (de Langen, 2003).

2.3 Factors influencing successful adaptation of innovations

The core element of this thesis is to understand what are the drivers and barriers for sustainable innovations. According to the literature, success and failure factors can largely be found in the **environment** in which a company innovates.

Context, or selection environments – **institutions, markets and the spatial structure**, influence the degree of success of innovative activities (Lambooy, 2002).
Spatial structure influences the availability of information, as interaction is dependent on spatial proximity between the actors involved (Bathelt, Malmberg and Maskell, 2004). Certain types of knowledge, the so called "tacit knowledge", cannot be codified and transferred, thus can only be learned through experience and personal contact. "Proximity matters" not only because cooperation is easier and cheaper when the distance between the partners is shorter, but also because high degree of mutual trust and understanding is required, which is related to shared values and culture (Maskell and Malmberg, 1995), hence the importance of clusters. While spatial proximity supports the interactions that are required for learning, it is an optimal degree of

cognitive proximity that is a necessary condition for interactive learning (Hall and Jacobs, 2009). There has to be sufficient distance for novelty, but also sufficient proximity for understanding (Nooteboom, 2000).
Furthermore, firms in clusters benefit from diffusion of information and news by just “being there” (Gertler, 1995). This spontaneous information exchange through co-location and participation in the cluster’s social and economic spheres was named by Bathelt, Malmberg and Maskell “a **local buzz**”. However, clusters cannot be permanently self-sufficient in terms of state-of-the-art knowledge creation (Bathelt, Malmberg and Maskell, 2004). Companies build channels which Owen-Smith and Powell (2002) call **“pipelines**” through which they interact with distant (often international) partners. Pipelines are important source of knowledge about external markets and technologies. Moreover, they intensify the local buzz and enhance its quality. That is why well functioning **knowledge networks,** both regional and global, are success factors for innovations – they facilitate knowledge exchange, support generation of new ideas and allow for learning from successes and failures.

Institutions defined as forms that shape human interaction, such as habits, routines, values and legislation or economic rules, both guide and constrain the behavior of entrepreneurs. New varieties that do not fit into the perception sets of people and into the environment, are bound to disappear (Lambooy, 2002). Therefore, not only competencies and skills of entrepreneurs condition the result of innovative activities, but also the external characteristics which influence what choices actors on different levels make.

Markets and institutions are territorially embedded and path-dependent. Knowledge is context-specific and accumulated in particular regions or clusters. Conditions in regions are different – regional capabilities can be seen as the combination of the human and physical resources available, the structures established in the region through time, and the regions specific institutional endowment as it is shaped by the previous rounds of knowledge creation (Maskell and Malmberg, 1995). New ideas are generated in interaction with past experience and with the environment. Thus we can say that for the success of innovation ‘**history matters’** and **‘geography matters**’.

Innovation studies have shown that most innovations tend to be of an incremental nature – new technologies developed and brought to the market are typically improved variants of existing technologies that can be used within existing infrastructure (Elzen and Wieczorek, 2005). The concept of “technological trajectory” is used to describe such a path of development (Dosi, 1982).
However, if innovations are to facilitate transition towards sustainability, they need to be of a more radical character. It is known in the literature as a *system innovation* – a change from one socio-technical system to another (Geels, 2005). Because of the co-evolution of a technological and socio-economic system and their mutual reinforcement, system innovations face a range of barriers to break an existing regime. These can be production barriers, regulatory barriers, user preferences tuned to existing regime, infrastructure requirements, investment needs, technological lock-ins, etc. (Elzen and Wieczorek, 2005).

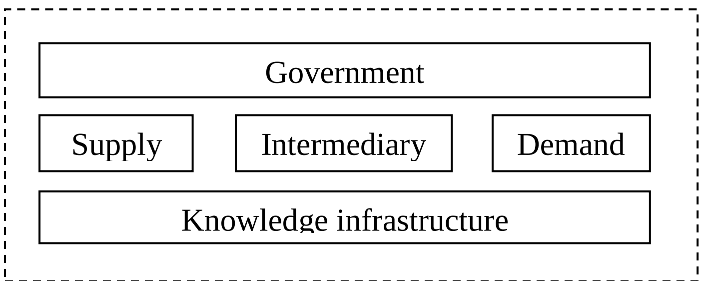
In the next part of this chapter we discuss specific success and failure factors *for new technologies* based on the desk research. First, we introduce the concept of innovation systems to explain the co-evolutionary character of technological and societal system. Then we briefly discuss the meaning of lock-in and path dependence with regard to technology. Finally, we present a classification of factors influencing success of innovations.

2.3.1 Innovation systems approach

The main idea behind the innovation systems approach is that the success of a new technology is not only determined by technological and economic characteristics, but also by the social system that develops, diffuses, implements or rejects it (Jacobsson and Bergek, 2004). Innovation systems are defined as "networks of institutions, public or private, whose activities and interactions initiate, import, modify, and diffuse new technologies" (Freeman, 1987).
The following parties form the structure of an innovation system (EIA, 2008):

- **Supply side** – entrepreneurs and companies producing new technology;
- **Demand side** –consumers and companies that use new technology;
- **Government** – the range of instruments and measures that focus on the transition path;
- **Knowledge infrastructure** – knowledge institutions;
- **Intermediary infrastructure** – organisations improving interaction between the various groups of innovation systems.

Figure 5. Structure of an innovation system



Source: EIA, 2008

There are several complementary innovation systems approaches, including technological systems (Carlsson and Stankiewicz, 1991), national innovation systems developed by Freeman (Freeman, 1987, 1988) and used by OECD (OECD 1999, 2002), sectoral systems of innovation (Malerba, 2001) and analysis of functions of innovation systems (Jacobsson and Johnson, 2000, 2001; Jacobsson et al., 2002; Bergek and Jacobsson, 2003). The innovation system approach has become a well-established heuristic framework that presents insight in the factors that explain processes of innovation (Lundvall, 2002).

Innovation in that approach is viewed as a network activity. It involves multiple actors or stakeholders that are interacting in a specific economic/industrial area under a particular institutional infrastructure (Carlsson and Stankiewicz, 1991). This implies that there is a technological innovation system for each technology and that each innovation system is unique in its ability to develop and diffuse a new technology (Jacobsson and Johnson, 2000). Thus it is not just a new technology competing with existing one, competition takes place between technological innovation systems. The new innovation system for biofuels would compete, for example, with the existing innovation system that focuses on fossil fuels (EIA, 2008).

2.3.2 Path-dependence and lock-in

As we said before, the successful development of technologies both influences and in influenced by the social, economic and cultural setting in which they develop (Kemp, 2000). Successful innovation depends on particular characteristics of initial markets, the institutional and regulatory factors and the expectations of consumers (Foxon, 2002). These factors favor to a certain extent incumbent technologies against newcomers, leading to a *technological lock-in*.

The main reason for the lock-in is increasing returns to scale that incumbent technologies enjoy. Arthur (1994) defines four classes of increasing returns. The first class is *scale economies* – for large fixed costs technologies unit production costs decline with increasing production volume. It means high sunk costs from past investments which reduce willingness to develop alternative technologies, and in the same time high costs for new technologies which do not benefit from scale yet. Another category of increasing returns are *learning effects.* As skills and knowledge accumulate through production and market experience (Foxon, 2002), what is known as a learning curve, unit costs decline. Also *adaptive expectations* play a role. Producers and users of a current technology are confident about its performance and quality, whereas there is uncertainty about new technologies. Finally, *network economies* mean that advances accrue to agents adopting the same technologies as others, like infrastructure develops based on attributes of existing technologies (Foxon, 2002).

Innovation systems are shaped by history and local conditions. There is a certain inertia when it comes to change. It often has to do with the dominant technology. For example, according to Unruh's (2000) we are in the state of *carbon lock-in*, as "industrial economies have been locked into fossil fuel-based energy systems through a process of technological and institutional co-evolution driven by path-dependant increasing returns to scale." It is important to note that lock-in relates not only to technology, but also to perceptions, behavior, organizations (van den Bergh et al., 2007) and institutions.

Changes are difficult and alternative technologies cannot easily displace the dominant one, unless new challenges occur. According Elliott (2000), the very obstacle to the rapid development of sustainable energy technologies is that "they are trying to establish themselves in an outdated (based on the existing types of energy technology) institutional, market and industrial context."
One of the advantages of renewable energy sources highlighted by the EU (Renewable Energy Road Map, 2007) is their decentralized character, which can translate into higher energy security. However, diffuse sources and smaller scale of technologies are in conflict with the existing system, based on the large scale concentrated forms of energy and managed by large scale centralized agencies, often monopolies (Elliott, 2000).

Another critical issue for the successful development and adoption of renewable energy sources is their price. Renewable energy is perceived as expensive, but it is mainly because the price of energy produced from fossil fuels does not reflect environmental costs of its production (Elliott, 2000). However, our economic system is based on cheap energy and consumers are not willing to pay extra for environmental benefits.

If renewable energy sources are to displace fossil fuels, the existing support infrastructure – financial, organizational and institutional environment, has to change as well. Some herald a fundamental change in the overall system of energy production towards decentralization. However, vested interests exist.

2.3.3 Classification of success and failure factors

Literature on this subject is rich and insightful. Listing success and failure factors proved to be a useful framework for empirical analysis.

For example, Wiegmans (2005) evaluated potentially successful barge innovations using the following general criteria: **costs** (investment and exploitation), **compatibility** (degree to which an innovation fits into existing technological or social/organizational infrastructure), **complexity** (degree to which the innovation is more difficult to understand than the current technology), **system dependability** (degree of which the reference situation might change, reducing the potential of the innovation) and **participation of market parties**. According to his findings, successful innovations are socially compatible, not technologically complex, socially acceptable and get high participation of market parties.

Innovation systems approach described before is highly relevant here. One of the characteristics of a system is that it has a function – it performs or achieves something. Several system functions are considered important for an innovation system to develop and thus increase the success chances of the emerging technology (Negro and Hekkert, 2008). These functions, understood also as key activities that take place in innovation systems, are:

Function 1: **Entrepreneurial activities.** Entrepreneurs are the driving force and the necessary condition for innovations. In Schumpeter's theory they are called "innovators", the ones introducing new elements into the economics system (Lambooy, 2002).
Function 2: **Knowledge development (learning)**. Scientific and technological knowledge has to be developed for the new technology. Possible knowledge sources are R&D, assessment/feasibility studies and experiments. Knowledge creation often takes place through learning by doing.
Function 3: **Knowledge diffusion through networks. Exchange of information** is very important for the innovation process. Workshops, conferences and network initiatives facilitate it.
Function 4: **Guidance to the search** by industry (success stories), government (policy goals) and/or the market. Also articles in professional journals raise expectations about new technologies.
Function 5: **Market formation** – creation of protected spaces for new technologies in order to make competition with embedded technologies possible. Possible instruments are niche market initiatives, specific tax regimes for new technologies, minimal consumption quotas and environmental standards that improve the chances for new sustainable technology.
Function 6: **Resources mobilization**. Resources in terms of both finance and human capital are necessary as basic input to all the activities within the innovation system.
Function 7: **Support from advocacy coalition** (government, industry, lobby, interest groups). Parties with vested interests will often oppose changes favoring a new technology. Advocacy coalitions have then an important role to play to break the resistance, put a new technology on the agenda, lobbying for resources, favorable tax regimes and to bring the development forward.

Innovation systems approach has been applied by Negro, Hekker and Smits (2007) to understand the trajectory of biomass digestion in the Netherlands. There are important lessons coming from their analysis: for the successful diffusion and implementation of a new technology long-term, clear and supportive arrangements and regulations are needed. Short periods of entrepreneurial activities by enthusiastic entrepreneurs do not lead to positive feedbacks with other system functions and the system functions do not build up continuously. Thus, the system never gains enough critical mass to overcome technological problems (Negro, Hekker and Smits, 2007).

Inspiring is also Foxon et al. (2005) work on UK innovation systems for new and renewable energy technologies. Their framework for analysis is based on the OECD National Systems of Innovation approach. Here the innovation process is characterized by flows of knowledge and influence, as well as market transactions, between different actors and institutions within the innovation system – small and larger firms, end users, governmental and regulatory bodies, universities, research bodies. It is also affected by incentives for innovation created by the institutional set-up (Foxon et al., 2005).

The authors characterize six new and renewable energy technology sectors in UK by identifying **primary determinants of innovation** within the sector (the role of government policy and actors in the sector in driving innovation), **knowledge creation, diffusion and exploitation** (knowledge sources and means of sharing it, key performers), the **role of public private partnerships**, the importance of **intellectual property rights** (IP) protection, the **international dimension of the innovation system** and other systemic factors such as market or policy systems. Having done that, they pinpoint several factors that influence the development and adoption of renewable energy technologies.

First, technologies often fail to move towards the next development phase because of **insufficient founding** and the **lack of adequate skills**. Second, large-scale deployment of a technology is often hampered by **existing and perceived risks**, and benefits are not regarded as strong enough to overcome these risks. The authors refer to four types of risks: *the technology risk* (whether a new technology will achieve expected performance levels, efficiency improvements and cost reductions), *the market risk* (uncertainty about future profits), *the regulatory risk* (changes in policy mechanisms due to changing priorities of governments), and *the systems risk* (when technology requires changes to existing technological and/or institutional systems). Market certainty and knowledge sharing are crucial. Further, **expectations and knowledge about future markets** generate environment for investment. A potential barrier might be the perception that a given technology is only a long-term prospect (e.g. in the case of hydrogen). Confidence is built both through long term vision and aspirations of the government and through actions undertaken by other players, for example large industrial companies. Another important issue is **protection of intellectual property rights**. The authors state that “some companies avoid university collaboration since they are unable to secure satisfactory arrangements over IP.” On the other hand, smaller companies tend to avoid patents in order to keep their knowledge confidential, what may impede project finance. Next, **public private partnerships** proved to play an important role in development of renewable energy technologies. Finally, appropriate **support for R&D** is needed, for both targeted and flexible research programmes.

Foxon et al. (2005) call for a stable and consistent policy framework that would support innovation through its various stages, and that would recognize that technologies are diverse and face different challenges.

Kemp, Schot and Hoogma (1998) also distinguish groups of barriers to sustainable technologies:

(1) **technological factors**

The technology itself needs to be further developed or it is expensive due to low-scale production and has not been tested by consumers on a large scale. The authors also mention fitting into the existing system and availability of complementary technologies.

(2) **Government policy and regulatory framework**

Government should send a clear message that there is a need for specific technologies. It can be done by developing technology policy to guide developers and investors. Uncertainty causes risk aversion. Another issue is if the existing regulatory framework is adequate and if government is willing to make alterations.

(3) **Cultural and psychological factor**
Unfavorable image or unfamiliarity with a new technology has a big impact, as it leads to skepticism and aversion.
(4) **Demand factors (economic barriers)**
Users often are not willing to change their preferences or bare higher costs, as the new technology has not proven what it is worth yet. Resistance can be especially strong if alteration of users' behavior is required. Price of the product is also a barrier. New technologies are often expensive owing to the small scale of production and because they have not benefited from dynamic learning economies on the supply side.
(5) **Production factors (supply side)**
There are numerous reasons why companies are reluctant to invest in new technologies: development process from prototype to mass product is long, cumbersome and risky; lack of incentives to introduce a new product and uncertainty about the demand; sunk investments in existing production facilities; companies do not want to risk their core competencies; loss of market share because of failed introduction of a new product. New entrants don't have these constraints, however they often face a barrier of insufficient capital – banks are reluctant to invest in risky projects and governments only grant subsidies for R&D and not for marketing a new product.
(6) **Infrastructure and maintenance**
Problematic issue arises when adaptation of the infrastructure is required: who is responsible for the development of the infrastructure and how the initial costs can be covered? Sunk investments in existing infrastructure and vested interests form a significant barrier.
(7) **Undesirable societal and environmental effects of new technologies**
Good example is the food vs. fuel debate. Growing crops required for the production of bio-fuels takes up a great deal of land, which prevents the use of that land for other purposes.

A similar classification of barriers and drivers for innovations we also find in van den Bergh et al. (2007). The authors analyse several sustainable transport innovations in the Netherlands, like public transport pass for students or electronic road pricing, and conclude that the following factors contribute to their success or failure: (1) **technological factors,** (2) **administrative and legal factors,** (3) **political and process related factors,** (4) **socio-cultural and psychological factors and** (5) **economic factors.**
A meaningful finding from the research that predominantly the political and process-related factors (institutions, interest groups, strong pioneers, passion and enthusiasm of initiators and other parties involved) together with socio-cultural and psychological factors (perception) determine whether a project succeeds or fails (van den Bergh et al., 2007), and not that much technology or economics. It confirms the importance of a social system in the adoption of a new technology.

The last study we would like to discuss is the report on European biofuels policies prepared by the Energy Research Centre of the Netherlands (van Thuijl and Deurwaarder, 2006). By analysing past experience of a selection of EU countries with biofuels, the authors identify common factors behind successes and failures.
The success stories of France, Germany, Spain and Sweden have the following factors in common:

- **fiscal support** for biofuels guaranteed for a longer term;
- presence of an **organisation firmly lobbying** for the introduction of biofuels;

- **participation of market parties** (car manufacturers or the oil companies) made the distribution of the biofuels possible, both technically and by providing guarantee to the customers that biofuels or blends with biofuels can be used in their cars without damage;
- the **political willingness** to support biofuels.

Factors that contributed to failures in The Czech Republic, Poland and Slovakia are:

- fiscal support was either changed or abolished one or several times;
- delays in the announced legislation and bureaucracy;
- lack of clear quality standards and quality control measures which led to a bad image for biofuels because consumers did not have confidence in fuel quality.

In general, system innovations require technological, organizational, social, cultural and/or institutional changes to make it to the market. Elliott (2000) compared development of wind power in UK and Denmark and concluded: “the successful deployment of new technology requires the existence, or the development, of suitable social and institutional contexts – a technical infrastructure, suitable financial networks, a skill base, along with appropriate pattern of social acceptance.”

2.3.4 Summary

Based on the literature review presented in Section 2.3, we prepared the list of most common factors influencing the success or failure of innovations. We use this list as a framework for empirical analysis.

Technological factors

The fewer questions around the new technology, the better its chances to make it to the market. The most common issues are:

- fitting in the existing infrastructure,
- country’s potential (necessary conditions, production inputs),
- final decision about applications,
- technology needs to be further developed,
- costs need to be brought down,
- production system needs to be optimized.

Government policy and regulatory framework

What the market parties expect from the government is commitment and reliability as a partner. Regulations influence the market conditions in which the companies operate; therefore unexpected changes are not welcomed. Government should also remove obstacles and market failures and by means of that create a level playing field. Support for R&D, facilitating regulations and incentive schemes are important. The following are crucial for innovations:

- government vision and strategy (clear goals),
- policy to guide developers and investors (not only “carrots”, but also “sticks”),
- facilitating legislation and regulations, market formation (niche market initiatives, specific tax regimes for new technologies, minimal consumption quotas and environmental standards that improve the chances for new sustainable technology),
- government priorities and political agenda,
- continuity and stability in government regulations,

- commissioning governmental programs, conducting/sponsoring research, evaluation, feasibility and comparative studies,
- support for R&D,
- consistency of regulations ,
- organizational complexity and flexibility (cooperation between different ministries),
- time horizon (short vs. long-term) of politicians, political shifts,
- government involvement in network activities (stakeholders perspective) and public private partnerships.

Psychological factors

Three elements can be distinguished here:

- **perception** (perceived risks and interests of firms, consumers and civil servants; realization of urgency for change),
- **image of the innovation** (unfavorable image or unfamiliarity with a new technology leads to skepticism),
- **expectations** about the future of an innovation (articles in professional journals and success stories raise expectations about new technologies. Failures, bankruptcy and closing down projects the opposite).

Perception is often shaped by media attention, especially when the affinity with the concept among the public is low. Resistance is especially strong when the change of behavior (e.g. lifestyle) is required. Strong pioneers and enthusiastic initiators can influence perception of stakeholders. It is important to communicate the benefits of an innovation to the public.

Knowledge development and diffusion

Scientific and technological knowledge has to be developed for the innovation, what often takes place through learning by doing. Important is the availability of knowledge sources and partners to cooperate with. As ideas come mostly from contacts with others, network activities play a critical role in innovation process. The quality of local buzz and global pipelines described in chapter 2.3 is relevant here. Pipelines allow access to knowledge developed elsewhere, while local buzz generates ideas and opportunities thanks to proximity. Important partners for collaboration are universities and other research institutes. However, due to Intellectual Property (IP) protection issues, companies sometimes choose for closed group of participants. Firms are often reluctant to share knowledge, which is justified by the high investment costs but can slow down innovation process on the other hand.
Summary of relevant issues:

- knowledge sources,
- local buzz and global pipelines,
- network activities for knowledge exchange,
- the community,
- intermediaries that bring parties together,
- joint initiatives between academia, research institutes and local projects,
- setting up platforms and information centers by actors,
- knowledge sharing vs. protection of IP rights.

Availability of resources

It comprises of two main categories of resources without which the innovation cannot be successful:

- **Human capital** (skilled staff for conducting research, but also managerial and marketing skills),
- **Availability of funding** – private (own), public (subsidies, incentive schemes), PPPs (Private Public Partnerships), venture capital, bank loans

Interest groups

Parties with vested interests will often oppose changes. Joining forces, lobbying for regulations and having strong supporters are therefore relevant for the success of an innovation. There are three groups that we take into account here:

- incumbent companies (vested interests),
- advocacy coalition for an innovation,
- environmentalists.

Past experience

As we argued in chapter 2.3, past experience has a powerful impact on the innovation process as it leads to path-dependence. Sunk investments and increasing returns to scale reduce incentives to innovate. Next to that, firms usually avoid involvements in activities that are not part of their core business. Companies tend to develop routines that are difficult to break, especially if they have led to successful results. The same holds for governments. Furthermore, governments often have a historically grounded relationship with certain industries, like energy and gas, which used to be government owned. It relates to technological, institutional and behavioral lock-ins.

However, past experience has not only negative connotations for innovations. Successes and failures are part of the learning process, having a history of working together often makes the next project easier for the participants. Moreover, historical factors may lead to competitive advantage in certain field, for example knowledge gained in agriculture can be applied to develop biomass.

3. Brief introduction to algae

Image: biodieselfever.com

Algae is technically defined as a range of autotrophic eucrayotic organisms. They are aquatic plants that lack roots, stems and leaves but have chlorophyll and other pigments for carrying out oxygen-producing photosynthesis (Reuters News, 2008; Spellman, 1999). There are two kinds of algae: microalgae and macro algae.

Algae is one of the oldest organism in the world. Fossil evidence show that algae has been on Earth for at least 1.8 billion years (USGS, 2009). Asia has a long history of consuming algae, and it remains a major producer. In 2006, the world produced 15 million tons of aquatic plants. East and Southeast Asia accounted for more than 99% of the volume, with China alone contributing 11 million tons(FAO, 2006). Conceivably, Asia (China, Japan, Korea, Philippines) is recognised as a strong knowledge centre for the cultivation of algae (Muylaert, 2009).

Algae has many commercial applications (Smithsonian, 2008). Some already exist in the market (e.g. cosmetics and food), some are still in research phase but promising (e.g. biofuels). There is also a difference between the values of the applications (Muylaert, 2009). Below we present a summary of two major applications of algae. For the list of possible applications see Appendix 2.

Algae to biofuel

Algae is a source of biomass, which is defined as the biodegradable fraction of products, waste and residues from biological origin, as well as the biodegradable fraction of industrial and municipal waste. As an organic material, biomass belongs to renewable energy sources.[3]

Shell and HR Biopetroleum, algae pond in Hawaii

The possibility of converting algae into a biofuel has received much attention in recent years. Unlike first generation biofuelss such as soybean biodiesel, it is a type of second generation biofuels. It gives a higher yield per hectare of land, is easier to blend into existing fuel pool and achieves greater greenhouse gas savings (Evans, 2007; BBC, 2006).

Turning algae into a fuel is nothing new. The petroleum crude oil that we use today came from all kinds of organisms 500 million years ago, including algae. It was the work of mother-nature, a combination of time, temperature and pressure (Sciam, 2009) that coverts these materials into Kerogens, an early form of fossil fuels (Schobert, 2002).

Investigation of algae as a biofuel gathered momentum in the 1970s. In 1978, the US government established the Solar Energy Research Institute, a move responding to the energy crises of the

[3] According to EU definition, *energy from renewable sources* means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases (2009/28/EC).

early and mid-1970s. Under this institute, research on alternative fuel also took place. The Aquatic Species Programme became part of this research effort, focusing on the use of aquatic plants as an energy source. Due to budget reduction, production problems and low oil prices (at one point as low as $10 per barrel), the programme was terminated in 1995 (Edwards, 2009).

The Japanese government established the Research for Innovative Technology of the Earth programme (RITE) in 1990. It was a ten years programme focusing on microalgal CO_2 utilisation. Unlike the US effort, RITE focused on a different production method and higher-value products. Some of these products are described as 'esoteric', an example is algae-based paper. The programme was stopped when the production technology was seen as unfeasible (NREL, 1998; Broere, 2008).

There are up to several million species of algae, each with different properties and some are better than others as a source of fuel. There are two main types of production technologies – open raceway ponds and closed photobioreactors (WUR, 2009; Muylaert, 2009). Few examples are shown in the pictures. Algae can be converted into "green crude" – a type of oil that is chemically identical to fossil fuels (SCIAM, 2008). There are several interesting aspects about algae fuel. Growing algae does not take up as much land as other biofuelss crops, putting less pressure on agricultural land use. According to the US department of Energy, algae could produce 100 times more oil per acre than soybeans, the leading source of US biodiesel (EESI, 2009). It is possible to feed algae with industrial waste (Solazyme, 2009). This contrasts starkly with corn and rapeseed, which use conventional fertilisers and generate pollution during the farming process. Algae has the ability to absorb CO_2 in great capacity. Producing 1kg of algae require between 1.8kg to 3kg of CO_2 (Becker, 1994; BBC, 2008).

Glen Kertz's (Valcent Products) vertical rack algae growing system (Image: static.huddler.com)

GreenFuel's Closed System Algae Bioreactor

The main obstacle preventing algae fuel from replacing fossil fuels is cost. The cost for algae-based fuel currently ranges from $10 to 100$ per gallon, it needs to come down to at least $3 if it is to be competitive (Sciam, 2008; AP, 2009). We did a simple calculation to verify this reality:

Figure 6. The production cost for algae

	Production cost (€ per GJ)
Crude oil	11
Microalgae biomass produced in a photobioreactor	154
Soybean biodiesel	11

Various sources

Our calculation only includes operation cost; the capital investment cost is not included (see Appendix 1). The production cost for crude oil and soybean biodiesel takes into account refining costs, while the production cost for microalgae biomass excludes oil extraction cost and esterification cost. The calculation reinforces the message that algae fuel remains an expensive option. However, it is possible to massively reduce the production cost through optimising the algae production process (WUR, 2009).

Start-ups of the development of algae fuel received a lot of investment in recent years. Their source of funding ranges from venture capitalists to Bill Gates to medical research charity (Sciam, 2008; FT, 2008). Major energy companies such as Shell and ExxonMobil also fund their own algae fuel development programmes (New York Times, 2009; Shell website). The $600 million investment recently announced by ExxonMobil dwarves the budget of the US's Aquatic Species Programme ($25 million over twenty years) and the Japanese RITE programme ($80 million for ten years).

The government is another source of funding; the Dutch government recently committed €25 million on an algae-related research programme (MinInv, 2009), while the US Department of Defense invests in developing jet fuel for military jets (Reuters, 2009).

Seambiotic, an open pond for growing algae in Israel (Image: news.cnet.com)

Algae as a source of food

Certain types of algae such as Porphyra are nutritious. They combine high level of protein, dietary fibre and vitamins with low levels of sugar and sodium. People have been eating algae for thousands of years, especially in Asia. It has been a food source in China since 500 B.C. where it is treated as a delicacy with medical value. Popular consumption of algae in Korea and Japan also led to their cultivation since the 17th century. Outside Asia, algae has served the same purpose in Mexico and Africa since as early as the 9th century A.D. Thanks to migration from these countries, algae consumption spilled to countries all over the world (Barsanti & Gualtieri, 2006).

Today, algae is part of the modern diet. Seaweed, a type of algae, is used as ingredients for sushi, soups and seasoning, as well as products such as wine, bread and even chocolate and jelly. Its thickening property also makes it an ingredient for jam and sauces (Barsanti & Gualtieri, 2006; Telegraph, 2009). On a more sophisticated level, algae is used to produce supplements of vitamins and amino acids. However, some research question the benefit of these supplements (NLM, 2008), some even suggests that the contamination of the algae may make these supplements harmful (Draisici et al., 2001; Eisenbrand, 2007).

Algae has the potential to help solve the world's food problem in the coming years. Although the world population is projected to reach 9.1 billion by the year 2050 (UN, 2009) comparing to 6.5 billion in 2005, a food shortage on a global level is actually unlikely. The problems are more on the regional level, especially areas with a high concentration of poor people. An example is the shortage of farmland; globally there is adequate unused potential farmland, but these lands are unequally allocated. In the Near East, North Africa and South Asia around 90% of the land are already being farmed (FAO, 2002). In this case, algae's comparatively higher yield per hectare and high protein content makes it not only a promising food source for human, but also as a potent fertiliser.

Recently there is concern that the nutritional value of algae is falling as a result of climate change. Higher concentration of CO_2 has led to faster algae growth but relatively less content of phosphorous (NWO, 2009). This reduction of nutritional value could reduce the commercial value of algae, but more importantly it could lead to lower fish stocks due to the impact on the ecosystem. Whether or not algae will develop into a major food source remains to be seen.

Production of Food Supplements and Cosmetics from Algae, Czech Republic (Image: www.iwt.be)

4. Policy background on renewable energy

National and European policies on biofuels and renewable energy are especially important for the development of algae technology, as they influence market conditions and the competitiveness of new technologies comparing to fossil fuels. Innovation climate and initiatives in that area are also relevant. We do not discuss innovation policy as such here, as it can be reviewed on different levels (European, national, regional, local) and comprises a lengthy material that goes beyond the scope of this thesis. Moreover, policies supporting the development of biofuels and renewable energy sources include measures to encourage innovations. Therefore, it will be sufficient to focus on these policies.

Climate change and oil dependence with all the consequences they bring are important challenges a policy has to respond to. A policy on renewable energies is a cornerstone in the overall EU policy for reducing CO_2 emissions (COM, 2006). In general, European Union has three important goals relevant for supporting renewable energy: (1) competitiveness of the EU economy, (2) security of energy supply, and (3) environmental protection (Bozbas, 2008).
The Renewable Energy Road Map (2007) names several reasons why renewable energy sources are a key element of a sustainable future: they are largely indigenous, they do not rely on uncertain projections on the future availability of fuels, and their predominantly decentralised nature makes societies less vulnerable. They achieve a dual objective of increased security of supply and reduced greenhouse gas emissions. However, to achieve significant CO_2 reduction and the objectives set out by the EU, all Member States have to take an action.

In the Netherlands climate change is very high on the agenda. In the country where 60% of the population lives below sea level it poses a serious threat. According to Pettenger (2007), the global leadership of the Netherlands in climate change policies seems to be driven by self-interest stemming from its vulnerability. Both Amsterdam and Rotterdam are among the top 10 port cities in terms of asset exposed to climate extrems[4] and among top 20 in terms of population exposure.
As Johnson (1995) put it, “if other nations do not follow its example, the Netherlands is doomed.” The Dutch government is actively involved in developing policies to reduce emissions from transport and to promote renewable energy sources.
Important guidelines for national policies on biofuels and renewable energy are the policies on EU level, therefore we discuss them first. Then the Dutch initiatives will be presented.

4.1 EU legislation

The first document where a target for the use of renewable energy sources was set (12% share of renewable energy in gross inland consumption by 2010) was the EU White Paper: *“Energy for the future: Renewable sources of energy”* (1997). The Green Paper *„Towards a European strategy for the security of energy supply”* (2000) was the start for a more comprehensive and pro-active energy policy. It set the objective of 20% substitution of conventional fuels by alternative fuels in the road transport sector by 2020.

Over the past five years the production and use of biofuels in Europe has been developing more rapidly. This is partly because of EU and national environmental policies aiming at reducing CO_2 emissions (van Thuijl, E., Roos, C.J., Beurskens, L.W.M, 2003). That resulted in the *Directive on the Promotion of the Use of Biofuels or Other Renewable Fuels for Transport* (2003/30/EC), the

[4] Rotterdam was ranked 7 with exposed assets of $114.89 bn; Amsterdam: $128.33 bn, rank 6 (Nicholls et al., 2008)

so called Biofuels Directive. The aim was to promote the use of biofuels and other renewable fuels to replace diesel or petrol for transport purposes in each Member State (Article 1, 2003/30/EC). According to Article 3, Member States should ensure that a minimum proportion of biofuels and other renewable fuels are placed on their markets. The following reference values for setting the national targets have been formulated:

- 2% share of biofuels in the transport sector by 31 December 2005,
- 5,75%, share of biofuels in the transport sector by 31 December 2010.

A great weakness of the directive was that the targets were not mandatory, which has led to low compliance among Member States.

Another important document was the *Directive on the Promotion of Electricity from Renewable Energy Sources* (2001/77/EC), the so called Renewables Directive, which targeted 22% of electricity from renewable energy by 2010.

In 2009 the European Commission published a new Renewable Energy Directive (2009/28/EC) amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. It sets mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy and for the share of energy from renewable sources in transport. The overall target: at least 20% share of energy from renewable sources in the Community's gross final consumption of energy in 2020 and at least 10% share of energy from renewable sources in all forms of transport in 2020.[5]

The new Directive should be implemented by Member States by 2010. In 2010 each Member State has to present a national renewable energy action plan, setting out national targets for the share of energy from renewable sources.[6]

In order to prevent negative environmental effects, sustainability criteria have been incorporated into the text. The reduction in greenhouse gas emissions must be at least 35%, measured over the entire chain (from production of raw materials to the end-use) and compared to fossil fuels. In 2017 these minimum criteria will be increased to at least 50% and in 2018 to 60%. There are also restrictions with regard to raw materials used for production of biofuels and to land use changes. Biofuels that do not meet these criteria cannot be counted towards the national target and/or obligation for biofuels. They are also not eligible for financial support schemes.[7]

The EU also makes funding for research on renewable energy available. For example, within the Seventh Framework Programme for Research and Technological Development (FP7) there is a budget of €2.3 billion for the "Energy" programme.[8] FP7 is the EU's main instrument for funding scientific research and technological development over the period 2007 - 2013 and is regarded as an important element in achieving the Lisbon agenda for growth and competitiveness.[9] The goal of "Energy" Programme is to find technological solutions to mitigate the consequences of climate change and to achieve a sustainable energy system with a variety of sources and a higher efficiency. Activities in the energy area include among others:[10]

[5] Renewable Energy Magazine 8/6/2009, http://www.renewableenergymagazine.com/paginas/Contenidosecciones.asp?ID=3595&Tipo=&Nombre=Panorama

[6] Renewable Energy Magazine 8/6/2009

[7] SenterNovem, http://www.senternovem.nl/gave_english/netherlands_biofuels_policy/index.asp

[8] European Commission, FP7: Tomorrow's answers start today, http://ec.europa.eu/research/fp7/pdf/fp7-factsheets_en.pdf

[9] European Commission, Community Research and Development Information Service CORDIS, http://cordis.europa.eu/ist/about/fp7.htm

[10] European Commission, FP7: Tomorrow's answers start today, http://ec.europa.eu/research/fp7/pdf/fp7-factsheets_en.pdf

- Hydrogen and fuel cells,
- Renewable electricity generation,
- Renewable fuel production,
- Renewable for heating and cooling,
- CO_2 capture and storage technologies for zero emission power generation,
- Knowledge for energy policy making.

4.2 The Netherlands

In 2001 the Dutch government adopted a transition approach to achieve sustainable energy system. As persistent environmental problems like climate change cannot be solved by intensifying current policies (Kern and Smith, 2008), system innovation is needed – a long-term transformation process comprising technological, economic, socio-cultural and institutional changes (VROM, 2001). The Fourth Dutch Environmental Policy Plan (NMP4, 2001) set energy transition as a target. In March 2001 the Ministry of Economic Affairs (EZ), responsible for energy and innovation policy, appointed itself as the "transition manager". The Dutch energy transition project took off.

Support for the transition is given by the Regional Organization for Energy Transition (ROET), which is an independent body created by the minister of VROM and EZ and which advices on policies for developing a sustainable energy system. There are seven associated platforms (as there are seven themes of energy transition[11]), one of them being the Biobased Raw Materials Platform. The Platforms involve representatives from industry, knowledge institutes and NGOs. They work as innovation networks that formulate ambitions, work out plans ("transition paths") and conduct transition experiments.

The work of the platforms was used as an input for strategic documents: *Clean and Efficient (New Energy for Climate Policy, 2007)*, *Government Vision on the Biobased Economy for Energy Transition (2007)* and *Energy Innovation Agenda (2008)*. By adopting these documents the government committed itself to the development and promotion of renewable energy sources. Future energy supply should be clean, reliable and affordable (EIA, 2008). The following goals were formulated for the Netherlands (EIA, 2008):

- Energy saving of 2% per year,
- 20% energy from renewable sources in 2020,
- 30% CO_2 reduction in 2020 compared to 1990 levels.

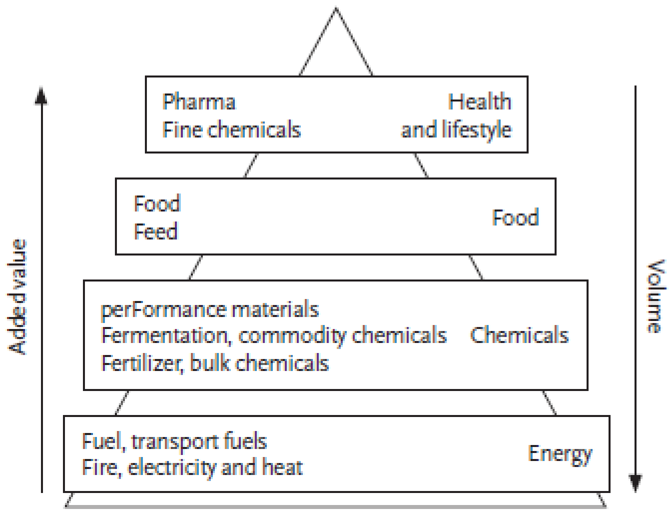
These goals cannot be achieved without radical innovations, therefore the Energy Innovation Agenda draws a list of programmes to promote innovative entrepreneurial skills with respect to energy (EIA, 2008).

One of the important steps in the transition is to match the agricultural industry, the chemical and the logistics sector, which are all very strong in the Netherlands. Biorefining will make it possible to co-produce chemicals, materials and energy from green raw materials and by means of that to improve energy efficiency and CO_2 balance. A *biobased economy* concerns replacing fossil-based resources with biomass.

[11] (1) New Gas, (2) Chain Efficiency,(3) Sustainable Mobility,(4) Biobased Raw Materials, (5) Sustainabl Ellectricity Suppply, (6) Built Environment, (7) Greenhouse as Energy Source.

Biorefining is one of the government's top priorities. It allows the isolation of valuable substances that can be used in high-grade products. The residues can be used for lower value applications, such as animal fodder, or for the production of 2nd generation biofuels. The wastes that are then left over can be converted into energy, particularly electricity. The agricultural product thus supplies far more raw materials than when it is used as a single product.[12] Figure 7 presents the value pyramid.

Figure 7. Added Value of Agricultural Products



Source: Government Vision on the Biobased Economy for Energy Transition (2007)

The government sees its role in launching biomass-based products onto the market and fulfils it by:

- implementing commitments and regulations, such as those for transport fuels;
- using its procurement policy to create a market demand and set a good example, also known as becoming a 'launching customer';
- developing new instruments, such as the Small Business Innovation Research Programme (SBIR) to stimulate the development and market applications of innovative biobased products;
- providing funding – the cabinet has made €438 million available for implementation of the Innovation Agenda. The government wants to encourage the market through clear and consistent government policy, in order to attract private investment capital in a sustainable energy system (EIA, 2008).
- removing obstructive legislation, improving cooperation, improving the demand for knowledge development, market promotion, education (EIA, 2008).

Energy transition is a strategic direction that should guide government's actions. However, it is argued that its impact on the energy policy is rather limited (Kern and Smith, 2008). Moreover, Dutch renewable energy policy lacked stability and couldn't provide sufficient incentives for developing new technologies. For example, the feed-in tariff for renewable electricity (MEP scheme) was introduced in 2003 and stopped in 2006, causing uncertainty and decreased market interest.

[12] Government vision…, 2007

A serious effort to promote biofuels started in 2006. Before that, the Dutch government was investigating different options to determine which biofuels to choose. The current so called 1st generation biofuels were not regarded as cost effective and the support for the development of 2nd generation was rather limited. Prior to 2006 biofuels were only fiscally supported on a project basis and the budget for this support was relatively small, at least not high enough to have a significant market penetration of biofuels (van Thuijl, E., Deurwaarder, E.P, 2006).

The new policy included the requirement that in 2007 some 2% of the petrol and diesel sold in the Netherlands had to consist of biofuels (Transport Biofuels Act 2007). The objective was to increase this target according to European indicative target to 5.75% in 2010. However, in October 2008 the Dutch government modified biofuels targets: the target for 2009 was reduced from 4.5% to 3.75%, and the target for 2010 from 5.75% to 4%. For 2008 the target was 3.25%.[13] Furthermore, the Dutch government has allocated a budget of €60 million for the period 2006-2010 to subsidize innovative biofuels projects, mainly advanced biofuels production technologies (Junginger, M., de Wit, M., Faaij, A., 2006). Currently second-generation biofuels are on the government's top priority list (EIA, 2008).

4.2.1 Algae in the Netherlands

There are several initiatives regarding algae in the Netherlands. First, there are companies that use algae for commercial applications (for health sector, cosmetics and aquaculture). Second, research is going on at the universities, with the leading role of WUR. Third, the Dutch government initiated studies to gain more knowledge about algae (decision about involvement in algae will be based on the results). And finally, there are collaborations between these parties and companies from different industries (agriculture, energy, chemicals) to develop specific applications.

Algae is one of the points on the agenda of the Biobased Raw Materials Platform. It has also been mentioned as a promising technology in two strategic documents: Government Vision on the Biobased Economy (2007) and Energy Innovation Agenda (2008). It is seen as part of the strategy to reduce CO_2 emissions. The abovementioned documents name the following activities that will be undertaken regarding algae:

- Studies will be made into areas such as aquatic biomass (algae);
- Encouraging development of algae via Small Business Innovation Research Programme (SBIR);
- The Innovation Agenda has made additional funds available to implement fundamental and long-term knowledge development, among others for knowledge development with respect to algae (aquatic biomass for biofuels).

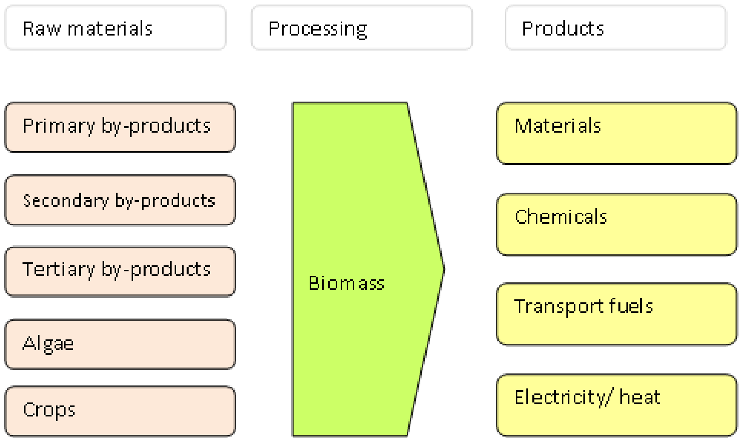
Recently the government has allocated €25 million for algae research programme *'Towards Biosolar Cells.'*[14]

One of the aims of the biobased economy is to match the economic strengths of the Netherlands: chemical industry, logistics, agricultural sector and knowledge institutes. Algae fits well in that structure. Knowledge from agricultural and chemical sector can be used to further develop algae technology. The algal biomass can be used in chemical and agricultural products. Leftovers can be used for energy purposes. The principle of "Closing the chain" it therefore realized.

[13] SenterNovem, http://www.senternovem.nl/gave_english/netherlands_biofuels_policy/index.asp

[14] The Ministry of Agriculture, Nature and Food Quality, 10.07.2009 http://www.minlnv.nl/portal/page?_pageid=116,1640333&_dad=portal&_schema=PORTAL&p_news_item_id=24490

Figure 8. Algae as a biobased raw material

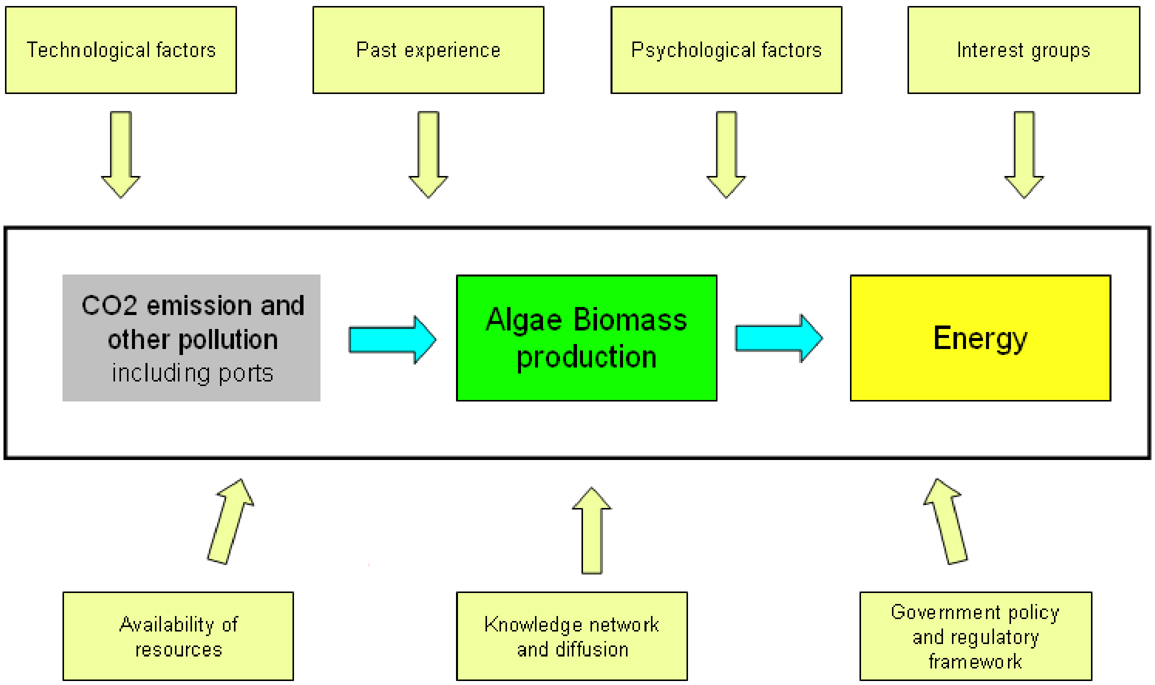


Source: Government Vision on the Biobased Economy for Energy Transition (2007)

5. Empirical part

In previous sections, we presented the theories behind sustainable innovations, the policy background of renewable energy, and the latest development on both the sustainability at ports and the technology of algae. In this part, we use our empirical information to address the main research question: **what is the potential of farming algae for energy purpose in the port of Rotterdam?**

In section 5.1, we will verify the factors behind the development of algae as a sustainable innovation; in section 5.2, we explore the role of algae in the port of Rotterdam; in section 5.3, we identify the obstacles behind developing algae farming in the port of Rotterdam.



5.1 Factors behind the development of algae as a sustainable innovation

Technological factors

Algae is already produced on the commercial scale for high added value applications such as cosmetics or food. As a biofuel, however, the production is still limited to the laboratory scale. To be a viable energy source the production needs to scale up, otherwise the production cost will be too high. Energy is considered worldwide as a low value product and our economy is based on cheap energy (Consultant, Sustainable Energy Consultancy, 25/06/09).

All the interviewees mentioned technology as one of the remaining obstacles for algae biofuel. Production systems need to be optimized to bring down the cost. That requires innovations in almost every step of the production and a lot of effort is put into research to discover breakthroughs. The expected time within which an application can be economically viable depends on (1) the value of the biomass in the application and (2) the number of innovations that are required to reduce the production costs for this application (Muylaert, 2009). Even algae fuel enthusiasts estimate a timeframe of 10 to 15 or even 20 years before the commercial scale of algae fuel production can be reached. To quote the Scientist from an energy company (19/06/09), it will take a bit of time to get to full scale production and a long time to get to maturity. The remaining problems to solve are:

- *Finding the right strains (suitable for a given application and for natural conditions)* According to the Algae Specialist (Ministry, 22/06/09), we look at only 2% of the species at the moment. An interesting comparison was made by the Consultant (Sustainable Energy Consultancy, 25/06/09): "algae is the same container term as plants. It is like saying: what can we do with plants? Can we use plants for bioenergy?" More research and pilot projects is needed to develop the knowledge.

- *Where to grow algae? How to achieve large industrial scale on a small area?* One of the advantages of algae is that it can be cultivated on the land that is not suitable for agriculture. However, there should be a nearby source of CO_2 and nutrients, like a power plant or a big city, otherwise transport costs are involved. Growing algae (macro algae, like seaweed) in the sea might be an option, but there are many questions such as the impact on ecosystems and harvesting methods.

Start-up GreenFuel uses 3-meter-high tubes to mix algae with sunlight, water and carbon-carrying emissions from power plants to create biodiesel fuel (Image: news.cnet.com)

- *CO_2 and energy balance.* As a Senior Manager from an energy company explained (11/06/09), the whole algae process has to be taken into account, from cultivation to extraction and purification of oils. For each step a certain amount of energy is needed, so it has to be proven that the balance is positive. It also affects the bottom-line profitability.

- *Yield.* Because of space constraints and the large amounts of algae that need to be produced for biofuels purposes, companies aim at maximizing the yield per hectare. However, the amount of energy we get from the sun is limited. The Professor (University, 2/07/09) pointed out that only 20% of the sun energy gets converted into biomass and that is the maximum yield. This means that in the Netherlands one can produce 130 tons of dry algae per ha per year, more in Italy and South of Spain (about 280 tons per ha per year). Some companies claim they can produce 1000 tons per ha per year. That is impossible, at least not on Earth.

- *Applications.* The same algal biomass can be used for multiple purposes. Algae produce both lipids and proteins. Lipids are used to produce biodiesel, proteins can be extracted for high value added applications. For the whole biomass to be cost effective, several products should be produced from that source. In principle it is not different from petroleum, from which different chemicals are produced and that is what yields the largest margins (Professor, University, 2/07/09) But as the Consultant (Sustainable Energy Consultancy, 25/06/09) pointed out, algae used for water purification might not be the right ones for producing biofuels. The Professor (University, 2/07/09) gives another example: cosmetics-bound algae product should not irritate skin, but for fuels there is a different set of requirements. Moreover, the volumes for those markets are incomparable. The fundamental choice is therefore: what do we want to use algae for?

- *Cost.* In the end it all boils down to money. Producing energy from algae is too expensive comparing to fossil fuels. On average the cost-price of production for all the systems is about €4 to €6 per kg of dry matter. Through optimisation it can be reduced to €0.40 per kg with a closed system (90% less) and 50% with an open system (Professor, University, 2/07/09). Increasing the scale of production is part of optimising. It means more automatisation, less staff per area and greater economies of scale.

All the interviewees agree that in general, the feasibility of biofuels from algae will in the long run largely depend on external factors, including the evolution of energy and raw material prices, the cost of CO_2 emissions and the political commitment to certain sustainability goals. It is consistent with the innovation systems theory, which draws attention to factors beyond the technology itself.

Psychological factors

Expectations

Algae is regarded as a promising technology. It ticked many boxes in terms of sustainable development, so it is looked at quite favourably (Scientist, Energy Company 3, 19/06/09). On the other hand, algae technology has to be further developed and has not been proven on the large scale yet. What works on the laboratory scale may not work on the industrial scale (the so called "valley of death"). That leads to disbelief. Some companies look for "quick winners" and are not willing to focus on a technology that requires at least 10 years to commercialise, especially one that requires high investments. Furthermore, there is no guarantee that costs can be reduced enough for applications such as biofuels. However, there is no convincing argument that it is impossible (Benemann, 2008). New technologies such as algae need believers. To quote the Scientist from an energy company, you need someone enthusiastic to push it forward, to build momentum (19/06/09).
But as Senior Managers from a venture capital (25/06/09) noted, things go in waves in the renewable energy industry. Algae, electric cars, smart grids - it all comes and goes. Hypes are created by companies that think they have made breakthroughs.
Success stories are important to convince sceptics, gain interest and funding. However, many firms make grandiose claims on their websites and corporate brochures with the intent of attracting capital investors, what has diminished the credibility of algal industry (The Algal Industry Survey, 2009).

Sense of urgency

An important issue for the development of algae technology is the sense of urgency. It has higher chances to become a priority if the need for alternative energy is great. Society is concerned about climate change and the security of supply and those problems are on the political agenda. But according to our interviewees, serious development of renewable energy technologies will not take place as long as oil prices remain low. One interviewee said that this is one of the reason behind the closure of the Aquatic Species Programme in the US. The Advisor from a port industry association (14/07/09) goes further: "expensive fuel is only painful for a certain moment. No fuel will hurt."

It is also argued that oil companies have no urgency to develop algae fuel because there is still plenty of oil in the ground (Advisor, Port Industry Association, 14/07/09). The view here is split. Many experts disagree on the current level of reserves. Odell argues that oil production should peak at around the middle of the 21st century. The sufficiency of the world's oil and gas until the third quarter of the 21st century is not in doubt, adding that near-future 'peak oil and gas' forecasts in the 60s, 70s and 80s have all been proven wrong (European Energy Review, 2007). For most of the 21st century, the supply of carbon fuel will remain 'relatively plentiful' (Odell, 2004). Birol, the chief economist of the International Energy Agency, holds a more pessimistic view. He argues that global oil production is likely to peak in 2020 and the the world will need to find 'six Saudi Arabias to meet the expected demand between now and 2030 (Independent, 2009).

Public opinion about energy issues

According to the European Commission's report on attitudes and opinions of EU citizens regarding energy technologies (Special Eurobarometer 262, 2007), most Europeans think that guaranteeing low energy prices and the continuous supply of energy should be priorities of national Governments. EU citizens fear high energy prices and expect their governments to actively counter this issue. A third (33%) of Europeans spontaneously relate energy issues with prices and 45% consider that their government should make guaranteeing low energy prices a top priority in their energy policies (see Table 1).

The same report confirms also that there is little sense of urgency regarding the environment in the society. When the world as a whole is considered, then climate change is perceived as the most serious problems we currently face (Special Eurobarometer 300, 2008), but on the national scale the EU citizens are most concerned about their daily life, economic stability, safety and health. The Netherlands is not very different from the EU25 average in that case. Protecting the environment was chosen as the most important issue facing the country by 15% of Dutch respondents (EU25: 12%), energy related issues (energy prices, energy shortages, etc.) by 16% (EU25: 14%). In the first place Dutch mentioned crime (53%), followed by healthcare system (38%) and immigration (36%). For the EU25 unemployment was a top issue (64%).

Table 1. Preferred top priorities in the Government's energy policy

Priorities in Government's energy policy	**EU25**	**NL**
Guaranteeing low prices for consumers	45%	27%
Guaranteeing a continuous supply of energy	35%	50%
Protecting the environment	29%	24%
Protecting public health	22%	28%
Guaranteeing (OUR COUNTRY) independence in the field of energy	18%	10%
Reducing energy consumption	15%	28%
Fighting global warming	13%	20%
Guaranteeing the competitiveness of our industries	7%	6%

Source: EC, Special Eurobarometer No. 262, 2007

Image

Biofuels attracted a lot of negative media attention due to the food vs. fuel debate. According to Managers from an energy company (11/06/09)**,** many arguments questioning the sustainability credentials of biomass are false. This motivated the company to start a campaign rectifying these fallacies. Getting the message across is not easy. Public perception is primarily driven by the media and the biofuels industry has not been traditionally strong in influencing the media (Senior Managers, Energy Company 1, 11/06/09). Therefore communicating the benefits to the public and educating people about the new technology is an important part of the innovation process.

Knowledge about algae is very limited in the society. The Algae Specialist from the Ministry (22/06/09) recognized that people do not have an opinion about algae yet because they know little about it. The government should educate the public fairly and honestly.

An artist's conception of a massive alage biofuel farm (Image: claytonbodiecornell.greenoptions.com)

It is useful to look again at the Eurobarometer results here in Table 2. Regarding sources of information, the majority of EU citizens trust above all scientists and environmental protection organisations to give them information about energy issues. The same holds for the Netherlands. It is worth noting that the Dutch respondents have a greater degree of trust for their national government (60%) comparing to EU25 average (29%). The Dutch government can play an important role in educating the public about energy issues.

Table 2. Most trusted sources of information about energy related issues
(summary of answers: totally and a lot)

Sources of information	**NL**	**EU25**
Scientists	82%	71%
Environmental protection organizations or consumer associations	65%	64%
The European Union	57%	44%
Regional/local government	53%	38%
Electricity, gas and other energy Companies	40%	35%
Journalists	34%	31%
National Government	60%	29%
Political Parties	24%	13%

Source: EC, Special Eurobarometer No.262, 2007

Sustainability is a concept that focuses on long-term problems. The concept is difficult to realize as private companies are restricted by a rather short-time perspective (which is a result of short-time horizon of banks, shareholders, managers). So has the government, because it is based on preference of voters (van den Bergh et al., 2007). Algae requires as a long term perspective that does not fit in the model of some organizations.

Government policy and regulatory framework

The interviews confirmed the key role of the government for the success of innovations.

<u>Consistency and reliability</u>

Considering renewable energy sources such as algae, the interviewees feel the government should stimulate the market by appropriate regulations and provide funding for research. But more importantly, the government should ensure stability of legislation and the continuity of goals. There is nothing more harmful to an innovation than a sudden change in the government support. Companies that decide to invest in a new technology need some degree of certainty, because they are providing funding to get a return depending upon certain market conditions (Senior Managers, Energy Company 1, 11/06/09). To stimulate the development of green energy, government has to be a reliable partner. In the Netherlands there were changes in subsidies

structure (*MEP case, see chapter 4.2),* which was very confusing for companies (Biomass Specialist, Public-Private Energy Network, 26/06/09).
At the moment renewables are not competitive compare to fossil fuels. It is mainly because the environmental costs, such as climate effects, are not included in their price. In a well-functioning energy market the most efficient solutions will automatically be found ("polluter pays"). As this situation has not yet been achieved due to market failure, there is a legitimate need for government intervention (EIA, 2008).

<u>The need for support</u>
Without the government driving the market of sustainable innovation, the market will fail (Senior Managers, Venture Capital, 25/06/09). The interviewees highlighted the importance of renewable energy targets and obligations, as they create the incentive to invest by creating a market. According to the Scientist from an energy company (19/06/09), the biofuels sector is driven by the CO_2 reduction targets such as the European biofuels initiatives. The low carbon fuel directives, which reward directly CO_2 reduction, will help low carbon fuels. Agreements on the international level are relevant for the success of local initiatives. For example, the future of Rotterdam Climate Initiative largely depends on the outcome of the United Nations Climate Change Conference in Copenhagen (6-18 December 2009).[15]

<u>Energy obligations</u>
Most of the interviewees share the opinion that governments have to force change in the way we generate and use energy, as the energy market is controlled by large companies and they do not change unless they have to. That is either through regulations or stiff competitions from new companies (Senior Managers, Venture Capital, 25/06/09). So by making the conditions under which companies operate more difficult, the government can stimulate the businesses to innovate (Senior Advisor, Bank, 7/07/09). Manager from Port Authority (19/06/09) gave an example of the CFK in spray cans. The government banned CFK because it was damaging the ozone layer. That drove innovations and the market responded by introducing an alternative. The Consultant (Sustainable Energy Consultancy, 25/06/09) warns that obligations without restrictions may not lead to sustainable solutions, as they would stimulate the lowest cost technology. In the case of biofuels that would be the so called 1st generation which is already available, instead of the 2nd generation which is more sustainable but requires further investments. Only by introducing certain sustainability criteria would the market be stimulated to look for better technologies.

<u>Generic vs. targeted approach</u>
Regarding algae technology, government involvement is needed to povide the momentum. Currently it is a small sector and without the involvement of big stakeholders such as international bodies, local and national governments, it will not grow (Scientist, Energy Company 3, 19/06/09). Recently the Dutch government initiated studies about algae (e.g. Muylaert, 2009 and Florentinus et al., 2008) to decide on the degree of support and appropriate measures. Because of limited resources, governments have to make choices. The Dutch government is looking for a clean, reliable and affordable energy source (EIA, 2008). The choice has not been made yet (Algae Specialist, Ministry, 22/06/09) and the industry sees this as a shortcoming of the current policies (Senior Managers, Venture Capital, 25/06/09). The government's focus gives the direction to research, which is desirable. But the Algae Specialist from Ministry (22/06/09) explained that the government does not want to be too specific, a more generic approach is preferred. On the other

[15] The Conference aims it to reach an international agreement on a new climate treaty as a successor to the Kyoto protocol, the first phase of which expires in 2012. Kyoto Protocol was adopted in December 1997 and entered into force on 16 February 2005.

hand, a drawback of a generic approach is that too many projects may fall into the same category/scheme. The message what technologies the government wants to support is not clear then. This is one of the dilemmas described by Kern and Smith (2008): a level playing field implies that the government does not select technologies directly. However, this is exactly what a variety of stakeholders expects.

Ambitious goals

In the Netherlands there are many green initiatives, some with very ambitious goals (e.g. Rotterdam Climate Initiative set the target of 50% CO_2 emission reduction by 2025 compared to 1990 levels). As one of the interviewees said, you should aim high, otherwise you will always be average (Manager, an international network organization for entrepreneurs, 22/06/09). But large number of initiatives makes it difficult to keep the attention on one subject for a long period of time. Moreover, political programmes are susceptible to elections (Senior Advisor, Bank, 7/07/09).

Organizational complexity

Governments are complex organizations. There are many ministries/ departments and many people involved in taking decisions, so it is a lengthy process. Cooperation and good communication are necessary to ensure consistency. The following ministries are relevant for algae in the Netherlands: the Ministry of Housing, Spatial Planning and the Environment (VROM), the Ministry of Economic Affairs (EZ), the Ministry of Agriculture, Nature and Food Quality (LNV), the Ministry of Transport, Public Works and Water Management (V&W) and the Ministry of Finance.

What the renewable energy industry would like to see from the Dutch government is a long term vision and a strategy for the development of renewables backed by adequate funding. The interviewees often relate to the large subsidies granted by the U.S. government (because security of supply is very high on the agenda) and to the proactive attitude of the German government. Regarding algae, the Dutch government could also play a role in facilitating knowledge development and exchange by bringing actors together, initiating studies, sponsoring research. It is important that the government supports innovation, because they work on the environment that influences companies (Manager 1, Port Authority, 12/06/09). Dutch government sees its role in removing obstacles to allow the industry to move forward (EIA, 2008). To make that happen, cooperation on various levels and between various parties in the innovation system is needed.

Interest groups

As discussed in Chapter 2.3, renewable energy technologies are in conflict with the existing system based on the large scale concentrated forms of energy and managed by large scale centralized agencies, often monopolies (Elliott, 2000). These large firms represent vested interests – they seek to maintain the existing system from which they derive private benefits.

Petro-chemical sector

According to the interviewees, the petro-chemical lobby is extremely powerful (Senior Managers, Energy Company 1, 11/06/09). This is supported by a recent report that ExxonMobil alone outspends the entire Clean-Energy Industry by 23% in Washingon Lobbying (Bloomberg, 2009). Biofuels industry, on the contrary, is relatively new, so the community is not well organized. There is a significant difference in the organization, size and availability of network on both sides. As the Consultant (Sustainable Energy Consultancy, 25/06/09) observed, petro-chemical industry is a money maker for the governments. There is a historically grounded relationship between the conventional energy suppliers and the government, as they used to be publicly owned (Consultant, Sustainable Energy Consultancy, 25/06/09). There is also evidence that the influence of the petro-chemical sector affects the academic circle. A disagreement on the amount of oil reserves between BP and an energy economics professor in Erasmus University Rotterdam led to the former labeling the latter a persona non grata, making it difficult for the professor to get funding for his department in Rotterdam, and contributed to his department being shut down in 1992 (European Energy Review, 2007).

Renewable energy targets (e.g. EU: 20% energy from renewable sources in 2020, 10% share of biofuels in transport in 2020) are seen by large oil and energy companies as a threat, as they will cause significant market loss (Senior Managers, Energy Company, 11/06/09). That is what the interviewees see as a main driver for these companies to enter renewable energy market. However, as long as they make money with the "old fashioned" ways of supplying energy, their involvement in new energy technologies will be minimal (Advisor, Port Industry Association, 14/07/09).

In their analysis of energy transition policy in the Netherlands, Kern and Smith (2008) argue that there is too much focus on "regime incumbents" – large energy companies from the existing energy regime dominate the industry representation, whereas newcomers are seen as innovators. This view was confirmed by the Advisor from a port industry association (14/07/09), who pointed out that majority of subsidies go to big companies, as they have the knowledge and expertise to apply for it. Similarly, they have resources to take part in conferences and other initiatives, which smaller companies lack. In that way the knowledge can be locked out.

The PhotoBioReactor Sculpture, BIOS Design Collective (by Charles Lee). Created to act as a piece of art, a renewable fuel source, and a bio-remediation plant, to "evoke thought and stimulate the imagination". (Image: ww.tomshardware.com)

<u>Lobby</u>

Most of the industry representatives we interviewed admit they lobby on local, national and international level for favorable solutions, interest, funding. The algal industry in the Netherlands is currently too small and too fragmented to (1) lobby for regulations, (2) be seen by large players as a threat. However, like other biomass it is supportive to agriculture, so agriculture lobby may play a role if it sees the potential in that product (Senior Managers, Energy Company 1, 11/06/09).

The lobbying effort of Algae biomass outside the Netherlands is also only at its infancy. The European Algae Biomass Association (EABA) was formed in June 2009, while Algal Biomass Organisation (ABO), the US counter-part of EABA, was founded in 2008. Despite the lack of history, there are signs that the algae industry's lobbying effort may soon bear fruit. A bill has recently been proposed in the US to recognise algal biomass as a biofuel feedstock, making algae a legitimate contributor to the government's renewable fuel target and so create a market (New York Times, 2009).

Other renewable energy sources, like wind or solar, do not form an obstacle to algae development. Most actors see sustainable energy not as one or two products, but as a whole range of different products (Senior Managers, Energy Company 1, 11/06/09). The perspective of Biobased Raw Materials Platform is that in 2050 we will need them all – solar, wind, biomass and we will still need fossil fuels (Algae Specialist, Ministry, 22/06/09).

Environmentalists

When it comes to environmental organizations, they are not opposing algae at the moment, their attitude has been described as neutral (Consulant, Sustainable Energy Consultancy, 25/06/09). Algae may solve many climate issues, like CO_2 emissions, water contamination, deforestation, etc. However, once the large scale production is reached, protests from environmentalists and communities (Not-In-My-Back-Yard) can be expected. Algae Specialist from the Ministry (22/06/09) reminds they were also protesting against wind farms.

Knowledge network and diffusion

A well-functioning knowledge network is a success factor for innovations. A knowledge network consists of global pipelines and local buzz. The former refers to access to knowledge developed outside a cluster, while the latter refers to information exchange and idea generation within a cluster. Partners in this network could be universities, research institutes or companies; could be local or foreign; could be big or small.

Universities and Research Institutes

There is a general consensus on the importance of a knowledge network for the development of algae. Pairing up knowledge institutes and companies is in fact one of the major task for two of the interviewees (Manager, Climate Initiative, 11/06/09; Biomass Specialist, Public-Private Energy Network, 26/06/09). Agricultural and technical universities and research institutes such as TNO and NWO are regarded as important players in the knowledge network. This is mainly because algae technology is still at the development phase, and the universities' own academic research provides the knowledge for this development.

There are not many universities in the Netherlands working on algae and many interviewees collaborate with foreign universities. Despite the hype and progress of algae technology, not many new universities or research groups have appeared in the Netherlands. This contrasts strongly with the United States where the opposite is happening (Professor, University, 02/07/09).

Development of algae technology requires a number of, not just one, innovations. Due to different specialization, no university or institutes possess the complete collection of knowledge, especially between technology of algae as a fuel and algae as a high-value product. This difference in specialization partly explains the absence of collaboration between the biggest petro-chemical company in the Netherlands and the biggest university in the field of algae in the Netherlands. One interviewee said they need a broad network of universities precisely because different universities have different skills in different areas. Some universities may be world renowned, but other universities simply have different things to offer (Scientist, Energy Company 3, 19/06/09).

Universities focusing on social science are also mentioned as valued partners in the knowledge network, albeit far less frequent than the technical universities. One interviewee said they work with a university to develop different scenarios based on the trend of green energy policies and the performance of the economy. These scenarios are then used to help the company 'prepare for the future' (Manager, Energy Company 2, 18/06/09)

R&D departments in the companies

R&D departments of companies tend to be the gateway of knowledge between companies and external knowledge sources such as universities. Universities also find them interesting because they provide knowledge and resources, which is why sometimes universities take the initiative to partner with companies. It is worth noting that while companies are interested in collaborating with several universities, universities also want to collaborate with several companies. This is because algae development requires knowledge in many areas, and universities do not want to be place in a vulnerable position where one company's policy change (e.g. shutting down the algae programme) spells chaos to the entire research effort (Professor, University, 02/07/09).

Informal knowledge network

Apart from collaboration and consortia, several interviewees confirmed that informal knowledge networks also exist. Knowledge are exchanged through 'drinking coffee together' (Professor, University, 02/07/09) or through personal relationships dating back to university days (Senior Advisor, Bank, 07/07/09).

Other nodes in the knowledge network

Universities and research institutes may be the most frequently mentioned knowledge partners, but they are not the only type of knowledge partner. One interviewee from the bank said that they regularly provide a 'coach' to help a young company. It is to the bank's interest to help since the bank will lose its loan if the company folds. Such a coach would be a senior entrepreneur knowledgeable in all business-related aspects. Most of the time the coach does it on a voluntary basis, although some do end up formalizing their role and take up a minority stake of the company (Senior Advisor, Bank, 07/07/09). Another interviewee thinks that even universities do not know everything. Sometimes knowledge is acquired through personal contact (Biomass Specialist, Public-Private Energy Network, 26/06/09). This point has been verified by another interviewee, who uses his personal contacts to get answers.

Intellectual Property and Knowledge Sharing

The world of algae is still very new. One interviewee estimates that at the moment we are only looking at 2% of the total number of algae strains. The absence of knowledge exchange means several research groups could be looking at the same, possibly dead-end, strain (Algae Specialist, Ministry, 22/06/09). Knowledge sharing can speed up the overall progress of algae research. However, companies that invest in the research are likely to want to retain the intellectual property (IP). This means a clause on the collaboration agreement with the universities stating clearly who owns the patent, and it makes knowledge sharing rather difficult (Consultant, Sustainable Energy Consultancy, 25/06/09).

Another interviewee said that the IP does not normally go directly to the company because the research may be subsidized by the government. In that case, the companies normally have the first rights to buy the IP. Sometimes companies enter into bilateral agreement with universities to work on secret research. Universities also see the implication of giving up the IP, which is why sometimes universities want to keep the IP just in case the company 'kills the technology' after buying the patent (Professor, University, 02/07/09).

The idea of forcing all the research groups to open up their secrets to the world is a bad one. One interviewee thinks that will stifle R&D as the right of IP is what drives the development forward

(Scientist, Energy Company 3, 19/06/09). Another interviewee suggests that it is the government's role to intermediate. One way is to provide funding under the condition that all the knowledge will be made public (Consultant, Sustainable Energy Consultancy, 25/06/09).

<u>Business Model</u>

One interviewee highlighted how an organisation's business model affects its ability to acquire knowledge. The interviewee named and compared a Dutch energy company with a German energy company. The German company has a megawatt production 6 times the Dutch company's; but it has a R&D department infinite times bigger – 270 staff versus zero. One of the reasons is because the German company adopts the Rhineland business model. This model traditionally allocates more money to the investment of the company and less to the shareholders, which partly explains why the German company can support a bigger R&D department (Manager, Energy Company 2, 18/06/09).

The fact that algae is still at the development stage means that it is particularly important to establish Global pipelines. The pipeline aspect of a knowledge network clearly attracts more attention than the local buzz aspect.

Past experience

When it comes to innovation, 'history matters'. Past experience may lead to path-dependency, which could create barriers (i.e. lock-ins) for the development of innovations. These lock-ins can be technological: incumbent technology may enjoy greater economies of scale; it may incur a higher sunk cost because of previous investments. They can be institutional: the opacity of politics may influence politicians' behaviour; institutional change may be costly due to high density of institutions.

<u>Willingness to develop algae fuel</u>

It has been suggested that we are in the state of carbon lock-in, i.e. we are locked into fossil-fuel based energy systems through a process of technological and institutional co-evolution driven by path-dependant increasing returns to scale. The lock-in implies that, regulations aside, alternative fuels should not threaten the position of fossil fuels unless there is enough capital to increase the scale of alternative fuels.

The case of carbon lock-in certainly exists. This could be technological: One interviewee said that their energy plants can generate electricity from coal and oil, but are not configured to cope with biofuels (Manager, Energy Company 2, 18/06/09). It could also be institutional: one interviewee said that politicians do not want to see the price of energy increase because of the impact on the economy (Professor, University, 02/07/09). The fact that our society is accustomed to relatively cheap fossil fuels means the customers are likely to resist if they see their energy bill going up. Several interviewees agree that our economy is based on cheap fossil fuels, and that nobody wants to see energy prices go up, especially customers.

However, this does not lead to energy companies giving up the development of algae fuel altogether. All energy companies we interviewed are carrying out R&D activities in the field of algae, although they also acknowledge that algae fuel is very much in the R&D stage. At the same time they have R&D activities in other types of alternative fuel, one interviewee explains that it is important to develop technologies 'closer to reality' as they generate income streams to support innovations that are further off (Senior Managers, Energy Company 1, 11/06/2009).

Some interviewees said that many people in the petro-chemical companies do not believe in algae fuel. The capital expenditure is too high and the date of materialization is too long. This is an example of the increasing return of adoption (Foxon, 2002) where the large setup cost and uncertainty of an innovation (i.e. algae) serves as an obstacle of its adoption.

One interviewee points out that the petro-chemical sector could do more. The interviewee understands that one major petro-chemical company is downsizing its effort in renewable energy because it wants to focus on biofuelss, which fits their existing infrastructure (Senior Managers, Venture Capital, 25/06/09). An example of path-dependency, where past investment determines the future investment strategy of the business.

Institutional lock-in

The petro-chemical sector enjoys a legislation advantage over alternative energy. Petro-chemical companies are older, they enjoy a closer relationship with the government through historically grounded relationships and tax revenue. One interviewee gave an example: oil platforms still get a license of 50 years while the offshore wind farm's is much shorter (Consultant, Sustainable Energy Consultancy, 2009).

The petro-chemical sector also enjoys an increasing return of adoption at lobbying. On top of more resources for lobbying, the fact that the petro-chemical companies have been around for longer and more experienced give them an advantage. One interviewee thinks that the petro-chemical lobby is extremely powerful within the national structures and the bio-fuel community struggles to match because they are relatively new, with less resources and not as well organized (Senior Managers, Energy Company 1, 11/06/2009).

Past experience with nature

Some interviewees believe that the Netherland's past experience with nature have an impact on its desire and ability to develop sustainable innovations. One interviewee reckons that the Netherlands is a pioneer in the issue of sustainability, and this is because for a long time the country had to deal with the lack of space, limited resources and the artificial construction of the country (Manager, Entrepreneur Network Organisation, 22/06/09). This experience with nature has a technical impact. One interviewee thinks that the Netherlands' role in algae development should be based on their traditional engineering skills, especially hydraulic engineering (Scientist, Energy Company 3, 19/06/09). Other interviewees mentioned that the country's position to develop algae technology is strengthened by its long history in agriculture and in the ocean.

Not all interviewees think that this past experience with nature helps the development of algae technology in the Netherlands. One interviewee thinks that despite appearing to be very green – an image partly derived from it's past experience with nature - the government is not 'fund generous' (Senior Managers, Venture Capital, 25/06/09). Another interviewee thinks that the country's history of fighting flood has no impact on the development of aquatic biomass. It is simply a coincidence (Algae Specialist, Ministry, 22/06/09).

Production technique

Dosi's concept of 'technological trajectory' states that innovation tends to be of an incremental nature and is brought to the market compatible with existing infrastructure. Our interviews reinforce this concept. One energy company tries to develop algae fuel by focusing on their existing skills such as engineering know-how, innovation process and project management. Another interviewee thinks that his region's agricultural legacy and existing biomass processing facilities makes it a good location for working with 'green stuff' such as algae (Biomass Specialist, Public-Private Energy Network, 26/06/09).

Availability of resources

There are two types of resources without which an innovation cannot be successful. The first type is human capital. People with various skills are required to transform an innovation into a successful product: entrepreneurs – described by Schumpeter as 'innovators' – to build an enterprise for the innovation; scientists and technicians to develop the technology; marketing professionals to bring the product to market; managers to control the finances and the production process; labour to man the factories. The second type of resource is funding. Algae technology is still under development, it still requires money to move to the next development phase.

<u>Skilled staff</u>

The first type of human capital is skilled staff. All interviewees agree that the role of skilled staff such as scientists and technicians is of paramount importance to the development of algae technology.

Most interviewees agree that there is a shortage of skilled staff in the field of algae. Algae is a relatively new field and there are not many universities focusing on this subject, so people with algae specific knowledge are rare and apart. Two interviewees think that more skilled staff is needed in the sea cultivation of algae. Land cultivation has a lot more experienced personnel around the world than sea cultivation, but the latter is regarded as having enormous potential (Algae Specialist, Ministry, 22/06/09; Consultant, Sustainable Energy, Consultancy, 25/06/09). It is thought that in the coming years a new generation of staff will come up and fill the gap, but for now the pool is very small.

One interviewee thinks this shortage is particularly stark in Europe. This is because the European society is too spoilt and has no urge to find a solution for the world. The interviewee reckons the hope lies in countries like China and India, where universities there 'spit out' millions of bright people (Advisor, Port Industry Association, 14/07/09).

Algenol Biofules and Dow Chemical Company are planning to build a pilot plant in Texas to produce ethanol from algae (image: greeninc.blogs.nytimes.com)

To counter this problem, companies try to plug the hole by establishing collaborations with different universities. One interviewee's company works with a network of universities in the US, the UK, Canada and the Netherlands (Scientist, Energy Company 3, 19/06/09). While another interviewee's company has 10 to 15 collaboration programmes in Spain alone (Senior Managers, Energy Company 1, 11/06/09).

However, countering this problem by developing a degree programme specifically for algae may not be a good idea. The mistake many algae group made in the past is that they make it too specific for algae and they forget that process design is for all processes, not just algae. Due to the similarities in the biological aspects, looking at a wide range of bio-based technology instead of just algae may lead to more progress. One of the interviewee's colleague went on to work on animal vaccines after gaining a PhD in an algae programme (Professor, University, 02/07/09).

Entrepreneurs

The second type of human capital is entrepreneurs. Several interviewees think that rather than the fossil fuel companies, the entrepreneurs will play a key role in pushing the development of renewable energy. One interviewee suggests that the R&D budget for major fossil fuel companies may only be enough to keep the 'green' factions happy (Advisor, Port Industry Association, 14/07/09). Another interviewee backed up this argument by citing that a major petroleum company has reduced the renewable energy budget by two third. This highlights the vulnerability of the renewable energy division in the major petroleum companies. Entrepreneurs may come up with a new business model that challenges the current energy market (Senior Managers, Venture Capital, 25/06/09). Entrepreneurs also tend to be under less time pressure than the R&D departments.

Many interviewees agree that good entrepreneurs are hard to come by. First, not all entrepreneurs have the basic entrepreneur skills, they need support in entrepreneurial skills such as legal, economics and most importantly, writing a business plan (Manager, Climate Initiative, 11/06/09). Second, there is the issue of integrity. More than one interviewee said that they have encountered entrepreneurs with questionable intentions. Third, some entrepreneurs love their product so much they forget they need to sell it (Senior Advisor, Bank, 07/07/09). One interviewee concludes that "preachers and engineers are not necessarily entrepreneurs and many entrepreneurs that claim to be engineers are normally not the best engineers" (Manager 2, Port Authority, 19/06/09). This seems to imply that it is probably more of a quest of an entrepreneur team, rather than a single entrepreneur who embodies all the qualities.

Funding

Our interviews conclude that there are three types of funding going into algae development.

Government funding

The MEP and SDE subsidies were mentioned in the interviews. The Netherlands used to have a subsidy called MEP for renewable energy producers, its coverage range from biogas to wind and biomass. This subsidy has, however, been suspended in 2007 (IEA, 2008) and was replaced by another scheme called SDE. SDE only pays out money when the market electricity price reaches a certain level (IEA, 2008). Several interviewees raised the issue that changing subsidies structure is confusing for companies and creates uncertainty.

Most interviewees think that the amount of government subsidies for renewable energy is not substantial. One interviewee is investing in a biofuels plant in the city of Rotterdam, and the subsidy they received is less than 1% of the total amount of investment. There is also a lack of government support in moving the development of second generation biofuels from stage one to stage two (Senior Managers, Energy Company 1, 11/06/09). This is, however, not the consensus. One interviewee thinks that the government (ministries and provinces) is very supportive, and not only financially. The government helps forming consortia and collaborations with companies. (Professor, University, 02/07/09). Such help could be considered as an indirect means of funding. Recent government projects such as the algae research programme 'Towards Biosolar Cell' and Energy Innovation Agenda show that the government is providing funding for the research community.

At the moment there is no subsidy specifically for algae in the Netherlands. The government wants to take a more general rather than specific approach (Algae Specialist, Ministry, 22/06/09).One algae start-up in Rotterdam did manage to receive a grant from the local government, but it was through a general scheme rather than an algae-specific scheme. It is worth noting that this scheme has not a formal selection process (Manager, Climate Initiative, 11/06/09).

Company's own resources

All the energy companies in our interviews are investigating algae. They fund the algae R&D projects out of their own pocket. These projects are partnerships and consortiums with other research institutes or companies. Sometimes providing funding is the only contribution of a company in a consortium. As one interviewee puts it, "we are a partner, we invest and there is nothing else we can do" (Manager, Energy Company 2, 18/06/09). Forming a consortium with research institutes sometimes qualify the company for government subsidies (Professor, University, 02/07/09), adding extra financial incentives for companies to form consortia. However, this touches the issue on who owns the intellectual property which we discussed before.

Financial sector

In previous chapters we included several examples on private capital flowing into the development of algae technology. However, none of our interviewees from the financial sector are currently investing in algae technology.

One interviewee, a venture capital, is not investing in algae because it is uncertain how much more money is required to make algae fuel happen. Given that the interviewee has a limited amount of funds to their disposal and a fund period, there is not a case to invest in algae (Senior Managers, Venture Capital, 25/06/09). Another interviewee points out that in the US there are many algae companies backed by venture capital, but they have very strict go and no-go decisions, and if the researchers fail to meet the targets, the funding stops (Professor, University, 02/07/09).

For the other interviewee, a bank, agribusiness and clean technology are part of their focus. However, the bank is providing neither loan nor venture capital arm to algae fuel development at the moment. Algae is a rather new type of energy, a new type of material, and the bank prefers to invest in technology that is more mature. It is less risky and it takes a shorter period of time to generates positive cash flow (Senior Advisor, Bank, 07/07/09).

5.2 What is the role of algae in the port of Rotterdam

5.2.1 The port of Rotterdam: a brief introduction

The history of the world's most famous port dates back to the 1400s. The construction of the Nieuwe Waterweg to the North Sea in 1872 accelerated the growth of the port. It became Europe's top port in 1938, and subsequent expansions pushed the port's operation further downstream, with Maasvlakte 2, the latest port area, being developed literally in the North Sea.

As of 2008 the port of Rotterdam is the biggest container port in Europe and ninth biggest in the world (Port of Rotterdam, 2009). It is located in North West Europe at the end of river Maas and river Rhine. It forms part of the Hamburg- Le Havre range (Port of Rotterdam, 2009), one of the most competitive port ranges in the world, alongside eight other large ports.

Contrary to the Latin approach popular amongst Italian ports and the trust ports found in the UK, the port of Rotterdam adopts a local municipal management approach (Brooks & Cullinane, 2006). The Port of Rotterdam Authority is a public corporation with the municipality of Rotterdam and the states as the only shareholders. The port of Rotterdam is a landlord port. The port owns the port land and infrastructure, leaving the rest of the port's operations to private parties.

Apart from handling cargoes and containers, the port of Rotterdam is also engaged in other activities. For example, it is home to a major petro-chemical cluster. The port houses more than forty petro-chemical companies and five oil refineries (Port of Rotterdam, 2009), including two of Europe's biggest in terms of capacity; it is a major storage and transport hub for vegetable oils and biofuels; new facilities for liquefied natural gas are expected to be operational in 2011 and 2012 (Reuters, 2009). Companies in the city of Rotterdam provide supporting services such as banking and legal. The wide range of economic activities relating to the arrival of goods and ships at the port combines to form the port cluster of Rotterdam (De Langen, 2003). The port has a port cluster association; it serves mainly as the spokesman and lobby group of the companies carrying out the activities of the port of Rotterdam. A breakdown of the number of companies active in the port cluster of Rotterdam is as follow:

Table 3. Companies active in the port cluster of Rotterdam

Forwarding	386
Shipping	547
Finance and services	67
Transport consultancy, consulting engineers & IT	127
Supplies associated industries	633
Transport	485
Warehousing and distribution	224
Other cargo handling services	307
Port promotion	25
Total	**2801**

Source: http://www.rotterdamportinfo.com/

Many organisations that form part of the port cluster of Rotterdam are located in the city of Rotterdam, the term 'Rotterdam' and 'the port cluster of Rotterdam' will be used interchangeably for the rest of this thesis.

5.2.2 What is the role of algae in the port of Rotterdam

"Since the worlds environmental problems will not go away, and pressures to clean up are likely to increase, companies and countries that invest now in 'clean green technology', including renewable energy technology, will be better placed competitively in the future" (Elliott, 2000).

As discussed in Chapter 2.2.1, ports are major sources of pollution. Port operations cause part of it, but ports are also attractive locations for various industries, such as power plants, chemical plants and oil refineries, as is the case in the port of Rotterdam.[16] All together they consume huge amounts of energy, emit CO_2 and produce waste and residual heat. There are two main consequences:

1) Climate change mitigation agreements require ports to significantly reduce their negative impact on the environment,
2) Due to rising CO_2 and energy prices and measures enforced by aforementioned regulations, port operations will become more expensive, ceteris paribus.

Port of Rotterdam has environmental goals defined under Rotterdam Climate Initiative: to halve CO_2 emissions in the region by 2025 in comparison with 1990 levels (Figure 9). Port's ambition is to have own activities climate neutral by 2012. Sustainability is one of the Port Authority's five key values.[17]

It means that despite expansion of the port and growth in port operations, CO_2 emissions have to be less. As the Advisor from a port industry association explained (14/07/09), port of Rotterdam is the gateway to Europe, so it has certain social responsibility. It was also confirmed by the Manager from the Port Authority (Manager 2, Port Authority, 12/06/09). The objective is to make Rotterdam, especially the port and the industry, the most efficient, the greenest, the best port in the world and to be an example to the world how a large industrial and port complex can act with respect to the environment. Because of its focus on sustainability, port of Rotterdam included strict environmental standards in tender conditions for the Maasvlakte 2, like certain modal split or zero emissions. Despite that, a tender for one spot could attract as many as 14 operators (Manager 2, Port Authority, 19/06/09).

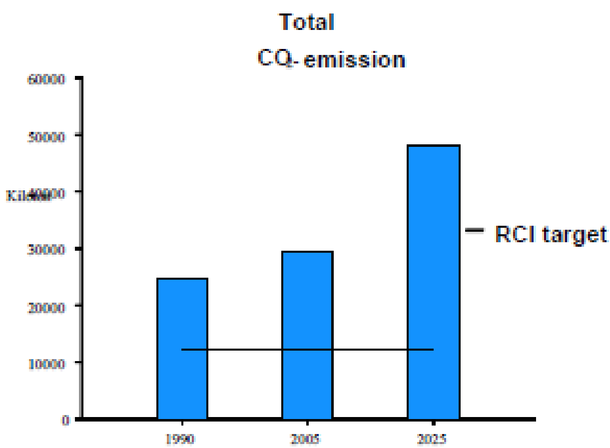
To achieve the environmental goals, it is not enough to reduce the energy consumption. Port's strategy includes many possible solutions: carbon capture and storage (CCS), wind energy, solar energy, the use of biofuels for transportation and ships (Manager 1, Port Authority, 12/06/09). Everything what could help is looked at favorably.

The underlying reason is to avoid the port becoming more expensive, what would worsen its competitive position on the world market. It would be especially difficult to compete with countries that do not pay that much attention to environmental issues.

According to our interviewee, CCS is an energy intensive process and it does not yield profits, so power plants will increase energy prices to cover that costs (Advisor, Port Industry Association, 14/07/09). Companies want to avoid putting money into the ground, which is why they are looking for possible options for using the CO_2 they emit. One example is supplying it to greenhouses, as it is done now in the port of Rotterdam.

[16] On top of the 5 oil refineries and 43 chemical and petrochemical companies mentioned in 5.2.1, there are also 3 industrial gas producers, 4 refineries for edible oils and fats and 1500 km of pipelines in the port of Rotterdam (Key Figures Industry, 2008. www.portofrotterdam.com)
[17] http://www.portofrotterdam.com/en/about_port/sustainable_port/index.jsp

Figure 9. Estimates of CO_2 emissions and RCI target



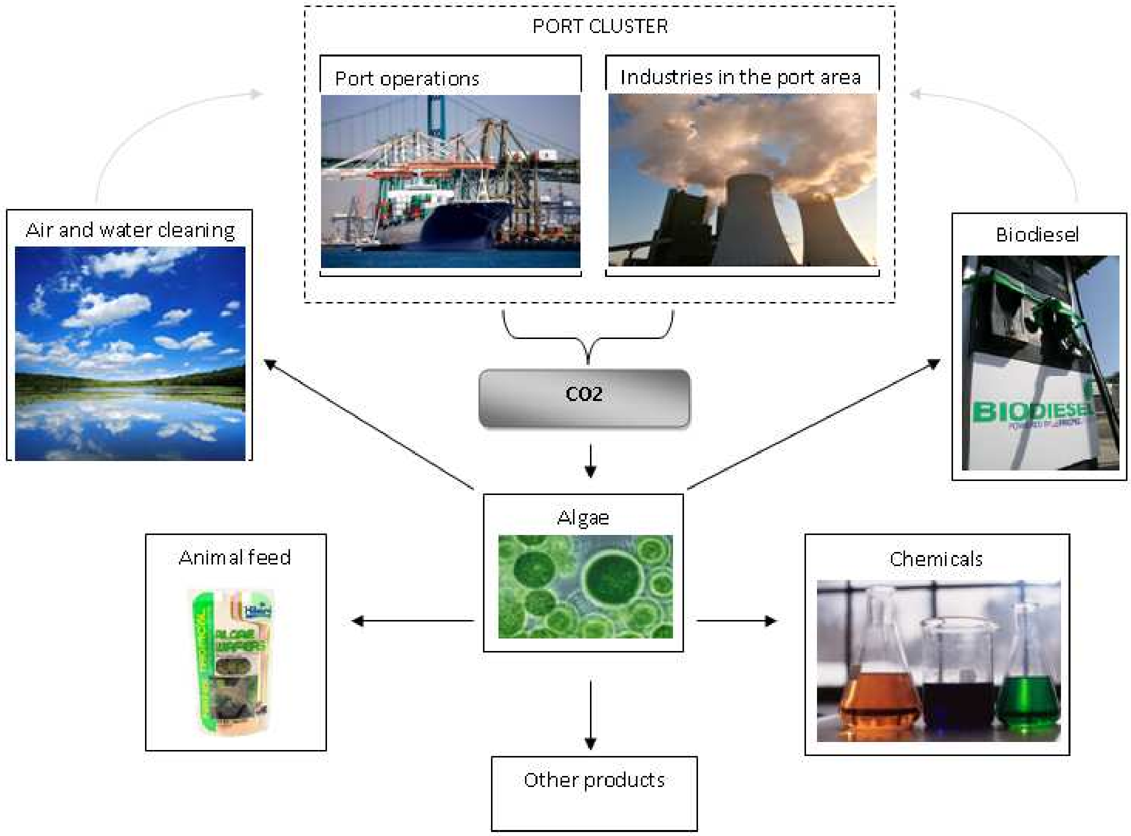
Source: DCMR, Baseline study Rotterdam Climate Initiative

Algae also made it to the port's R&D agenda. The Manager from the Port Authority (19/06/09) named the reasons behind this decision: with factors such as CO_2 and residual heat, algae seemed logical for the port of Rotterdam. It reduces emission, creates a new business line in the bio area, finally it shows that the port of Rotterdam is ahead of time, is innovative.

Indeed, the port of Rotterdam has several advantages with respect to algae: various pollution sources that can be used as nutrients, bio refineries and chemical companies which could process the biomass, good logistical position to serve as transport node, oil and petrochemical companies for the distribution of biofuels. Algae could be also used for water purification purposes. The port of Rotterdam is expected to play a crucial role in the bio based economy. Soon it will be the site of the largest renewable diesel plant in Europe.[18] Adoption of algae technology could further strengthen that image.

[18] Neste Oil builds Europe's largest renewable diesel plant in Rotterdam, http://www.nesteoil.com/default.asp?path=1;41;540;1259;1260;11736;12695

Figure.10 The role of algae in the port



Source: own elaboration

As Rodney Chase (Deputy Group Chief Executive, BP Oil) said, "it could be well that the first country to seriously address the issues of creating a market for renewables would become the central location for a major new international business sector – with all the positive consequences that carries in terms of economic activity and employment. There is great scope in all of this for government and business to work together to build the right conditions for renewables." That could apply to the port of Rotterdam.

However, port's Innovation Agenda has rather an indicative character and algae was not picked up on the broader scale. To our knowledge, there is no research project for algae in the port of Rotterdam at this moment.

In the next chapter we will try to understand what may be the cause of that by analysing the remaining obstacles to the adoption of algae in the port of Rotterdam.

5.3 The outstanding obstacles for developing algae farming in the port of Rotterdam

Based on the desk research and the interviews, we identified major obstacles to develop algae farming in the port of Rotterdam.

Risk aversion

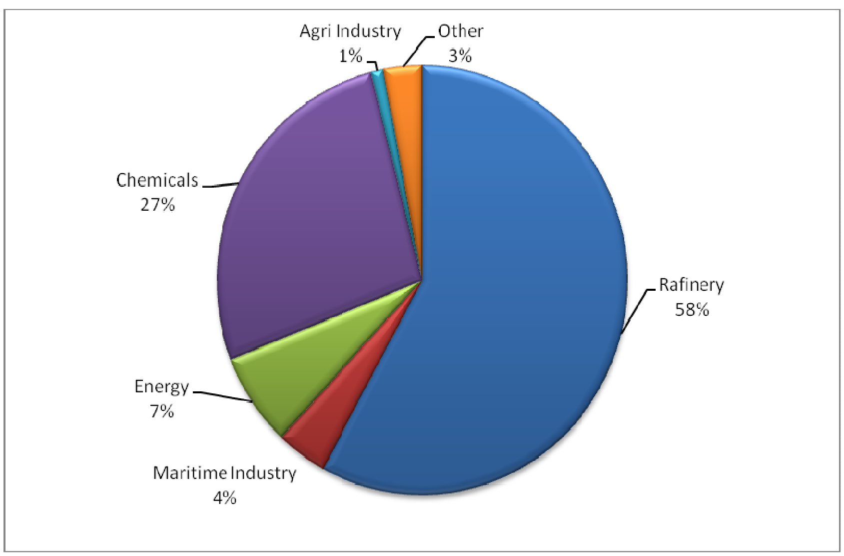
Port is primarily interested in commodities and transshipment (Manager 1, Port Authority, 12/06/09). Activities undertaken by the port should generate cargo, because that is what brings

profits. Growing algae in the port is not seen as such an activity, hence the opposition (Manager 2, Port Authority, 19/06/2009). Moreover, it is not part of the core business, so it means risks.
It is very relevant for the port. The flow of containers is vulnerable to interruptions and problems can easily spread over the whole chain. That is why the port business is rather risk averse and does not want to implement changes unless necessary. Focus is on the operational, day-to-day issues (Senior Advisor, Bank, 07/07/09). Companies prefer quick wins and incremental rather than radical innovations.
Path dependence plays a role here. It also has to do with the sense of urgency, which is rather limited on the individual firm level. As a result, everyone is waiting for someone else to act first (Senior Advisor, Bank, 07/07/09). That is why strict environmental standards and government regulations are necessary to bring about the change. Especially that the petro-chemical sector constitutes a large part of the port cluster in Rotterdam.

Regime incumbents

Large representation of "regime incumbents" is not a breeding ground for innovations and can slow down changes. As we said before, these companies are characterised by inertia and are usually not the first ones to change. What is more, because of increasing returns to scale there is little incentive for them to invest in new technologies.
Port of Rotterdam is the site of some of Europe's biggest oil refineries: Shell's Pernis (Europe's biggest, with a capacity of about 412,000 barrels of oil per day), BP Rotterdam (Europe's second biggest, 400,000 bpd), and Kuwait Petroleum's (80,000 bpd plant).[19] There are also 6 crude oil terminals and 19 independent tank storage and distribution terminals for oil and chemical products (2008).[20] In future, after completion of Maasvlakte 2, this numbers will rise. Petroleum and chemicals take up 85% of the land in the port (Figure 10) and in 2006 they accounted for 25.6% of the direct seaport related added value.[21] There is an uneven distribution of power, which may slow down the transition to a sustainable energy supply in the port of Rotterdam.

Figure 11. Land use in the port of Rotterdam



Source: Port Statistics 2008, www.portofrotterdam.com

[19] http://www.reuters.com/article/marketsnews/idAFL732962220090723?rpc=33
[20] http://www.portofrotterdam.com/mmfiles/key_figures_industry_tcm26-19699.pdf
[21] http://www.portofrotterdam.com/mmfiles/added_value_and_employment_tcm26-9707.pdf

Entrepreneurs

The importance of entrepreneurs has been discussed in previous chapters. Several interviewees agree that entrepreneurs are needed to develop algae farming in the port of Rotterdam. As one interviewee based in Rotterdam puts it, the most innovative solutions are not coming from large companies, but passionate individuals (Manager, Entrepreneur Network Organisation, 22/06/09).

Our interviews suggest that there is no shortage of ideas in Rotterdam, and the entrepreneurial spirit in Rotterdam seems to be high. One interviewee said that there are at least eight top eco-entrepreneurs in Rotterdam, which is something one will not find in other cities in the Netherlands (Manager, Entrepreneur Network Organisation, 22/06/09).

The challenge, rather, lies in the quality of the entrepreneurial skills. One interviewee mentioned the ability to communicate, saying that it is incredible how many people are afraid of sitting down and writing a couple of lines. Communicating ideas is a challenge for many people (Manager 2, Port Authority, 19/06/2009). Another interviewee mentioned the ability to prepare a business plan. Interviewees, including the ones from the financial sector, confirmed that only ideas with a good business plan will secure funding. Despite meeting entrepreneurs coming over with new ideas on a daily basis, one interviewee thinks it is clear that many of these entrepreneurs need support to write a business plan (Manager, Entrepreneur Network Organisation, 22/06/09). One interviewee thinks that it is the delicate balance of technical and commercial skills that is lacking. A nearby technical university supplies Rotterdam with technicians and ideas, yet their lack of business and marketing related knowledge handicapped their ability to turn their ideas into a product. Some technicians also get carried away by the features of their products, and forget that they have to make the product appeal to customers (Senior Advisor, Bank, 07/07/2009).

Some interviewees also mentioned the implications of failing in business in the Netherlands. One interviewee thinks that in the Netherlands there is no culture for failure, 'if you stick out your neck, you get punished'. The idea of sticking to your job for 40 years is still heavily valued (Advisor, Port Industry Association, 14/07/2009). This implies that a failed entrepreneur attracts negative social stigma. Another interviewee said it is harder for a failed entrepreneur to get a bank loan. Formally it is not an issue, but informally bankruptcy is an obstacle (Senior Advisor, Bank, 07/07/09).

Entrepreneurship is risky. One interviewee estimates that only one in twelve businesses is successful (Advisor, Port Industry Association, 14/07/2009). Improving the entrepreneurial skills and changing the culture of entrepreneurship could lead to the creation of more business start-ups and a better chance of deriving innovations that make algae farming possible in the port of Rotterdam.

Lack of R&D capacity in the port cluster of Rotterdam

Apart from entrepreneurs, the R&D departments of companies are also key sources of innovation. As mentioned in previous chapters, R&D departments are part of the knowledge network, the gateway of external knowledge and are collaboration targets for knowledge institutes and fellow R&D departments. The location of R&D departments in Rotterdam should help bring in innovations and best practises to the port.

However, one interviewee points out that there are not many R&D departments in Rotterdam. The poor R&D capacity of Rotterdam is partly to do with their foreign ownership. Many major companies in the port of Rotterdam – petrochemical or container companies - are owned by foreigners with headquarters outside the Netherlands. Their R&D activities also stay outside of the Netherlands; as a result these companies do not contribute to the innovation capacity of Rotterdam (Senior Advisor, Bank, 07/07/09). This is confirmed by two other interviewees. One said that the R&D arm of their business sits in Spain and the United States, and their Rotterdam operation is only responsible for trading and plant development (Senior Managers, Energy Company 1, 11/06/09). The other interviewee said that their algae development programme takes place in Hawaii (Scientist, Energy Company 3, 19/06/09).

The interviewee suggests that the absence of a technical university is another handicap of the R&D capacity of Rotterdam. The nearest technical university is 30 minutes away by car, so not within the city (Senior Advisor, Bank, 07/07/2009). The magnitude of this handicap is questionable. Other interviewees based in Rotterdam still have collaborations with this technical university despite the distance. One Rotterdam based interviewee even managed to establish collaborations with two universities in Singapore through this technical university (Manager 2, Port Authority, 19/06/09). As previously mentioned, Erasmus University Rotterdam used to have a department for international energy studies which could contribute to the energy aspects of algae farming. However, this department closed in 1992.

The idea of merging Erasmus University Rotterdam and Hogeschool Rotterdam to establish an all-round university has been dismissed as too complicated. The two schools are too large. A university with a bureaucratic organisation creates a difficult climate for innovation (Senior Advisor, Bank, 07/07/09).

Land use

Some interviewees mentioned the problem of land use. This seems to be a valid concern. The port of Rotterdam has long suffered from land shortage. It was mentioned in Port Vision 2010 (drafted in 1993) and again mentioned in Port Vision 2020 (Port of Rotterdam, 2004). Although the construction of Maasvlakte 2 will offer new space, it will not be enough to support algae farming. According to one interviewee, it will take around 4000 hectare of land to farm enough algae to match the energy output of a coal-fired power plant (Advisor, Port Industry Association, 14/07/2009). Maasvlakte 2 is only going to offer a net 1000 hectare of new space (Port of Rotterdam, 2009).

There are two issues. First, developing an innovation does not necessarily take up a lot of space. One interviewee briskly dismissed the issue of land use, saying that when an innovation starts, the land use is small (Manager 1, Port Authority, 12/06/09). However, there must be enough room for the production to scale up, otherwise the unit cost of algae will remain high. Algae-related innovation may not take up too much room to develop, but the farming of algae will. Roof-top algae farming is being considered.

Second, many interviewees think that sea-cultivation of algae has more potential than land-cultivation. Given the port's proximity to the sea, perhaps sea-cultivation is a more sensible option. Trouble is that it is hard to get the algae, which is floating at sea, to absorb the flue gas (e.g. CO_2) coming out of the chimneys of the power plants. Since flue gas absorption is the main motivation behind algae farming in the port of Rotterdam, the inability of sea cultivation to fulfil this task makes it less interesting.

General policy obstacles

Algae is a new form of biomass and is not included in the existing regulations. Funding can be obtained through generic programmes, but the scale is rather small. It is not sufficient to bring algae technology to the market. Together with the lack of direction given by the government, it creates uncertainty about the market prospects.

Changing the situation requires intensive lobbying, joining forces and involvement of market parties that would give credibility to the process. There are no strong algae supporters to be found in the port of Rotterdam that would move the process forward.

Momentum

Our interviews suggest that algae development in the port of Rotterdam is losing momentum i.e. the enthusiasm is waning, both commercial and political. There are two start-ups related to algae in the port of Rotterdam. One has gone bankrupt, while the other one is still struggling to start operation since its establishment two years ago (Advisor, Port Industry Association, 14/07/09). Then there is the risk of the Rotterdam Climate Initiative (RCI) being scrapped if the outcome of this December's United Nations Climate Change Conference in Copenhagen is unfavourable (FD, 2009). These events may dampen the enthusiasms of developing algae in the port of Rotterdam in two ways: first, by giving the impression that algae farming in the port of Rotterdam has no commercial future; second, by removing the urgency to reduce CO_2 because there is no common target to meet, this is perhaps more damaging because despite algae's water purification ability, CO_2 reduction is also major selling point of algae farming in the port.

6. Conclusion

The aim of the thesis was to gain insights in the functioning of an innovation process and evaluate the potential of algae farming in the port of Rotterdam. Our starting point was the question: what are the common factors behind success or failure of innovations? Various literatures and interviews show that these factors can be found in the environment in which a company innovates. It is the societal and institutional setting together with the past experience that largely influences the success of an innovation. Political support, social acceptance and the willingness to undertake entrepreneurial activities are important features.

The focus of our thesis is on sustainable innovations. According to the literature, incremental innovations along established paths are not enough to achieve environmental sustainability. A *system innovation* – a change from one socio-technical system to another – is required. As ports face many environmental problems related to negative externalities (pollution form transport, port and industrial activities), sustainable innovations are necessary to meet social, political and economical expectations. CO_2 emission targets, rising fuel and energy prices and the welfare of inhabitants of port cities are the driving forces for sustainability. Sustainable innovations have another role in the economy: it is itself an industry with opportunities to make profits. Ports that take the initiative to invest in sustainability can improve their operating conditions and image, and attract new types of businesses that generate income and jobs.

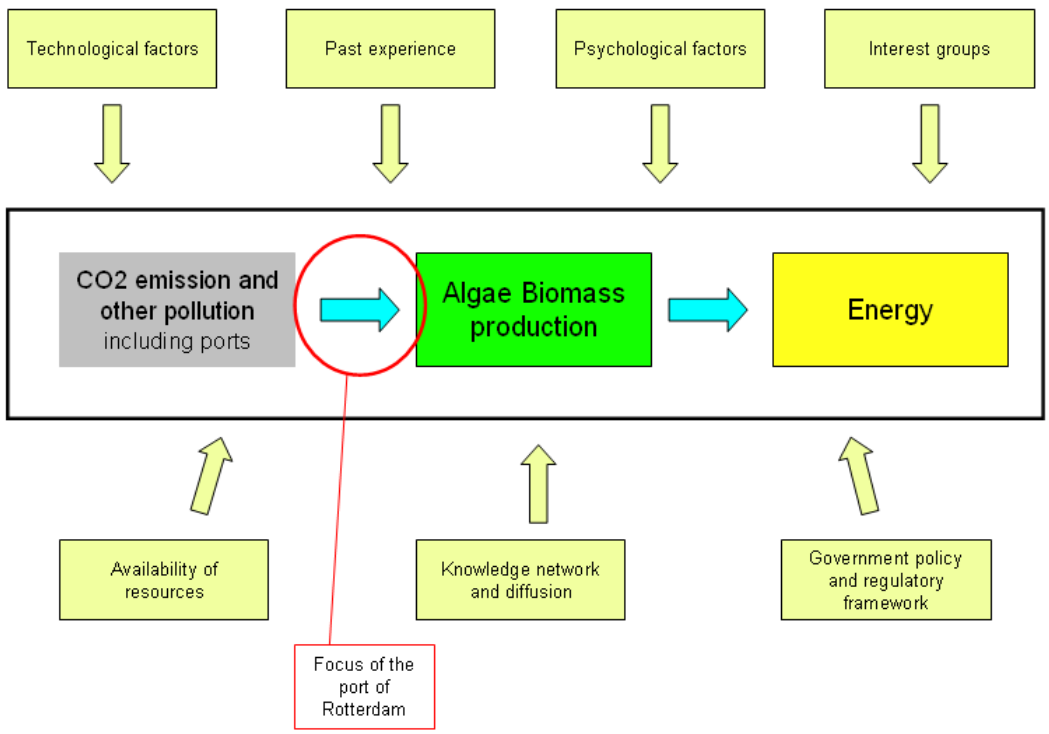
Ports are well positioned to innovate. They generate different types of economic activities that take place inside and outside the port. The wide range of port activities and parties that carry out such activities suggests that ports should be analysed as port clusters. The geographical and institutional proximity amplifies the linkages between port cluster participants and knowledge spill-over. It is argued that the presence of trust, leader firms, intermediaries and especially collective action regimes all contribute to the innovation in the port cluster. Ports have both the incentives and the potential for sustainable innovations, and they should produce and adopt new ideas that could help to reduce the environmental impact of their growth. System innovations are not without their obstacles; production barriers, regulatory barriers, user preferences tuned to existing regime, infrastructure requirements, investment needs, and technological lock-ins are some examples (Elzen and Wieczorek, 2005).

The empirical evidence analyses the barriers of farming algae as a source of biomass for energy purpose in the port of Rotterdam. According to the institutional triangle, firms (in that case port of Rotterdam) both influence and are influenced by the environment. Therefore we also analyzed the general setting for algae fuel in the Netherlands. Our research was based on seven groups of factors relevant for the success of an innovation: (1) technological factors, (2) government policy and regulatory framework, (3) psychological factors, (4) knowledge development and diffusion, (5) availability of resources, (6) interest groups and (7) past experience. The aforementioned factors were selected from the literature and verified during the interviews. We notice two issues behind the current state of algae development as a biomass**:**

- The political clout of the petrochemical sector is still holding back the development of alternative fuel, including algae. This clout is the result of technological and institutional lock-in, and it works by restricting the government’s willingness to create a market for alternative fuel. It is clear that the government has not the resources to be the only investor behind 2nd generation biofuels, especially algae, so private investment is crucial. However it is hard to bring in private investment if there is not a market.

- Regarding the knowledge of algae biofuel, the building of global pipelines seems to attract more attention than local buzz. Knowledge networks frequently involve collaboration with universities and companies located outside the companies' local area, even country. This is partly because local buzz only takes place in clusters, and at the moment there is no known algae biofuel cluster. Parties involved in algae biofuel development, such as universities and companies, are still rare and apart. This is because the idea of algae as a biofuel is still relatively new and its early R&D phase makes it unattractive to many private investors.

The main findings suggest that there is a gap between the theory and practice for algae in the port of Rotterdam. Bearing in mind the ambitious target set by the RCI, several parties recognize the potential of growing algal biomass in the port. However, little has been done to turn it into reality. The port of Rotterdam is not interested in growing algae for energy purpose. Algae biofuel's technology is too complicated and too immature. The port also experiences risk aversion, dominance of regime incumbents in the port (strong petro-chemical sector), focus on incremental rather than radical changes and finally with the perception that algae as a biofuel is only a long-term concept, as technological issues need to be solved. For the port of Rotterdam, it is the potential to reduce CO_2 emissions and to purify water (environment cleaning function) that makes algae interesting. Both applications are "quick wins" that could help the port to achieve its sustainability targets. The following diagram is a summary of our findings. The seven factors influence the development of converting pollution into energy via algae farming, and the focus of the port of Rotterdam lies in the pollution reduction ability of algae, rather than converting algae into a biofuel:



Carbon capture and storage (CCS) remains the preferred method of CO_2 reduction for the port of Rotterdam. CCS has more to do with the logistics function of the port rather than cost effectiveness. It is closer to the port's warehousing tradition, so closer to the port's mentality. On the other hand, CCS was described by Vergragt (2009) as "another technological lock-in." It confirms that the very obstacle to the rapid development of sustainable energy technologies is that "they are trying to establish themselves in an outdated (based on the existing types of energy technology) institutional, market and industrial context" (Elliott, 2000). To bring about the change the continuous effort made by various actors on different levels is needed, as innovation is a network activity.

The lack of clear and long lasting support for biomass and algae from the Dutch government only makes the idea of algae biofuel even more risky. At the moment, the algae industry in the Netherlands is small and fragmented, making it virtually impossible to successfully lobby for regulations and resources. However, this can change in the future. More knowledge institutes, private investment (most recently ExxonMobil) and organization ability are expected to enter the field of algae biomass development.

6.1 Policy recommendations

If the Port Authority would like to see algae cultivation happening in the port of Rotterdam, it should take the leading role in the process to give it a positive stimulus. Scattered initiatives should be joined to build the critical mass. It could be done by initiating studies or starting a forum of interested companies. Important is to communicate the benefits to convince skeptics and fight disbelief. But first a joint vision regarding algae should be formulated to ensure the commitment. It also includes making a decision which applications will be researched.

For development of algae new consortia are needed and PA could act as an intermediary to bring partners together. Various types of knowledge and expertise are required, for example from knowledge institutes, energy sector, agriculture and chemical industry. These are new forms of collaborations which are not formed spontaneously, hence the need for an intermediary.

Next to that, room should be made for pilot projects and demonstrations in the port of Rotterdam. First because enabling trial and error is crucial to learning, and second because "seeing is believing."

Port of Rotterdam is well positioned to bring algae to the Rotterdam Climate Initiative agenda. It could increase the level of the public's knowledge about algae, bring in new entrepreneurs, resources and partnerships. It may be also the way to gain more support from national government.

Making algae one of the priorities and ensuring the continuity of support is the first step to boost the innovation process. It should be also the government's approach.

Further, our evidence suggests that currently there is a gap between the CO_2 absorption quality of algae and its application in the port of Rotterdam. There is not enough land for land cultivation, while sea cultivation may not allow the algae to absorb the flue gas. Innovations are needed to bridge this gap, and one way to achieve this is to convert more ideas into solutions. One way to do this is to encourage more people to build enterprises around their ideas.

Our interviews informed us that entrepreneurs in Rotterdam face three hurdles. First is the punishing culture for those who ‘stick out their necks’; second is the general level of entrepreneurial skills; third is the difficulty of obtaining a loan after bankruptcy. Although we would also like to recommend policies that help giving failed entrepreneurs a second chance, the literature of legislations involved is broad and goes beyond the scope of this thesis. Bearing this in mind we recommend the following policy.

<u>Incorporate entrepreneur skills into the secondary school curriculum</u>
The idea is to include entrepreneurial skills in the national curriculum of all three streams of Dutch secondary education. For example, profit and loss calculations could be part of the mathematics curriculum; writing business letters could be part of the Dutch language curriculum; a business presentation can be part of the oral exam. Ideally, providing there are enough resources, each student (or student teams) should try to start an enterprise before completing the curriculum.

This recommendation has several advantages. First, the scope of the national secondary curriculum is wider. In 2007/08 there are 941 thousand people in secondary education (CBS, 2009), while the number of unemployed as of April to June 09 is 373 thousand (CBS, 2009) and not all of them will seek entrepreneurial skills training. A national curriculum therefore covers more people than the re-training agencies for the unemployed. Second, tweaking the existing curriculum is unlikely to be too expensive. Third, young people can combine the entrepreneurial skills with the energy and drive that comes with their youth. It also helps young people to deal with economic downturns. In times of recession, young people are always the first to become unemployed. This was clear in 2001 in the Netherlands when the economy started to decline (CBS, 2005). Finally, shaping the attitude of young people towards entrepreneurship helps to reshape the entrepreneurs-punishing culture in the Netherlands.

A further recommendation is to incorporate such a curriculum in the Dutch civic integration exam, which already focuses on the Dutch language and society. Given the high proportion of foreign born residents in Rotterdam, the city is in a good position to benefit from this policy.

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Appendix 1. Calculation of algae production cost

Crude Oil

1) Oil price per barrel as per 13/07/09 (Bloomberg, 2009) = 58.95 USD
2) Barrel of oil equivalent in GJ (BFIN, 2009) = 6.1
3) Euros/USD exchange rate (Bloomberg, 2009) = 0.7175
4) Crude oil cost as a percentage of the total retail cost of gasoline (EIA, 2009) = 66%

Calculation = 1) x 3) / 2) / 4) = €11 per GJ

Microalgae biomass in photobioreactors (WUR, 2009) = €153.5 per GJ

Soyabean Biodiesel

5) Operating cost of Soybean fuel production (Haas et al., 2006) = 1.995 USD per Gallon
6) Biodiesel conversion megajoules per Litre (BFIN, 2009) = 35.7
7) Litre per Gallon (BFIN, 2009) = 3.79

Calculation = 5) / 6) x 3) / (6) / 1000) = €11 per GJ

Appendix 2. Applications of algae

Table summarizes possible applications of algae.

Applications	Description
High quality applications	Algae have been used for high-quality applications since the 1970s. The total production is estimated at 5000 to 10 000 tonnes per year and the current market for algae and derived products is estimated to be around 5 to $ 6.5 billion per year (Pulz and Gross, 2004).
Pigments	Natural colorants in food or animal feed and cosmetics. The total market value of pigments from algae is estimated at $ 1 billion.
Health	Algae is rich in minerals, vitamins and certain prebiotics, therefore can be used as a nutritional supplement. The total value of the market is currently about 1.25 to 2.5 billion $.
Poly-unsaturated fatty acids - PUFA's	such as omega 3 fatty acids. The market value of algae for such applications is currently about $ 1.5 billion. PUFA are today primarily made from fish oil. There is demand for a vegetarian source of PUFA's.
Algae as food for larval fish in aquaculture	The total market value of algae as fish feed is about $ 0.7 billion
Cosmetics	Algae is used in the cosmetic industry, for example in skin care products or sun creams
Use of algae for water and exhaust air purification	Algae can process waste and convert it into a biomass that can be further used
Discharge of wastewater	Algae can be used to bind N and P from waste streams
Carbon capture and storage	Algae can bind CO_2 from flue gases of oil, gas or coal
Removal of persistent organic and inorganic pollutants from wastewater	The high oxygen concentrations in algae cultivation may accelerate the degradation of persistent organic pollutants. The algal biomass should be then considered as a heavily polluted waste product. It can be handled by a co-firing in coal plants.
Use of algae biomass for food, animal feed or	The biomass of algae can be a source of bulk raw materials for food, animal feed and chemical industry. Algae biomass is rich in proteins and

chemicals	lipids and low in structural carbohydrates such as cellulose and lignin. Algae have a biomass composition comparable to that of soybean (Becker, 1994).
Pet Food	Because of the favorable protein and lipid composition, it is potentially suitable for animal feed. An important source of animal food is soy, a major cause for the massive deforestation of tropical forest.
Bulk raw materials for chemistry	such as raw materials for the production of polymers, paints, etc.
Organic fertilizer	Algae biomass is rich in N and P. In the longer term it can be expected that the prices of N and P for use in fertilizers will increase. For N, this is due to the high energy required for production of NH3 from N2. For P, this is due to the depletion of natural P stocks. When prices for N and P increase, recycling of N and P from wastewater by algae economically attractive.
Energy	Because of rising energy prices, there is a strong demand for alternative energy sources. Liquid fuels such as oil are important for the transport sector. In particular, the aviation industry needs a liquid fuel with high energy, low freezing point and a low ignition temperature. Biodiesel and bioethanol from plant sources can theoretically replace petroleum. Sustainability of biodiesel and bioethanol from rapeseed, palm oil or sugar is under question, because of competition with food and the large area required for the production. Algae can provide an alternative.
Biodiesel	Algae contain a relatively high concentration of oil. Oil from algae can be burned directly or converted into biodiesel through transesterification
Biogas	The algae biomass can be directly converted into biogas via anaerobic digestion. The advantage here is that the algal biomass does not need to be dried or processed after harvesting. One gram of algae biomass can provide approximately 0.5 liters of biogas. Anaerobic digestion is particularly relevant when the algal biomass is highly contaminated, for example when algae were used to purify polluted waste water. The advantage of anaerobic digestion is that the nutrients used to produce the algae can be recycled.
Co-firing	Biomass can be burnt directly after drying, e.g. in combination with coal.
Hydrogen	Under specific conditions, algae can produce hydrogen gas (Melis, 2007)
Bioethanol	Some algae contain many polysaccharides (e.g. starch) which may be converted into bioethanol. The opportunities and challenges are similar to those of biodiesel production from algae.

Source: own elaboration based on Muylaert, 2009.

Appendix 3. List of the interviews

Interview 1: Manager, Climate Initiative, 11/06/2009
Interview 2: Senior Managers, Energy Company 1, 11/06/2009
Interview 3: Manager 1, Port Authority, 12/06/2009
Interview 4: Manager, Energy Company 2, 18/06/2009
Interview 5: Manager 2, Port Authority, 19/06/2009
Interview 6: Scientist, Energy Company 3, 19/06/2009
Interview 7: Manager, Entrepreneur Network Organisation, 22/06/2009
Interview 8: Algae Specialist, Ministry, 22/06/2009
Interview 9: Senior Managers, Venture Capital, 25/06/2009
Interview 10: Consultant, Sustainable Energy Consultancy, 25/06/2009
Interview 11: Biomass Specialist, public-private energy network, 26/06/2009
Interview 12: Professor, University, 2/07/2009
Interview 13: Senior Advisor, Bank, 7/07/2009
Interview 14: Advisor, Port Industry Association, 14/07/2009