ECN
Energy research Centre of the Netherlands

Four European futures for the Rijnmond Industrial Megasite

Innovations for a green and efficient process industry

A. de Groot

ECN-C--06-011

Revisions			
A	17 November 2005, draft version		
B	17 February 2006; final version		
Made by: A. de Groot 27/6/06	Approved by: P.P.A.C. Pex 4/7/06	ECN Energy Efficiency in Industry Molecular Separation Technology	
Checked by: S. Spoelstra 4/7/06	Issued by: P.T. Alderliesten 27/6/06		

Acknowledgement/Preface

This study was performed within the project "Europese Transitiescenario's voor energie en milieu" for the Ministry of Economic Affairs (1-2817) under ECN project number 7.7611. The input of project leader Jos Bruggink and his colleagues at the unit Policy Studies is gratefully acknowledged.

Abstract

The impact of different directions in which the global (energy) economy could develop on the chemical and petrochemical industry in the Rotterdam Rijnmond area is assessed, using four general energy scenarios developed at ECN.

The objective of the study is to investigate how different technologies, which are currently being developed, can play a role in the future chemical and petrochemical industry in the area. It is important to investigate if implementation of technologies is feasible and if their implementation contributes to (future) policy goals. In doing so the study not only considers different visions of the future Rijnmond area, but also the role of the complex process of transition toward such an energy system.

The chemical and petrochemical industry is a global industry. Developing the region in a specific direction does not only require a strategic vision but also attracting (further) investments to realise a transition. In doing so the Rijnmond area competes with many other different locations. The comparative advantages (and disadvantages) of the Rijnmond area depend strongly on the scenario chosen.

The scenarios represent different developments on two axes representing the stability of energy prices (in particular oil prices) and the success of the international energy policy (quantifiable in terms of CO_2 prices). Consequences of the four resulting scenarios for the Rijnmond area are elaborated by determining (1) strengths and weaknesses, (2) plausible strategies and (3) storylines for the Rijnmond in each of the scenarios. Finally, considering the whole of the different scenarios, the study analyses which type of innovations are necessary in most of the scenarios (robust technologies) and which are essential for achieving the defined strategy in at least one scenario (critical technologies).

Contents

List of tables

List of figures

Summary

The chemical and refining industry is an important sector of the Dutch economy[1]. It is also a sector with a large impact on the Dutch energy system, responsible for roughly one fourth of the Dutch energy consumption. In this study, we consider how a more sustainable chemical industry could develop. The scope is on identifying which innovations are necessary to achieve a more sustainable future of the chemical industry.

Implementation of innovations requires more than just developing new technology. A more sustainable chemical industry implies a transition process incorporating many non-technical issues. This study builds on the general transitions scenarios for the European energy system developed by Jos Bruggink for ECN's 50th anniversary (Bruggink, 2005). Because a regional focus is increasingly seen as a key element of transition management, the study focuses on the Rijnmond area rather than on the chemical sector in general. In the strictest sense the Rijnmond encompasses the refining and petrochemical industry situated in the area around the Rotterdam Port. However, the Rijnmond "Megasite" is considered much wider, including the Moerdijk and Vlissingen and Geleen sites and the strong links with the chemical industry in Antwerpen and the Ruhr areas.

The first part of the study focuses on the main issues in a transition process. In Chapter 2 we consider the technical and economic complexity of the chemical industry. Which are the factors which shape the chemical industry? There are strong links between processes up- and downstream in the chain from feedstock to end product. Geographical proximities can play an important role in the creation of new activities, both on the scale of a site as well as on the global scale. They can often explain why activities exist in a specific location. But the chemical industry is also very flexible. It has also shown that it is capable of adapting to changes in commodity prices and feedstock availability. Understanding the ground rules is important in understanding how introducing new technology may necessitate a transition process.

Chapter 3 discusses the business perspective on the transition more explicitly. "The Rijnmond" does not exist as a separate entity: it is the sum of all the companies which have chosen to locate part of their processing capacity in the area. For a large part the Rijnmond consists of companies operating globally. Decisions to invest in the Rijnmond are continuously weighed against opportunities elsewhere. It is therefore important to make a distinction between the interests of the separate companies and the interest of local and national governments. We have chosen the perspective on the level of the local government, specifically the Rotterdam Port Management, and the question how the availability of specific technology could influence there role.

The second part (Chapters 4-7) discusses the impact of four different scenarios on the Rijnmond megasite. Each chapter discusses a different scenario. Each chapter begins by highlighting the developments which are relevant for the Rijnmond and analysing threats and opportunities. Subsequently for each scenario an explicit strategy is formulated for the regional authorities and a storyline is suggested how the strategic objectives could be achieved. Finally the role of technology and the barriers to implementation of technology in the scenario are analysed.

The discussion in Chapter 8 shows how strongly the different scenarios could steer the development of the Rijnmond in different directions, adding to the uncertainty with respect to the future of the area.

[1] In 2004 the turnover of the Dutch chemical industry corresponded to 36 billion Euros.

The scenarios are used to identify *robust* and *critical* innovations. In general it can be said that the more peripheral innovations, focussing on heat and process integration and more efficient separations, are found to be robust: they appear in most or all scenarios. Innovations, which centre on the core-processes, are less robust. But in most scenarios it is this type of innovation which is the critical technology: as it is prerequisite to realise a specific strategy.

1. Why study the European future of the Rijnmond?

1.1 Innovations for the future Rijnmond

The Dutch energy system is not sustainable. It relies largely on fossil fuels for which the resources are limited. Furthermore, in the conversion of fossil fuels into final energy, large amounts of CO_2 are emitted, which is believed to affect the global climate considerably on the longer term. A lack of sustainability implies the need to change to a (more) sustainable system[2]. It suggests that the future will have to be different from today.

Even if the sense-of-urgency may be perceived differently, and therefore the timeframe in which change becomes unavoidable, there is no debate about the necessity to create a more sustainable Dutch energy system in the longer term. This study focuses on one part of the energy system specifically, on the future of the chemical industry in the Netherlands and how it is affected by the need to become more sustainable. The chemical industry, because it is energy intensive, is an important part of the Dutch energy system as well as a sector with a large economic impact.

Innovation plays an important role in the transition to a more sustainable energy system. And even more so in a sector which is as technology-oriented as the chemical industry. The main question is therefore "what technologies will the chemical industry need to be prepared for the future?". However, addressing this question is more complex than it seems.

- For one, it is widely accepted that the introduction of radically new technology involves much more than the just the development of technology. Implementation of technological innovations may require or bring about far-reaching changes in infrastructure and economic relations, in policy and legislation or even consumer perceptions of technology. Transition theory teaches us that, rather than limiting our analysis to the outcome, we need to take into account the process of implementation.
- Secondly, the Dutch energy system cannot be seen as separate from the European energy system. Increasingly Dutch energy policy is becoming part of a larger common European energy policy. More and more internationally operating energy companies are playing a role alongside the traditionally important national players. Therefore, if we consider the opportunities and benefits of different technologies, we need to do so in a European perspective.
- There are many unknown factors in predicting the future benefits of (energy) technologies, but above all, the world around us may develop in many different ways. There are different "futures" to consider.
- It is not only sufficient to describe the end-result of a successful transition (for a specific scenario). We are mainly interested in impact of having the technology available. Therefore, in evaluating the benefits of a technology, we need to consider explicitly what difference the technology makes.

The approach chosen in this study takes into account these factors in attempting to clarify which role different technologies could play in the future (petro-)chemical industry in the Rijnmond area[3]. Based on European energy transition scenarios developed by ECN [Bruggink, 2005], we consider the outlook for this region in an international perspective. By describing how the

---

2 In the end any system, which is not sustainable, will run into limitations, whether this is because resources become depleted or because the (political, ecological, economic) impact of the system on its environment becomes unacceptably high.

3 Typical for the transition approach is to consider the petro-chemical industry not as an isolated sector, but in its interaction with the other (economic) sectors. Therefore, the focus is on the Rijnmond area, which not only contains one of the main global petrochemical complexes, but also the Rotterdam port to which the petro-chemical industry is closely tied (see section 2.1).

Rijnmond develops in each of these scenarios and which roles technology clusters might play, we are able derive for specific technologies:

- how robust they are (do they play an important role in all scenarios or in just one?),
- how critical are they (are they essential in realizing the strategy within one or more scenarios).

But also, it helps in making explicit the assumptions about the future world, which are (in many cases implicitly) underlie the development of a technology.

Given the complexity of the approach, the ambition of the study is not to provide final answers. Above all, it is meant to help create a dialogue between different stakeholders by offering for discussion specific and concrete visions for the future of the Rijnmond.

1.2 Creating a dialogue between stakeholders

Society is expected to benefit from the introduction of new energy technologies, ranging from cleaner cars, affordable technologies to generate electricity from renewable sources to more efficient industrial processes. Governments spend large amounts of public funding with the objective of developing or accelerating the development of those technologies, which could make the energy system more sustainable. Making choices is essential, as many different technologies can contribute to a more sustainable society. What makes the selection of technologies very complex is the many uncertainties which have to be taken into account:

- *A long road from laboratory to market*
  Uncertainty lies in the technology development itself. It is difficult to foresee, in an early stage of development, what performance and economics of the mature technology could be. Additionally, the risks and the amount of effort required to bring a technology to the market may be perceived differently by different stakeholders
- *Incomparable benefits to society*
  Competing technologies may have benefits to society, which are difficult to compare. In transportation, for example, it is desirable to compare technologies ranging from more efficient hybrid-vehicles, conventional vehicles using natural gas or biofuels to fuel cell cars fuelled by hydrogen. Where one technology may reduce the emissions of locally hazardous pollutants (NO_x, PM10) to very low values, others will be much more cost-effective when it comes to bringing down CO_2 emissions or reducing dependency on foreign oil.
- *The need for a transition process*
  Introduction of radically new technologies can have far-reaching consequences for infrastructure and economic relations, in policy and legislation. It also requires alignment of interest of many stakeholders involved in the implementation. Such a process of change (or transition), because it is both a long-term process and involves many different stakeholder, requires common visions and goals, but also early commitment of those involved. Uncertainty in the introduction of break-through technologies is enhanced by the need for such a transition-process.
- *A changing world*
  To add to the complexity in choosing technologies, the world is a rapidly changing place. This is particularly true with respect to the energy system. Expectations surrounding future availability of resources as oil and gas differ widely. But also the effect of environmental policy on the future energy system is uncertain. To what degree will the energy system be shaped by the need to limits its environmental impact and how will policy (e.g. CO_2 emissions trading or energy taxes) or lack of policy influence the developments?

Given the important role technology is expected to play in creating a more sustainable Rijnmond, it is necessary to consider carefully which technologies "deserve" to be supported because they can contribute to a more sustainable society. Rather than a simple cost-benefit analysis, selection of technologies for creating a more sustainable chemical industry in the

Rijnmond requires a dialogue between the different stakeholders. A transition is only possible if all stakeholders agree on the feasibility and the desirability of such a transition.

This study is explicitly directed at different stakeholders in the Rijnmond area.

- The national government, in particular the Ministry of Economic Affairs (EZ), is responsible for the national energy policy. One of its main interests in such a dialogue is in assessing the effectiveness of technologies in creating a more sustainable energy system. Furthermore it can aid in evaluating the type of policy instruments, which could be effective in realizing desired transitions.
- For the local government in the Rijnmond, on both provincial and municipal level, the economic importance or the Rijnmond is paramount. For the well-being of its citizens a sustainable future of the Rijnmond area, both economic and ecologic, is essential.
- Research institutes (like ECN) and universities can profit from such a dialogue in selecting the right technologies for further development. Maybe even more important, aligning their visions with those of other stakeholders can greatly enhance the likelihood of successful technology transfer to industry.
- For industry the dialogue can be an element in the formulation of long-term strategies. It can also help direct government on different levels in choosing the most effective instruments and setting a research agenda.

1.3 Energy transition policy and the Rijnmond

Transition management as a key to sustainability policies in the Netherlands
The publication of the Fourth National Environmental Plan (NMP4) in 2001 signalled a breakthrough for the academic work of a group of Dutch social scientists active under the heading of transition management. The NMP4 presents a list of persistent environmental problems such as climate change and resource depletion that can only be solved by society-wide and complex system innovations. Transition management provides a governance paradigm for addressing such persistent problems. According to this paradigm, transitions are processes of socio-technical evolution in which economic, institutional and technological structures develop interactively and change drastically in the long run. Transition management prescribes ways in which society-wide and complex system innovations can be guided. Two major elements of such a transition approach are the stimulation of technological innovations in market niches through participative involvement of companies, research institutes and civil society and the creation of challenging visions. Transition management was identified in the NMP4 as a key element in working toward a sustainable future.

International dimension of Dutch energy transition policy must be strengthened
The ministry of Economic Affairs is responsible for energy policy in the Netherlands. It has embraced the message and promise of transition management with vigour since early 2002. As a first step the responsible policy makers have set up an intensive dialogue among numerous stakeholders to define jointly a set of so-called transition paths. A transition path describes the preferred technological innovation routes towards sustainability goals in the energy domain for the Netherlands. In early 2004 this participatory process culminated in a white paper summarising the present state of energy transition policy. It distinguishes a number of preferable transition paths clustered in five main themes for energy sustainability[4]. The report also outlines the policy steps ahead. The on-going second step involves the selection of transition experiments within each theme that are designed to learn how specific energy systems function in concrete projects. In late 2004, the state-of-affairs and the way ahead for energy transition policy as described in the report has been reviewed by a joint team of two high-level advisory boards of the Dutch government, the VROM-Raad and the AER (Energy Council)(Vrom-

[4] The five main themes are: “Green resources”, “Alternative motor fuels”, “Chain efficiency”, “Efficient and green gas” and “Renewable electricity”.

raad/AER, 2004). The review compliments the ministry on its pioneering role, but suggests strengthening the international dimension of transition policies considerably.

Importance of the Rijnmond for European energy transitions
The Rijnmond industrial megasite plays a central role in the European energy sector. The Rotterdam harbour is the most important one in European oil logistics, the Rijnmond refineries take care of balancing European markets in oil products and the Dutch petrochemical industry supplies a substantial share of Europe's demand for bulk chemicals. For the Netherlands, the Rijnmond forms the heart of the Dutch industrial sector including an impressive array of ancillary industries and services. No wonder that the carbon-intensive activities of the Rijnmond have received due attention in energy transition policy. During the preparatory phase of Dutch energy transition policy in 2002-2003 (Project Implementation Transition), a separate subproject dealt with the Rijnmond, because it was considered a main area for transition experiments. Clearly, a transition towards a sustainable energy system implies enormous opportunities and threats for the future of the Rijnmond industrial megasite. In terms of the main themes for energy transition as defined by the Ministry of Economic Affairs, three are intimately related to transitions in the Rijnmond ("green resources", "alternative motor fuels" and "chain efficiency") and the other two ("clean and efficient gas", "renewable electricity") are of more than average relevance.

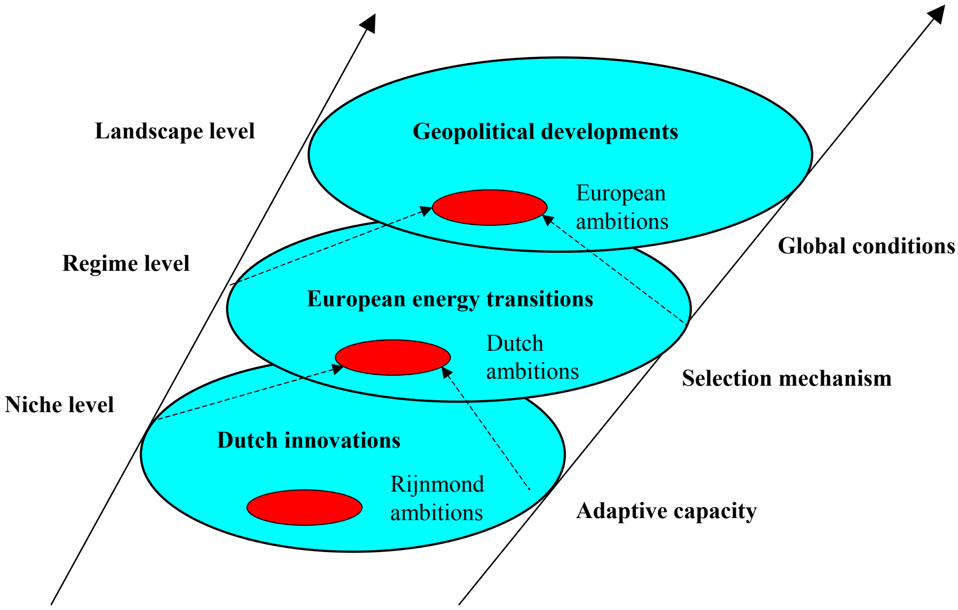


Figure 1.1 *The Rijnmond as European innovation niche*

Assessing innovation niches from a European perspective
Strategic niche management can be viewed as the creation of an optimal balance between protecting new technological options against premature failure in early stages of the innovation cycle while on the other hand gradually exposing them to inevitable market pressures at later stages of the innovation cycle. Within the framework of this study, the different levels which transition theory distinguishes (niche level, regime level and landscape level) can be interpreted more or less on a geographical level (Figure 1.1) From a European perspective the Netherlands can be viewed as a niche for experiments where variation is stimulated and adaptive capacity is maintained. However, Europe is the selection environment that ultimately determines survival and success. At the same time, it must be clear that the selection environment itself is not immune to geopolitical and socio-cultural changes at the global level. Indeed, the European energy regime will evolve in different directions dependent upon those global changes and Europe's own ambitions at the global scale. The future of energy in the Netherlands will emerge as a result of anticipating on potential European energy transitions. A closer look at the future of the Rijnmond industrial megasite in the light of potential European energy sector developments

would be particularly helpful in strengthening the international dimension of transition policy. Earlier studies have concentrated on identifying the potential for such technological innovation and creating challenging visions for a sustainable future. Clearly, energy system innovations, particularly those affecting the future of the Rijnmond, will evolve at the European level. The main purpose of this study is to evaluate the proposed sustainable innovations and visions in the framework of a range of potential European energy regime changes as described in four contrasting scenarios.

Focus on green resources and chain efficiency
This study forms part of a set of studies each concentrating on a major theme of Dutch energy transitions. The Rijnmond assessment study is somewhat different because its focus is not only thematic (combining the themes “green resources” and “chain efficiency”) but also regional (Rijnmond only). Because energy transition policies are geared towards stimulating regional alliances between the public and the private sector, such a regional focus has clear advantages[5]. Moreover, the energy transition themes green resources and chain efficiency are potentially very wide and heterogeneous. In the case of green resources it includes for instance the cultivation of a wide variety of biomass feedstocks on the upstream side of the market and the production of a wide variety of end products on the downstream side of the market. Similarly, the theme of chain efficiency potentially covers a wide range of industries and a wide variety of resources and end products. In order to come up with concrete results a judicious narrowing of focus is a prerequisite.

1.4 Earlier transition studies on the Rijnmond

Final report of the “Sustainable Rijnmond” study (December 2002)
When the Ministry of Economic Affairs started implementing the transition approach in energy policy in early 2002, one of the main themes was “Sustainable Rijnmond”. The effort on this theme aimed at identifying promising transition experiments in the Rijnmond. At that time several other projects were already addressing the long-term position of the Rotterdam Harbour and Industrial Complex. Deltalinqs, an umbrella organisation of mainport companies was just finishing the INES Mainport study. ROM Rijnmond, a public-private alliance of regional and national authorities and major companies was completing the Energy Rijnmond study. Both studies contained a wealth of information on potential initiatives in energy and environment that could be fruitfully incorporated in the “Sustainable Rijnmond” project. The latter study ((Brouwer, Diepenmaat& van der Ven, 2002) therefore concentrated on a dialogue with stakeholders in a limited number of market innovation niches. The dialogue specifically addressed the following transition paths:

- Waste heat utilization: construction of low-temperature heat infrastructure to connect industrial sources with demand in nearby residential, commercial and greenhouse sectors.
- Waste materials processing: regulatory and technological innovation to stimulate recycling and use of industrial waste materials.
- Central steam production: integration and rationalisation of medium-temperature heat production and use.
- Methanol production: setting up a new chain for methanol production including upstream biomass supply, gasification and synthesis, downstream markets.
- Hydrogen infrastructure: expanding the present regional hydrogen system based on central electrolytic production for use in refineries with promising alternative conversion plants and demand categories.

[5] The strong regional element in alliances has been one of the insights gained in the first phase of the transition process.

"To C or not to C": vision formulation for a sustainable Rijnmond (December 2003)
In early 2003 it was decided to bundle the transition project of the Ministry of Economic Affairs with similar activities of Deltalinqs and ROM Rijnmond under the heading R3 (Rotterdam ROM Rijnmond). The new R3 initiative concerns a public-private alliance focussing on sustainable enterprise in the Rotterdam Harbour and Industrial Complex. On the basis of the earlier report, R3 prepared a strategic vision on a sustainable future for the Rijnmond ((Soest, 2005), (Soest, 2003)). The Shakespearian allusion of the title refers to the dilemma of the Rijnmond with respect to two different trends: defending the present hydrocarbon-oriented position in a climate-friendly world (concentrate on clean fossil fuels) or promoting the transition to renewable resources in a climate-friendly world (concentrate on introducing biomass fuels and resources). The strategic vision formulates the ambition of the Rijnmond to continue its key position for the logistics and conversion of carbon-containing fuels and resources in Europe. It stipulates that this ambition is only realistic if the Rijnmond succeeds in maintaining a leadership position with regard to efficiency. Functioning as an innovation niche for technological experiments in the area of energy efficiency improvement, clean fossil fuels and renewable resources is seen as a pre-requisite for such a position.

Added value of this report
The present report builds on the achievements of the studies mentioned above. But it addresses, more explicitly, the different directions in which the world around the Rijnmond could change and the role of technology in coping with different developments. Knowing that real progress in designing strategies can only be achieved by an iterative process of discussion between all the stakeholder, much emphasis has been placed on defining the different steps in building strategies from scenarios. The report aims to complement earlier efforts by providing views on strategic niche management for the Rijnmond industrial megasite from the point of view of European energy regime changes.

1.5 Four European energy transition scenarios

Scenario approach articulates hopes and fears
If the Netherlands wishes to take contrasting directions in European energy transitions into account, these directions can best be described in terms of alternative scenarios. The scenario approach offers a familiar toolbox for strategic analyses in the energy sector and is used widely by energy companies, planning bureaus and multilateral organisations. The scenario approach helps to understand the nature of the driving forces affecting our future and the uncertainties determining their potential impacts. Scenario analysis thus serves to articulate long run hopes and fears. On the one hand, it helps to identify robust responses in order to reach desirable ends (developing so-called shaping strategies). On the other hand, it helps to initiate pre-emptive actions in order to prevent undesirable consequences (developing so-called hedging strategies). Finally and more modestly, it generates early-warning signals and helps management to rehearse for contingencies. These three goals should help in setting an actionable agenda for strategic niche management. Of course, the scenario approach is not appropriate for all kinds of management problems. It is only effective in case of vague, complex and long-term concerns with lots of turbulence and potentially disruptive impacts. That is certainly the case, when we talk about sustainability problems.

Driving events for technology development and energy transition
Two major discontinuities that would dramatically change the urgency and direction of energy RD&D and the prospects for new technology implementation are the arrival of a global peak in oil production and the failure of global climate change policies. The first event would undoubtedly lead to sharply rising and permanently volatile oil prices. This would dramatically increase the pace of oil substitution in the transportation sector and petrochemical industry. It would first lead to increasing pressure on expanding gas supply and ultimately enforce early and increasing reliance on either biomass-based or coal-based fuels. A peak in global oil production

could arise because of a combination of surprises of a political or economic nature on either the demand or supply side or both in the decade 2010-2020. The second event would imply a continuing stalemate in post-Kyoto climate change policy negotiation leading to vanishing prospects for greenhouse gas emission markets and disregard for the CO_2 emission reduction potential of new investments in the decade 2010-2020. These two events lead to bifurcation points with respect to market forces and regulatory impacts that are the key driving forces of the energy sector in the long run.

Outline of European energy transition scenarios
If we accept that the key driving events mentioned would steer the future course of European global ambitions in the energy sector in different directions, it is possible to venture opinions on the consequences for European energy transitions. These consequences can be described in four contrasting storylines.

- FIREWALLED EUROPE - Oil production peaks in the period 2010-2020. No viable post-Kyoto climate change policy emerges. The European energy sector turns back to coal and nuclear in the next 50 years.
- FOSSIL TRADE - Oil production follows oil demand smoothly in the period 2010-2020. No viable post-Kyoto climate change policy emerges. The European energy sector continues business as usual in the next 50 years.
- SUSTAINABLE TRADE - Oil production peaks in the period 2010-2020. Post-Kyoto climate policies develop effectively. The European energy sector turns to large-scale trade in renewables in the next 50 years.
- FENCELESS EUROPE - Oil production follows oil demand smoothly in the period 2010-2020. Post-Kyoto climate policies develop effectively. The European energy sector diversifies strongly keeping all options open for the next 50 years.

The roles that Dutch companies can play on the European level differ fundamentally between these four scenarios. Making robust strategic choices for energy innovation policies in such contrasting scenarios is the challenge for strategic niche management.

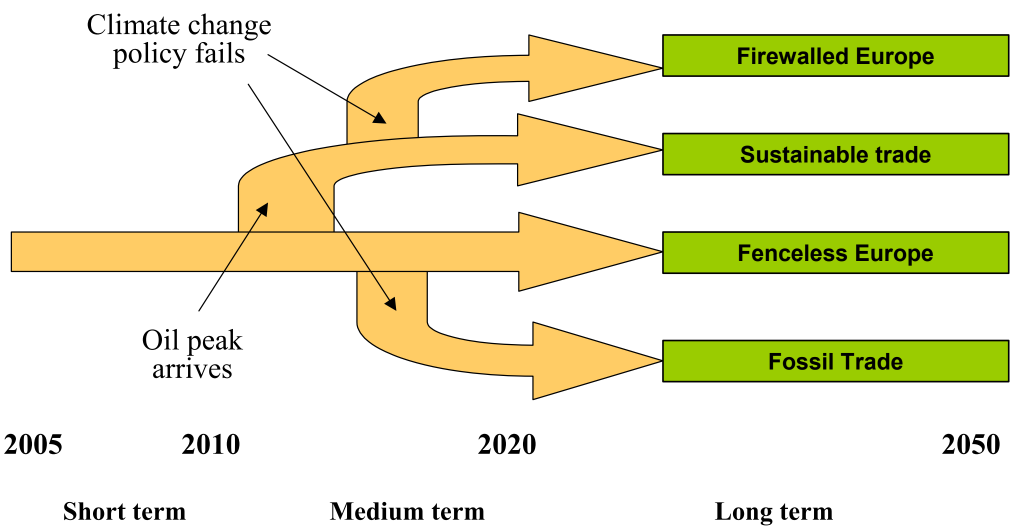


Figure 1.2 *Four European energy transition scenario's*

For a comprehensive analysis of these European energy scenarios we refer to a separate study (Bruggink, 2005). This study argues that the arrival of a global peak in world oil production or the failure of concluding a post-Kyoto climate change agreement are not only plausible events but would also have a dramatic impact on European energy futures. The report provides extensive story lines on the global developments, European transition regimes and national innovation systems on which the scenario discussions in this report are based.

1.6 Scope and overview of study

Evaluating the long-term future for introducing green resources and efficient chain management on an industrial megasite like the Rijnmond requires a basic understanding of the technological, infrastructural and organisational complexities of refineries and the related chemical industries. So we start the analysis with a broad overview of the major features of the Rijnmond in Chapter 2. The concept of a design hierarchy is introduced to illustrate that it is useful to characterise how radical processes (need to) change to make the innovations possible.

Strategic niche management required for an area as the Rijnmond is in no way comparable to traditional command-and-control concepts of public management. Public authorities responsible for industrial megasites have only indirect, non-coercive and facilitating means at their disposal for influencing investment opportunities in refineries and related industrial activities. In Chapter 3 we examining the strategic options open to public authorities when it comes to influencing private investment opportunities on industrial megasites.

The second part of the study considers the Rijnmond in each of the four scenarios. Although the focus is to identify the technological innovations which would enable a successful transition to a more sustainable Rijnmond possible, the emphasis is on the transition process and awareness that a transition relies on stakeholders in the Rijnmond to adopt innovations.

PART I Understanding the complexity of the Rijnmond

2. Connectivity in the Rijnmond

2.1 The Port of Rotterdam and the Petrochemical Megasite

2.1.1 A brief historical perspective

Europe has traditionally had a strong chemical industry. Figure 2.1 reflects the current position of the European chemical industry in a global perspective. Although the Asian share is rapidly increasing, the European chemical industry still is the world's largest producer.

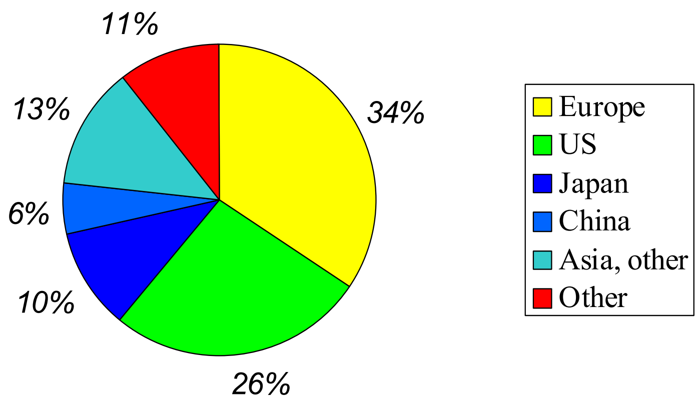


Figure 2.1 *Comparison of the contribution of the European chemical industry to the global turnover (total annual turnover 1841 billion (10^9) Euros in 2002)*

We cannot predict how the chemical industry could change (as we aspire to do in this study) without considering how it has changed. And chemical industry has strongly changed since it began. It started as inorganic chemistry, producing alkalis (soda ash Na_2CO_3 and potash K_2CO_3) and sulphuric acid in the 18th and 19th century. Production of fertilisers is probably the largest achievement of the inorganic chemical industry: it played an essential role in creating modern society, as it “freed” the workforce from the soil.

Today's modern society is unthinkable without fertilisers but also without plastics and fibres, which are the main products of the organic chemical industry. Organic or carbon-based chemistry originated initially “on top” of the coalmines. In Europe for example the Ruhr area was at one time the area with the strongest chemical industry in Europe. Syngas production (town gas), cokes, acetylene and coal tar were the most important organic products of the carbochemical industry. Technologies were developed to produce a wider range of chemical products from coal, for example by direct or indirect liquefaction of coal. However, they were never fully employed. As demand for base organic chemicals like ethylene, propylene and benzene skyrocketed with the development of a plastics and another rapidly replaced fibre industry, coal, cheaper, commodity: oil.

In Europe the start of the petrochemical industry after the second world war was slow compared to US. A low demand for products, a strong coal based chemical industry and the low refinery capacity combined initially to delay the switch from coal to oil (Gielen, Vos& Van Dril, 1996). However, when the shift to oil was made, the Rotterdam port started to play its central role in Europe. The first refinery to settle in the Rotterdam Port was the Shell refinery commissioned in 1936. Between 1947 and 1957 Texaco (then Caltex), Esso, Kuwait (then Gulf) and BP joined Shell, increasing the number of refineries to five. In the same period international petrochemical companies started up activities in the port area: Dow Chemical (US) in the Botlek, ICI (UK) in Rozenburg and Esso Chemical (now ExxonMobil). Continuously the port was extended to be able to accommodate oil tankers increasing in size from 21 000 tons in 1937, 100 000 in 1959 to 500 000 tons in 1973. The importance of Rotterdam as the port for crude oil was emphasised by the construction of oil pipelines connecting Rotterdam to Antwerp and to the Ruhr area.

From 1960 to 1973 (the first oil crisis), rapidly increasing demand for the petrochemical products (plastics, synthetic fibres and rubber) resulted in a rapid expansion of the petrochemical industry in the port area. Coal was further replaced by oil as feedstock, driven by the increasing availability and lower cost of oil.

2.1.2 Impact of the chemical industry on the Dutch (energy) economy

The VNCI, the Dutch Federation for the Chemical Industry, formulates the importance of the chemical industry for the Netherlands as follows (Roller, 2004): “Within the industrial sector, the Dutch chemical industry is responsible for:

- 10% of the employment
- 15% of the production
- 20% of the export
- 25% of the investments
- 30% of the R&D spending “

In a European and even a global perspective, the Dutch petrochemical industry occupies a unique position, which is strongly linked to the role of Rotterdam as one of the largest ports in the world and in particular the European oil port. The petrochemical sector, predominantly organic basic chemical industry[6], is concentrated in the Rijnmond area. The first refineries were built directly adjacent to the terminals of the Rotterdam port. As its activities expanded new areas around the port were developed (Botlek, Europoort), and the refinery and chemical industry extended to nearby areas as the Moerdijk and Vlissingen area. Although the activities are now spread over a number of locations, the Rijnmond-Moerdijk-Vlissingen area can be considered as one large chemical site. Such a complex of plants, which are strongly linked, can be indicated as a “chemical megasite” (CBIT, 2004).

The links of the Rijnmond Megasite extend even further, because the processes in this area are closely related to the chemical site of DSM (previously the Dutch State Mines) in Geleen and to the nearby Antwerp area, where a strong fine-chemical industry has been created since the 1960's. In this study where we use the “Rijnmond site” or “Rijnmond”, we refer to the cluster of refining and chemical industry around the Rotterdam port, the Moerdijk and Vlissingen area (Dow, Terneuzen) and the DSM site, including its ties to the Antwerp and Ruhr areas. These links become visible in (but go further than) the pipeline system connecting these areas (see Figure 2.2).

[6] The chemical industry can be split into different sectors: Organic basic chemicals, inorganic basic chemicals, other basic chemicals, chemical products or fine-chemicals.

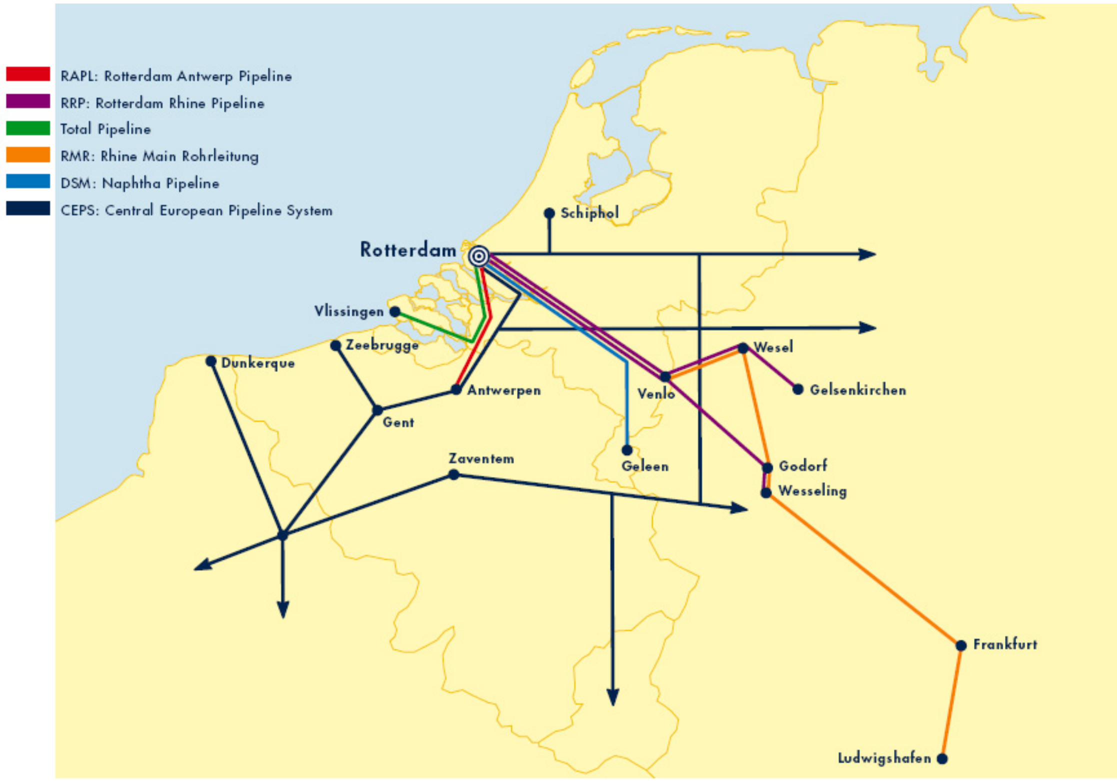


Figure 2.2 *Pipeline links between the Rijnmond, Antwerpen and the Ruhr area (Port of Rotterdam, 2003)*

The chemical industry does not only have a strong impact on the monetary economy of the Netherlands, but also on the energy economy. This becomes evident by comparing the energy consumption in the chemical industry and refinery (Figure 2.4) to the total energy consumption in the Netherlands (Figure 2.3). Energy consumption in both figures relates to the energy, which is consumed, not to the energy input.

More than 40% of the energy consumption in the Netherlands (1227 PJ) is used in industry. The bulk (837 PJ) is used in the chemical industry. More than 25% of the national energy consumption therefore relates to a single sector of the economy. The Rijnmond has been the focus of the transition activities on grounds of both its importance for the Dutch energy system and its economic importance.

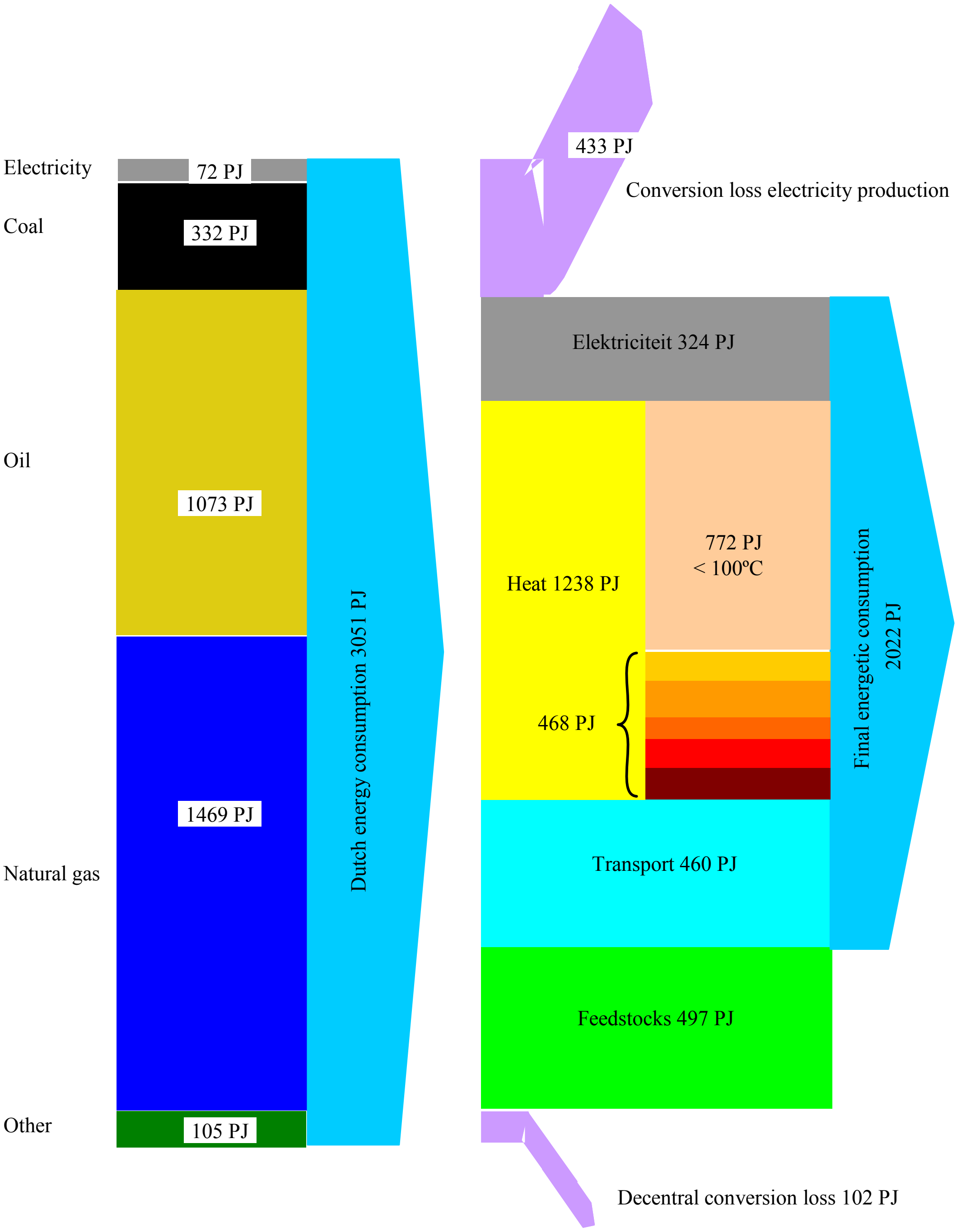


Figure 2.3 *Energy consumption for the Netherlands in 2000 in PJ/year (Spoelstra, 2005)*

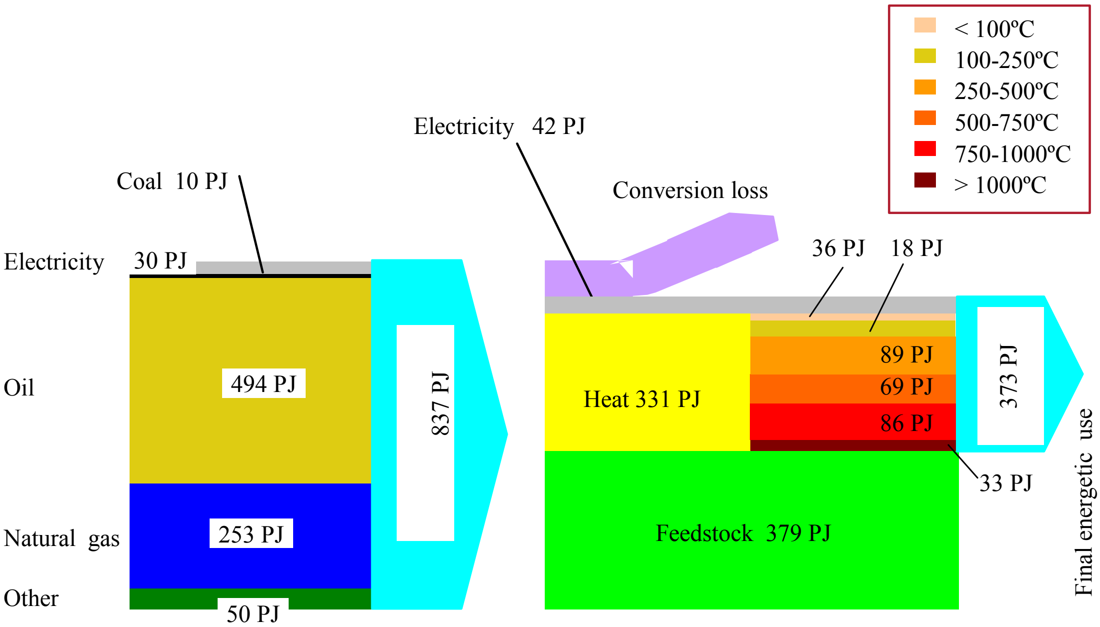


Figure 2.4 *Energy balance for the Dutch chemical and refining industry in 2000 in PJ/year (Spoelstra, 2005)*

Of particular interest is the energy balance of the Netherlands with respect to oil shown in Figure 2.5. The import of oil amounts to 6324 PJ (mainly crude oil) and the export to 4557 PJ (being the export of crude oil and transport fuels). With 707 PJ supplied to international shipping and aviation, the domestic consumption is 1073 PJ[7,8]. These numbers emphasise the important role of Rotterdam in supplying the European market with oil and oil products. Half of the domestic consumption (524 PJ) is used in industry, the other half mainly in the form of transport fuels gasoline and diesel. The 524 PJ oil consumption in industry includes both the use of oil to produce final energy carriers (heat, electricity), conversion losses and the input to the chemical industry (naphtha, etc.).

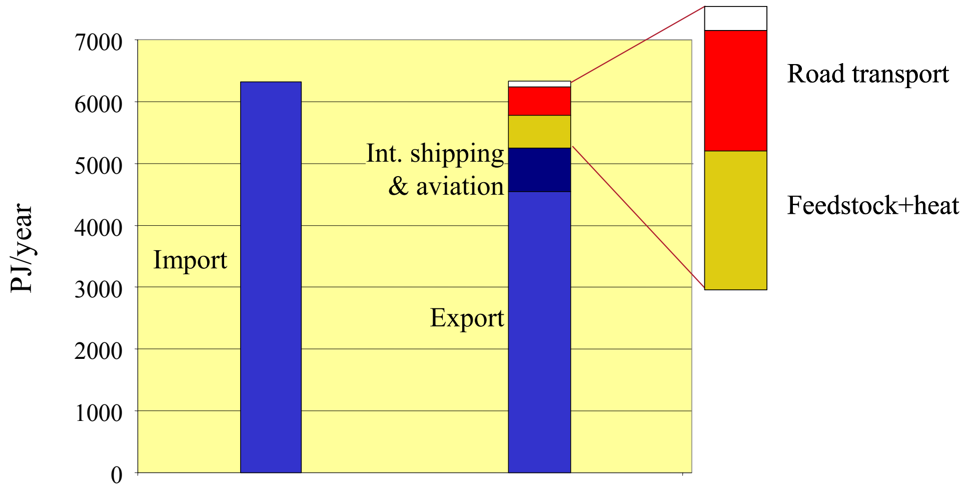


Figure 2.5 *Oil energy balance of the Netherlands (PJ/year for the year 2000) showing the large flow of oil and oil products exported (CBS, 2005)*

7 Import, export and domestic consumption do not add up exactly because the reserves change from year to year.
8 The consumption refers to the energy which is "lost", either because it is consumed in the engine of a vehicle or because it is used in the process of producing chemicals or transportation fuels (i.e. the difference between energy input and energy output of the petrochemical process).

2.1.3 Reactions, separations and thermal integration

There is more to learn from the energy balances in Figure 2.4 and Figure 2.3. One of the most striking aspects is the demand for heat. On a national scale the heat demand dominates the final energy demand. The largest part of the heat demand is low-temperature heat: space heating and hot water in the built environment. In industry, however, predominantly high-temperature heat is needed. In the chemical industry the energy consumption is split roughly between heat and feedstock with a relatively small role for electricity. The conversion losses in Figure 2.4 refer to the losses in producing the final energy carriers (for example losses in the steam boiler if this is not integrated into the chemical plant).

The purpose of the chemical industry is converting one chemical (the feedstock or reactant) into another chemical with a higher value (the product). The core of the chemical process is therefore the reactor where reactants are brought together and react to form the desired products. In an ideal reactor all reactants are taken up by the reaction and fully converted to the required product.

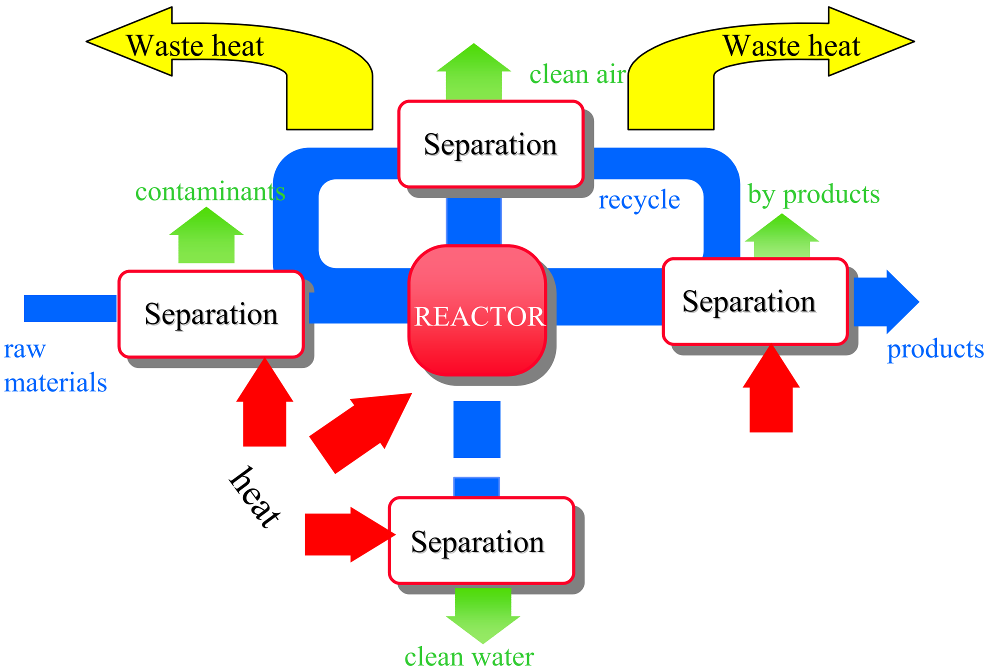


Figure 2.6 *Key energy aspects of the chemical process: reactions, separations and thermal integration*

Of course, in reality things are different:

- In most reactions it is difficult or impossible to convert all the reactants, introducing the need to separate products from unconverted reactants and in some cases to recycle the unconverted reactants back to the reactor inlet.
- In general not only the desired products are formed, but also a range of by-products, which need to be separated and used effectively or form waste products from a process.

As a result of this lack of selectivity and conversion in reactions, separation processes play an important role in the chemical process. Figure 2.6 illustrates the different roles separation processes play in converting raw materials to products. Product separation in the petrochemical industry is often a substantial part of investments. Other essential separations are the separation of waste impurities to avoid emissions to air and water and the removal of contaminants from the feedstock.

Distillation columns are widely used to separate products. But both the heat required for the selective evaporation (which forms the basis of the process) and the investments tend to increase as strongly as the streams are more difficult to separate[9]. These separations have been estimated to make up as much as 40% of the investments in new plants.

The second issue determining the energy consumption in the chemical industry is the thermal balance of processes. Chemical reactions in general either consume heat (endothermal reactions) or produce heat (exothermal reactions). If a process consumes heat, this heat has to be supplied (for example by external firing). If a process produced heat, the heat has to be removed (often rapidly) from the process by cooling the process flows. Heat transfer is also necessary because reactors will generally operate at elevated temperature to enhance kinetics (and/or equilibrium conversions) for the desired chemical reactions. Because heat is always transferred to a lower temperature, most of the heat generated, either as a utility or in the process, ends up in the cooling water or in the ambient air. Although the chemical industry is an overall producer of heat (Neelis, 2004){Bach, Neelis, et al. 2004 18661 /id}, its main final energy consumption is still heat (cf. Figure 2.4).

Considering the total industry, the final energy consumption is more complex. But for the chemical industry the energy consumption is determined mainly by the factors indicated above:
1. Feedstock input is determined by the selectivity of processes (how much of the input to a process is converted to the required end-product).
2. Heat requirements are determined by the need to supply heat to chemical reactions (even if the industry is a large net producer of heat) and the energy consumption in separation processes.

2.2 Petrochemical industry basics

In terms of primary functions it is simple: a refinery produces transportations fuels (gasoline, diesel) from crude oil and the petrochemical industry converts “waste” products from the refinery into plastics and fibres. The reality is infinitely more complex. The number of products and intermediate flows in the refinery and in the petrochemical complex is enormous; the route from crude oil to end product involves a large number of steps and (to add to the complexity) in general involves many different individual companies. Figure 2.7 attempts to capture some of this complexity into a simple diagram. Roughly the products of the current petrochemical megasite fall into five categories:

Transportation fuels. The main products of the megasite (in terms of energy flows) are the transportations fuels, gasoline and diesel. Part of the product of the refining activities, in particular naphtha is further processed in the petrochemical industry. In the Dutch situation, 15-20% of the refinery outputs is used in the petrochemical industry.

Base chemicals. The basic process downstream of a refinery is the steam cracker in which naphtha is converted into the basic building blocks for the petrochemical industry: ethylene, propylene, butadiene and aromatics[10]. Most of these building blocks are used in the Rijnmond, but the area is also a large exporter of base chemicals as well. For example, pipelines for ethylene and propylene connect the Rijnmond to Belgian, French and German chemical industries.

[9] Two materials become more difficult to separate as their boiling points lie closer together.

[10] There is no steam cracker in the immediate area around the port: the production of base chemicals is located in Moerdijk (Shell), Terneuzen (Dow) and Geleen (DSM).

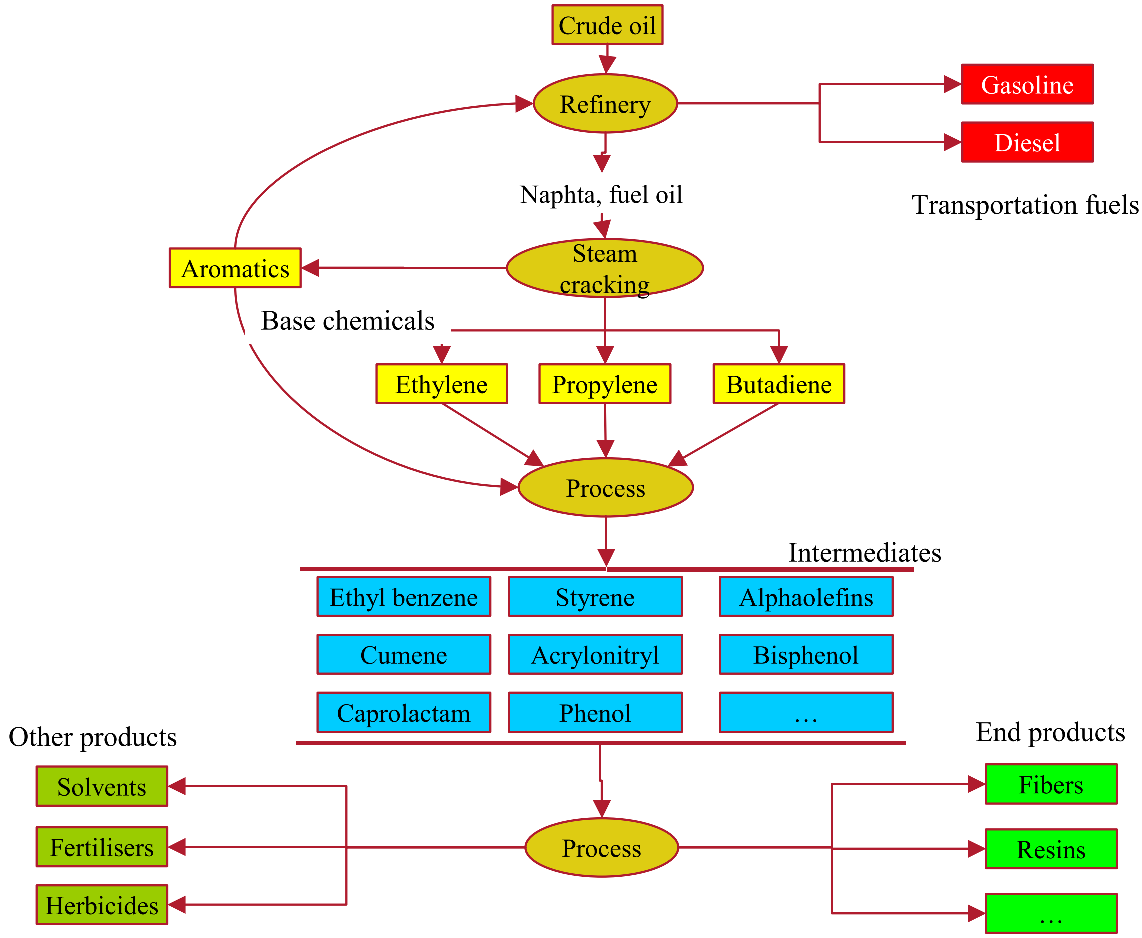


Figure 2.7 *Simplified scheme of the material flows in the petrochemical megasite*

Intermediates. The base chemicals are subsequently used to produce a large number of intermediate chemicals. Important intermediates are styrene, ethylene benzene, phenol, cumene, acrylonitryl. Again part of these intermediates is exported and the remainder serves as the feedstock for the final processing steps in the petrochemical process chain.

Polymers. This final step in the chain is the production of polymers or plastics from the intermediates. The five main plastics are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinylchoride (PVC) and Polyethylene terephthalate (PET).

Other chemicals. The petrochemical industry also produces a large number of other chemicals, including solvents and herbicides. Furthermore the inorganic chemical industry (mainly the fertilizer industry and chlorine production) are relevant to the development of the site.

The Rijnmond is not just refining and petrochemical industry. Production of inorganic base chemicals is an important activity as well. There is a strong production of industrial gasses with an extensive pipeline infrastructure for distribution of different gasses connecting sites in the Netherlands, Belgium and France. Partially the inorganic chemical industry supplies the other producers with the inorganic chemicals needed to produce intermediates, polymers, solvents and others. Other products are derived purely from the inorganic base chemical industry, for example fertilisers. For the organic industry other energy carriers are used as feedstock, for example natural gas. As a result, natural gas, both as a fuel and as feedstock plays an important role the Rotterdam industry along side oil (in the form of naphtha). The importance of natural gas can be illustrated by referring to the ammonia industry, which is natural gas based and is responsible for an energy consumption of 80 PJ/a, which corresponds to 10% of the energy consumed by the Dutch chemical industry.

2.3 Organic chemistry: the petrochemical industry as a living organism

2.3.1 The petrochemical complex as an organism

Carbon chemistry is often called "organic chemistry" because it is the basis of living organisms. Organic chemistry is also the name given to the petrochemical industry. The similarity between the living organism and the petrochemical megasite is more than a name. In many ways the (carbon based) petrochemical industry resembles a living organism. This analogy can be very useful in understanding how the petrochemical industry could change over the coming decades.

Co-dependency in the chemical megasite. The different components in a living cell cannot exist as isolated entities, but combining their functions they form a viable system. In the same way the different elements in the petrochemical megasite are mutually dependent: refineries require outlets for the by-products[11] of motor fuels. Steam crackers process refinery by-products, and need to have customers for the variety of products they produce. In general, *because* many of the processes in the petrochemical industry are not very selective in their output, they produce a large number of different products. In order to produce the main products economically, it is necessary to sell the by-product for further processing. On the other hand, plants producing intermediates or polymers will only be located where such an affordable supply of feedstock exists. The relationship between producer and user of the intermediates is symbiotic. There are many different designs possible, many different routes by which the products can be further processed. But the similarity between the cell and the chemical megasite is the necessity to combine the different functions to achieve viability for the whole system.

Organic growth of megasites. Development of chemical megasites can be considered as an almost organic process. Although there are sites which are developed as integrated systems right from the start ("green fields)"[12], most petrochemical megasites have been realized over decades by expanding and renovating elements gradually. In many cases the core components of refineries and petrochemical base may be as much as 50 years old. Adding new components to existing plants in order to increase the capacity ("de-bottlenecking") or performance is an important way in which expansion activities occur. The current combination of activities in the petrochemical megasite is determined much more by historical developments than by a comprehensive master plan.

Adaptation to the external environment. This brings us to the third aspect in which petrochemical complexes resemble living organisms: they are adaptive. There are many factors affecting the activities in a chemical megasite. Demand for products changes constantly. This can be due to a shift in end products, for example the growth or fall in demand of a specific type of plastic. Or new technologies may open the way to using other intermediates than before. Acetylene as a starting material for many reactions has been almost completely replaced by ethylene-based chemistry. Alternative pathways are being developed to replace "selective" oxidations to produce alcohols, ketones and aldehydes by processes based on carbonylation and hydroformylation. Regulations also affect the overall process in the megasite. A recent example is the regulation concerning the sulphur content of transport fuels. Desulphurisation requires large amounts of hydrogen and is therefore changing the hydrogen balance in refinery complexes completely.

The most important factor is the availability and price of feedstock. The refinery and petrochemical activities in the Rijnmond have developed into one of the largest complexes in the world, because the port could provide crude oil at low prices. The type of feedstock

[11] Considering diesel and gasoline as the main products.
[12] An example of such a site which is currently built the Shanghai Chemical Industrial Park (http://www.scip.com.cn/en/index.asp)

available may also be an important factor. Availability of high-ethane natural gas in the US, for example, leads to a very different set-up than in the case of the Rijnmond because the natural gas in the Netherlands contains only small amounts of ethane. In general a trend toward a more important role for natural gas in the petrochemical industry is becoming apparent. In particular shifts in price ratio of different potential feedstock materials have been historically important. The quality of crude oil has played an important role in the past and will do so even more in the future. Looking at the future, it is important to realize that adapting to important changes in feedstock availability and changes in demand will be the main driver for changes in the processes used in the refinery and downstream petrochemical activities.

Logistic as a key to survival. The final aspect in which the petrochemical complex resembles a living organism is the continuous transport of materials to and from the megasite. The primary function of the petrochemical complex, its reason for existing, is the transformation of materials into other materials. Being able to supply materials and to transport them further is one of the key factors, if not the most important, for the survival of the organism or chemical megasite. As indicated above, it is not incidental that the petrochemical activities have developed around the Port of Rotterdam. The ease with which materials can be transported, determines the distance over which they can be transported. Crudes can be transported in tankers from one side of the world against moderate transport cost. Gaseous chemicals (for example ethylene), which require pipelines for transport, need to find customers much closer to the chemical megasite, while other products can be transported as granulates over much longer distances. The connections to feedstock sources, between processing steps and to the markets can be considered as the lifelines of the chemical megasite. Such a megasite will be extremely sensitive to changes in these lifelines.

2.3.2 The role of scale

There is however also an important difference between petrochemical megasites and living organisms: scale. One of the most astounding levels of complexity in nature is the integration of all essential functions in organisms, which may be smaller than one micron. By contrast in the petrochemical industry size is dictated by processes, which are only economic and efficient at a very large scale.

In general scale-up tends to reduce the specific cost (i.e. cost per unit of product) of a process. The most basic reason is the material cost. Scaling-up a reactor or heat exchanger decreases the amount of steel required (kg/m^3 and kg/m^2). But there are many other examples of processes where investments drop with scale. Compressors do not only become more efficient with scale: a large-scale process will enable other technologies. One of the main improvements in ammonia production was the replacement of reciprocating machines by rotating equipment.

Another essential example is distillation. Based on differences in boiling points and the difference in density between gas and liquid phases, two or more chemicals can be separated in a distillation column. The more difficult the chemicals are to separate, the higher the distillation column needs to be. Distillation column of 10's or even more than 100 meters high often dominate the skyline of chemical complexes. A special characteristic of the distillation process is that the height of the tower is (almost) independent of the flow rate: the same height is required for a very small and for a very large flow. Obviously, however, it will never be economic to build a 50-meter distillation column for a very small flow. Economies-of-scale therefore dictate a minimum size for any process requiring separation by distillation.

Many unit operations in the chemical plant are difficult to downscale. In fact, the enormous scale at which it operates characterizes the refinery and petrochemical industry. Throughputs of crude distillers and steam crackers, which form the heart of these complexes, are measured in thousands of tons per day or even per hour.

2.4 Changing directions: looking for consistency in change patterns

The Rijnmond today forms a complex cluster of strongly interconnected activities. It is not only one of the largest ports in the world, but also hosting a unique set of global players in the refining and petrochemical industry. Most plants are located here because of the synergy with other plants, for example using the product of one plant as feedstock in the next or delivering essential intermediates for the neighbouring plant. Pipelines exchanging feedstocks and intermediates, delivering steam, oxygen or hydrogen, connect many plants. It is a difficult task to start to understand how all these activities fit into one bigger picture of *the* Rijnmond, but it is clear that understanding the coherence is key to understanding how it has become what it is.

Now try to picture how this area could change in the coming decades. Other processes, feedstock's and technologies, other products and new stakeholders may become important. Assessing how the area might change seems a daunting task because the number of different possibilities seems endless. However, as the analogy with the living organism has shown, all these processes are not independent and if the current activities are strongly linked, the same will be true for the changes in the coming decades. The elements put forward in the previous section to help us understand how the Rijnmond has become what it is, should also offers us some handles on how it can evolve further. Most importantly it has shown us that processes, feedstocks, technologies and stakeholders are linked. Therefore, to understand how the megasite could change, rather than discussing all possible singular changes in process, feedstock, etc., we need to consider how these changes are linked. Which changes logically fit together? Which developments are exclusive? In other words we need to understand in which *directions* the Rijnmond megasite can move.

Technological innovation will be an important part of long-term structural change. Innovation focuses on both reducing cost (feedstock, energy, capital), risks (safety, environmental impact) and on maximising product value. Specific objectives of innovation include:

- Reducing cost of feedstock and energy carriers
- Reducing investment cost
- Minimising environmental impact and increasing safety
- Creating products with higher added value

The direction of technological innovation, however, will be conditioned by changes in the European and global energy regime. The impact of environmental regulations (air pollution, climate change, etc.), global competition with Asia and the Middle East or demand for greener products will depend on these changes. Although basic objectives (maximising added value and minimising environmental impact) will be common drivers for innovation in all scenarios, the balance of external drivers will drive innovation in different directions.

2.5 Structuring technological innovations using a design hierarchy

As indicated in the previous section, there are many technological options. A way of structuring all these possible technical changes is to consider a "design hierarchy". This term has been introduced to indicate that there are priority levels in the design of complex technical systems, to help designers do "first things first". An example can illustrate the importance of this approach. Return on investment on many district-heating projects in the Netherlands has been low in the past. Investments in district heating systems were made before improving insulation of houses. As heat demand became much smaller, the profitability of heat grids tumbled.

It illustrates an important point for the Rijnmond, because it shows the need to determine how the design of one part of the system can be affected strongly by changes in other parts of the system. In chemical engineering many different design methodologies are used to determine in which sequence to tackle different aspects of the design (Korevaar, 2004). The most well known approach was developed by Douglas (Douglas, 1988) another example, which is useful when looking at the chemical industry as a whole, is the design hierarchy in Figure 2.8.

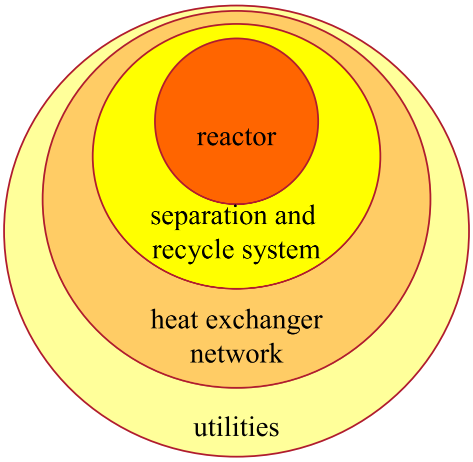


Figure 2.8 *Example of a design hierarchy for chemical plants given by (Smith, 2005)*

For the Rijnmond megasite, which is based on chains of processes which are moreover strongly cross linked, taking into account the interaction between different parts of the system is important. Examples of possible developments in the Rijnmond, which have important "down-stream" consequences, are:

- Technological changes in the core processes could significantly alter the waste-heat balance (and therefore the return on investments in for example heat networks).
- Changes in feedstock (for example from oil to biomass) may shift the availability of base chemicals for downstream processing.
- Rise and fall in product demand may affect the demand and profitability of intermediate products.

There are two important reasons for keeping the design hierarchy in mind. The first is that it helps us to define consistent sets of technologies (technological directions). Companies will try to avoid making investments if future developments may threaten the profitability of these investments. For example, it is not likely that in a Rijnmond, which faces large challenges in adapting to a strongly changing product demand, much effort will be put in optimising the existing production facilities.

The second reason is that if investments are made; companies will be less willing to make investments in a different direction. This effect is referred to as lock-in. An example is, that it is more difficult to make investments in improving the core processes in a site were the heat management has been fully optimised. It simply means that investments in reactor technology will have a longer payback time.

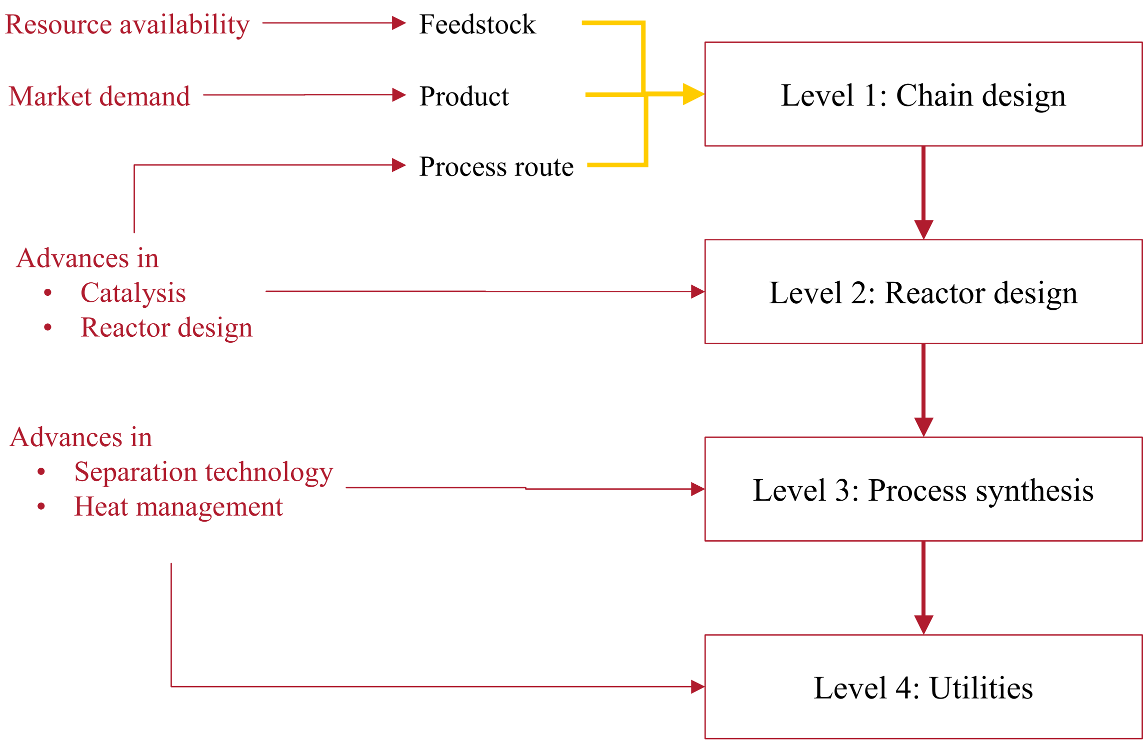


Figure 2.9 *"Design Hierarchy " for the Rijnmond*

The main issue is that some changes in the design will strongly effect many of the other design aspects of the system, while other changes have a much smaller impact. For example, a change in feedstock will affect the design of the core processes (reactor), it will affect downstream processes because other intermediates are produced and it affects the required separation technology, the thermal integration with other processes, etc. Changing the feedstock therefore has a large impact. On the other hand, replacing the steam boiler by a combined heat and power plant, which may have a considerable impact on the energy consumption, does not lead to the need to change other parts of the system. In Figure 2.9 attempts to represent a general Design Hierarchy for the Rijnmond. The highest level is the level of the chain design (see Figure 2.10). Changes in feedstock, product or process route impact all levels below, while the impact of reactor design works through on both the "process synthesis" and "utilities" level in Figure 2.9. Changes in process synthesis and utilities have the least impact on the system.

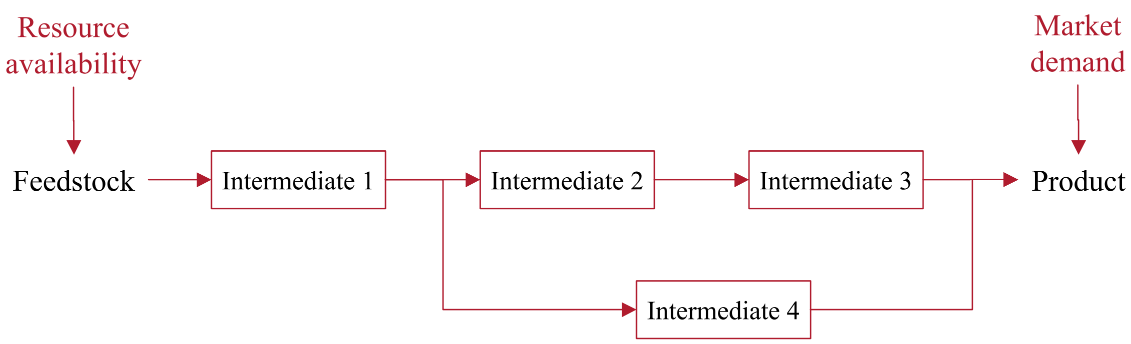


Figure 2.10 *The production chain*

LEVEL 1: CHAIN DESIGN

Changing demand for final products

Evidently, development of demand for final products in the different scenarios is the key to understanding how the megasite might change. How will the market for gasoline and diesel develop and how will it affect the petrochemical industry? What new regulations on sulphur or aromatics content are to be expected for the hydrocarbon fuels? Will the role of plastics continue to increase in the same rate as in the past decades? How will the competition of the new Asian economies affect the demand? Are biopolymers going to play an important role? As figure 2.7 illustrates, changes in product mix will affect many other aspects.

Changing supply of feedstocks
One of the main drivers for change will be the feedstock situation. Increasing oil prices are the primary factor, but availability of alternatives, for example biomass, will partially shape the future Rijnmond as well. Basically there are two directions in which the feedstock can change. The first possibility will be a shift from crude oil to other fossil fuels, i.e. to natural gas or coal. Availability of oil will be the main driving factor for such change.

The second, and more radically departing from the current system, is the replacement of a substantial part of the oil by biomass feedstock. Obviously this development can be driven by high oil prices, but sustainability is an important driver for using biomass as a feedstock as well.

Process routes
In many cases there is not a single route to a specific end product and the production of a single product can involve a considerable number of intermediate steps. A product (or intermediate) may be by a different route, depending on availability of feedstock or markets for by-products, depending on the existing situation, etc.

It is important to realise that new technologies can be enabling for new process routes. In many cases a more direct, and therefore more material efficient, route is conceivable. However, the technology for such a route is not available, either because the process itself forms a challenge or producing the required input materials for the process is costly. Important reductions of feedstock use and energy consumption may therefore become possible in changing circumstances. A careful selection of the chemical route to the end product is therefore worthwhile.

LEVEL 2: REACTOR DESIGN
When the different process steps have been determined, it makes sense to open the black boxes we have used to represent the process steps and to assess how the process steps themselves can change. The key in optimising the process design is to aim for high conversion and selectivity. The objective is mainly to maximise product yield and to minimise energy-consuming separation steps and recycles down stream. Novel reactor concepts and catalysis are areas, which can contribute to this objective.
LEVEL 3: PROCESS SYNTHESIS
Process synthesis has been the key to much of the efficiency improvement achieved over the last two decades. The basis of process synthesis is that a reactor seldom produces just the required product. Instead reactors produce mixes of products, by-products and waste streams which need to be separated an/or further processed. Heat is either produced or generated in a reaction introducing the need to supply heat to or from the process or to recover heat from the process flows. Recycles and different pressure and temperature levels make the system look less like a reactor and more like a chemical plant. Process integration focuses specifically on improving on three areas: thermal integration, recycling and separation. In the last 20 years pinch technology has contributed to substantial improvements in efficiency by process integration.

LEVEL 4: UTILITIES AND WASTE-MANAGEMENT
Using greener utilities and processing waste streams in an effective manner is a “last resort” in the hierarchy of options for the chemical megasite: reducing use of utilities like steam and electricity and avoiding waste is more effective in the long run. However, it is also the easiest way to reduce energy consumption and reduce emissions. The enormous savings through

combined heat and power systems (both in terms of primary energy and CO_2 emissions) in the last decade is an example of the impact of more efficient utilities.

In particular there are three options which could lead to a substantial reduction of fossil fuel use and/or reduction of CO_2 emissions[13] from the chemical complex without the necessity of changing the core processes: using carbon capture and sequestration to produce hydrogen, use of biomass for production of combined heat and power and the use of renewable electricity from off-shore wind-parks.

Contemplating directions in which the Rijnmond could change, there are two key elements. The first is to understand in more detail what technological innovations are *possible*. An overview of technologies which could play a role in the future Rijnmond falls outside the scope of this study, but many overviews have been made, e.g. (ACS, 2001) (Alsema, 2001) (Klipstein, Robinson, 2001). The other essential aspect is understanding which stakeholders (may) play a role in the process of reshaping the Rijnmond and to what degree their interests are or can be aligned, as will be discussed in the next chapter.

[13] Whether energy consumption or emission reduction is important, depends on the scenario (see chapter 4 and further).

3. Competing for international business: strategic niche management of megasites

3.1 Investment decisions are made elsewhere

In many technology assessment studies the focus is on identifying which technologies would be useful to have available in the future. These studies evaluate how a technology, once available, can contribute to achieving certain policy goals, whether it is lower emissions, a more competitive industry or less dependence on foreign energy imports.

Resources for R&D are always limited and the background for such assessments is often the question which technologies should be prioritised. Two aspects are above all relevant: risk and impact. Technologies may be able to contribute strongly to achieving policy targets, if successful, but represent a high-risk investment. Other technologies may have a much smaller impact, but a much larger chance of success. In managing a technology portfolio, risk and impact have to be weighed against each other.

In many studies “risk” is translated into the chance of technical success or failure. What are the technical difficulties, which are to be expected in bringing the innovation to the market? In the present study we emphasise the importance of the socio-economic environment of the innovation. Key question in this respect is: which stakeholders would be prepared to make to necessary investments to commercialise the technology and under what conditions? In this chapter we consider who the stakeholders in the Rijnmond area are and what drives them.

The comparison in the previous section of the petrochemical megasite in the Rijnmond to a living organism perhaps reflects more strongly on the technical aspects than on the business perspective. In contrast to the living organism, the individual firms forming the chemical megasites represent many different and diverging interests. As the study “To C or not to C” (Soest, 2003) concludes, one of the main problems in adapting to the changing circumstances is that there is no “problem owner” in the site. Interests of the individual firms, the regional government and national government are not necessarily aligned. Change at the megasite is not based on a single decision on the level of the megasite: it is the result of many individual decisions. These may (or may not) head in the same direction. As “To C or not to C” reflects: *“the strategic decisions on technologies, product portfolios, and choice of location are not taken in Rotterdam but in Houston, Paris, London, Kuwait or Salt Lake City”.* The question is, how changes on the level of the megasite can be implemented if they are based on individual decisions of all the companies located (partially) in the area.

Let us for a moment consider which decisions shape the site. The most basic type is the decision of a single company to expand, relocate or downsize activities in a specific type of production process in the Rijnmond. Table 3.1 summarises these “single business” decisions, which can either reinforce the existing activities or represent a new activity in the area. Furthermore the company taking the decision can be a resident company (i.e. already active in the area) or a new player. As we will further on evaluate the different directions the site management could pursue in different scenarios, one of the questions is which of the fields in the table is the key to achieving the desired change. Evidently, these are only the most basic types of decisions. There are also decisions, which concern agreements reached between companies. Companies can form joint ventures, close (long-term) contracts for the delivery of intermediates or supply of utilities. They can also initiate cooperations, for example on waste-management or logistics.

Table 3.1 *Types of single business decisions determining the direction of the Rijnmond*

Activities \ Players	Resident	New
Reinforcing (marginal, evolutionary)	The decision of a company to expand/downscale the capacity of the existing plant or change to a new process	A company decides to locate a plant in (or relocate to) the Rijnmond adding to the current (type of) activities
Change of direction (disruptive, revolutionary)	A firm which is currently active in the site decides to: • go into a novel[1] type of business and locate the new plant in the Rijnmond • close its business or relocate elsewhere, whereby this type of business completely disappears from the Rijnmond	A company not previously active in the site is attracted to the area bringing a novel [1] type of business.

[1] Novel refers to activities, which are new specifically to the Rijnmond (they may exist elsewhere).

Change on the level of the Rijnmond can only be realised if there are companies willing to start activities in a specific direction. An important aspect of the assessment is the question how the Rijnmond can maintain its current economic importance in the different scenarios while striving for a minimal environmental impact. We are thus tempted to consider the Rijnmond as a single entity and not as the collection of independent firms, which constitute the Rijnmond. Although the companies operating in the area currently have vested interest in the form of investments, which they want to exploit as long and profitably as possible, their decisions to continue or expand activities are made in an increasingly open and global economy.

Analysing the strengths and weaknesses of the Rijnmond, one could focus on the strengths and weaknesses of the companies currently operating in the area, defining strength in terms of the power to compete with companies elsewhere. But this does not coincide with the perspective of the site as a whole, in which we interpret strength as “the ability to attract new businesses and hold on to the existing businesses” (to achieve change). In other words, this concerns the competition between regions or sites in attracting business. For the longer-term perspective associated with the scenarios, the latter approach is the most valuable. Therefore we will focus on the way the region can look at the future in the different scenarios and strive for change by attracting new players. We choose the perspective of a public “site management” competing for international business.

3.2 The role of the Public Site Management

Public site management is currently one of the main tasks of the Port Management. The Port Management has been instrumental in shaping the Rijnmond in the past decades. Its role has been to attract new businesses to the megasite. It has been very effective in using the synergistic advantages of the Rotterdam area, both in attracting new businesses and in reinforcing bonds with existing businesses. One of the concepts that has proved to be highly successful in Rotterdam is collocation. A new company sets up its operations on or next to the industrial site of an existing company, making it possible to realize significant operational synergies and substantial cost reductions(CBIT, 2004). Substantial cost reduction for new and existing companies has also been realised by an efficient management of utilities. The main global players in the area of industrial gasses have production facilities and infrastructure in place and tank storage companies and pipeline operators offer their services to the chemical operators.

Joint ventures for combined heat and power plants have been successful (and have contributed largely to energy savings in the megasite).

The role of the Port Management focuses on bringing together the relevant parties at the table at the right time and develop initiatives exploiting the synergy as best as possible. But its role is also in developing an independent vision of the future directed at anticipating long-term changes. An example is the concerted effort, which has led to the position of the Rotterdam port as the world's greatest methanol hub.

3.3 A framework for analysing strengths and weaknesses of megasites

The logical starting point for the strategy of public site management is a SWOT analysis (Strength, Weakness, Opportunities, Threats). A useful approach can be found in the study referred to earlier(CBIT, 2004), which analyses the strengths and weaknesses of different international chemical megasites. This study relates characteristics of different chemical "megasites" to what these characteristics mean to the stakeholders: the individual business, the cluster and the government. The value of this approach lies in the fact that it recognizes explicitly that the different stakeholder have different interests. And if we talk about the strength and weaknesses of a specific site (e.g. the Rijnmond), these advantages "translate" to specific benefits, as shown in Figure 3.1

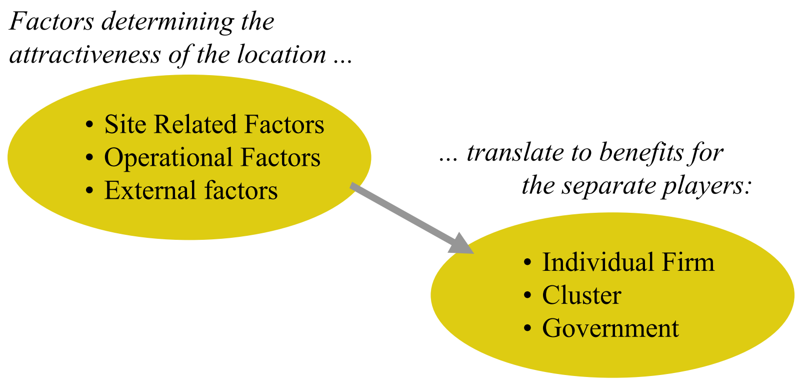


Figure 3.1 *Methodical identification of site characteristics and measurable stakeholder benefits*

Measurable benefits for the national government are:
- Direct and indirect employment
- Tax revenue (long-term)
- Realising broader environmental policies and targets
- Public support

The public site management will be interested above all in the "return on investment" of policy to maximise the benefits for companies of common facilities and infrastructure. Utilisation of site infrastructure and realisation of synergies are the relevant benefits.

In this study we are interested in answering the question: "under which conditions are individual firms operating in the Rijnmond area prepared to invest in the development of a specific technology?" To answer that question, we do not need to consider the benefits on the macro- or meso-level. We need to address how the individual firm, operating in an international context and considering making investments in new plant capacity, will assess the comparative advantages (and disadvantages) of the Rijnmond and hence on the translation of these advantages and disadvantages to benefits to the individual firm. Decisions on investments are based on what can be achieved for their specific operations in terms of the following measurable benefits:

- Material acquisition Cost
- Inventory Carrying Cost
- Cash-to-Cash Cycle time
- Transportation Cost
- Response time
- Inventory
- Logistics cost

Instead of attempting to capture all the stakeholder benefits, in this study we have concentrated on identifying the benefits to the individual company as a key element in the capacity of the site to attract business to the Rijnmond. Therefore the strengths and weaknesses of the Rijnmond should be assessed specifically with the measurable benefits to the individual firms in mind. Table 3.2 summarises the separate factors determining the attractiveness of a site to the individual firm.

Table 3.2 *Factors determining the attractiveness of a location according to (CBIT, 2004)*

Site Related Factors	Operational Factors	External Factors
• Rail / Road / Port	• Raw materials /feedstock	• Environmental regulations /procedures
• Pipeline	• Logistics	• Availability of qualified labour
• Storage	• Labour	• Tax regulations
• Space	• Waste treatment/disposal	• Industry organizations
• Utilities	• Product specialization	• Government subsidies
• Clear point of contact	• Technology	• Government sponsorship
• Clear consistent policy	• Market Demand	• Ease of permission

3.4 Strengths and weaknesses in attracting business to the Rijnmond

In the previous section we discussed in a general sense the main factors determining attractiveness of a megasite. Here we consider these factors again, but now specifically for the Rotterdam/Rijnmond region. The perspective again is the perspective of global businesses assessing the attractiveness as a location for investments.

Transport infrastructure

The Port of Rotterdam serves as a transit port for many goods. At the Port of Rotterdam many goods are transported further by ocean going vessels. However, the most important assets of the port are its connections to other economic centres. The main connections are by road, by railroad and by barges operating on the Rhine and Maas River. In the second half of the 20th century, Rotterdam became the main entrance to the Northwestern European markets. The bulk transport, accounting for 3/4 of the goods transhipped annually, provided the raw materials to the refining and petrochemical industry in the Rijnmond as well as the Ruhr area.

Road traffic in the Rijnmond area is becoming more and more congested. It is very much a theme in the public debate. Being able to access all destinations within the Rijnmond area by car within reasonable time, limiting health impacts of road traffic in the area and the minimising economic cost of congestion are conflicting issues. Any discussion an a sustainable future of the Rijnmond needs to take these aspects into account.

Market Demand
The refineries in the Rijnmond area are the main suppliers of the European gasoline and diesel market. Although the largest part of the gasoline and diesel production is used in Europe, part of the refineries production is also exported to other continents.

The chemical industry in the Rijnmond area is mainly devoted to production of intermediates and semi-finished products. The bulk of these products is made into end products elsewhere. The type of products, which the Rijnmond supplies, includes (building blocks for) plastics, fibres and solvents and is used to manufacture anything from consumer goods to building materials.

Demand for these products is expected to grow in a moderate rate in Western Europe. However, from a global perspective, markets are shifting elsewhere. Within Europe the economic centre of gravity is shifting south and, with the extension of the EU, towards the East. Eastern and Central Europe represent rapid growing markets for which the Port of Rotterdam is not the most obvious point of access. Other ports, like Hamburg, are successfully attracting a growing share of the transport by container ships.

The second trend (or perhaps of a even greater impact for the Rotterdam port) is the strong emergence of the Far Eastern economies like China and India. Due to the much lower wages in these countries, an increasing range of end products like clothing and electronics is being manufactured cheaply in this region. End products are being shipped in large quantities to the European market by container ships. In the longer term, displacement of the end-product manufacturing poses a serious threat to the market for the chemical industry in the Rijnmond area. In the wake of this development new megasites are rapidly being developed in the Far East. The most important of these sites is the Shanghai Chemical Industry Park.

Raw materials /feedstock
Making use of the most appropriate technology and economy-of-scale has enabled Rotterdam to minimise transport cost for crude oil. Over the past decades this has been a very strong driver for the development of the Rijnmond. Utilising the advantages of the Port of Rotterdam in supplying feedstock's at competitive costs seems to be one of the key issues in the future of the Rijnmond as well.

Although relying on imported feedstock puts Rotterdam at a disadvantage relative to competitors who can benefit from cheaper feedstocks, competition from the Middle East has not had a large impact on business as yet. Transport cost to the European markets, higher labour and capital cost have protected the Rijnmond against the competition from the Middle Eastern producers. However, it is clear that in the future Rotterdam will have to evolve to be able to continue competing against the Middle East and other areas, which possess cheaper feedstocks (for example Russian natural gas).

Energy carriers other than oil.
The availability of natural gas and an extensive natural gas infrastructure is regarded as one of the most important assets of the Dutch energy system. In order to accomplish the Dutch ambition as the European gas broker, long-term contracts with Russia and increasing LNG facilities could complement the role of the decreasing Dutch natural gas reserves. If the role of the Dutch natural gas system evolves along these lines, availability of natural gas at world market prices could lead to an increasing reliance of the Rijnmond on natural gas as a feedstock. On the other hand, key technologies, which are necessary to enable natural gas to replace a substantial share of crude oil, like oxidative coupling of methane to ethylene, are still in the early stages of development.

If coal is to become an important energy carrier in the future (the petrochemical industry becoming the carbochemical industry), the point of departure for Rotterdam is favourable as well. Of the European ports, Rotterdam is by far the largest coal handler(Port of Rotterdam, 2005).

The ambitions of the port go beyond the current (fossil) energy carriers, like coal, oil and gas. The Port Management takes an active role in particular in two energy carriers which can come from "green" resources in the future: methanol and biomass. It has identified the import of biomass as one of the possible future developments that fits in the strategy of the Rijnmond towards a less carbon-intensive chemical megasite and in which the area has major comparative advantages. The main comparative advantages of the Rijnmond with regard to biomass trade and utilisation are the facilities and experience with bulk transport as well as the synergy due to the fact that it is the location of both major energy and chemical industries. Plans for a large-scale biomass syngas facility have been elaborated with the key stakeholders although financing is a major barrier. One of the key short-term requirements is to assess how a market for raw biomass and a market for syngas can be created that offer long-term security. Technologies and legislative frameworks that offer guarantees with respect to the environmental impact of production, transport and conversion of biomass are essential.

Pipelines
The pipeline infrastructure connecting the Rijnmond to other sites is very extensive (see Figure 2.2). An ethylene pipeline runs from Rotterdam via Antwerp to the DSM site and connects to the German ethylene network reaching Frankfurt and Ludwigshafen.

A network of pipelines for industrial gasses (nitrogen, oxygen and hydrogen) connects Rotterdam to the major Belgian sites (Antwerp, Mons, Liege) and the North of France (Maubeuge, Dunkerque) as well as to the DSM site in Geleen (NL).

The crude oil pipeline network transports crude from Rotterdam to Antwerp and the Ruhr area. Oil product pipeline systems include the Central European Pipeline system (the Netherlands, Belgium, Germany, France) and the naphtha pipeline to DSM (Geleen).

Utilities
Three major global industrial gas suppliers (Air Liquide, Air Products, Linde) have production facilities in the Rijnmond delivering hydrogen, nitrogen, CO and oxygen to the petrochemical industries. Furthermore, joint ventures have been set up (by energy companies together with industrial parties) for combined heat and power plants. Reduction of upfront investment cost ([CBIT, 2004] quotes up to 20-40% of the total investment cost) is seen as a major benefit to investors in the area.

Services
In addition to the standard utilities (heat, water, industrial gasses), there is a wide range of companies offering other services to the chemical industry. These services include direct services such as tank storage (varying from crude oil, oil products, chemical products to edible oils), blenders/traders in lubricants, waste handling and incineration, transportation and cleaning services. Furthermore the presence of many internationally operating engineering and contracting firms reflects the availability of a skilled labour force.

Space
Space is an important issue in the Netherlands, with almost 400 inhabitants per km^2 one of the most densely populated countries in the world. For the Rijnmond part of the solution is land reclamation. Within 10 years the harbour is expected to expand with the construction of the 2nd Maasvlakte. Furthermore, the Port Management is very much focused on utilizing the space in the port very efficiently. However, space, or rather lack of space, is relevant beyond the immediate spacing issues in the Rijnmond, which may be solved by land reclamation and efficient use of land. Given the high population density of the Netherlands, a lack of space influences the future activities in the Port in many other ways.

One of the most important consequences is the fierce competition for land between agriculture and other purposes. Extensive use of land, for example for large-scale production of biomass for use as an energy feedstock, is not feasible in the Netherlands. Substantial replacement of oil or gas as a feedstock based on domestic biomass is not an option. Any scenario in which biomass plays an important role will rely at least partially on imported biomass. As transportation of large volumes of biomass is one of the most critical issues, the Port of Rotterdam is an essential stakeholder in this scheme.

The most important reason for using fossil fuels is the high energy density. In general renewable energy is much less concentrated, and much of the effort in converting renewable energy into a useful form is concentrating the energy into a transportable form. In a country as densely populated as the Netherlands, finding space for "generation" of renewable energy is difficult. As a result options in the Netherlands for renewable energy are limited. The potential for hydropower, geothermal energy and tidal power is small and it is generally difficult to find suitable locations for on-shore wind. Ambitions for domestic Dutch renewable electricity focus largely on the potential for offshore wind along the North Sea coast. Import or renewable secondary energy carriers may play an important role in the integration of high shares of renewable energy. In which form import of renewable energy might take place is uncertain. In addition to renewable electricity, energy carriers such as methanol, ethanol and even hydrogen are possible. Again the Port of Rotterdam may plan an important role here.

Labour
Well-trained personnel are available for the chemical industry operating in the Rijnmond. However, the flexibility of labour is considered low. Availability of all levels of technical personnel is critical and the low number of students for technical studies is considered troubling. Although the general assessment is that high level of knowledge is available, a widening gap between fundamental (long-term) and industrial (applied) R&D is perceived. A shift from the traditional chemical engineering studies towards more application and product-oriented programmes is evident.

Government and policy
According to VNCI a lack of interest of the Dutch government for the international position of the industry (in particular the chemical industry) is perceived (Roller, 2004). The main objection to the Dutch policy with respect to the chemical industry is a "lack of continuity and consistency in policy". Government decisions are furthermore characterised by a long lead-time.

According to an international comparative study (CBIT, 2004), environmental legislation is perceived as "strict, but transparent and fair" by a majority of chemical operators in Rotterdam. In the VNCI survey quoted previously, the companies active in the area indicate that too strict regulations could threaten the level playing field. An example of legislation considered strict is the EU REACH proposal, which regulates registration of chemicals.

The Port Management
The Rotterdam Municipal Port Management (RMPM) was founded more than 70 years ago and has played an important role in shaping the area. It leases sites to businesses and has successfully developed the collocation strategy, where the Port Management actively seeks to realise synergies between neighbouring companies.

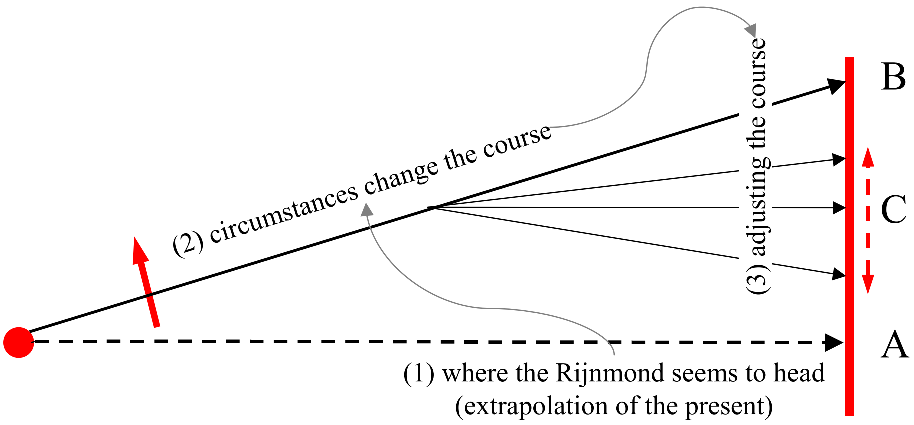
Furthermore, much effort is put into aligning common interests of the companies present in the area. A survey by the organisation for the Dutch Chemical Industry (Roller, 2004) characterised the prevailing position of the companies as "willingness to cooperate and change". The cooperation between industrial companies located in the Rijnmond area is formalised in a number of organisations, for example DeltaLinqs.

PART II: Rijnmonds future in four European transition scenarios

The goal of working with scenarios is to be able to work out a strategy, which helps us cope with a changing world. The figure below illustrates this process. We have an idea where we are going to be in 20 or 50 years. In the figure point “A” represents this point where we (implicitly) assume were we are headed.

Circumstances change: oil prices double or a successful climate policy penalizes CO_2 emissions. As a result, instead of ending up where we expected, we end up elsewhere (in “B”). We use the scenarios to assess how changes in the world around us change where we are heading. To cope with the large uncertainty in predicting how the world might change, we use different scenarios and analyse the consequences of those scenarios (and therefore different points “B”).

But the important element in the analysis is, that we can determine how we could react to those changes. What should our strategy be in this scenario? As indicated in the introduction, a key element in any strategy to make the Rijnmond more sustainable is technology (see section 1.1). We can use technology to adjust the course to a more sustainable future than that towards which we are heading autonomously. But to achieve this, we need to know both where we are going (“B”) and where we could end up (represented by different points “C” in the figure). By considering how these futures differ, we can determine which technologies we need to carry out the strategy.



The four scenarios discussed in the next 4 chapters outline the general development in the Netherlands, the EU and the world around us. We consider each of the scenarios from the point of view of the Rijnmond, by highlighting the elements, which impact this area. Both aspects indicated above are influenced by the events depicted in the scenarios. We can assess for each scenario how the changing world affects the course of the Rijnmond, but the degree to which the Rijnmond is free and capable of adjusting its course differs from scenario to scenario. Therefore, for each of the scenarios we focus on a number of key questions:

What are the relevant aspects of the scenario for the Rijnmond?
The external developments influence both the way business is done in the Rijnmond as well as its ability to change. Therefore we consider these two issues explicitly:

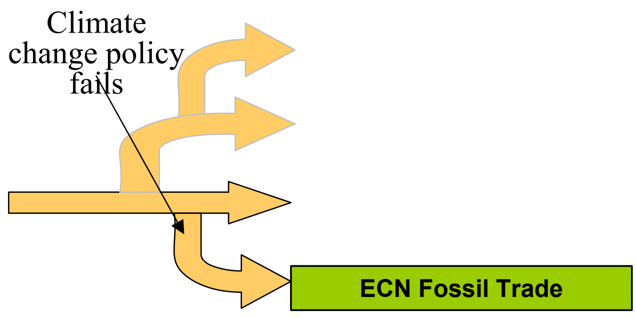
- What are the most important external developments with respect to the *current activities* in each of the four scenarios (with emphasis on refining and petrochemical processes)?
- What are the relevant factors, which stimulate or complicate *strategies of change*? To what degree do the events and developments in the scenario determine how far the Rijnmond can adjust to changing circumstances (capacity to change).

What are the opportunities and threats for the Rijnmond?
The external developments are translated into opportunities and threats.

Formulate an explicit strategy for the Rijnmond
In writing this study, we have chosen the perspective of a “site management”, whether this is the current Port Management (see chapter 3) or a “virtual management executed by different organisations. The external developments determine what the site management strategy could be within the scenario. For each scenario we therefore formulate an objective taking into account the strategy.

Describe what the desired outcome of the strategy could be (Storyline)
Subsequently we consider how the Rijnmond area would develop, given the strategy.

4. Fossil trade



"Business (-as-usual)"
The EU and Dutch policy react to the failure to intensify and extend Kyoto by moving from mitigation towards adaptation to climate changes. Psychologically close to the current society, with a strong(er) emphasis on entrepreneurship. The trend to a smaller government continues.
For the Rijnmond Fossil Trade is "Business as Usual". The main ingredients are stable energy prices and the absence of an effective climate policy. International competition with the new economies dominates the agenda

4.1 Relevant external developments in the scenario FOSSIL TRADE

External factors influencing the continuity of current activities in the Rijnmond:
- Availability of fossil fuels at moderate prices.
- Increasing global trade and importing energy carriers, increase in volume of trade passing through the Port of Rotterdam.
- Increasing trade leads to strong competition, in particular with Asia.
- Strategy of Middle-East oil exports, to focus on exporting more value-added products, can only partially threaten refining activities in Rijnmond due to moderate oil prices.
- Economic growth leads to increase in demand in petrochemical end products.
- Use of coal as well as volume transhipped in Rotterdam increases gradually.
- LNG rapidly becomes an important energy carrier.

External factors affecting the capacity to change:
The energy system
- Low degree of regulation of market.
- Large infrastructural projects will be difficult to realize (low margins, no “leaders”).

Europe
- Within the EU, member states choose a variety of directions for the energy system (EU diversity remains/increases).
- Focus on economic competition with Asia and US becomes more important as energy security (i.e. international availability of fossil fuels) or environment protection are less the “big issues” for government.
- National agenda's dominate (subsidiarity): R&D relevant for the Rijnmond will focus on competitiveness (efficiency, new products) and reduction of “other” emissions.

Transition
- Main task/mission of Port Management is to stimulate economic activities in area.
- Lack of challenges for publicly financed R&D; strategic importance of public funded R&D lies in its value in attract new players and/or increase compositeness of existing operations.
- Strong lock-in on fossil pathways: introduction of new pathways is difficult.
- Innovation, with a focus on new products and increasing added value, comes from existing players and networks.

4.2 Defining a strategy for the Rijnmond

Threats
- Competition of strong (petro-) chemical megasites near new markets (e.g. Asia).
- Dominant national focus of the energy policy of the member states of the EU makes it difficult to achieve a level playing field for the chemical industry within Europe.
- Strict EU regulations (e.g. on emissions) could disturb an international level playing field for European industry.
- Shift to unconventional oils and coal liquids may favour on-site conversion in countries of origin.

Opportunities
- Extended depreciation period for existing facilities creates room for investments to improve these facilities and introduce coal conversion facilities.
- Increasing diversification of the Rotterdam port in energy transport (from oil to coal, LNG)

Outlook
As sharp increases in oil prices stay away and CO_2 prices do not attain levels, which threaten to disrupt the markets for fuels or polymers, there appears to be no drive for fundamental technological changes in the Rijnmond. However, there is no room for complacency in the boardroom of the site management. Competition from Asian consumer goods manufacturers leads to further displacement of manufacturing activities from the EU towards low-cost areas. The resulting decrease in demand for plastics and fibres puts pressure on prices for plastics and other products. Strengthening the economic basis of the area requires getting the current players to invest in the Rijnmond (instead of looking only Eastward).

Strategic objective of the public site management in FOSSIL TRADE
Strategy is defensive, aimed at preserving the current position. There is no urgency to change the core business, but it is necessary to act on the threat of further displacement of petrochemical activities towards Asia and the Middle East. A smooth transition to unconventional oil and coal must be stimulated

4.3 Storyline

In essence, strengths and weaknesses in FOSSIL TRADE are the same as today. Reinforcing the position of the Rijnmond therefore focuses on continuing the current elements: utilising the benefits of the Rotterdam port, collocation as a strategy to make the most of synergies between companies, creating and maintaining an infrastructure connecting the area to other chemical complexes (Antwerpen, Frankfurt) and providing for the same level of services found today.

EU policies on bio-fuels are revised in favour of improved incremental (conventional) technologies. A policy focus on efficiency (hybrid internal combustion - electrical vehicles) and reducing emission, which harm quality of life in urban areas (cleaner combustion, end-of-pipe), leads to emphasis on regulations with regard to fuel quality for gasoline and diesel. Anticipation on these changes is crucial. For example being able to supply more hydrogen for desulphurisation and other hydrotreatments becoming increasingly important. But also capturing the (petrochemical) opportunities, which go with the decreasing, use of aromatics as fuel components (and their availability for other purposes).

Attracting incremental investments to stay upfront
There is a fundamental advantage for the new megasites springing up around the Pacific Rim: they are building modern plants, incorporating state-of-the-art technologies. As a result the comparative efficiency advantage of the Rijnmond, with its high degree of integration, becomes smaller or the Rijnmond even starts to lag behind. It is necessary to innovate to recapture the current position, but with hardly any new plants being built, a different strategy is required to stay competitive.

Emphasis changes toward fine chemicals, but the market for bulk chemicals (and its energy consumption) remain important. Energy policy shifts toward supporting the introduction of technologies, which increase the competitiveness of the region (rather than on sustainable development). The production of fine chemicals, with a higher added value, becomes more important as competition with Asia increase. Competitiveness comes from being able to adapt quickly to changing circumstances and incorporate new technology rapidly. Therefore focus is on technologies, which are more flexible than the technologies used (currently) in production of bulk chemicals. However, the existing production of chemicals from primary feedstocks (naphtha, natural gas) is still the key to economic viability of the Rijnmond area. The (North-Western European) market for end products still creates demand for intermediates. Adding new capacity will be generally not is achieved by construction of new plants. Emphasis is therefore on increasing throughput of existing plants and on development of new, more direct routes toward functionalised chemicals.

The main drive for the strategy of the Dutch government and of the Port Authority is to make the Rijnmond an interesting site for *incremental* investments. Its high level of utility services and logistic infrastructure are already clear assets in this sense. The focus on site-integration remains a priority and is expanded as the Rijnmond starts to deliver heat to external costumers, for example by the new district heat network connecting the Rijnmond and Hoogvliet.

Realising synergy between companies can be translated into increased exchange of heat and material flows between businesses. This requires increased flexibility, which can be achieved by innovations in the area of separation technologies and thermal systems (high-temperature heat pumps, heat storage).

The strategy of reducing upfront investments, by making optimum use of the investments, which have been made in the past, could be carried even further if integration on a process level could be feasible. However, the economy-of-scale, which is characteristic for bulk processes, is a limiting factor. In this area, further development of process integration and intensification technologies plays an important role. Key technologies here are catalysis and multifunctional reactors.

Gas and Coal
Although oil prices do not peak, a gradual increase in prices leads to renewed interest in other energy carriers. As the natural gas reserves in the Dutch underground decrease, new LNG terminals increase the LNG capacity in the Port of Rotterdam. Increasingly the Rotterdam Port is used to land coal-based liquid fuels from Australia and US. Coal gradually becomes more important to the Rijnmond. A coal-based syngas project in Rijnmond is initiated by a joint venture of industrial partner and coal research is identified at a national level in several EU countries (including the Netherlands), leading to a number of national programs.

4.4 Innovation

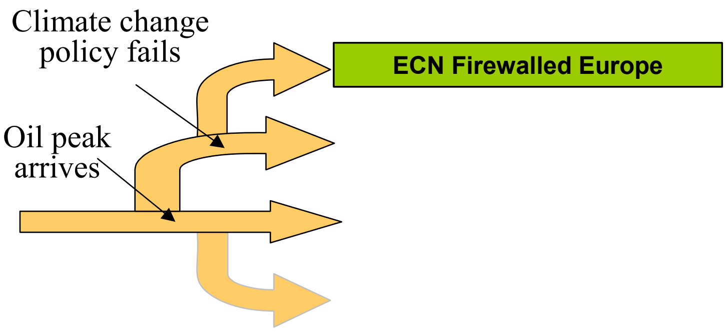
In FOSSIL TRADE the current emphasis in research on process integration technologies (SenterNovem, 2004)is continued. Process integration technologies (e.g. membranes, heat pumps, heat transformers) are developed as generic components. Long-term R&D at the research institutes (ECN, TNO) gradually gives way to more applied research as consortia are formed of potential manufacturers and end-users looking at specific applications. Technology transfer from the research environment to the commercial environment is realised by co-development and demonstration projects in the Rijnmond.

The implementation of process intensification is more difficult because this is much less an incremental and generic technology. Its focus is on development of novel reactor types, which are (significantly) more flexible than the current large-scale bulk processes. Because it relates closely to the core business of chemical companies it is difficult to set up pre-commercial research in the public domain. The associated intellectual property (IP) issues and its long-term development character complicate the necessary industrial participation.

Therefore the research strategy contains two elements. Fundamental research, carried out mainly at universities, focuses on developing know-how on a number of key aspects of novel reactors. Selected areas are for example new catalyst development (including coating technology), adsorbent development, reactor modelling, etc. Technology development carried out at research institutes (again both TNO and ECN) focuses on developing reactors for new processes and process routes.

Coal related research in industry focuses on cost reduction of coal gasification and process integration in coal conversion systems. The national program, carried out at universities and research institutes focuses mainly on coal-to-intermediate technologies. Emphasis is on fundamental research on syngas-to-liquids, C1-chemistry and direct liquefaction technologies.

5. Fire walled Europe



Together we stand
European solidarity, uncertain world. Creating safety and security are the main priorities. A strong mandate for national and European governments. To a high degree, the EU determines the playing field for the Netherlands.
In Firewalled Europe the Rijnmond faces decreasing refining activities as the oil price increases, putting pressure on the petrochemical sector as well. The ecology vs. economy debate sways strongly toward supplying jobs and financial security.

5.1 Relevant external developments in FIREWALLED EUROPE

External factors influencing the continuity of current activities in the Rijnmond:

- Availability of oil decreases, threatening profitability of both refining and petrochemical industry through overcapacity and demand fluctuations.
- Trade volume through the Rotterdam port decreases as goods are produced more and more on the European market and global trade flows are stagnating.
- Demand for type of end products does not change strongly, but basic organic chemical industry is limited more and more to supplying manufacturers of end products within EU.
- Increase of gasoline/diesel prices leads to lower demand through substitution (e.g. biofuels, hydrogen) and reduced mobility.
- Emphasis of national policy is on efficiency and recycling in industry, which may provide compensating value, added activities in Rotterdam.
- Competition with Asian producers of final products becomes less dominant due to protected internal markets.
- Volume of Coal and LNG transhipped in Rotterdam becomes more important rapidly.

External factors affecting the capacity to change:
The energy system

- Electricity generation shifts from natural gas to coal and nuclear, emphasis on energy saving.
- Strong regulation of energy markets (transport fuels, electricity).
- Demand for hydrogen and biofuels, if these can be offered at prices comparable to fossil based (GTL, gasoline/diesel).
- Biomass production and import aims not on energy but primarily at food and materials.
- High-energy prices drive the use of (biomass) waste stream for energy production (electricity, heat).
- Strong links between energy markets for heat, electricity and fuels.

Europe

- Europe focuses on internal cohesion, much attention for security (of supply).
- Strong coordination by EU, both on RD&D and on targets and measures.
- Strong lead of EU on defining targets and means for R&D on coal and nuclear research and recycling/efficiency.
- Division of tasks within Europe leads to increasing national differences. Concentration of national research efforts prioritise areas, divergence between member states in used primary sources and technologies, but the member state energy infrastructures are strongly linked.
- Central regulations for regional environmental problems.
- Active involvement of governments (EU, national) in the negotiation of long-term contracts with Russia and Algeria.

Transition

- Strong influence of government on innovation, but R&D networks (linking industry, institutes and universities) lack dynamics.
- Stronger grip of government on processes requires a more preferential type of relationship with government (old energy companies make come-back). Governments are prepared to "protect" the large investors (at the cost of the consumer).
- Government sees an important role for the Port Management in realizing the required objectives (Initiating and attracting new activities, realizing efficiency improvements).
- National R&D on prioritised areas through core institutes together with multinationals and national champions.

5.2 Defining a strategy for the Rijnmond

Threats

- Substitution of gasoline and diesel reduces demand for refineries.
- Higher prices for oil put pressure on demand for "traditional" petrochemical end-products (plastics, solvents).
- Increasing competition of Middle-East (with a strategy to export high value products rather than oil).
- Biorefining may decrease the need to work in highly integrated industrial megasites.
- Coal-derived transportation fuels may be internationally traded and threaten the transition to local coal refineries in the Rijnmond.
- Countries with abundant supply of coal within EU (i.e. Poland) are actively promoting a domestic chemical industry.

Opportunities

- Rotterdam has an excellent infrastructure for coal handling.
- The Rijnmond offers an attractive location for large-scale bio fuel production and hydrogen production.
- A high oil price favours locations, which have a high efficiency and are flexible with respect to feedstocks.
- Focus on efficiency and recycling in the national policy offers opportunities for the region.
- Direct regulations (recycling, efficiency) can be more effectively met by using site synergies instead of taking measures on the level of individual plants.

Outlook

A rapid increase in prices of crude oil occurs and further increases are expected. This level of oil prices threatens to have a serious impact on the European economies. On the level of the EU regulations are anticipated which aim at increasing security of supply. For example, liberalization of the energy markets is under discussion and investments by energy companies in nuclear and coal generating capacity are encouraged by intervention in the electricity market.

R&D budgets for technologies offering less reliance on imported energy, including advanced coal conversion and hydrogen technology is stepped up.

For the Rijnmond the outlook is pessimistic. The competition with the Middle East will be fierce. Rather than exporting the crude oil, the Middle East increasingly is expected to focus on exporting those intermediates, which can be transported (in the form of granulates or by tankers). The synergy between the petrochemical and the refinery industry is at a risk, because large-scale import of those intermediates, which can be, produced much cheaper elsewhere threatens to change the mix of base chemicals required by the chemical industry.

Strategic objective of the public site management in FIREWALLED EUROPE
Strategy aims at countering the threat of loss of activity because of decreasing global trade and high oil prices. Disappearing activities need to be compensated by stimulating and initiating new activities. Core of the strategy is start a coal megasite by attracting different types of coal based activities and creating links to the petrochemical industry. Mission is to actively promote energy and material efficiency in the megasite and related product chains.

5.3 Storyline

Increasing prices for gasoline and diesel, but demand for hydrocarbons remains
Substitution of oil based transportation fuels gasoline and diesel (C8+ hydrocarbons) by other fuels is a necessity in this scenario. But changes in feedstock preferably should not require completely changing the refuelling and drive train technology. Therefore hydrocarbon fuels remain dominant. Initially natural gas based fuels gain prominence: CNG and gas-to-liquid (GTL) fuels. In a later stage competition is (initially) mainly between different routes for producing liquid fuels and unconventional oil resources (e.g. tar sands). The high price of transportation fuels enables parallel development of different routes, for example both hybrid[14] vehicles (using hydrocarbon fuels) and fuel cell vehicles. Environmental regulation focus on health effects, for example by combating particulate emissions.

The Rijnmond aims at keeping a central role in supply of hydrocarbon fuels to North-Western Europe. One of the first possible steps towards a carbochemical complex in the Rijnmond is the construction of a large coal gasification plant, a joint venture between oil and energy companies. This plant supplies syngas to different users in the chemical industry and to the combined heat and power plants on the complex. Further links to the chemical industry are initiated by locating a direct coal liquefaction demonstration plant on the site, which delivers both gas and liquid chemicals. The cokes are used in the gasifier. National institutes play an important role in the increased interest in research in advanced coal conversion (gasification, supercritical plants) and for the production of base chemicals.

Other fuels and feedstocks co-exist
Increasing oil prices lead to the reformulation of EU goals and targets on the use of other transport fuels. Instead of focussing on specific solutions, for example biofuels, a variety of directions (including NG, hydrogen and biofuels) are pursued.

- **Biofuels** do not achieve a dominant role in the Rijnmond. There is a strong decrease of the current cattle feed import flows through the Rotterdam port (e.g. soy beans). EU regulations give a strong priority to production of food and materials. Utilising side streams from the food industry is an economic necessity for the food producers. Collocation of the companies further processing the “waste” streams or an extensive system for transporting these streams

[14] Hybrid vehicles are efficient vehicles combining an electrical drive system with an internal combustion engine.

to a central location (possibly the Rijnmond) can be (part of) the answer. Here the biomass feedstock is processed to biomaterials, which can partly replace the materials currently made from oil. But, because the scale, which is achieved, is of a different magnitude than the current activities, there is no strict necessity to locate these activities in the Rijnmond. The task for the public site management to initiate a “biopolymer megasite” is therefore a difficult one.

- Progress in fuel cell technology may lead to **hydrogen** filling in an increasing share of the demand for transportation fuel on the longer term. Supplying hydrogen from central production facilities, for example from **coal**, for the Rijnmond is a business opportunity, which fits well with the current activities. Hydrogen plays an important role in reducing dependence on oil imports. With the government as the architect for the energy infrastructure and allied with the multinational energy companies, an extensive hydrogen pipeline infrastructure can be realised. Interesting is the link to the large investments in on- and offshore wind energy parks by the energy companies in the framework of the national wind program. As the amount of offshore wind capacity increases, the hydrogen grid can also be used to buffer a considerable amount of excess electricity. This agrees well with the strong integration, which takes place in FIREWALLED EUROPE between the different energy carriers (fuels, electricity, heat) and the role of the new energy companies. Synergy between fuel and materials, however, is much smaller than in the current oil-based system.

- The use of **natural gas** for transport applications is marginal: natural gas is reserved for applications where it can be utilised more efficiently, for example for highly efficient cogeneration and as feedstock in industry. LNG import terminal capacity increases strongly. Joint ventures of oil and gas companies (e.g. GU/Shell) are created.

Efficient use of resources
Developments are driven by high cost of feedstock. But the demand for plastics is only slightly affected by the higher prices. EU regulations prescribing the (partial) use of less energy intensive materials, for example in packaging, have a stronger impact on demand. Strict regulations on recycling of plastics have been introduced. Intensive research on back-to-monomer technology leads to breakthroughs in this area. Rijnmond's ambition is to attract new businesses in recycling as an extension of its integrated waste and recycling management.

High natural gas prices make district-heating projects viable. Long-term security required for projects is supplied by long-term agreements between government and energy companies. Large-scale projects directed at heat exchange between companies are slightly more difficult. The conversion of oil based to a coal based chemical industry affects all of the steps between feedstock and intermediates. The rapidly changing activities in the Rijnmond in the FIREWALLED scenario makes it more difficult to close the long-term contracts necessary for thermal integration between companies.

5.4 Innovation

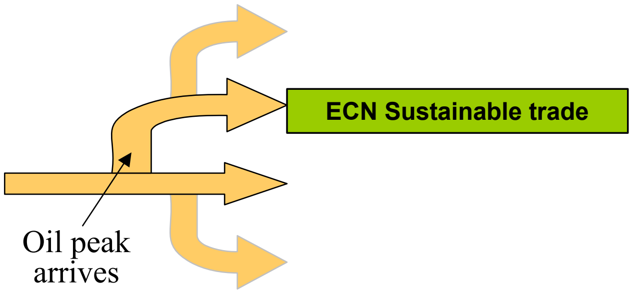
Priorities for research and development are set at a central European level. The core institutes have an important role in carrying out the R&D and have to compete on a European level. On a national level this means concentrating on a limited amount of subjects. The Dutch research focuses on two specific issues. A research megasite around the Wageningen University, including other agro-oriented research institutes, develops technologies for biorefining. The objective is biochemical processing of side streams from the Dutch agriculture and food industry into valuable biomaterials. Important areas of research:
- Biomass harvesting and processing and biomass tailoring for materials production.
- Fractionation and separation technologies for a wide range of biomass feedstocks.
- Technology for thermal, chemical and mechanical processes (gasification, liquefaction).

- Technology for biological processes (biosynthesis, bacteria for degradation of lignocellulosic materials).

The second research cluster, which includes ECN, universities and energy companies, develops a range of technologies for conversion of coal into intermediates and the subsequent processing to fuels, polymers and fibres. The main programmes:

- Technologies for coal based chemicals (e.g. pyrolisis) are revived.
- New intermediate-routes based on coal are developed.
- Improvement of gasification technology.
- Gas-to-liquid technologies (based on coal syngas).
- Back-to-monomer recycling technologies.

6. Sustainable trade



Sustainable world
An effective and purposeful government empowers a strong drive towards sustainability. The government initiates, stimulates, facilitates but emphasis is placed on removing barriers by participating in building constructive international frameworks. "Green" refers to the way the environment is taken into account in our decisions, but also reflects as a positive attitude toward innovation (" green technology").
In Sustainable Trade much changes in the Rijnmond. Increasing oil prices and changing demand put the current activities under pressures, both from the input (changing feeds) and from the output side (changing products).

6.1 Relevant external developments in SUSTAINABLE TRADE

External factors influencing the continuity of current activities in the Rijnmond:
- Increasing prices, for oil and other fossil energy carriers.
- Shift from fossil based transport fuels to other energy carriers.
- Demand for other end-products (greener, cleaner).
- Little protection for current activities (tariffs, specific R&D focus on improving position of Rijnmond).
- Trade system for CO_2 emissions becomes effective and gradually more forceful.
- Pressure on Rijnmond to reduce CO_2 emissions substantially (e.g. through emission ceilings).
- Emphasis in EU on a new role for agriculture (the bio-based economy).

External factors affecting the capacity to change
The energy system
- Strong shift to non-fossil fuels (with emphasis on renewable electricity and biomass).
- Economic incentives to produce with low emissions (e.g. CO_2 trading or ceiling) lead to introduction of more efficient technologies in electricity production (e.g. NG based fuel cell systems).
- Large-scale importation of renewable energy carriers (partly by sea).
- Strong emphasis on energy efficiency in end-use.

Europe

- EU policy works through a system of emission trading and emission ceilings.
- Little protection of EU internal markets (part of the deal with developing countries).
- Important role for EU and global funding: limited national R&D.
- Mix of core institutes and competitive funding, but also some co-funding of national break-through technologies for energy conservation.

Transition

- Attracting new players is essential for changing the structure of the Rijnmond; key question is how (or if) synergy with old players is achieved.
- Public-private alliances become important.
- "Old" domains (agriculture, chemical industry) diversify.
- Highly innovative climate, with ample possibilities for protected experiments.

6.2 Defining a strategy for the Rijnmond

Threats

- High oil prices threaten the continuity of current refining and petrochemical activities.
- The diversity of new fuels replacing gasoline and diesel facilitates transfer of part of the processing to less centralised locations.
- Biorefining may decrease the need to work in highly integrated industrial megasites.
- Strong competition from BRIC[15] & other developing countries in global open market.

Opportunities

- Excellent infrastructure for biomass transport and conversion in Rotterdam.
- Synergy of agro-know-how (Wageningen) with chemical industry (Botlek).
- Position of the Dutch food and feed industry gives unique "cascading" opportunities.
- Innovative climate & financial incentives (oil prices / CO_2 trading) combine to offer possibilities to create a highly knowledge-based region in the Rotterdam - Antwerp area.
- Economic incentives to produce with lower emissions.

Outlook

An impulse is given to the level of global cooperation with the ratification of the comprehensive Greenhouse Gas Emission Control Agreement. The EU sets out vigorously to formulate new policies on technology development and international cooperation. At the same time the increasing prices for oil and gas instil a sense of urgency at the level of business leaders and policy makers.

For the Rijnmond all things point toward change. Higher prices for oil and an effective CO_2 emissions trade system will inevitably effect the activities in the Rijnmond on the medium to longer term and it is clear that it is necessary to anticipate on these developments. New EU directives on Biofuels and on Renewable energy are expected to boost the level of activities in the area of biomass and a EU Research program on biorefineries is initiated. Opportunities for the Rijnmond seem to lie primarily in the area of biomass.

Strategic objective of the public site management in SUSTAINABLE TRADE
Strategy focuses at a structural change in activities towards greener feeds and greener processes by attracting new players and becoming main port for new energy carriers. With international relations characterized by open competition, attracting the process steps with high added value to the Rijnmond is the challenge.

6.3 Story line

The most important changes in the Rijnmond are related to the new role of biomass. The site management takes an active role in creating opportunities for new activities based on biomass and defines two priorities:

- Creation of a reliable and effective biomass market.
- Demonstration new technologies for biomass conversion and biofuels production.

The market for biomass

Long-term security for the import of biomass is seen as the most important condition for development of the Rijnmond to the European biofuels industry: creating markets with long-term contracts and with an international label which guarantees that the biomass has been produced in a sustainable manner. The public site management takes an active role in the process of contracting biomass flows in other countries and making the experiences available to the community of companies which need to secure biomass flows for their operation. It also gives space to parties, which aspire roles as intermediaries for biomass acquisition aiming at establishing a biomass exchange.

It also participates, on behalf of the Dutch government, in the international forums, which aim at creating sustainability labelling. With its close links to the industry operating in the Rijnmond the opinions voiced by the public site management are highly valued.

Feedstocks for a new chemistry

Large-scale conversion of biomass plays an important role in the vision of the future of the Rijnmond. Syngas will not only be used to produce biofuels (for example Fischer-Tropsch diesel), but will also be supplied to the petrochemical industry by a syngas network. The area keeps its options open with regard to the form of biomass to be imported: woodchips, pyrolisis or HTU oils, carbon. But by initiating and operating the syngas infrastructure, the threshold for new players, both users and producers is lower.

Competition of biofuels, ethanol and other alternative fuels lead to lower demand for gasoline and diesel from oil. As refineries are tuned towards a maximum output of transportation fuels and the general level of activities in the refineries decreases, availability of naphtha becomes lower. Initially syngas is used to replace syngas produced from fossil fuels (mainly natural gas), but as the price ratio between syngas from biomass and fossil feedstocks decreases new processing routes emerge. Syngas and (bio-) methane form the feedstock for a new C1-chemistry. The position that Rotterdam has builds up as mainport for methanol is extended by large-scale import of biomethanol for olefin production (MTO). Synergy between an increasing use ethanol for transportation (and the role of Rotterdam in import of ethanol from other parts of the world) and use of ethanol as a feedstock in chemical industry is fully exploited.

Shift to biorefineries

All of the above is more or less business as usual for Rijnmond. But as the international agreements on free trade leads to increasing flows of goods, from which the Port of Rotterdam profits as well, it also changes the location where conversion into more added value intermediates takes place. There is a trend that developing countries, instead of exporting raw materials (for example wood chips) increasingly process these raw materials themselves. As the margins on processing biomass in the Rijnmond instead of (for example) Brazil decrease, the reaction of the chemical industry is to focus on using the imported biomass much more efficiently. The bio refinery concept is introduced which is characterised by two aspects:

- The feedstock is used in a cascade of processing steps, extracting the most valuable products first through biochemical processing and subsequently, in increasingly thermochemical

[15] Brasil, India and China.

steps, converting the less valuable products. In the last step, the waste fraction can be used to produce electricity and heat.
- The bio refinery process has the potential to produce a variety of new platform chemicals. The current platform chemicals produced from oil and gas is simple chains (e.g. ethylene, propylene) or rings (benzene). Platform chemicals from bio refineries are the highly complex C5 and C6 molecules, which form the basis for biomass material.

Creating a bio refinery does not only require development of the processes within the bio refineries, but also a chemical industry that is capable of utilising these new platform chemicals. This, in contrast to the thermo chemical (syngas) routes, requires a fundamentally changing chemical industry.

Processing the imported biomass more efficiently, leading to higher value crops, is one part. The industry also turns toward using domestic agriculture products, in many cases dedicated crops. As a new EU agriculture policy focuses more on crops, which can be used to produce high value products, a trend towards further integration of the biochemical processing industry and the agriculture sector becomes apparent. EU regulations come into effect, which stimulate the use of biomaterials. In the first place the objective is to replace plastics with a lifespan shorter than 2 years (this presently constitutes more than 30% of the plastics produced). Gradually the system grows toward bio refinery systems using all fractions of the biomass effectively.

Impact of the changing energy system
The changes in the energy system at large also affect the Rijnmond. Large offshore wind parks generate a substantial part of the electricity. Rotterdam is one of the (very) few locations on the Dutch coast capable of absorbing power on such a scale. The electrical infrastructure in the Rijnmond area is fortified and where possible load management is integrated into the industrial activities, for example using demand management for electricity intensive processes. Hydrogen production plays a role, but a limited one. With high penetration of renewable electricity, the role of hydrogen fuel cells will be limited to load-management and transportation in densely populated areas. A centralised infrastructure with production facilities in the Rijnmond does not evolve.

Strong emphasis on reducing energy consumption of households for heating does nothing to promote large-scale district heating projects. Solutions in SUSTAINABLE TRADE go towards renewable electricity and heat pumps. This stimulates the development of heat pumps and heat storage, technologies that also diffuses to industry. Gradually heat production from natural gas, which currently plays such a large role in the Rijnmond, is reduced by intensified process integration and by using the heat produced in thermal biomass processing (gasification, electricity production)

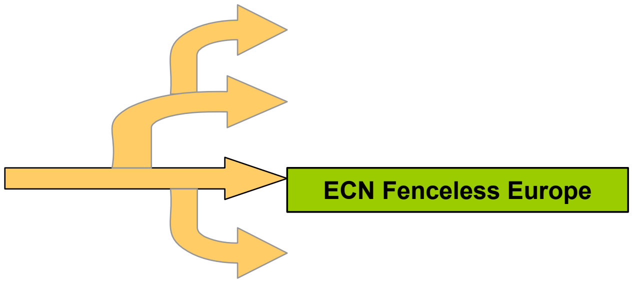
6.4 Innovation

The role of national R&D is relatively limited in this scenario. Much of the research is carried out at a European level, forming an important element in global and bi-lateral international climate agreements. The focus of the Dutch R&D policy is therefore to stimulate research and implementation by the companies operating in the Rijnmond and (in particular) new players in the area. In enabling this research, one of the main issues is making available knowledge of Dutch universities and institutes in a number of key areas (agriculture, biotechnology, catalysis, process technology, etc) to private businesses through cooperative development projects.

Focus of research and development, both in the EU and in the Netherlands, is on conversion of biomass to valuable products. Both the syngas and the biorefinery route (new platform chemicals) are being pursued. The syngas route requires development of a range of technologies, which convert C1-molecules (e.g. CO, methane, methanol) into functionalised higher hydrocarbons. The biorefinery route requires development of new crops, which have been optimised towards yield of specific components, fractionation technologies (separation) and development of biochemical conversion processes.

Today a large amount of heat is required in the chemical industry. In the current system this heat is supplied largely by combustion of fossil fuels. As converting (imported) biomass into heat is economically unattractive, new technologies are required to reduce the heat demand (e.g. advanced separation technologies) or produce this heat more effectively (high temperature heat pumps).

7. Fenceless Europe



Out-of-the-box
An enterprising world. The individual, as a consumer, as an entrepreneur, is a powerful force shaping society. The consumer is demanding cleaner products and is conscious of the links between different aspects of society (for example combating poverty, energy supply and security). There is an open mindedness with regard to experiments with new market forms (e.g. cooperative electricity production by consumers).
Fenceless Europe for the Rijnmond constitutes a challenging scenario. On one hand low oil prices form a barrier to greener feeds. On the other hand the demand for cleaner products and cleaner production are forcing the area to change. The successful international climate policy does encourage the required changes.

7.1 Relevant external developments in FENCELESS EUROPE

External factors influencing the continuity of current activities in the Rijnmond:

- Stable oil prices (and for other fossil energy carriers).
- Shift in demand in end products: consumer drive for greener products[16].
- Diversification of European energy policy leads to change in demand for transport fuels.
- Public pressure on Rijnmond to produce greener and cleaner.
- Penalties on energy inefficiency and emissions stimulate innovation.

External factors affecting the capacity to change:

The energy system
- Liberal markets, centralized regulation is weak.
- Economic incentives to produce with lower emissions (emission trade systems).

Europe
- European member states are free to set there own (energy) policies.
- Important role of government is in the international arena: free trade, development agreements and international climate policies.
- RD&D budgets shift gradually to the EU.

Transition
- Instruments to introduce new infrastructure are limited by diversity in energy carriers and lack of market regulation.
- Low protection of experiments, much innovation/dynamic.

[16] Consumer behaviour is often erratic and seldom consistent. However, FENCELESS EUROPE presupposes that influential consumers groups are sensitive to “green” marketing strategies. This creates added value for products with perceived green value, although it does not sweep aside the concept of the consumer as “homo economicus”.

- Initiating and stimulating demonstration projects involving innovative technologies is one of main instruments for the Rijnmond to attract innovation.
- Government does not set agenda for research: consumers do.
- New actors dominant: challenge is to entice them to settle in the Rijnmond.
- Widening R&D gap between private and public (EU) funded research, makes it difficult for the regional government (and the Port Management) to manage/stimulate innovation in the area.
- Shift from process to product development.
- Little attention will be paid to improving existing plants and generic technologies.
- Rapid product-cycle offers opportunities for innovation.

7.2 Defining a strategy for the Rijnmond

Threats
- Competition of strong (petro-) chemical megasites near new markets (e.g. Asia).
- New energy carriers emerge; diversity (biomass, green gas, hydrogen?) makes it difficult to react effectively.
- Low oil prices make the outcome of a EU policy on greener fuels uncertain.
- Public pressure on Rijnmond to produce greener and cleaner puts pressure on government policy sparing the petrochemical sector.
- Discussion on added value of products: here or in developing countries (import of crude bio-oil or bio based products).

Opportunities
- High degree of innovation makes implementation of new technologies less difficult (for example because more possibilities exist for financing projects, openness toward new technologies, etc.).
- Increasing demand for (high value) greener products.
- Low oil prices enable optimising depreciation of current facilities and a gradual shift towards greener production.
- An effective CO_2 emissions trade systems enables the industry to realize the potential projects with low cost/ton effectively.

Outlook
An impulse is given to the level of global cooperation with the ratification of the comprehensive Greenhouse Gas Emission Control Agreement. Its scope, including the way it has succeeded anticipating on trade conflicts between the developing world, the BRIC countries, Europe and the US, gives a boost to the confidence in growth and stability of markets. Confidence in technology development as a key instrument in competing on the growing international markets is high.

But the Rijnmond is in two minds about the future. Opportunities abound, with growing trade and growing markets, but the position of the Rijnmond is uncertain. Attracting new players to the area, with its emphasis on large-scale oil-based refining and petrochemical industry, could be difficult. There is a lack of convergence on one or two new energy technologies. Because this introduces a strong element of chance in choosing a strategy for the Port Management, it is more difficult to align stakeholders.

Strategic objective of the public site management in FENCELESS EUROPE
Strategy focuses on shifting (part of) the activities towards greener production by attracting new players. Reassess the existing strength of high integration leads to a dual strategy: a medium term strategy based on exploiting the current position and a long-term strategy focusing on becoming a biochemical megasite.

7.3 Storyline

Bio fuels in trouble
The "greening" option, which seems to match the assets of the Rijnmond so well, is large-scale thermo chemical biomass conversion. It matches the current activities in scale, it fully uses the transport infrastructure and seems to fit in with the close ties between petrochemical and refinery industry, which characterises the current situation. However, in FENCELESS EUROPE large-scale bio fuels production by thermo chemical routes from biomass (e.g. gasification followed by Fischer-Tropsch) is not seen as the solution. Low oil prices make it impossible for these bio fuels to compete with gasoline and diesel directly. Lower ambitions in the EU directive on bio fuels reflect this. Although gas-to-liquids fuels are used on a large scale to enhance the properties of the gasoline and diesel (including a fraction produced from biomass), the cost of dedicated biomass feedstock inhibits major penetration of biomass syngas based GTL fuels. For the longer term using the lignin side streams from bio refineries as feedstock could lead to a different perspective. But going directly to this type of megasite seems unrealistic.

Low added value for the new fuels
The diversity in FENCELESS EUROPE does not correspond well with a large-scale conversion to hydrogen as a fuel: the infrastructure for hydrogen is very sensitive to economies-of-scale. On the other hand, the propositions of electric vehicles using fuel cells (e.g. clean and silent vehicles) as well as distributed generation with micro-CHP systems matches the consumer demand for high-value durable goods. Combination of moderate fossil fuel prices with CO_2 storage capacity makes the option of exporting hydrogen from the Rijnmond area for transport attractive.
Prices of gasoline and diesel remain low, but there are drivers for other fuels:

- An effective CO_2 tax stimulates the use of **natural gas** for transportation.
- **Hydrogen** introduction is based on rapid development of fuel cell technology. Introduction is accelerated because fuel cells are not only developed for the transport market but also for a variety of other markets including residential combined heat and power systems.
- Growth in the use of **ethanol** as transportation fuel is based on advances in production technology.

Characteristic for these fuels is that the added value in the Rijnmond is low: for natural gas and ethanol the role of the Rijnmond is only transhipping (although for ethanol this could change in the longer term). And although production of hydrogen adds more value, the margins are not comparable to refining oil. Furthermore, as the demand for gasoline and diesel decreases, availability of refinery products for the petrochemical industry becomes less.

CO_2 capture and sequestration
One asset the Rijnmond is able to play out full in this scenario is CO_2 storage. The availability of concentrated CO_2 flows from industry, an effective emission trading system and the low fossil fuel prices combine to increase competitiveness of the businesses operating in the Rijnmond area. The site management takes an active role in this area. It brings together a consortium which carries out a demonstration project, operates a pipeline for transporting CO_2 from the Rijnmond to an oil field in the North Sea for enhanced oil recovery (EOR) and actively works with the Dutch government and the EU to create the regulatory framework. As most

technology for carbon capture and sequestration is off-the-shelf technology, CO_2 storage takes off rapidly. Technological innovation leads to more efficient and economic methods for separation of CO_2.

The long-term strategy for bio refineries
The most important assets in that strategy outside of the Rijnmond are the feed and food industry in the Netherlands and the knowledge, which is concentrated in the agricultural sector, and the Wageningen University. The site management formulates a strategy focussing on attracting companies, which can add value to the secondary streams from food and agriculture. Using the knowledge in the area of logistics and markets it strives to become an intermediate between the food and feed industry and agriculture on one side and the chemical industry on the other side.

Demand for products with new functionalities (for example biodegradable) or for diversity in products (new fibres for clothing) stimulates processing routes, which can deliver more on-demand products. The starting position is very favourable for the Netherlands, with the Wageningen University and the knowledge intensive agriculture sector. Because of the scale (relatively small) and the specific knowledge required, biochemistry is an area, which flourishes in this scenario, but not necessarily in the Rijnmond. Key to concentrating these activities in the Rijnmond is the development of bio refineries, which are able to process each part of the biomass and produce a range of products. For this type of biomass processing the co-sitting strategy, which is so successful in the Rijnmond area, can be fully utilised.

7.4 Innovation

The R&D strategy reflects the duality of the scenario. On one hand the low fossil fuel prices enable continuation of the current refinery and petrochemical activities, albeit with a stronger emphasis on reducing green house gas emissions. Capturing CO_2 and sequestrating the captured CO_2 in empty fields below the North Sea enables the current players in the Rijnmond to continue there current activities. Research by these companies is directed towards less carbon intensive routes from oil and gas to “traditional” plastic and fibres.

On the other hand, attracting new players to the Rijnmond requires development of new technologies, which enable the conversion of biomass (waste streams as well as dedicated crops) to valuable products. The bio refinery route requires development of new crops, which have been optimised towards yield of specific components, fractionation technologies (separation) and development of biochemical conversion processes.

8. Discussion and conclusions

8.1 Results from the four scenarios

The four scenarios developed by ECN (Bruggink, 2005) have been used to assess the impact on the Rijnmond area of different global developments.

FOSSIL TRADE
Of the 4 scenario's, FOSSIL TRADE for the Rijnmond corresponds most with a "business-as-usual" scenario. It is a difficult scenario for the Dutch government in the sense that it is difficult to influence the direction of developments. The companies operating in the Rijnmond are operating in a very competitive and open global economy. Aligning their interest with that of the Rijnmond region is challenging.

The technologies which are necessary in this scenario to reduce energy consumption and increase the competitive advantages of the industry located in the Rijnmond, correspond largely with the subjects emphasized today in the Dutch long-term energy research policy: advanced technologies separation and thermal integration (heat pumps, heat storage).

It seems unlikely that the Rijnmond will succeed in attracting large structural investments in new production capacity in the current global economy. But the need to withstand increasing competition with the Far East makes it necessary to achieve structural changes. Reducing cost by offering flexibility in process integration through chain management and new technologies is important in this scenario. Novel reactor processes and concepts appear to be essential.

FIREWALLED EUROPE
The bleakest scenario is FIREWALLED EUROPE. The forced reliance on domestic fuels and resources leads to a large influence of the national government and (above all) of the EU on the processes in the Rijnmond. The dominant transition is one from oil to coal. Although the Rijnmond will have to compete mainly with other European sites (above all those with an easy access to coal), the change is from one inherently large-scale technology to another (from a petrochemical to a carbochemical complex). However, even if the transition from oil to coal is successful, much effort is going into doing the same things with coal. The scenario does not offer many opportunities for (sustainable) growth in the Rijnmond.

SUSTAINABLE TRADE
In contrast the SUSTAINABLE TRADE scenario, combining "sense-of-opportunity" and "sense-of-urgency", does offer many opportunities for the Rijnmond area to evolve in new (more sustainable) directions. Building from its current strength in logistics, the Rotterdam port has the potential to compensate its diminishing importance as an oil port by diversifying to other energy carriers, which can range from importing raw biomass from the Baltic states to becoming the transfer port for imported green energy carriers like methanol and ethanol.

In the long-term the Rijnmond will not be able to compete with processing to added-value products in the region of origin if the biomass is converted in the Rijnmond into (relatively) low-value products like electricity and heat (and to a lesser degree syngas). Development of bio refinery concepts, which focus on extracting valuable products in a series of steps, will be necessary. New platform chemicals, based on the complex C5 and C6 molecules available in biomass material, play a key role. This means developing a range of specific technologies (engineering of crops, fractionation, biochemical reactors and separations), using the existing expertise in agriculture and (food) processing.

FENCELESS EUROPE
There is a strong duality in the Rijnmond in the FENCELESS EUROPE scenario. On one hand the relative slow increase in oil prices enables continuation of the current refining and petrochemical activities. Making use of the available resources in the form of locations for potential CO_2 sequestration close to the Rijnmond, a successful international climate policy could even increase the competitiveness of the current industries.

However, growth is expected above all in other sectors. Other transportation fuels are emerging and new technologies are leading to greener feedstocks and new intermediates in the chemical industry. Although the presence of a strong agriculture and food sector are clear assets, the transition from a petrochemical to a biochemical complex is difficult to achieve. It is not clear what needs to be done to attract the new players to the Rijnmond.

8.2 Core and peripheral processes

The technologies selected within the Dutch EOS R&D program for the industry align well with the technologies in the FOSSIL TRADE scenario. This is logical if we consider this as the business-as-usual scenario for the Rijnmond. Comparing this scenario with the other scenarios, it becomes evident that different technologies are appropriate for the specific scenarios. In general the scenarios show different outcomes with respect to:

- The comparative advantages of the Rijnmond area.
- The technological innovations, which would enable a successful transition.
- Instruments available to the government to influence the general direction in which the Rijnmond develops.

In three of the 4 scenarios, the role of oil in the petrochemical industry becomes less dominant. In FIREWALLED EUROPE and SUSTAINABLE TRADE the availability of oil decreases, necessitating a shift in primary feedstocks. In FENCELESS EUROPE realisation of a comprehensive international climate policy and new emerging technologies lead to a decreasing importance of oil based transportation fuels.

A key outcome of the scenarios is the wide range of technologies, which are important in the different scenarios, illustrating the necessity to take into account different possible futures in developing R&D strategies[17]. In particular the emergence of different feedstocks (for example coal, biomass, natural gas) leads to a range of feedstock specific technologies.

The link between the production of transportation fuels and the chemical industry is very strong in the current situation. In all scenarios, except FOSSIL TRADE, these ties become less pronounced, with varying consequences for the chemical industry. But other primary feedstocks and other intermediates imply change in the core technologies of the (petro-) chemical industry. These change are not limited to replacing one intermediate by another: the changes are more structural. The two main possible structural developments, a greater reliance on syngas technology (building longer chains from short molecules) and use of biomass derived platform chemicals, require a new type of chemistry.

In general, technologies, which focus on improving efficiency without changing the core processes, are more robust because they are more generic. New technologies for separation technologies and heat integration are useful in all of the scenarios. However, the large-scale conversion of the Rijnmond site from a petrochemical to a (largely) biochemical cluster (which is the direction in which both FENCELESS TRADE or SUSTAINABLE TRADE develop in the longer term) could completely change the thermal balance of the cluster (and threaten

[17] Reasoning backwards, i.e. from technologies which are seen as essential, scenarios can be used to *make explicit the assumptions* about the future which are often implicit in adoption of a specific strategy or technology

return-on-investment on heat networks), because less heat is produced and low temperature waste heat can be utilized for fermentation and other bioprocesses.

8.3 What innovations do we need?

Critical and robust innovations
Considering which technologies are likely to evolve in most scenarios allows us to assess which are the robust innovations. Developing these technologies is attractive because it minimises the risk that developed technologies will not be implemented because of a lack of drivers. On the other hand, funding a technology that is relevant only in one scenario could be of interest, if it is critical to achieving higher sustainability in this scenario.

It is interesting to consider innovation in the light of two different strategic approaches: hedging and shaping.

- A *hedging* strategy is a largely defensive strategy aimed at containing risks. In terms of the Rijnmond, it focuses largely on holding on to the current players and activities.
- A shaping strategy puts emphasis on realizing the opportunities, which translates to new activities and new players.

Although hedging is dominant in the FIREWALLED and FOSSIL TRADE scenarios and the other two scenarios rely more on shaping strategies (Bruggink, 2005), all four scenarios contain elements of both strategies.

FOSSIL TRADE
Hedging:
- Attracting businesses and holding on to existing businesses by reducing up-front cost through integration, e.g. by heat transformation and storage technologies.

Shaping:
- Lowering cost of incremental investments by developing technologies with a less pronounced economy-of-scale (membrane separation, process intensified reactors).
- Developing novel, more direct, process routes from primary feedstocks to end products.
- New coal liquefaction technology.

FIREWALLED EUROPE
Hedging:
- Developing a syngas infrastructure to supply current users of natural gas (e.g. ammonia industry) with coal based syngas and develops appropriate process technology for syngas conversions (purification, methanisation, etc.).
- Attracting businesses and holding on to existing businesses by reducing up-front cost through integration: heat transformation and storage technologies.

Shaping:
- Development of new C1-routes to enable a shift to a more syngas based chemistry.
- Biomass fractionation & enzymatic hydrolysis of cellulosic material to simple sugars.

SUSTAINABLE TRADE
Hedging:
- Developing a syngas infrastructure to supply current users of natural gas (e.g. ammonia industry) with biomass based syngas and develops appropriate process technology for syngas conversions (purification, methanisation, etc.).
- Reducing energy cost by offering opportunities for heat integration.

Shaping:
- Development of new C1-routes to enable a shift to a more syngas based chemistry.
- Biomass fractionation & enzymatic hydrolysis of cellulosic material to simple sugars.

- Develop routes to intermediates using functionalised, biomass based materials.

FENCELESS EUROPE
Hedging:
- Developing a infrastructure to transport and sequester concentrated CO_2 flows from the Rijnmond.

Shaping:
- Development of new C1-routes to enable a shift to a more syngas based chemistry.
- Biomass fractionation & enzymatic hydrolysis of cellulosic material to simple sugars.
- Develop routes to intermediates using functionalised, biomass based materials.

8.4 Conclusions

8.4.1 General conclusions on the future of the Rijnmond

The Rijnmond area may look very different in 30 years from now. Key words are urgency, uncertainty and diversity.
- The two main drivers, which have lead to the leading position of the Rijnmond area, are the relatively low cost at which oil is available in the Rijnmond and the importance of the European market. The awareness that these drivers could rapidly change leads to a sense of *urgency.*
- But the world around us could develop in many different directions. The effect of the development of oil prices and the success (or lack of success) in developing international climate policy has been used as the principle axis to design scenarios for the Rijnmond. The very different outcomes for the Rijnmond in the different scenarios characterise the large *uncertainty*, which surrounds the future of the Rijnmond.
- Technology can play an important role in adapting to the changing world. One of the objectives of the scenario-work is to consider how different the technological needs are in different scenarios. The study shows that there is a large number of different technologies which could become appropriate. The *diversity* in possible activities in the future Rijnmond makes it more complicated to select transition paths.

8.4.2 Conclusions concerning transition paths and technologies

- We find that the more robust technologies are the more peripheral innovations (separation technology, process integration).
- Core technological innovations (different process routes, new reactor concepts), are more specific to certain scenarios. But they are critical to achieving a more sustainable strategy in the scenarios with moderate increases of oil prices.
- The need for novel conversion technologies appears to be driven mainly by changes in feedstock. Changes in feedstock also imply a weaker link between the refinery sector and the chemical industry.
- Within each of the scenarios, two different strategies could be followed: hedging (defensive) and shaping (pro-active). Interestingly, they require different technologies. Defining one's strategy is an integral part of the selections of technologies for further development.
- Innovations in conversion technologies (leading to other feedstocks and intermediates), are essential within "shaping" strategies.

References

ACS (2001): *New Process Chemistry - Technology Roadmap*. American Chemical SocietyACS.

Alsema, E.A. (2001): *ICARUS-4. Sector study for the refineries*.

Brouwer, G., H. Diepenmaat & B. van der Ven (2002): *Op weg naar een Duurzaam Rijnmond*, Min. van Economische Zaken (EZ).

Bruggink, J.J.C. (2005): *The Next 50 years: Four European energy futures*. ECN, Petten, The Netherlands.

CBIT (2004): *Louisiana petrochemical megasite study - part 1: A review of existing megasites and an identification of factors contributing to succes and failure*. Center for business and information technologies, University of Lafayette, Louisiana, USA.

CBS (2005): *www.statline.cbs.nl (accessed 08-2005)*.

Douglas, J.M. (1988): *Conceptual Design of Chemical Processes*. McGraw-Hill, New York.

Gielen, D.J., D. Vos & A.W.N. van Dril (1996): *The petrochemical industry and its energy use. Prospects for the Dutch energy intensive industry*. Netherlands Energy Research Foundation (ECN), Petten (Netherlands), ECN-C--96-029.

Klipstein, D.H. & S. Robinson (2001): *Vision 2020: Reaction Engineering Roadmap*, the Center for Waste Reduction Technologies of the AIChE.

Korevaar, G. (2004): *Sustainable chemical processes and products - New Design Methodology and Design Tools*, Technical University Delft, ISBN 90 5972 021 0.

Neelis, M., P.W. Bach, M. Patel & K. Blok (2004): *Analysis of energy use and carbon losses in the chemical industry*.

Port of Rotterdam (2003): *Facts and figures on Rotterdam's oil and chemical industry*.

Port of Rotterdam (2005): *http://www.portofrotterdam.com/abouttheport/UK/Statistics/*.

Roller, E. ter, P. van Duivendijk, I. Laumans, R. Coster & I. van Honschooten (2004): *Goed, Beter, Best*. VNCI/Cap Gemini.

SenterNovem (2004): *Lange termijn EOS onderzoeksprogramma's*.

Smith, R. (2005) *Chemical Process Design,* McGraw-Hill, New York.

Soest, J.P. (2005): *Rijnmondse Routes*, Strategisch Platform R3, ROM-Rijnmond, Rotterdam.

Soest, J.P. van, G. Brouwer, H. Diepenmaat, C. Jordan & A. van der Weiden (2003): *To C or not to C, that's the question.* ROM Rijnmond R3, BOR03.067A.

Spoelstra, S. (2005): *Nederlandse en industriële energiehuishouding*. ECN-I--05-004.

Vrom-raad/AER (2004): *Energietransitie: klimaat voor nieuwe kansen (samenvatting en bijlagen)*. ISBN 90-8513-012-3.

Abreviations

BRIC = BRasil, India, China
HIC = Harbour industrial complex
RMPM = Rotterdam Municipal Port Managment
VNCI = Dutch chemical industry federation (Verenigde Nederlandse Chemische Industrie)