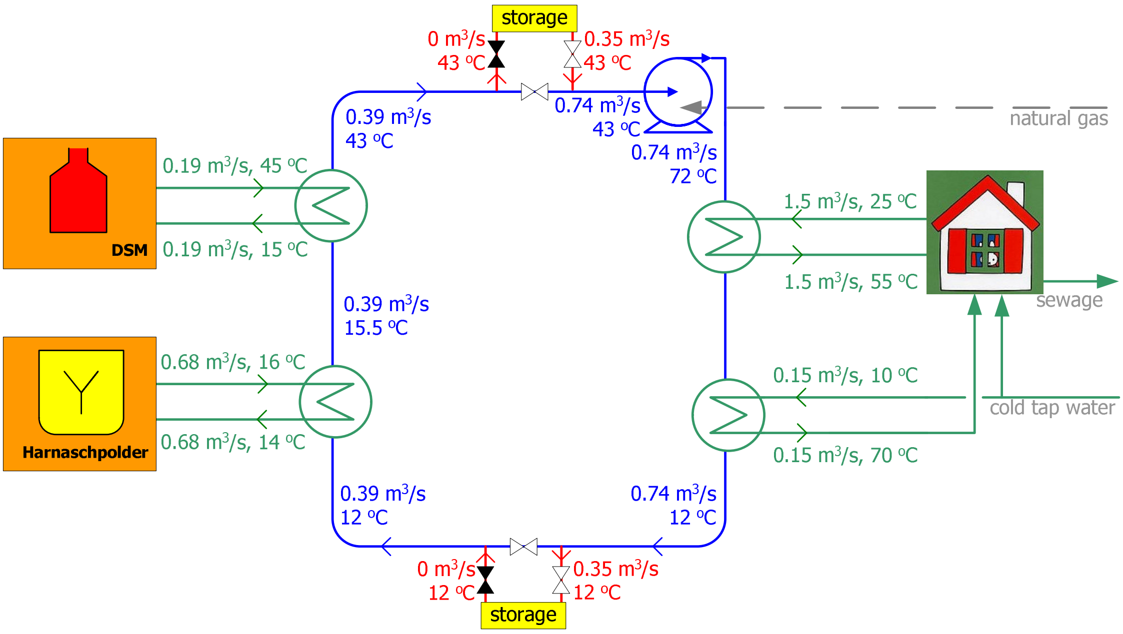
Utilization of waste energy for residential heating in Delft

Conceptual design for a city heating system



EWI 01
E.J.L. Chappin, 1101870
A.M. Klompenhouwer, 1109170
W.L. Oosterwijk, 1049224
E.M. Schapers, 1105663

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Foreword

This report describes the results of the second part of the design of a city heating system in Delft with the use of waste heat. In the first part we worked towards a Basis of Design, which consists of a list of requirements and a first sketch of the system. In this phase we further developed the design. This report provides a conceptual technical and organizational design for the city heating system in Delft and also a design for how to go about in the decision making process, including the covenants necessary for realizing this technical and institutional design. The conceptual design can be used as a starting point or visualization of the project in the decision making process.

We would like to thank our supervisors, M. Houwing, J. Koppenjan, J. Groenewegen and P. Jacobs for their time and suggestions. We would also like to thank P. Rommens from Delft municipality for his contribution and G. van Toledo for the useful information and expertise.

Executive Summary

After the ratification of the Kyoto protocol in 2002 the Dutch government has developed incentives to reduce greenhouse gas emissions. Based on these policies the municipality of Delft has formed its own policy concerning the reduction of greenhouse gas emissions within their municipality and is therefore exploring the possibilities of sustainable city heating systems.

The research question of this project was:
Which energy system can the municipality of Delft best apply for city heating with waste heat, taking into account the interests of Delft and of the stakeholders that Delft is critically dependent of, i.e. the heat suppliers, the housing corporations and the future network operator?

The deliverable of this report is the design of the complete city heating system combining as many sinks as possible with many sources. This design is represented in three design domains: the technical, institutional and process domain. Delft municipality can use the technical and institutional design as a starting point for the negotiation process with the stakeholders. This negotiation process is also a deliverable of this project and is called the process design. It is presented as a start-up covenant, which contains and specifies the start-up agreements necessary for realizing the district heating system. The framework or layout of the decision making process is thus designed.

The parties involved are Delft municipality, DSM, Delfluent, heat suppliers from the Botlek area, Eneco, the housing corporations Vidomes, Woonbron and Duwo, residents, Platform Warmtetarieven and emergency suppliers.

Based on the requirements defined earlier in this project, concrete agreements on technical and institutional issues are made in eight rounds of decision making. The following rounds are defined. 1. Analysis; 2. General layout of the system; 3 Property rights, transactions and technical layout; 4. Emergency and initial supply; 5. Resident participation; 6. Specification of the design 7. Evaluation and 8. Implementation. Details on these requirements go beyond this executive summary and can be found in Chapter 6.

In addition to a technical, institutional and process design of the city heating system, there are some recommendations we would like to make to Delft municipality. First, we recommend some further testing and elaboration of the technical design, while it may be possible to further optimize the design. If Delft wants to extend the system to include more heat suppliers and more energy sinks, we also recommend to investigate the compatibility of this design with the specifications of the heat suppliers from the Rotterdam Harbour. A sensitivity analysis is recommended. The most relevant performance criteria to take into account in the sensitivity analysis are the costs of the system and the amount CO_2 emissions avoided. A second recommendation is that Delft municipality should monitor emerging opportunities for introducing competition. Competition in generation and retail of heat is not possible at present, because there is no market price for heat (it is currently considered waste). If scarcity increases, competition can and should be introduced in the system, because this reflects government regulation with regard to energy policy. Finally, we would like to recommend Delft to keep an open mind during regarding the substantial (technical and institutional) design throughout the decision making process. Although Delft can enter the decision making process with our conceptual design, the design process carried trough with stakeholders may yield some unforeseen opportunities and solutions, that can add to the quality of the design.

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1 Introduction

After the ratification of the Kyoto protocol in 2002 the Dutch government has developed incentives to reduce greenhouse gas emissions. Based on these policies the municipality of Delft has formed its own policy concerning the reduction of greenhouse gas emissions within their municipality and is therefore exploring the possibilities of sustainable city heating systems. Delft has outlined its policy for increasing efficiency of energy use in its 3E climate plan (Delft municipality, 2003). The Trias Energetica concept (Ecofys, 2005) defines three ways to achieve this goal: maximize the use of sustainable energy sources, use non-renewable energy sources efficiently and/or minimize energy use. Delft considers a solution to increase the efficiency of the use of non-renewable energy: the use of (industrial) waste heat for city heating. Delft municipality, the problem owner of this design project, is exploring the possibilities for this type of systems. For implementing this opportunity, Delft municipality is dependent on the co-operation of the critical stakeholders: the heat suppliers, the housing associations and the future network operator.

In the previous phase of this project, a Basis of Design was made for this city heating system. A Basis of Design entails a complete list of the requirements for a system. This list can be found in Appendix 1. The four main requirements derived from this list were robustness, compliance to interests of critical stakeholders, total benefits – total costs and contribution to the reduction of CO_2 emissions. Robustness can be defined as the degree to which a system or component can still function in the presence of partial failures or other adverse, invalid, or abnormal conditions (Definition Robustness). Based on these main requirements, the following design alternative was selected: a system that combines as many sinks as possible (residential areas) with as many sources as possible (see Figure 1). For more information about the first phase of this project we refer to the first report of this project (Chappin, et al., 2005). In this second phase the design for the system is further elaborated and detailed.

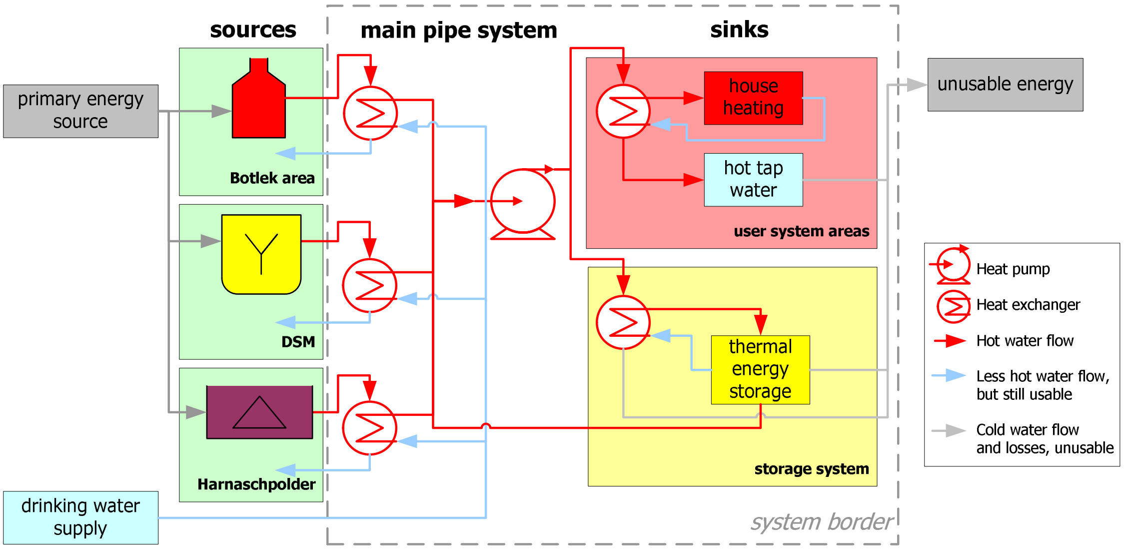

Figure 1. System diagram for city heating system.

1.1 Research question for the design of a city heating system

The research question of this project is:
Which energy system can the municipality of Delft best apply for city heating with waste heat, taking into account the interests of Delft and of the stakeholders that Delft is critically dependent of, i.e. the heat suppliers, the housing corporations and the future network operator?

The term 'best' in the research question cannot be defined uniformly, due to the deviation in perceptions and goals of the stakeholders involved. To be able to answer the research question and to clarify the word 'best', sub-questions are formulated.

- How can the city heating system be designed in such a way that it results in optimal system robustness?
- How can the city heating system be designed in such a way that all critical actors accept it?
- How can the city heating system be designed in such a way that the benefits and costs of the whole system and the separate actors are in balance?
- How can the city heating system be designed in such a way that optimal CO_2 reduction is achieved in the municipality of Delft?

1.2 Demarcation based on design decisions made earlier

In the analysis phase we demarcated this project geographically and in time. Geographically we demarcate our research to the region of Delft. The time demarcation was set at 40 years. First there is a development and implementation time of 15 years (until 2020). The implementation time is divided in three phases of each five years during which new residential areas will be connected to the system. Then there is a system lifetime of 25-35 years (until 2045), depending on when the system was implemented. After 2020 some small neighborhoods will still be connected to the system, but they are very small compared to the rest and will not influence the system significantly. The system will be operational after 2010. To determine dimensions and capacities of the transport system we will work with the final capacity that is expected after 2020.

In the first phase, as said before, we chose the design alternative that includes many sources and sinks in the design. We have chosen to focus only on a city heating for Delft. Other possibilities outside Delft, such as applying heat in greenhouses are not considered yet. A few actors are considered critical and will need to form the centre of the decision making process: housing associations that are active in the districts where the city heating system is to be implemented, housing developers, heat suppliers and distribution network operator. The institutional environment of the system, i.e. the informal and formal rules is assumed to be given and thus not considered a design variable. The solutions chosen for the city heating system in Rom-Rijnmond will serve as an example for this design.

1.3 Deliverables of this report

The deliverable of this report is the design of the complete city heating system combining as many sinks as possible with many sources. This design is represented in three design domains: the technical, institutional and process domain. Delft municipality can use the technical and institutional design as a starting point for the negotiation process with the stakeholders. This negotiation process is also a deliverable of this project and is called the process design.

Technical design choices that have to be made are the suitable placement of and choice for pumps, heat pumps, heat exchangers and pipelines. Another choice regarding the technical design concerns the flexibility of the system: choices are to be made on the storage capacity, reserve capacity (stand-by sources) and the real options: elements that can be connected to the system in a later stage.

Choices for the institutional design include governance structures that have to be applied for the different transactions. This defines relations between actors. Another choice encompasses the distribution of costs and benefits. A last choice to be made concerns the definition of property rights of CO_2 and heat contained in sewage water.

The major decisions that are to be made for the process design are the selection of critical actors (e.g. which heat supplier, which energy company), the division of the CO_2 credits (since this functions as a very important way of compensation), the choice for a process manager, the choice for the experts, the construction of a time-path, the choice of steps, the deliverables for each step and the exit- and entry moments and conditions. These choices should be made after technical and institutional choices are clear, because only then do we have an overview of the decisions to be made and of the outcome of these decisions.

The design choices of the different domains are represented separately for reasons of clarity and convenience. However, trade-offs and dependencies exist for design choices within and between domains. That is why our design process was iterative. Only the results of this iterative process are represented in this report.

1.4 Methodology and tools used

The design process is based on systems thinking. We did not design a single element, but an entire system that consists of technical elements, institutional elements and decision-making elements related to the design process. In Figure 2, we have illustrated how these elements are related. The substantive design will cover the technical as well as the institutional aspects of the system. Furthermore, because the design is executed in a multi-actor context, the decision making process will also be designed.

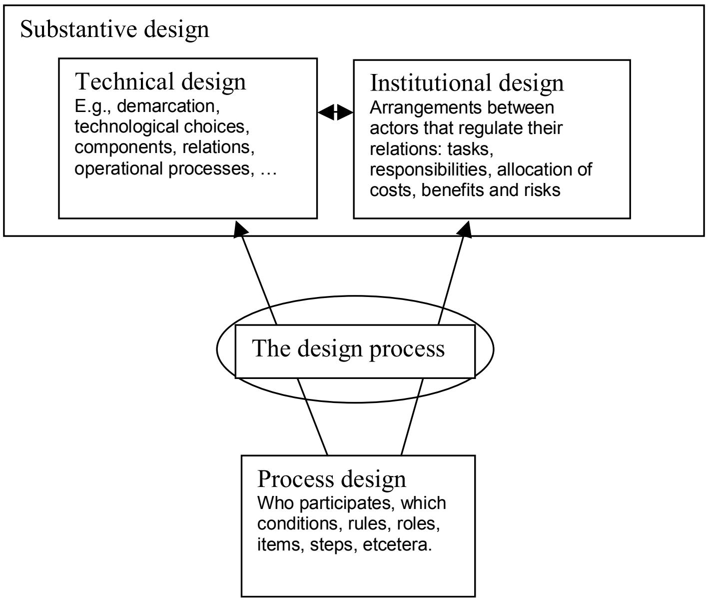

Figure 2. Elements of a multi-actor systems design (Koppenjan and Groenewegen, 2004).

The meta model as developed by Westerberg et al. (1997) (Figure 3) is a model that can be applied when designing a multi-actor system. Because it is designed at a general level, it allows the designer to choose which specific tools and models are applied to different stages and aspects in the design. We will provide a description of the specific tools used in the appropriate chapters. In this report, we will cover the grey part of the meta model. We first design a system and then develop and execute tests to come to the final conceptual design and to formulate recommendations for improvement of the conceptual system.

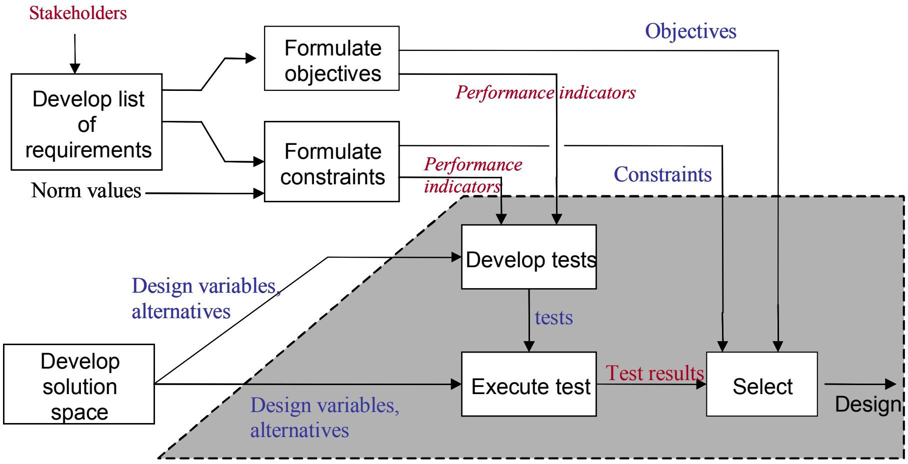

Figure 3. Metamodel (Westerberg et al., 1997).

1.5 Structure

This report is structured as follows. We start in Chapter 2 with the start up agreement or covenant containing the agreements that are necessary to make in the first phase of the design process. In Chapter 3 a description of the conceptual design of the technical and institutional part of the city heating system is given. In Chapter 4 we will provide the specification of the core parts of this design. Chapter 5 encompasses the testing of the system. We will end with a conclusion; a covenant containing all the agreements necessary for this city heating system, and recommendations in Chapter 6.

2 Start-up covenant for the decision making process

In order to accomplish the design and implementation of a district heating system, stakeholders must go through a decision making process, during which decisions are to be made about the technical and institutional design. Delft municipality is initiator of this project and will realize the implementation of the district heating system. For this end, Delft municipality invited the necessary stakeholders. Based on discussions between those stakeholders and the municipality, a start-up covenant is realized. In this chapter, we present this start-up covenant, which contains and specifies the start-up agreements necessary for realizing the district heating system. Our role is the role of process architect; we develop or design a framework for the decision making process. We have defined the agreements based on the stakeholder analysis performed in the first part of this project (see Appendix 2). The agreements are also based on our own design activities. During our efforts to come up with a technical and institutional design, we have uncovered the most important decisions and trade off's to be made.

During the entire process, there are several aspects to be taken into account: speed, substance, openness and protection of core values. De Bruijn et al. (2002) have developed different design guidelines in order to guarantee these four key requirements. Based on these guidelines and aspects some more specified requirements for the design of the process were put forward in the previous phase. These requirements are complemented with some new ones and were kept in mind during the design of the start-up covenant and the other process covenants. The main requirements for the process design are:

1. Critical actors must participate during the whole decision-making process.
2. The process should have low entry and exit barriers.
3. The core values of a future network operator, the housing association, the heat supplier and the developer must be protected. These core values are derived from the stakeholder analysis showed in Appendix 2.
    a. Improvement and maintenance of construction and technical quality and/or the lettability of the buildings for the housing association
    b. Continuity and making profits for a future network operator
    c. Continuity and making profits for the heat supplier
    d. Continuity and making profits for the developers
4. At the beginning of the process a process manager must be selected. The choice for this process manager must be based on consensus within the group of critical actors.
5. Depending on the group of critical actors, experts must be consulted in order to guarantee the substance of the process; the actors must agree upon the choice for these experts.
6. The process must consist of different steps: the process design must explicit the deliverables, actors and roles, rules and structure of each step.
7. A general timeline for the process rounds will be constructed. This timeline has to be agreed upon by the critical actors.

This list is not complete and that is why in Appendix 2 the requirements are further specified per decision making round. A central concern during the decision making process is how trust and learning can be incorporated. In the first part of this report, the creation of trust has been identified as a requirement to the process. Because the design and implementation of a district heating system are new to most of the participants, it is important that participants learn from each other and that they can trust each other. The goal of the start-up covenant is to design a process in which trust is promoted and participants can learn from each other, such that this process can lead to a successful design and implementation of a residential heating system based on industrial waste heat. Before designing the process, we must think of how we can test if the process matches the requirements. Because the quality of the process design cannot be measured objectively, we must resort to other types of testing. A possibility is to rely on expert judgment (see also Chapter 5 on testing).

For the decision making process it is also important for Delft municipality to know how it can convince parties of involvement in the project and where possible difficulties in convincing lie. From the first phase of our project we can derive the following difficulties and ways to convince parties of participation:

Table 1. Perceived difficulties of actors and ways to convince to participate from first phase of our project.

Actor	Perceived difficulties	Ways to convince
Housing associations	Financial issues (additional costs leading to higher rents) Limitation of freedom of choice for supplier	Image improvement Being innovative Compensation with new working areas Improvement of the quality of the buildings
DSM	Decreasing flexibility Increase of costs (due to operational adjustments)	Achievement of CO_2 credits Financial rewards for delivered energy Image improvement
Delfluent	Decreasing flexibility Increase of costs (due to operational adjustments)	Financial rewards for delivered energy
Botlek area	Decreasing flexibility Increase of costs (due to operational adjustments)	Achievement of CO_2 credits Financial rewards for delivered energy Image improvement
Developer	Lack of technical knowledge	Cooperation with the participating energy company Image improvement
Distribution network operator	Additional costs without sufficient benefits	Vertical integration with supply Prospect on making profits

In Appendix 3, we explain the framework for the decision making process. This framework provides the justification of the agreements presented in the start-up covenant We first list the decisions that needed to be made in the design of the decision making process and in the decision-making process itself and we will go into the deliverables of these decisions. Then we identify the actors whose participation is required to make each decision. In order to guarantee speed and substance of the process, we identify catalysts that can be used to motivate actors to participate. Finally, we group the decisions in different phases or decision-making rounds. Within the decision making process, the following design phases are considered relevant: analysis, conceptual design, specification, evaluation and implementation. After designing this process framework we applied it to our project. The results of this application can be found in the covenants represented in this report. The start-up covenant is represented in this chapter. The other agreements necessary are discussed in the chapter on process design, Chapter 7. For making these covenants, we used a covenant made by H. de Bruijn and E. ten Heuvelhof as a guideline (De Bruijn and ten Heuvelhof, 2000).

Start-up covenant for the design of a system for the utilization of waste energy for residential heating in Delft

This paragraph contains a proposal for a start-up covenant. This covenant is structured like a contract that contains the agreements that will shape the rest of the decision making process. An explanation of the covenant and the agreements it contains is presented in Appendix 3.

2.1.1 Advice

E.J.L. Chappin
A.M. Klompenhouwer
W.L. Oosterwijk
E.M. Schapers

We have been asked to propose a decision-making process for the design and construction of a residential heating system based on waste energy in Delft. This proposal is open for discussion with the subscribers of the contract. Subscribers are Delft Municipality, DSM, Delfluent, Eneco, the housing corporations Vidomes, Woonbron and Duwo, SenterNovem and Prof. dr. J.P.M. Groenewegen.

We design a decision making process departing from the following situation:

- The process is aimed at designing a decision making process for the design and construction of a residential heating system based on waste energy in Delft
- Delft has had contacts with DSM and Delfluent, to act as suppliers of heat to this system. Both have expressed interest but no commitment.
- Heat suppliers from the Botlek area could be involved in the project as heat supplier in case of expansion of the project. To commit them to this possible role of heat supplier, they need to be involved in the decision making process.
- Eneco is at risk of loosing clients for gas delivery. They should be compensated for this loss. Moreover, Eneco is the operation of the regional electricity and gas distribution systems in Delft. Therefore, they are involved in the decision-making process.
- Housing corporations own the buildings that are to be restructured and that are candidate sinks for the heating system. Their main interest is to avoid an increase in the rental price and energy costs for households, and to improve the quality and comfort of the buildings.
- SenterNovem is an agency for sustainability and innovation. It is willing to act as an independent expert.
- Prof. dr. J.P.M. Groenewegen is professor of Institutional Economics at TU Delft and is willing to act as an independent expert.
- Considering the new and uncertain nature of the system to be designed, it is important that the decision making process promotes trust and provide opportunities for learning. This must be reflected in the process arrangements.

The parties are of the opinion that:

- It is desirable to discuss the design and construct a residential heating system in Delft
- That a go/ no-go decision should be taken by the critical parties (Delft, Eneco, DSM, Delfluent and the housing corporations).
- The critical parties feel jointly responsible for reaching an agreement about a go/no go decision.

2.1.2 Process manager

Agreement 1.
Process manager for the decision making process is Peter Rommens from Delft municipality, department of Programs and Projects (Programma's en Projecten). He will act independently of the representatives of Delft municipality within the process, i.e. the department of District City Affairs (Wijk- en Stadszaken).

2.1.3 Process rules

Agreement 2.
During the decision making process, parties are allowed to recall decision made earlier if it contributes to the substance and/or progress of the process.

Agreement 3.
Parties are free to enter the decision making process if no party issues a veto. Parties can only exit the process if they can justify their choice to the other parties.

Agreement 4.
All parties are allowed to conduct their own research or to have it conducted. The experts consulted may however not become participants or stakeholders in the process.

Agreement 5.
Parties wish to reach decisions by consensus at all times. If consensus on a particular decision cannot be reached, the decision can be postponed. This may require transformation of the decision into a process agreement.

Agreement 6.
Valuable and proprietary information will be kept inside the process. The ownership of this information remains with the owner, even when this information is shared with others.

Agreement 7.
In case of a conflict, the process manager will try to solve the conflict. If the conflict cannot be solved, arbitration will be sought. The arbiter will be someone who has no interest in the project at all.

Agreement 8.
All responsible parties commit themselves to timely application for subsidies and licenses, and to timely start the required procedures.

2.1.4 Organizational set-up

Agreement 9.
Competition is a legal obligation. Although currently not feasible due to the limited number of suppliers, the participating stakeholders are striving for competition in the future. This has several

implications for the organizational set-up of the transportation company, the distribution company and the general lay-out:

- Whenever there is chosen to let the transportation and management of the transportation network be done by a new company, this company will be given a temporary license, after which competition must be introduced.
- Whenever there is chosen to let the distribution and delivery be done by Eneco, Eneco will be given a temporary license. After expiration of this license, the introduction of competition or a public procurement procedure is obliged.
- The general lay-out of the system will be constructed in such a way that expansion of the system is feasible.

2.1.5 Process structure and organization

Agreement 10.

The process will discuss the design and implementation process for a district heating system based on waste heat in Delft. This is split up in 8 rounds. Round 1: Analysis. Round 2: General layout of the system. Round 3: Property rights, transactions and technical layout. Round 4: Emergency and initial supply. Round 5: Resident participation after announcement by letters to residents in the areas to be restructured. Round 6: Specification of the design. Round 7. Evaluation. Round 8. Implementation. Within each round, participants may propose modifications of the agenda of that round. The modification is accepted or denied according to agreement 5.

Agreement 11.

Participants in the different rounds are as represented in Table 2. This table can be updated according to agreements 2 and 3. The table shows only stakeholder-participants in the process. Other, independent participants, such as the process manager and experts, are not represented in this table.

Table 2. Rounds, participants and their roles.

Round	Stakeholder	Roles
1	Delft municipality	Problem owner
	DSM, Delfluent	Heat supplier
	Eneco	Energy company
	Housing corporations Vidomes, Woonbron and Duwo	Housing corporation
2	Delft municipality	Problem owner
	DSM, Delfluent	Heat supplier
	Eneco	Energy company
	Housing corporations Vidomes, Woonbron and Duwo	Housing corporation
	heat suppliers from the Botlek area	Possible future heat supplier
3	Delft municipality	Problem owner and member of the heat company
	DSM, Delfluent	Heat supplier and member of the heat company
	Eneco	Heat distributor, distribution network operator and member of the heat company
	housing corporations Vidomes, Woonbron and Duwo	Housing corporation and member of the heat company
	Selected building contractor for infrastructure	Building contractor and member of the heat company
	Heat suppliers from the Botlek area	Possible future heat supplier and possibly also member of the heat company
	Platform Warmtetarieven	Household representatives

	EZ, VROM	Ministries with authority to adjust emission plans and to adjust or lobby for adjustment of laws and regulations
4	Delft municipality	Problem owner and member of the heat company
	DSM, Delfluent	Member of the heat company
	Eneco	Heat distributor, distribution network operator and member of the heat company
	housing corporations Vidomes, Woonbron and Duwo	Member of the heat company
	Selected building contractor for infrastructure	Member of the heat company
	Emergency suppliers TU Delft, Greenhouses Westland	Emergency suppliers
	heat suppliers from the Botlek area if they decide to become members of the heat company	Member of the heat company
5	Delft municipality	Problem owner
	Eneco	Heat distributor, distribution network operator
	Housing corporations Vidomes, Woonbron and Duwo	Housing corporation
	Residents who responded to the letter	Voluntary representatives of residents
6	Delft municipality	Problem owner and member of the heat company
	DSM, Delfluent	Heat supplier and member of the heat company
	Eneco	Heat distributor, distribution network operator and member of the heat company
	Housing corporations Vidomes, Woonbron and Duwo	Housing corporation and member of the heat company
	Selected building contractor for infrastructure	Building contractor and member of the heat company
	Heat suppliers from the Botlek area if they decide to become members of the heat company	Member of the heat company
	Platform Warmtetarieven	Household representatives
7	Delft municipality	Problem owner and member of the heat company
	DSM, Delfluent	Heat supplier and member of the heat company
	Eneco	Heat distributor, distribution network operator and member of the heat company
	Housing corporations Vidomes, Woonbron and Duwo	Housing corporation and member of the heat company
	Selected building contractor for infrastructure	Building contractor and member of the heat company
	Heat suppliers from the Botlek area if they decide to become members of the heat company	Member of the heat company
8	Delft municipality	Problem owner and member of the heat company
	DSM, Delfluent	Heat supplier and member of the heat company
	Eneco	Heat distributor, distribution network operator and member of the heat company
	Housing corporations Vidomes, Woonbron and Duwo	Housing corporation and member of the heat company
	Selected building contractor for infrastructure	Building contractor and member of the heat company

	Heat suppliers from the Botlek area if they decide to become members of the heat company	Member of the heat company
	Selected building contractor for in-house equipment	Building contractor

Agreement 12.
The decision making process starts up in September 2005. For each round and the tendering procedure for the building contractor the time periods are arranged. These time periods are presented in Table 3 and are indicative, because using strict deadlines during the process can contribute to strategic behaviour and endanger the substantive quality of the design. The covenant for the utilization of waste energy for residential heating in Delft should be finished by February 2008.

Table 3. Time periods per round.

Round	Time period
Round 1	3 months
Round 2	4 months
Tendering procedure building contractor	6 months
Round 3	8 months
Round 4	3 months
Round 5	2 weeks
Round 6	3 months
Round 7	1 months
Round 8	2 weeks

Agreement 13.
Administrative decisions are made by the directors of members of the heat company. They will form the ‘steer group’. Operational decisions are made by the actors mentioned in table 1 together with other employees of the companies participating in the steer group. They will form the ‘workgroup’. This workgroup can be split up in project groups if necessary for a fluid decision making process. Persistent conflicts in the steer group can be solved by arbitration. However most of these conflicts should be solved in the workgroup, as they prepare the decisions for the steer group.

2.1.6 Evaluation

Agreement 14.
Evaluation of the design of the city heating system will be executed as follows: SenterNovem will verify and validate the technical design as independent expert. Prof. dr. J.P.M. Groenewegen, Professor of Institutional Economics at TU Delft, will verify and validate the institutional design as independent expert. Based on the judgment of these experts, or of additional experts put forward during the process according to agreement 4, Delft municipality, DSM, Delfluent, Eneco, the housing corporations Vidomes, Woonbron and Duwo and a building contractor will take a go/no-go decision for implementation of the design.

3 Conceptual design of the city heating system

To come to a conceptual design of the city heating system for Delft municipality we have made several major and minor design choices. These choices are based on the conclusions of part 1, on the description of the design space of a city heating system for Delft municipality (see part 1) and on best practices, in particular on the case of Rom-Rijnmond. During the design process we have kept in mind the principles of good architecture of Klir and Elias, which are; consistency, orthogonality (independent functions specified separately), propriety (no unnecessary functions), parsimony (no repeating of functions in different forms), transparency, generality (a function can be used for as many purposes as possible), open-endedness (functions can be used in other ways than designed) and completeness (max satisfaction of requirements) (Klir, 2003). We think that these principles are not only useful for architecture but also for the design of a complex socio-technical system such as this city heating system, because they prevent making mistakes. We will come back to these principles when testing the system.

In this chapter we will give an overview of the most important choices that shape the conceptual design and the reasoning behind the choices. To represent these choices in a clear way, we have divided the conceptual design into two different topics: the technical design choices and the institutional design choices. These topics are then divided again in the design choices for the core elements and in the design choices for the non-core elements of the design. The choices made in the design of the core elements affect the main stakeholders directly. They are also of vital importance to the start-up phase and the performance of the system. The non-core design choices are the choices for which the performance of the system is less sensitive. These choices are thus of less importance and fall outside the scope of this design. For reasons of completeness an initial choice for these non-core elements has been made in such a way that a complete view of the conceptual design can be given. The specification of the core elements of the design will be discussed in Chapter 4.

3.1 Technical conceptual design: design choices for the city heating system

3.1.1 Core design choices for the city heating system

Sources and sinks

The first major design choice that forms the start of the rest of the system is the choice to design a system that only connects the sources and sinks in and around Delft. This means that in our design we prefer to use the heat sources AWZI Harnaschpolder and DSM instead of the heat from the industry around the Rotterdam harbour. The first main reason for doing this is that the two sources in Delft provide enough heat to serve the residential areas that will be reconstructed around Delft until 2020 (Oosterwijk, 2005). This is proven with a back-of-the-envelope calculation in Appendix 4. Thus, when looking at the coming 15 years, the heat from Rotterdam is not necessary. Second, less energy is lost during transport (due to the shorter distance). In the last place the investments needed to construct the pipelines will be much smaller. If, for reasons of security of supply or an increase in demand a connection to Rotterdam harbour area is needed, the initial design can be extended.

To increase the viability of the system the heat should be supplied to as many residential areas as possible, as explained in the conclusion of the first report of this project (Chappin et al., 2005). However when looking at the map of Delft (see Figure 4) there is one residential area that is much further away from the heat sources and that is Wippolder (number 4) and is therefore more expensive to connect to the system. That is why in the first design this area will not be connected to the heating system. Of course the option to connect Wippolder in a later stadium (for example when another round of central heating boiler replacements is necessary) will be kept open.

Table 4. Number of households per residential area (Municipality of Delft).

Sink		Households
1	Harnaschpolder	1,200
2	Spoorzone (incl. Centre)	5,759
3	Poptahof	2,681
(4)	Wippolder	0
5	TU Noord	1,754
6	Voorhof	1,652
7	Buitenhof	5,954
	Total	**19,000**
Source		
F	Harnaschpolder	
G	DSM	

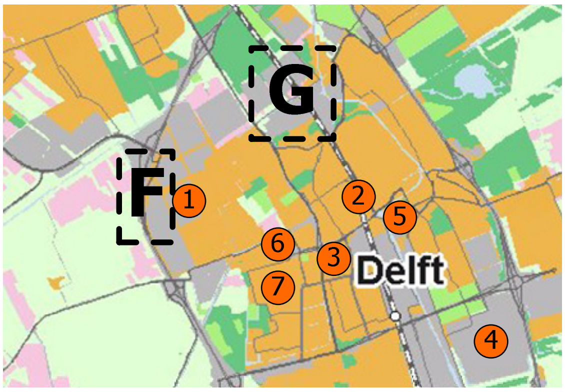

Figure 4. Map with sinks and sources.

Layout of the network

For the final design of the connection between sources and sinks we choose to adopt an indirect heating network. This means that the cool water from the industry is not directly used in the houses, but the heat is exchanged to a second distribution network. (see Figure 5) This is a similar technical configuration as was chosen in the Rijnmond area. Some advantages of such a configuration is that it allows for an unbundled institutional design and that it is modular: new sources and sinks can be added to the network without changing the functioning of the system (Rom-Rijnmond, 2004).

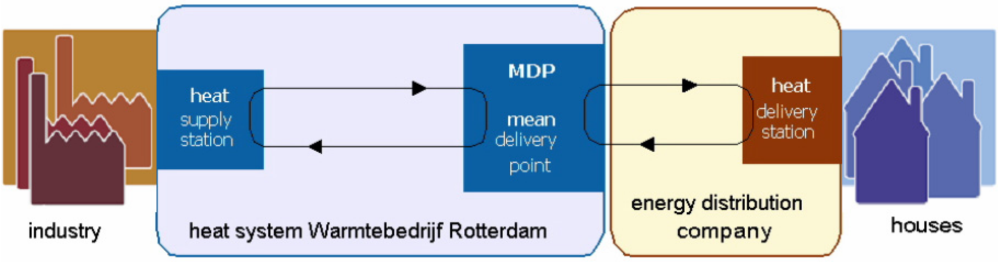

Figure 5. Technical configuration of an indirect district heating system. (ROM-Rijnmond, 2004).

The system has a transport and a distribution component. The transport system holds a water loop, connecting the sources via Heat Supply Stations (HSS) to a Main Delivery Point (MDP). Heat is distributed to the households using a similar water loop. This loop connects the Main Delivery Point to the Heat Delivery Stations (HDS) placed in residential areas.

The placing of the Main Delivery Points and Heat Delivery Stations in Delft should be chosen strategically to ensure that the investments costs of the distribution and transportation system will not be unnecessary high. Looking at Figure 4, one can see a few groups of sinks. Therefore we will place three MDP’s near these groups; one MDP for Harnaschpolder, one MDP for the districts Spoorzone and TU Noord and one for Poptahof, Voorhof and Buitenhof. In a MDP the heat is exchanged and upgraded by heat pumps to the necessary temperatures and there is room for the necessary expansion that occurs in the pipes and possibly for storage of heat. Also water pumps and other operating equipment can be placed here. A Heat Delivery Station can be seen as a small control room and is needed for every 500 houses (SenterNovem, 2005).

Low temperature heating and cooling

In all residences, we choose to install low temperature heating. This has a few advantages compared to radiator heating. Radiators function through radiation and convection of heat. They operate at a temperature of 90°C. Floor and wall heating have a higher share of radiation heating, allowing them to operate at lower temperatures (55°C), which makes them more energy efficient and more comfortable (Novem, 2002). An additional advantage of low temperature heating is that less heat pump capacity is needed. Another advantage is that it can easily be combined with a cooling system. Of course housing corporations are free in their choice to implement other systems, but in this initial design phase we will design for low temperature heating. Next to the heating also cooling is possible with this system. The cool water that is stored in an aquifer can be pumped into the houses to provide the extra service of air-conditioning.

Pipeline network

The transportation network will consist of two ring structures. Both connect the sources to the MDP's, one transporting hot water, the other cold water. The layout of the distribution networks depends on the structure of the residential area, but will probably consists of a combination of a ring and a tree layout: one for hot tap water, one for heating and one for cooling. These double networks are necessary so that every household can individually make the choice to switch between heating and cooling. Only the heating and cooling pipelines will have a return pipeline. The tap water is drained off by the sewer system.

Storage

A storage facility is needed to accommodate variations in supply and demand patterns. Especially heat demand is expected to vary substantially (e.g. between day and night and between summer and winter). The advantage of using heat storage is that it increases the reliability of the system. Failure of one of the heat sources or Heat Supply Stations will not necessarily lead to a shortage of heat supply.

The storage facility that will be used is an aquifer. According to Braak et al. (2001), there are sufficient possibilities for heat storage in aquifers in and around Delft. In order to get a license for underground energy storage from the Province a thorough geohydrological investigation is necessary and the net heat put in the ground (i.e. the energy balance) should be close or equal to zero. That is why hot and cold water is stored in the underground in two separate chambers. The advantage of such a configuration is that the residents connected to the heating system can also be equipped with an environmentally friendly cooling system in summer as an alternative for air conditioning. The same system has been applied in Zuidpoort in Delft (Delft municipality, 2005a).

Water with a high thermal energy content can be stored in an aquifer and the water can later be entered in the transport system. For an aquifer an existing ground layer of sand and gravel is used, mostly at a depth of 30-100 meter. The natural temperature of the groundwater in this layer will be 10-12 °C. By infiltrating warm water a warm water source is created. The water will stay in the ground layer, because in such a deep layer the movement of groundwater is very little. In the winter periods, during peek demand, this warm water can be extracted from the aquifer and used in the heat pump. The heat pump subtracts the heat from the water and after using it for heating houses (called active heating), the water has cooled off until approximately 12 °C. This water can be stored in the cold aquifer and then in the summer be directly used for cooling, without using a heat pump. This is called passive cooling. The heat pump is thus only necessary for heating (Warmtepompen in de glastuinbouw, 2005).

The two storages of the aquifer will be implemented in proximity to one of the MDP's. We will use one aquifer for the complete system. The heat and cold to be stored comes from the transportation system; the going pipeline supplies heat in the summer and the returning pipeline supplies cold in the winter.

Next to the storage in an aquifer there is also some buffer or storage in the pipelines. This is also used to overcome the fluctuations in demand.

Emergency and backup sources

In our design we also consider sources for emergency or temporary energy supply, for example during the building phase of the areas or in case one of the main industrial sources fails to deliver heat for a period of time. Many existing heat networks have newly constructed emergency heat plants attached to their networks (SenterNovem, 2005). However, for Delft municipality environmental friendliness is very important and therefore we propose to use existing heat power installations for emergency or temporary energy supply (Delft municipality, 2003). Greenhouses for instance are close-by and have heating systems based on industrial waste heat in combination with aquifer storage and could thus be used as backup for storage and supply. Another emergency source could be the TU Delft. This university has its own combined heat and power plant (CHP) and a heating system. In this initial design we choose to opt only for connection to the TU Delft CHP, because this CHP is close to the sink TU Noord, so that the necessary investment in pipelines are not too high. For later phases the option to make agreements with greenhouse owners about connecting their systems to the Delft network is kept open.

3.1.2 Non Core choices for the technical design

The choices explained in this paragraph will not influence the performance of the system as much as the core elements and can be altered easily if necessary.

Heat Pumps

In our design, a decision needs to be made about where heat pumps will be placed. It is economically more favourable to equip the MDP's with one large-capacity heat pump and distribute the heat to the households, rather than equipping hundreds of households with their own pumps. However, it may turn out that too much heat is lost during transportation between the MDP's and the HDS's, harming the energetic efficiency of this solution. Hence, there is a trade-off between costs and energetic efficiency.

Whether there is one heat pump per MDP or multiple placed in series or parallel is not dealt with in this report. For capacity and cost calculations we assume there is one large heat pump, upgrading the temperature of the complete amount of water demanded. In these calculations we assume that the heat pumps are all at an equal distance from the sinks (end consumer). The exact size of each heat pump is therefore not important.

Heat exchangers

The placement of the heat exchangers is at the sources DSM, Harnaschpolder and the backup source TU Delft (3 heat exchangers) and at the MDP's (2 times 3 heat exchangers). This means that 9 heat exchangers will be installed. More information about the operating temperatures of the heat exchangers will be given in the specification (see Chapter 4).

Metering

The usage of the heat, cold and water use will be measured per household, to make individual pricing possible. This can be done with regular water flow meters.

3.2 Institutional conceptual design

The conceptual design is based on the information gathered in the first part of this project. Compared with this result, we have adapted the approach for the institutional design somewhat, to include issues of trust and learning explicitly in the design.

As said in the fist part of this report, we use a four-layer framework for our institutional design. (see Appendix 5). We indicated that we only design the third and fourth level of this framework, i.e. actors and games and governance structures, and take the institutional environment (the first and second level of the framework) as a given. In this conceptual design, we focus on defining the unclear property rights and we suggest governance structures for the most important transactions. Other, more detailed, institutional design choices, such as tariff setting, will be discussed in Chapter 4 (specification).

As was mentioned in the first part of this report, Transaction Cost Economics (TCE), as part of New Institutional Economics (NIE) stream, is used for determining the most efficient governance structures. Although TCE is very useful to this end, some limitations can be identified. First, TCE neglects the notion of trust (Nooteboom, 1996 and 1999a). Trust is an important factor to ensure that partners follow through on a deal and that they will do the best of their ability, even if they are not coerced to do so and have no direct material interest in doing so (Nooteboom, 2000). This is especially relevant for a design such as this, which encompasses many new relationships and transactions. Second, TCE does not include innovation and learning, which is also important for successful design and implementation of this new type of system.

In order to solve these limitations of TCE, Nooteboom introduced the Inter-firm Relations theory that combines the perspective of social exchange theory with elements taken from TCE. Thus, he combines NIE with Original Institutional Economics (OIE). He used this as a basis for the analysis of problems and forms of coordination in inter-firm relations. In his theory the focus is on the narrow definition of intentional trust. In this narrow definition it is expected that damage will not be caused, even though there is both an opportunity and an incentive for the partner to cause damage (Nooteboom, 2000).

According to Nooteboom (2000) trust is conditioned by:
- relations of friendship
- kinship or clans
- norms and values of decent behaviour
- orientation to voice

Trust can already be present when a relation starts, in the form of previous experiences, reputation, kinship and simultaneous co-operations. During the decision making process and the period after that trust is expected to be conditioned by norms and values of decent behaviour and maybe later also by relations of friendship. This trust should be retained over time by avoiding opportunistic behaviour. According to Axelrod in Nooteboom (2000) the rational decision to turn to opportunistic behaviour is based on a trade-off between advantage now and loss of value from an ongoing relation in the future. During the decision making process parties will come across these kind of trade offs. Renunciation of opportunities for opportunism will enhance trust.

Since trust and learning are important in this kind of project, we will use these concepts as a criterion for our institutional (and process) design, alongside with TCE. Whenever TCE indicates several options for efficient coordination of transactions, trust and learning will be decisive.

3.2.1 Institutional design; core choices

Property rights

Before describing interactions, it is necessary to define property rights. During a real-life design process, this definition would occur as a result of negotiations of the actors involved, leading to win-win package deals. In the first part of this project, we defined three sets of property rights that are not clearly defined at present: the property rights for CO_2 credits and the property rights of heat and cold. The property rights for infrastructure and appliances are unambiguous and are not discussed in this paragraph. For the ease of reading, we here refer to the company responsible for transportation and management as the heat company.

In 2008, DSM and AWZI Harnaschpolder will be bound to a cap system for CO_2 emissions. The size of this cap is based, amongst other factors not discussed here, on the amount of product produced at the facilities. Introduction of the heating system does not alter produced amounts for both facilities. However, the system will lead to a reduction in CO_2 emission through reduced demand for fossil fuels for heating. The amounts of CO_2 emissions avoided therefore depend on the technical design.

The property rights for CO_2 savings have not been established in law or regulations. Upon introduction of the system, households will consume less energy from fossil fuels. Therefore, if CO_2 emissions trading is implemented, they will pay less for their energy consumption than they would have with a conventional heating system. Consumers therefore benefit from the reduction of CO_2 emissions caused by the system. According to us, the property rights of CO_2 credits belong to the party that enables the reduction of CO_2 emissions. In this case, the heat suppliers form the beginning of the supply chain and with the supply of their waste heat, CO_2 emission reduction is realized. However, the heat company and the consumers also incur costs for the functioning of the city heating system and therefore part of the benefit obtained by the heat suppliers would need to be returned to the heat company and the consumers. We have identified two ways to allocate these credits to the heat suppliers:

1. Heat should be treated as a product (just like electricity). When an industrial company becomes a heat supplier, the cap increases accordingly. This is a long-term solution, but would be best considering that more industrial companies will become heat suppliers with increasing scarcity of fossil fuel.
2. The cap should be increased in the next 5-yearly National Emission Plan (fixed by the Ministries of Economic Affairs and VROM).

Both are beyond the scope defined in this project, because they relate to the second level of institutional design, i.e. formal laws and regulations. We therefore advise Delft municipality to negotiate with the Ministries in order to realize the before-mentioned changes.

Property rights of heat belong to the party who has produced this heat. However, in the case of AWZI Harnaschpolder, the demarcation of who produces the heat is not so obvious. The reason is that the influent of AWZI Harnaschpolder (sewage water) still contains heat, which is produced by households. During the treatment process, heat is added to the water. Therefore, both households and AWZI Harnaschpolder are considered owner of the heat in the effluent. The allocation of these rights should be decided upon during the decision-making process. We assume that a proportional allocation is reasonable, where a part of the value of the heat from AWZI Harnaschpolder belongs to the household and another part to Delfluent. This proportional allocation should be determined by research.

The heat flows in the system depend on the technical design. An important issue is where heat losses occur (i.e. in which parts of the system), who controls these losses and who pays for them. We expect that the majority of losses occur during transport and the related activities of upgrading and storage. Therefore, we suggest that the company who controls these losses, i.e. the heat company, is also made responsible for them through property rights. This suggests that the heat company buys heat from the heat suppliers and sells it to Eneco. The property rights of cold are attributed to the owner of the heat pumps, that produce the cold.

Core transactions

As the name suggests, waste heat from industrial processes is currently considered waste. Since it is not considered a product, there is no market value for heat. In the Netherlands, the market value of heat supplied to households is determined with the '*Niet meer dan anders*' (not more than otherwise) principle.

Although liberalization is legally obliged in the energy sector, there are just a few heat suppliers, who on a medium time-scale are all needed for sufficient supply of heat. Therefore it is not possible to introduce competition on production. That is also why distribution companies (delivery companies) cannot purchase heat according to a market mechanism, resulting in a situation in which they cannot obtain lower prices and there can be no competition between them. Although competition might be possible between these distribution companies on the level of service provision, we suggest not to introduce it in order to convince the present supplier of energy in this region to participate in this project as a deliverer. In the same line of reasoning, it is not necessary that the distribution company buys heat directly from the supplier. On the contrary, as said in the section about property rights, it would be better to control losses, when the heat is bought by the transportation company first, after which it sold to the distribution company.

Because there is no competition for delivery and because the transaction for distribution network capacity has high asset specificity, low frequency and high uncertainty, distribution activities and distribution network operation should be vertically integrated. Delft has different possibilities for the selection of this vertically integrated distribution company. It can choose for a tender every five (or so) years, as is done for regional bus companies. Another option is to choose for a distribution company that is owned by the local governments (like Eneco). We choose the latter for several reasons. The reason is that the service to be delivered is complex and has a critical nature. Interruption or service will not be tolerated. Finally, this had the advantage that the current energy supplier (Eneco) is compensated for the loss of demand for gas.

On the longer term, we expect competition to become possible for delivery and production. This would cause a (financial) split up between delivery and network operation. With increasing pressure to reduce fossil fuel consumption (due to increasing prices for fossil fuels and CO_2 emission trading), the value of 'waste' heat is expected to increase and the interest of industries to become a heat supplier are expected to increase accordingly. Therefore, a market price of heat will be created. In our institutional design, we want to foresee this development. Therefore, we suggest that the distribution company is issued a temporary license for heat and cold delivery. (for 10 years perhaps). After this temporary license, the heat company together with the residents should decide whether competition or a public procurement procedure should be introduced. This decision will be influenced by the level of service Eneco provided during the temporary license. In case a public procurement procedure is chosen, Delft municipality will be responsible for the tendering procedure. Network operation will remain a public activity.

Purchase of network capacity is another core transaction. Infrastructures, such as a heat transport and distribution network, require high investments, with a long payback time. This leads to a situation where it would be inefficient to construct multiple networks. Such a situation is typically referred to as a natural monopoly. Therefore, there will be just one network and thus one network operator. The question is whether the operation of the transport and distribution networks is considered two separate activities. We assume that they are, because this enables a modular design and thus facilitates expansion of the system without reconsidering the institutional design. Moreover, the resulting transaction (purchase of heat and cold) can be efficiently organized with a classical contract (low asset specificity, high frequency and low uncertainty).

A third core transaction is the construction and ownership of the infrastructure. Earlier, we defined the transportation and distribution networks as two separate networks for the purpose of operation. However, for ownership, another choice is made. The design and construction of such a network is characterized by high uncertainty. Moreover, the construction of both parts of the network (transportation network and distribution network) is interconnected and thus interdependent. This would create a need for an expensive transaction because of high uncertainty and few parties. Therefore, a transaction between constructor of the distribution part of the network and the constructor of the transportation part of the network would become very expensive. Moreover, the production costs will be lower if the entire network is constructed by one firm (economies of scale and acquisition of knowledge).

That is why we choose to have the entire network owned by one party, i.e. the heat company. Who will be this heat company? We suggest using a partnership of the main actors (see Appendix 3), both public and private. This PPP should have an open entry structure. In the first period, the transportation company acts as a transportation network operator as well as a heat trader. The system can evolve in different directions. For instance, the number of heat suppliers may rise, which enables possibilities for competition. These new heat suppliers could become member of the heat company. The same holds for housing corporations and distribution and delivery companies. The advantage of this open structure vis-à-vis a temporary license is that the longer term responsibilities of the heat company are ensured. During negotiations with heat suppliers a time period for the supply of heat should be fixed. We suggest a 10 year period to start with, as after these ten years competition might be introduced.

The question is how the construction will be organized. The heat company could construct the infrastructure itself, but lacks the knowledge and experience to do so. Therefore, we suggest that the construction (and maybe other activities) is done by a building contractor. Based on the characteristics of the transaction between the building contractor and the owner of the infrastructure (see Table 5), we suggest a relational contract. TCE does not provide us with the means to choose between the different relational contracts possible. Based on the importance of trust and learning, we suggest a public-private partnership between the heat company and the building contractor.

Public-private partnership is a relational contract between one or more government bodies and one or more commercial parties. There are different possibilities for the relationship between the building contractor and the heat company, which differ in the distribution of responsibilities, of risks, of the different phases of the project (Kenniscentrum PPS, 2005).

- Innovative tendering
    - Design and construct
- Public private partnership:
    - Joint venture
    - DBFO: design build finance operate
    - DBFM: design build finance maintain
    - DBM: design build maintain
    - DBFOM: design build finance operate and maintain
    - BOT: build operate transfer

The Kenniscentrum PPS advises to always use a public procurement procedure when choosing for a PPP. There are different public procurement procedures: the open procedure, the restricted procedure, and the negotiated procedure with or without the publication of a public contract notice. We choose the open procedure to allow all parties interested to apply. In this case, the PPP concerns the construction of a new type of infrastructure. This implies that there is little knowledge at the moment of tendering. Therefore, it is assumed that involvement of the building contractor in the design stage is necessary and with that BOT (where the building contractor is not involved in the design) is not considered a suitable form of PPP. Involvement of the building contractor in the operation phase however, seems to not be a logical choice. The operation of the network is a complex task, which needs appropriate knowledge. Therefore we assume that the heat company will be responsible for this. The building contractor should neither be involved in financing the construction of the infrastructure, since in that case he should receive financial rewards in a later stadium. This could only be the case when he is involved in the operation of the network or when he is co-owner of the network. As we described before and as was showed in the ROM-Rijnmond case, this would not be a logical choice. With the abovementioned, DBFO, DBFM, DBFOM, BOT and a Joint Venture are not suitable and the one that remains is DBM. Therefore, we choose a DBM construction.

The above mentioned design choices lead to the following roles and responsibilities:

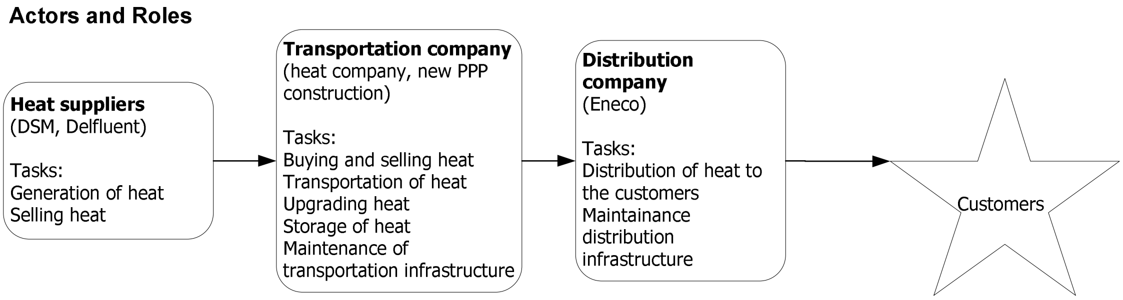

Figure 6. Actors and roles in the value chain of the heat supply network.

3.2.2 Institutional design; non- core choices

The non-core transactions along with the aforementioned core transactions and the chosen governance structures are represented in Table 5. It should be noted that transactions for heat and cold are assumed to have the same characteristics with respect to asset specificity, frequency and uncertainty. Therefore, they are not treated as separate transactions.

Table 5. Transactions, characteristics and governance structures.

Transactions/agreements necessary between:	**Description**	**Transaction characteristics**			**Possible governance structures**
		Asset specificity	**Frequency**	**Uncertainty**	
Heat suppliers with transportation company (heat company)	Definition of allocation of CO_2 credits	High	Low	Medium	Trilateral relational contract
	Purchase of CO_2 credits	Low	Monthly	Low	Classical contract
	Payments for thermal energy	Low	High	Low	Classical contract
Emergency heat suppliers with transportation company (heat company)	Definition of allocation of CO_2 credits	High	Low	Medium	Trilateral relational contract
	Purchase of CO_2 credits	Low	Low	Medium	Classical contract
	Payments for thermal energy	Low	Low	Low	Classical contract
Transportation company (heat company) and distribution company Eneco PROCESS	Organizational setup of transport and distribution company (vertically integrated or not)	High	Low	High	Relational contract
Transportation company (heat company) and distribution company Eneco	Purchase of heat and cold	Low	High	Low	Classical contract
Transportation company (heat company) with distribution company and heat supplier	Delivery specificities (tariffs, failures)	Medium	Low	Medium	Trilateral relational contract: tariffs and responsibilities are fixed by negotiation.
Transportation company (heat company) with building contractors	Construction of infrastructure	High	Low	Medium	Relational contract, public procurement procedure
Housing corporation - building contractor	Restructuring of houses, choice of appliances and	High	Low	Low	Bi lateral, relational contract

	construction and procedures				
Housing corporation - Customers	Rental agreement (customer’s wishes) and billing	Low	Low	Low	Classical contract
Distribution company Eneco- customers	Billing for delivered heat, cold and services	Low	Monthly	Low	Classical contract
Distribution network operator and distributor of heat / cold	Distribution network capacity	High	Low	High	Vertical integration
Heat company and municipalities	Investment capital	High	Low	Medium	Relational contract: PPP
Heat company and subsidy providers	Investment capital	High	Low	Low	Bi lateral, relational contract
Municipality and distribution company Eneco*	License for heat and cold delivery and distribution	High	Low	Low	Bi lateral, relational contract
Municipality and transportation company (heat company) *	License for heat and cold transport	High	Low	Low	Bi lateral, relational contract

4 Specification of the core elements

Some of the design choices made in the last chapter will need some more detailing in order to give a good complete view of the conceptual design.

4.1 Technical specification: core design choices for the city heating system

Technical decisions are based on calculations. Only outcomes of these calculations are given in this chapter. Detailed descriptions on these calculations can be found in Appendix 4.

4.1.1 Operating temperatures and volume flows

The operating temperatures for the systems should be chosen carefully. The temperature in the distribution system must be high enough to heat tap water and to create the warmth necessary. The temperature of the transport system on the other hand, should not be too high because the higher the temperature difference between the main water loop and the environment, the more energy will be dissipated into the environment. Moreover, the temperature of the water loop at the Heat Supply Station near the source should be lower than the temperature of the effluent streams of the sources, because otherwise the heat exchangers will not work, as energy flows from hot to cold. If the water loop is warmer, heat from the loop will transfer to the effluent streams instead of the other way around. The temperatures and the volume flows of the system at its maximum capacity, during the winter peak, are calculated with the help of an energy balance and pinch technology. The results of these calculations can be found in Figure 7.

Cold water with a temperature of 12 ^oC is heated by the effluent stream of the Harnaschpolder to a temperature of 15.5 ^oC. The waste heat of DSM then further heats this stream until it reaches a temperature of 43 ^oC. This temperature is not high enough, so heat pumps are needed to upgrade the water flow to a temperature of 72 ^oC. The right hand side of Figure 7 will deliver the warm water for heating and tap water to the houses at a temperature of respectively 55 and 70 ^oC. In this figure the water from the aquifer storage is necessary to increase the flow of water in the transport system otherwise the peak demand will not be met.

4.1.2 Pipeline capacities

The dimensions of the pipelines in the distribution system depend on the type of connection that the supplier will choose. This is called the maximum connection capacity of the heat network. This connection capacity is for security reasons much higher than necessary. A household pipeline will need to be able transport the maximum flow in the system of 0.057 L/s for house heating and 0.0056 L/s for hot tap water. But if the entry capacity is dimensioned just as gas, then a flow of 0.31 L/s maximum connection capacity for house heating and a flow of 0.20 L/s for hot tap water is used in households. We will dimension the distribution network according to this idea.

The capacity of the pipelines in the distribution system will differ per residential area. An overview of needed capacities are listed in Table 6. The capacity of the transport network is at maximum demand 0.74 m^3/s. Based on the figure drawn the transport network is estimated to have a length of 5.9 km. The distribution network from MDP to HDS is estimated to have a length of 1.1 km. (see Figure 9).

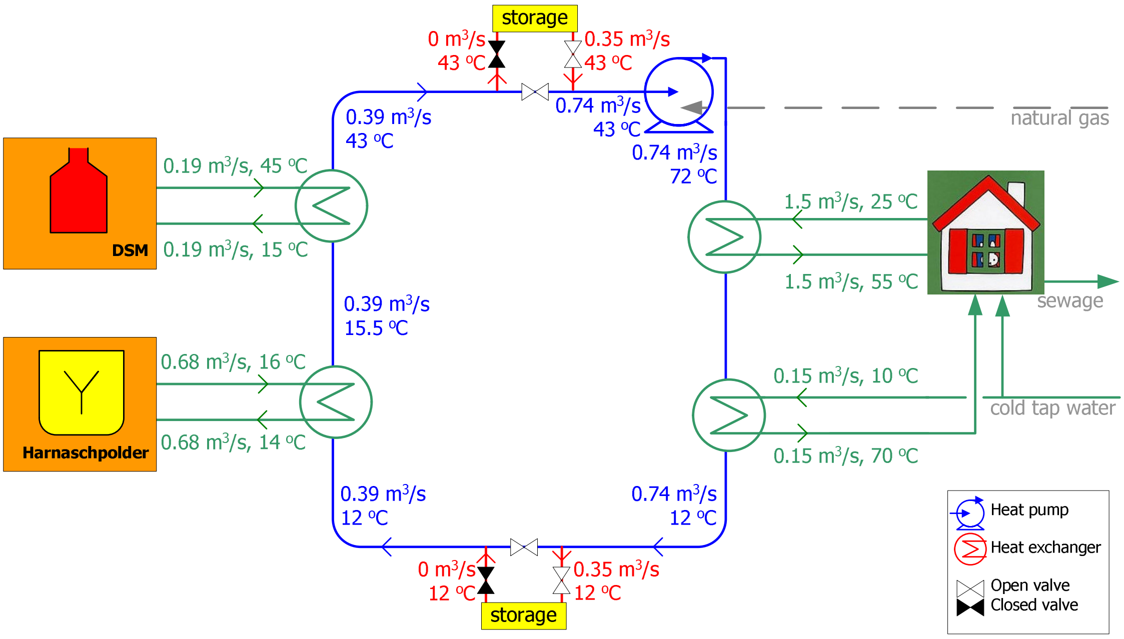

Figure 7. System diagram with temperatures and volume flows at maximum capacity.

Table 6. Volume flows per residential area.

Residential Area	**Number of households** (w.e./area)	**Volume flows (m³/s)**
Harnaschpolder	1200	0.069 for house heating 0.007 for tap water
Spoorzone (including Centre area)	5759	0.330 for house heating 0.032 for tap water
Poptahof	2681	0.154 for house heating 0.015 for tap water
TU Noord	1754	0.100 for house heating 0.010 for tap water
Voorhof	1652	0.095 for house heating 0.009 for tap water
Buitenhof	5954	0.341 for house heating 0.033 for tap water

4.1.3 Capacity calculations heat pump

The necessary total capacity of the heat pumps is 89 MW. The expected losses are taken into account. The efficiency of a heat pump is judged by the COP, Coefficient of Performance. This number indicates the relation between the heat that the pump creates and the energy input necessary. The higher the COP the more efficient the pump is. The estimated COP is calculated to be 1.87.

Kempkes et al. (2002) distinguish four types of heat pumps: one combined with a gas turbine, an electrical pump, a pump based on two-step absorption and one based on one-step absorption. The gas turbine heat pump and the electrical heat pump are the most promising heat pumps, from an economical and energetic perspective (Kempkes et al., 2002). We choose to use gas turbines because they are cheaper (Kempkes et al., 2002) and because it does not require the use of electricity (which is in The Netherlands produced normally of natural gas with an energetic efficiency of around 50%).

4.1.4 Pipelines

A standard pipeline for a heating system can be found in Figure 8; it has a steel inner pipe, with polyethylene wrapped around it. Between those layers there is a PUR foam layer for isolation. In the curves expansion is possible. In the foam a leak detection system is installed (SenterNovem, 2005). These pipes are used for hot flows. Less sophisticated pipelines can be used for cooling.. The temperature difference with the surroundings is much smaller, and thus less losses are expected.

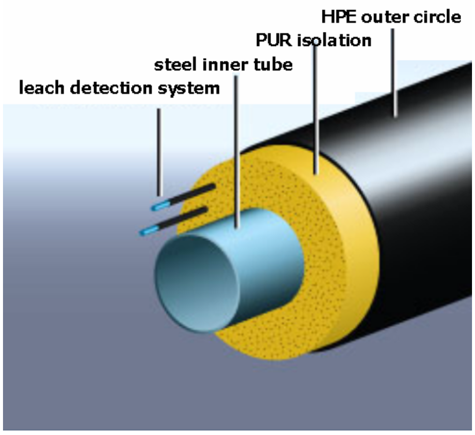

Figure 8. Pipeline.

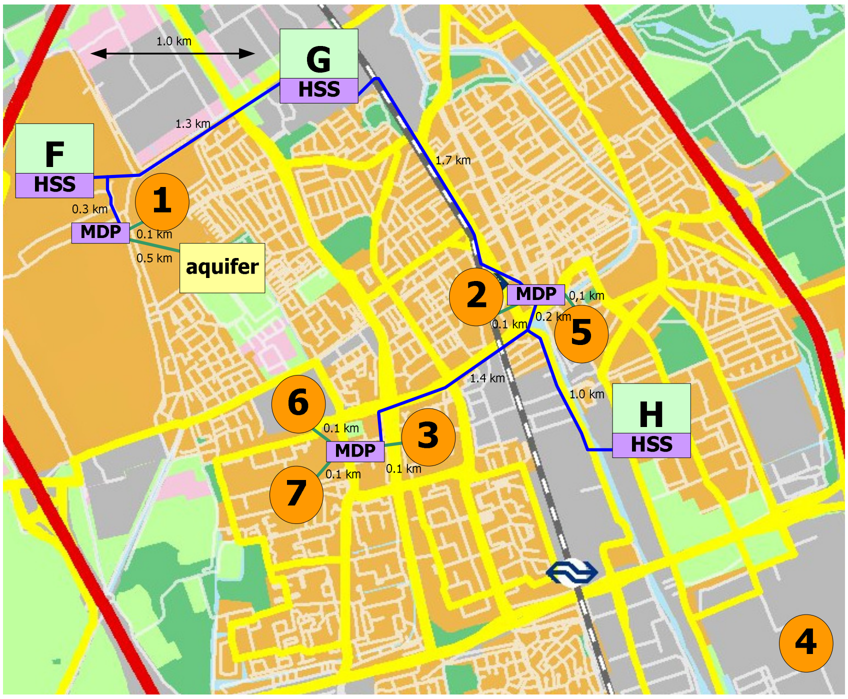

Figure 9. Sources and Sinks connected in Delft.

4.1.5 Detailed lay out of the network

In Figure 9 a detailed map can be found that shows the placement of all the core elements on a map of Delft. The pipelines of the main transport system are (as much as possible) placed next to the railroad track, since this railroad will be replaced underground in the coming years. Combining these construction activities will probably give possibilities to save costs. Other pipelines are placed next to roads, for ease of placement.

Now that the technical design choices are made clear we will look at the consequences of these choices for the institutional design.

4.1.6 Water pumps

The network will be constructed under free flow where possible. This means that pumps are not needed because of the use of gravity energy in the water. Where this energy is not large enough, pumps are needed to transport water through the pipelines. These pumps will preferable be placed in MDP's. We will not further discuss or calculate the capacity and number of pumps needed in this project.

4.2 Institutional specification: core design choices for the city heating system

4.2.1 Tariffs and responsibilities

The best division of revenue flows and responsibilities are represented in Figure 10. The actors are represented in the squares, the arrows stand for the revenue flows from one actor to another. Revenue flows can be paid in different ways. Next to regular money flows also the flow of CO_2 credits and groenfinanciering, (cheap loans for environmental friendly projects) are mentioned. As said earlier, the tariffs for the consumers will be determined based on the '*niet meer dan anders'* (not more than otherwise) principle and will consist of a fixed and a variable part. Due to the complexity of establishing these tariffs and the limited time available, no estimations of the tariffs are presented in this report. However it is important for all parties to follow the developments around the tariff setting in heat networks, since DTe (the regulator for the energy market) and other parties are trying to find a solution to determine the tariffs for heat.

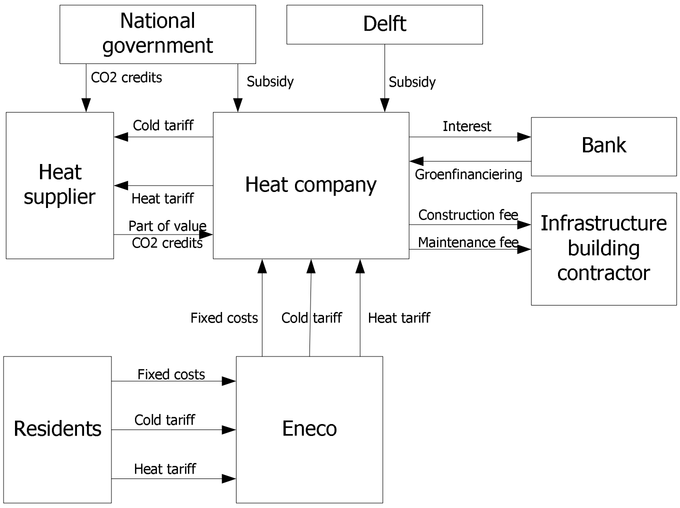

Figure 10. Revenue flows in the value chain of the heat supply network.

4.2.2 General timeline

It is important that the implementation time of the heat networks in the different areas correspond with the restructuring periods planned for these areas. The connection of households to the network is divided in different phases, as specified in Table 7 and Figure 11.

Table 7. Phases of connection to the network in number of households.

Period	**Households connected in this period** (w.e.)	**Total households connected at end of period** (w.e.)
until 2010	8,500	8,500
2010-2015	5,500	14,000
2015-2020	2,000	16,000
from 2020	3,000	19,000

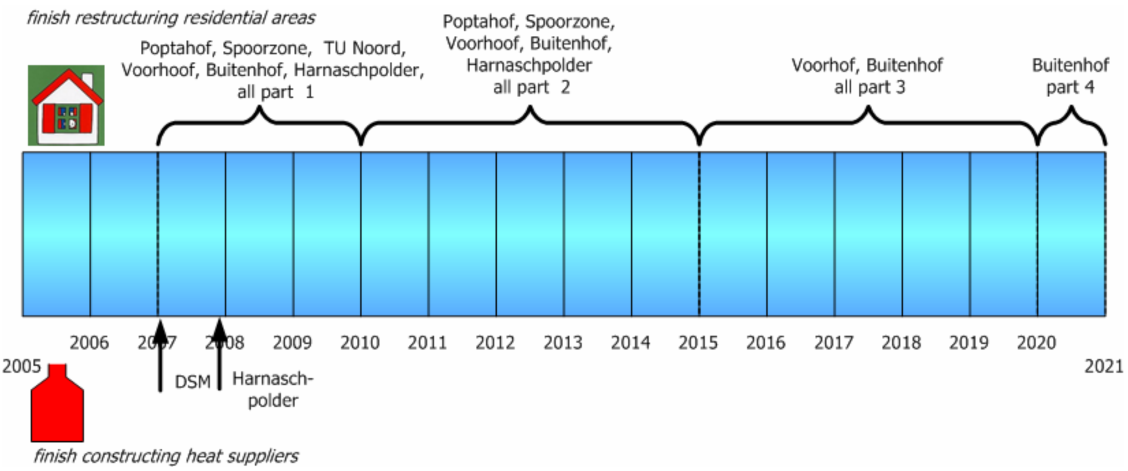

Figure 11. Timeline of restructuring of residential areas and waste water treatment plant.

As a result of this spreading over the time it is not possible to establish the whole heat network at once. That is why the concept of ‘stringing together the beads’ from the Rom-Rijnmond case is used. This means that an individual area (‘a bead’) that is restructured will be connected to the closest (backup) source temporarily. As soon as more areas are restructured and ready for heat supply, the separate areas will be connected to each other and to the main transportation network (‘stringing together the beads’) (Rom-Rijnmond, 2004).

It is also important for the timeline to consider the administrative agenda. It is vital for the speed of the process that participants timely apply for subsidies, for instance for European pilot projects and licenses, for instance MER (Environmental Impact Assessment).

5 Testing

After designing the system it is time to test the system and to see if the system is designed according to the list of requirements of the Basis of Design from the first phase (see Appendix 1). In the meta model this verification phase is covered by the development and execution of tests. For testing the conceptual design we did not develop new tests, but made use of existing testing methods. We used experts, technical calculations and we verified our own design by comparing the requirements and performance indicators that we formulated in phase 1 to the design we made. Next to these methods we also used the design principles of Klir (2003) to see if we designed our system in a good way. In the coming paragraphs we will separately verify different elements of our design. Due to time limits it was not possible to fully validate all the different aspects of the system.

5.1 Test of the technical design

We have listed performance indicators based on the requirements identified in the first part of this project. Technical calculations used in this section can be found in Appendix 4. The tree main requirements for the technical design cover and technical and economic feasibility, sustainability and energy use and robustness and reliability. They are elaborated on in Appendix 1.

5.1.1 Technical feasibility

First we perform a verification of the technical design. Energy and mass balances should be in equilibrium. Pinch analysis is used to address the need for heat pump capacity. Finally, safety of the system is discussed.

Energy balances

We divide the system in two sub systems: the left and the right one. For both sub systems an energy and mass balance is made. This is visualized in Figure 12.

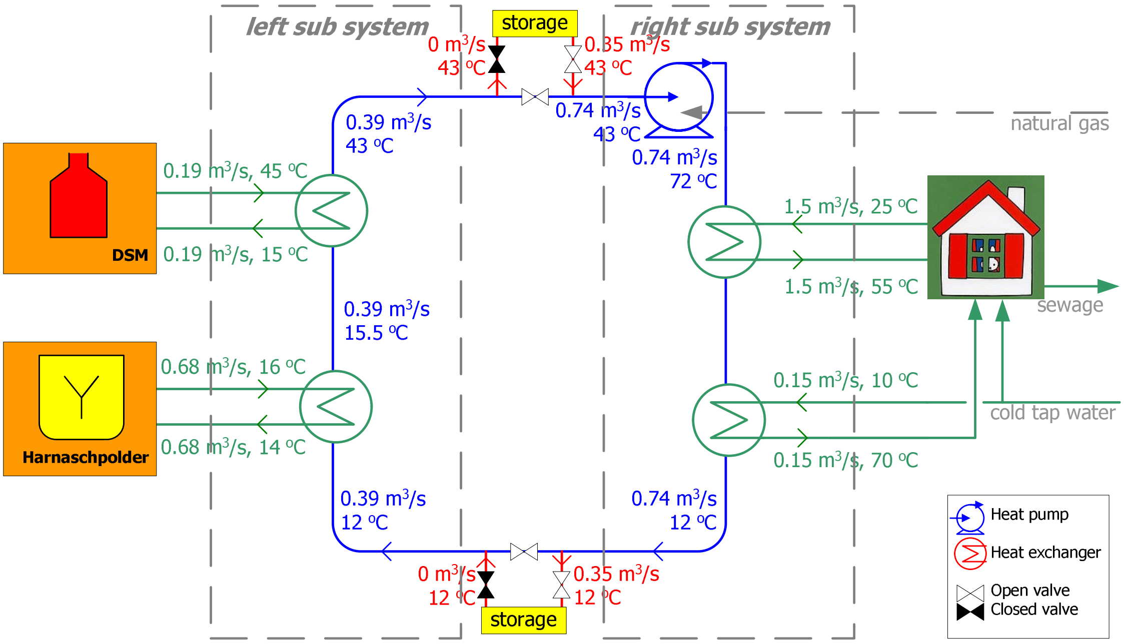

Figure 12. System diagram with sub systems.

An energy balance is based on the first Law of Thermodynamics: no energy can be created nor get lost. Only the energy form (e.g. thermal, potential) can change. While we only look at thermal energy the energy stream going in a system must therefore equal the energy stream out of the system.

Therefore in general the following formula holds:
$\Delta Q = Q_{in} - Q_{out} = 0 \rightarrow Q_{in} = Q_{out}$

For the left sub system this can be worked out to:

$$Q_{in} = (C_{p,water}\varphi_v \rho_{water}\Delta T)_{Harnaschpolder} + (C_{p,water}\varphi_v \rho_{water}\Delta T)_{DSM} = Q_{out} = (C_{p,water}\varphi_v \rho_{water}\Delta T)_{Transport\_left} \rightarrow$$
$$C_{p,water}\rho_{water}(\varphi_v \Delta T)_{Harnaschpolder} + C_{p,water}\rho_{water}(\varphi_v \Delta T)_{DSM} = C_{p,water}\rho_{water}(\varphi_v \Delta T)_{Transport\_left} \rightarrow$$
$$\varphi_{v,Harnaschpolder}\Delta T_{Harnaschpolder} + \varphi_{v,DSM}\Delta T_{DSM} = \varphi_{v,Transport\_left}\Delta T_{Transport\_left}$$

For the right sub system this can be worked out to:

$$Q_{in} = (C_{p,water}\varphi_v \rho_{water}\Delta T)_{Transpor\_right} = Q_{out} = (C_{p,water}\varphi_v \rho_{water}\Delta T)_{Heating} + (C_{p,water}\varphi_v \rho_{water}\Delta T)_{Tapwater} \rightarrow$$
$$C_{p,water}\rho_{water}(\varphi_v \Delta T)_{Transpor\_right} = C_{p,water}\rho_{water}(\varphi_v \Delta T)_{Heating} + C_{p,water}\rho_{water}(\varphi_v \Delta T)_{Tapwater} \rightarrow$$
$$\varphi_{v,Transport\_right}\Delta T_{Transport\_right} = \varphi_{v,Heating}\Delta T_{Heating} + \varphi_{v,Tapwater}\Delta T_{Tapwater}$$

While we only transport thermal energy in water, al values for and $C_{p,water}$ and ρ_{water} are equal. They are therefore excluded. The calculations seem to be correct while the sub systems are in balance energy-wise.

Mass balances

Mass balances are derived from energy balances. As with energy, mass cannot be created nor destroyed. Only the chemical form can be changed (the order of atoms and molecules). While no chemical reactions occur in the city heating system, the following formula holds:
$\Delta M = M_{in} - M_{out} = 0 \rightarrow M_{in} = M_{out}$

For the left sub system this can be worked out to:

$$M_{in} = (\varphi_v \rho_{water})_{Harnaschpolder} + (\varphi_v \rho_{water})_{DSM} = M_{out} = (\varphi_v \rho_{water})_{Transport\_left} \rightarrow$$
$$\rho_{water}(\varphi_v)_{Harnaschpolder} + \rho_{water}(\varphi_v)_{DSM} = \rho_{water}(\varphi_v)_{Transport\_left} \rightarrow$$
$$\varphi_{v,Harnaschpolder} + \varphi_{v,DSM} = \varphi_{v,Transport\_left}$$

For the right sub system this can be worked out to:

$$M_{in} = (\varphi_v \rho_{water})_{Transport\_right} = M_{out} = (\varphi_v \rho_{water})_{Heating} + (\varphi_v \rho_{water})_{Tapwater} \rightarrow$$
$$\rho_{water}(\varphi_v)_{Transport\_right} = \rho_{water}(\varphi_v)_{Heating} = \rho_{water}(\varphi_v)_{Tapwater} \rightarrow$$
$$\varphi_{v,Transport\_right} = \varphi_{v,Heating} + \varphi_{v,Tapwater}$$

While we only transport water, al values for and ρ_{water} are equal. They are therefore excluded. The calculations seem to be correct while the sub systems are in balance mass-wise.

Pinch analysis

The necessity of the heat pump in this system can also be made clear with the help of a pinch analysis diagram. In this diagram it is made visible that without a heat pump the heat will not reach the necessary temperature (see Figure 13). Pinch analysis is normally used to couple hot streams with cold streams within a plant or industrial area. This function cannot be used to its full potential in this case. Firstly, this is caused by the use of a heat pump, which is in our analysis represented as a heat source. Secondly we have designed a transport network between the sources and the sinks. As with the energy and mass balances we divided the system in two sub systems. This is normally not possible with Pinch Analysis. We therefore adapted Pinch Analysis.

In this diagram the need for a hot heat source (in our case the heat pump) is visible. The middle piece is the transport network. Thermal energy in the water from the storage facility is also included in this area. This figure also visualizes the energy balance of the system.

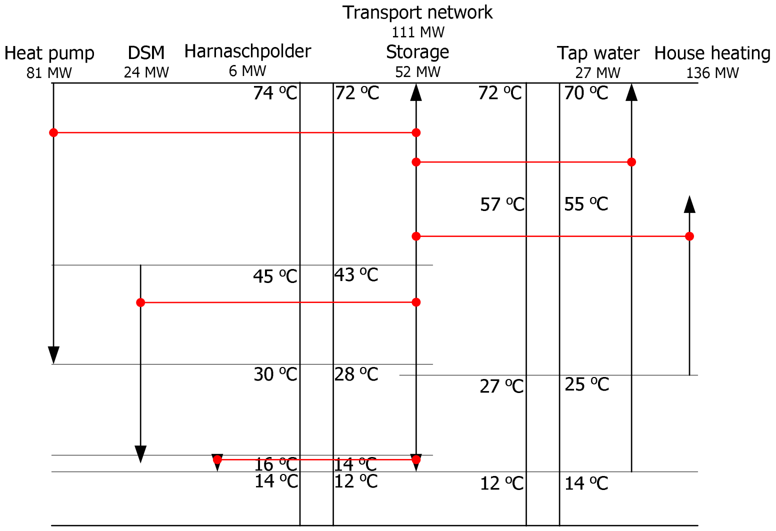

Figure 13. Pinch analysis.

Safety

The safety of the system can be measured as group risk. This is defined as the number of deaths by an accident multiplied by the probability of an accident per year. Since this requires a extensive risk assessment, we cannot provide a quantitative estimation. Safety is expected to be higher than the current system, because hazardous gas infrastructure and equipment is replaced by pipelines of hot (but not boiling) water at relatively low pressure and heat exchanger.

Downtime and hinder

Since housing corporations are an important participant in the decision making process, we expect downtime and hinder during transition to be minimized. Moreover, since the transition to the city heating system occurs during restructuring of residential areas, we expect additional impact to be small.

5.1.2 Economic feasibility

Cost calculations

We have estimated the equipment costs and main investment costs involved in the city heating system. The estimates are based on Airco Noord (2005) Kema (2005), Novem (2003), Novem (2004) and Technojet (2005). Other costs are energy costs for end users and maintenance both for in house equipment and for the infrastructure.

A comparison of in house equipment costs between the city heating system we designed and a conventional natural gas heating system is presented in Table 8. It can be concluded that equipment investment costs are significantly lower in the city heating system.

Table 8. In house equipment costs per year.

City heating system (euro/year)		**Conventional natural gas heating system** (euro/year)	
Floor heating	171	Central heating boiler	119
Pipes	6	Smoke outlet	5
Maintenance	68	Gas pipes in house	8
Control panel	7	Central heating system and radiators	71
		Individual airco installation	80
		Maintenance	113
		Control panel	20
Total	**252**	**Total**	**416**

Energy costs for consumers (euro / kWh) are not decided upon is this design. However according to the 'Not more than else' principle, consumers will not face higher energy costs.

An overview of investment costs for the infrastructure is presented in Table 9. The investment costs are in the order of 21.5 million euros. With an expected lifetime of 40 years this equals 537,000 euros of depreciation costs per year. Yearly maintenance costs are expected to be 2% of the investments in equipment (Novem, 2004). This results in an additional cost of 391,000 euros per year.

Table 9. Investment costs in city heating system.

City heating system (euro)	
Heat pump	13,400,000
Passive cooling	1,500
Control panel	35,000
Heat exchanger	32,000
Transport pipelines	5,900,000
Distribution pipes	110,000
Aquifer fixed costs	13,000
Aquifer advise costs geology	21,000
Installation costs	1,950,000
Total	**21,462,500**

Benefits

Income is generated in two ways: significant parts of the investment costs can be covered by subsidies. Reduction on interest for loans is possible with the 'Groenfinanciering' (Rabobank, 2005). Other incomes come from the energy tariffs levied from end consumers. The tariffs

include a heat tariff, a cold tariff and a fixed yearly tariff. In the future the value of CO_2 emission credits may add to the benefits of the system. Consumer tariffs can be in the same order as they are for the (comparable) residential area Zuidpoort of Delft (Eneco, 2005): a fixed tariff of 273,70 euro/year and a tariff per GJ of approximately 20 euros. Consumers in Zuidpoort are not billed for cold.
Upon introduction of CO_2 emission trading another source of benefits may be introduced. The expected value of CO_2 credits is assumed to be 50 euro per ton CO_2 (Ministry of Economic Affairs, 2004b). The costs for the reduction of CO_2 emissions (0.50 Mton per year) is expected to be 537,000 euro per year (the depreciation of the infrastructure costs). Therefore the CO_2 reduction of this system is achieved at 1.07 euro / ton.

5.1.3 Sustainability and energy use

Contribution to sustainability can be measured with a set of indicators. First we estimate the amount of fossil fuel that can be replaced by currently unused energy. We estimated this amount by taking the difference between fossil fuels used before and after implementation of the system. This amount is 270 GWh and represents 49.1% of the energy used in the regular gas system. Additional saved energy use is reached by replacing air-conditioning by the passive cooling system as designed in the city heating system. Air-conditioning is normally an energy intensive luxury product. In our system no substantial extra is required. This effect is not quantified. Second, we calculate the amount of energy saved by implementation of the system. In our calculations, we have assumed that no energy savings are realized, because we have not taken into account improved insulation of restructured houses or the fact that we have installed low temperature heating, which is less energy consuming than conventional heating. Therefore, energy savings can be expected although this is not reflected in this test.

A higher systems energy efficiency results in a more sustainable system. Therefore the energy efficiency (total usable energy out / total energy input). Total yearly energy demand is estimated to be 532 GWh. Yearly net energy supply is estimated to be 648 GWh (DSM: 206GWh, Harnaschpolder: 50 GWh, Auxiliary energy input to heat pump: 392 GWh). Therefore the energy efficiency is 82%.

In order for this system to be relevant, the total energy delivered by city heating system in Delft should be compared with total energy use in Delft. Since we performed our calculations based on average energy use per household, we can compute the score to this indicator by dividing the number of households connected to the system by the total number of households in Delft = 19,000 / 49,000 = 39%. We conclude that the system has relevant contribution to Delft's energy objectives.

Contribution to sustainability is often expressed in the amount of emissions avoided. The yearly amount of CO_2 emitted is related to the gas use for the heat pump(s). The combustion of 1 ton CH_4 leads to an emission of 2.75 ton of CO_2. The total amount of CO_2 emitted equals 1.41 Mton per year. The amount of CO_2 emitted per year before introduction of the system was 1.91 Mton. This means that 0.50 Mton CO_2 emission per year is avoided. Compared to the total emissions in Delft (4.93 Mton) this is a reduction of 10%. Economic values for these avoided emissions are estimated in the section about cost calculations below. Local NO_x (ton / kWh) emissions are unknown. Therefore the avoided emitted NO_x per total emitted NO_x in Delft is also unknown. Finally regional environmental impact due to heat dissipation is assessed. A grade can be determined based on the outer temperature of the pipelines and the ecological sensitivity of surrounding soil. The transportation system is operated at a temperature of 43°C. Due to their insulation, very little environmental impact is expected. Moreover, the pipelines are located close the current railway system. The surrounding soil therefore has a low ecological sensitivity. We believe a high grade for environmental impact is justified.

5.1.4 Robustness, redundancy and reliability

Robustness and reliability of the system are tested in this paragraph. First we elaborate on the robustness against fluctuating demand (on a long term, seasonal and daily). Second we look at redundancy of the system as a way to provide robustness against supply variations.

Robustness against demand variation

Robustness against long term demand variation can be obtained with the reserve margin. On basis of data of Energiened (Energie in Nederland, 2005) we estimated the needed reserve margin for the capacity of the city heating system. We therefore incorporated 2 trends in the change of demand of heat. The first trend entails the total amount of households. It can rise from 19,000 to 24,000 by connecting more areas than suspected or monotonous increase households per area. The second trend is the decreasing demand for gas for heating and tap water we have seen the last 25 years. We assume the declination of demand has been at a constant rate (which equals 3.25%) and this trend will continue for 10 more years. Than demand will be constant. These trends predict a *decrease* in needed capacity in 40 years of 1.9%. Therefore we assume no reserve capacity is needed.

Robustness against seasonal variation in demand can be estimated based on a load duration curve. As a design choice we fixed the ratio between average capacity utilization and maximum need capacity of the system at 2. This assumption is compared to the natural gas demand fluctuations of Flanders (VREG 2003). The patterns are comparable and the fluctuations are within the assumed limits. The ratio R between peak demand and average demand is estimated to be 1.9 for natural gas. Because this is smaller than 2, so our system is robust for seasonal variations.

Robustness against daily variation in demand can be assessed by comparing the maximum standard deviation in house temperature that can be achieved by the system to the standard deviation of households. Because there is a flexibly operable storage system, the heating system is expected to be flexible enough to accommodate daily variations in demand.

Robustness against variation in supply

The redundancy of the system is related to the number of sources and the number of sinks. The number of sources is two for the time scope of our design. Through technical, institutional and process-related design choices, we have left open the possibility of adding other sources to the system in a later stage. This may be needed if DSM decides to end or modify its activities in Delft after the contract period for heat supply has ended. Currently, DSM considers moving two third of its production capacity to China. Therefore, we dimensioned our design based on one third of the total capacity of DSM. During peak load, the system will only use 57% of this amount, and 7% of the heat available from Harnaschpolder. We can conclude that our system is robust against variation in supply.

Six residential areas are connected to the system as sinks. In principle, our design allows for expansion with more sinks, but this was not the aim of our design. We have increase redundancy of the system by incorporating emergency or back-up sources in the design.

Reliability of the system

The reliability of sources is indicated with the downtime for each source (hours / year). Because continuous operation of both DSM and Harnaschpolder are critical to the business performance, downtime is expected to be very low. Exact figures are not available. Because we have incorporated a flexibly operable storage facility as well as emergency suppliers, the system is reliable despite possible source downtime.

Operational and strategic flexibility of the sources

The flexibility of sources is indicated by the fastest rate of changing output (kWh / hour). Sources are not flexible because their output is assumed to be constant. Because of storage, a lack of flexibility of sources has no influence on the flexibility of the output of the system as a whole.

The final issue relating to reliability and robustness is the perceived diminished operational and strategic flexibility of sources. According to our institutional design, suppliers of heat commit themselves to supplying a fixed amount for a fixed period (we suggested 10 years). This reduces their operational and strategic flexibility. DSM for instance will have to take this obligation into account when making investment decisions regarding production facilities.

5.2 Test of the institutional design

To verify the institutional design stakeholder consultation is necessary. This can be seen when looking at the performance indicators for the institutional design as formulated in phase 1. These were:

1. Suffice laws and regulation
   a. Be in accordance with all national, European and global laws
   b. Perceived presence of trust (grade 1-10)
2. Perceived fairness of tariffs (grade 1-10)
3. Perceived goodness of fit of the organizational (governance) structure by the stakeholders (grade 1-10)
4. Perceived freedom of choice of heat deliverer for end consumer (grade 1-10)
5. Expert test

As you can see the performance of most of these requirements are measured with a grade from 1-10. For the assignment of these grades consultation of stakeholders is necessary. Due to cost and time constraints this is however not an option right now. Therefore we will try to verify the institutional design with the opinion of an expert of Rom Rijnmond (the best practice case that we used) combined with a qualitative comparison performed by ourselves, of the design made and of the requirements and performance indicators of phase 1. We will discuss the verification per requirement (for a list of requirements see Appendix 1).

Ad 1. The design has to match with the institutional environment, (be in accordance with all national, European and global laws, be in accordance with the goals and expectations written down in the Delft municipal 3E plan which in total reduce the CO_2 emission reduction with 33500 ton per year in 2012 etc.). The only issue here is the lack of competition for generation and delivery of heat in our design. As we explained before, competition is not possible in the current situation. However, we expect this to become possible when heat becomes a valuable product with a market value. Our design allows for introduction of competition in a later phase. Also, the design is based on the municipal 3E plan so the plans of Delft municipality are taken into account in the design..

Ad 2. Take into account that trust and competence building are important (Original Institutional Economics). Since no grade can be given for this performance indicator it is hard to evaluate the design for this requirement. However in the design repeatedly is pointed at the importance of trust. So we can conclude that trust is definitely taken into account.

Ad 3. The design has coordinate transactions efficiently. The governance structures for transactions are determined with the help of Transaction Cost Economics together with Original Institutional Economics. When a choice had to be made between several possible optimal governance structures this choice was always based on the option with the best possibilities for the creation of trust and learning. If the transactions turn out to be efficient in practice can only be evaluated after the implementation, however in theory the transactions are coordinated in a most efficient way.

Ad 4. The design has to deal with appropriate definitions of actors and games; (deal with problems arising from unclear sewage water and CO_2-credit property rights and use the advantages of PPP to create a base for support among stakeholders). In the design of the institutional part of the system attention is paid to unclear property rights, however no definite conclusions have been drawn yet, as more information is needed for this. It is also pointed out that the parties should be kept aware of the developments in defining tariffs for heat. Since these issues have not been dealt with enough more attention should be paid to this in the future.

Ad 5. After showing the institutional design to an expert of the Rom-Rijnmond project, ir. G. van Toledo we received the following comments. First of all, tendering the transport and the distribution at once will lead to problems in the phasing of the project. In Rotterdam the transportation network is made first. (This is already a very big project for municipalities, energy companies and industry) The next step is that the energy companies can place the distribution network in different phases. This way they can fulfil all the wishes of the different end users, such as hospitals, housing corporations etc.

This is an aspect that we did not take into account yet, because we believe that the scale of the project in delft is much smaller and the end users are less different from each other as in Rotterdam. However more research could be performed on this.

Secondly, innovative tendering (Design, Build, Maintain, Finance and Operate) is not a very logical choice in this case because the demand for this system is not very clear. This is a risk that a building constructor is not willing to take. Especially since the design process is very complex in the tuning of the different technical aspects. Therefore he suggests to use a Build Maintain and Operate contract.

We suggest a DBM contract; Design, Build and Maintain. We did this because we feel it is important to use the knowledge of the building contractor in the design process. The operation is done by an energy company. This could be the same as the building contractor, but this is not necessary.

5.3 Test of the process design

In the first phase of this project the requirements for the process design were formulated on a very high abstraction level. This was done because without a conceptual technical and process design it is very difficult to specify the content of the process design and without content no clear requirements could be formulated. During the design of the process we also identified more specific requirements for every decision making round. (See Appendix 3).

In the verification phase we test the covenants of the process design to see if the requirements from Appendix 1 are met. In the first phase we also identified performance indicators for testing the requirements. These performance indicators were:

1. Involvement of critical actors: amount of critical actors active in decision making process (%)
2. Perceived ease of entry and exit (grade 1-10)
3. Acceptance of protection of core values (grade 1-10)
4. Perceived satisfaction of the choice for a process manager (grade 1-10)
5. Acceptance of consulted experts (grade 1-10)
6. Perceived clarity of process (grade 1-10)
7. Perceived effectiveness of process (grade 1-10)
8. Progression of process (# contracts / process step)
9. Expert test

These performance indicators imply just as was the case with the institutional design that stakeholder consultation is necessary to see if the requirements are met. However due to time and cost constraints we have not been able to consult stakeholders. The verification is therefore done in the same way as the institutional design. This means that expert judgment is used in combination with qualitative verification performed by ourselves; by comparing the performance indicators and requirements mentioned with the design made. We will discuss the verification per criteria.

Ad 1. Critical actors must participate during the whole decision-making process. This criteria is met throughout the whole design of the process. For every round we have appointed the stakeholders that are necessary for completing the round successfully. In practice it can never be guaranteed that stakeholders will stay during the whole decision making process. But if the intentions of the stakeholders are good than there is a big chance that the stakeholder are willing to participate during the whole decision making process. Trust between the different parties will play an important role in this.

Ad 2. The process should have low entry and exit barriers. In the process rules of the start-up covenant it is stated very clearly what the barriers for entry and exit are. This means that all parties should be aware of these rules and will know what to do if they want to leave or enter the process. Because of the openness in rules it is likely that in practice the entry and exit barriers will be perceived as low.

Ad 3. The core values of a future network operator, the housing association, the heat supplier and the developer must be protected. A thorough investigation of the core values of the critical actors was made in the first phase of the design (see Appendix 2). In the analysis round the core values of the critical actors are taken into account when determining the design space and variables. In practice trust will play an important role in the protection of core values.

Ad 4. At the beginning of the process a process manager must be selected. The choice for this process manager must be based on consensus within the group of critical actors. In the start-up agreement a choice is made for the process manager. A perceived difficulty with the chosen process manager could be that the different parties will not see him as an objective party, because he is part of Delft municipality. Delft municipality really wants to go on with this project so that may lead to some problems.

Ad 5. Depending on the group of critical actors, experts must be consulted in order to guarantee the substance of the process; the actors must agree upon the choice for these experts. This requirement can almost literally be found in the start-up agreement. In practice it might lead to problems if all parties conduct research that have different outcomes as this may lea to stagnation of the process. Again trust is very important.

Ad 6 and 7. The process must consist of different steps: the process design must explicit the deliverables, actors and roles, rules and structure of each step. The process has been divided into rounds. On paper such a division in rounds looks very clear, but in practice many of the discussions will not be kept within the boundaries of the decision-making rounds. Especially when it comes to making package deals between parties aspects form different rounds will be taken into account. It is the task of the process manager to keep the overview of the rounds and to make sure that decisions are taken in the rounds. He should also keep track of the losers and winners in every round and use this strategic information in negotiations.

Ad 8. A general timeline for the process rounds will be constructed. This timeline has to be agreed upon by the critical actors. It is important for all actors to have some kind of idea of the general timeline of the project. That is why for every round we have given an indication for the duration of the round. A pitfall is that parties must not feel strained because of the timeline chosen.

Ad 9. The expert, ir. G van Toledo did not give many comments on the process design, except that he would like to see a more precise description of the roles that different parties will perform in the process. This was more elaborately done in the first phase of this project, which he did not see.

In paragraph 2 is already explained that it is important to realize what the difficulties are for parties to participate and how to convince them to join or stay in the decision making process. That is why no further attention is paid to this here.

5.4 Principles of good architecture

In addition to the specific design requirements we formulated in the first phase of this project, we now want to judge how well our design complies with Klir's design principles for a good systems architecture (Klir, 2003). Klir identifies eight principles of good architecture. They will be dealt with subsequently.

According to Klir, an architecture should be consistent. The technical, institutional and process designs are designed as a coherent whole and are tuned to accomplish the overall result. Therefore, this principle is well followed through.

The requirement of orthogonality indicates that independent functions should be specified separately. This system accomplishes three functions: house heating, heating of tap water and house cooling. Since households can use the different functions independently of each other, we can say that this principle is met.

Propriety reflects a situation where a system has no unnecessary functions. We have not identified unnecessary functions in our design.

A parsimonious design is a design in which functions are not repeated in different forms. The heating and cooling functions is accomplished in one way only. For instance, there is no additional gas-fired boiler in the house and there is no additional air conditioning installation. Moreover, there is one set of institutional arrangements and one accompanying decision making process.

A fifth design principle is transparency. We have chosen general layout that reflects transparency, both in the technical and in the institutional sense. The same holds for the decision making process.

The principle of generality advocates the use of a function for as many purposes as possible. Our design is accommodated to serve different purposes. From a technical point of view, the main purpose is a reduction of the use of fossil fuels, with as a consequence a reduction of CO_2 emissions. From a technical and institutional point of view, another purpose is met, i.e. the creation of trust and learning. Thus, we have utilized the function to maximize its benefits.

Open-ended ness reflects a design of which functions can be used in other ways than designed. The functions of the design, i.e. city heating and cooling, can be used only in the way designed. However, the design is open-ended insofar as it allows for future expansion and for the introduction of competition.

The last design principle is the principle of completeness. An architecture is complete when it satisfies requirements maximally. The requirements of the main stakeholders have been taken into account throughout the design. Since there are trade-offs between requirements, it is not possible to satisfy them all fully. However, we believe that we have designed the system is such a way that it is satisficing for the main stakeholders. Since the design is not accomplished in a real life setting and because we have not performed further optimization, we cannot be sure the requirements are satisfied maximally. We conclude that we have a good, but not necessarily optimal, design.

5.5 Reflection on the tests

The different parts of the design have been verified separately, using the requirements that were defined in phase 1 for these different parts. However the different parts of the design should also be tested on all requirements. For example the institutional design should also be tested on costs. Next to separately testing of the different parts (technical, institutional and process) a testing of the whole integrated design is necessary. Due to time and costs constraints we will not perform any more tests for this. However with the comparison of the designed system to a conventional gas system and with the comments of the Rom-Rijnmond expert on our design we think that we have covered the integrated design as well.

6 Conclusions and recommendations

After the ratification of the Kyoto protocol in 2002 the Dutch government has developed incentives to reduce greenhouse gas emissions. Based on these policies the municipality of Delft has formed its own policy concerning the reduction of greenhouse gas emissions within their municipality and is therefore exploring the possibilities of sustainable city heating systems. Delft has outlined its policy for increasing efficiency of energy use in its 3E climate plan (Delft municipality, 2003). The Trias Energetica concept (Ecofys, 2005) defines three ways to achieve this goal: maximize the use of sustainable energy sources, use non-renewable energy sources efficiently and/or minimize energy use. Delft considers a solution to increase the efficiency of the use of non-renewable energy: the use of (industrial) waste heat for city heating. Delft municipality, the problem owner of this design project, is exploring the possibilities for this type of systems. For implementing this opportunity, Delft municipality is dependent on the co-operation of the critical stakeholders: the heat suppliers, the housing associations and the future network operator.

The research question of this project was:
Which energy system can the municipality of Delft best apply for city heating with waste heat, taking into account the interests of Delft and of the stakeholders that Delft is critically dependent of, i.e. the heat suppliers, the housing corporations and the future network operator?

The term ‘best’ in the research question cannot be defined uniformly, due to the deviation in perceptions and goals of the stakeholders involved. To be able to answer the research question and to clarify the word ‘best’, sub-questions are formulated.

- How can the city heating system be designed in such a way that it results in optimal system robustness?
- How can the city heating system be designed in such a way that all critical actors accept it?
- How can the city heating system be designed in such a way that the benefits and costs of the whole system and the separate actors are in balance?
- How can the city heating system be designed in such a way that optimal CO_2 reduction is achieved in the municipality of Delft?

The deliverable of this report is the design of the complete city heating system combining as many sinks as possible with many sources. This design is represented in three design domains: the technical, institutional and process domain. Delft municipality can use the technical and institutional design as a starting point for the negotiation process with the stakeholders. This negotiation process is also a deliverable of this project and is called the process design. It is presented as a start-up covenant, which contains and specifies the start-up agreements necessary for realizing the district heating system. The framework or layout of the decision making process is thus designed.

To realize the conceptual design presented in the previous chapters not only the start-up covenant is necessary. That is why in this chapter we will give a proposal of a covenant containing all the agreements that have to be made in the different decision making rounds. These agreements match the design as described in Chapter 2 and Chapter 3. Just as the start-up agreement, the content of this proposal is based on the framework of Appendix 3 and also further explained in that Appendix. The process covenant is a formal representation of the design decisions made, and can be seen as the conclusion of our design.

6.1 Conclusions of the design: covenant for the utilization of waste energy for residential heating in Delft

E.J.L. Chappin
A.M. Klompenhouwer
W.L. Oosterwijk
E.M. Schapers

6.1.1 Advice

We have been asked to propose a decision making process for the design and construction of a residential heating system based on waste energy in Delft. The parties involved are Delft municipality, DSM, Delfluent, heat suppliers from the Botlek area, Eneco, the housing corporations Vidomes, Woonbron and Duwo, residents, Platform Warmtetarieven and emergency suppliers.

We design a decision making process departs from the following situation:

- The process is aimed at the design and construction of a residential heating system based on waste energy in Delft
- Delft, DSM, Delfluent, Eneco, Vidomes, Woonbron and Duwo and a building contractor have signed a covenant that describes the process agreements surrounding the decision making process.
- Heat suppliers from the Botlek area could be involved in the project as heat supplier in case of expansion of the project. To commit them to this possible role of heat supplier, they need to be involved in the decision making process.
- Eneco is at risk of loosing clients for gas delivery. They should be compensated for this loss. Moreover, Eneco is the operation of the regional electricity and gas distribution systems in Delft. Therefore, they are involved in the decision-making process.
- Housing corporations own the buildings that are to be restructured and that are candidate sinks for the heating system. Their main interest is to avoid an increase in the rental price and energy costs for households, and to improve the quality and comfort of the buildings.
- The residents and their representative body Platform Warmtetarieven are mostly concerned with costs and quality and comfort of the buildings.

The parties are of the opinion that:

- It is desirable to design and construct a residential heating system in Delft
- All parties feel jointly responsible for the design and construction of the system.

6.1.2 Agreements

Round 1. Analysis

Agreement 1.
All parties agree that the technical design space consists of at least:
Which sources and sinks, general layout of the network, storage, location of the pipelines, placement (location and number) of heat pumps (at MDP or HDS's), phases of connection to the network (which residential area when), real options: which ones are acceptable, which emergency / reserve capacity sources (= real options), type of in-house heating system and capacities.

Agreement 2.
All parties agree that the main requirements for the technical design consists of are that the energetic system of Delft must increase sustainability (requirement 1), the city heating should be

in compliance with the user's needs (requirement 2) and the system has to be technically and economically and legally feasible (requirement 3). The detailed explanation of these requirements is described in Appendix 3.

Agreement 3.
All parties agree that the institutional design space consists of the governance structures (transactions and transaction mechanisms) and actors and games (parties involved in different transactions, property rights). The institutional environment is not subject of the design.
This means that at least the following design variables exist:
Start-up agreement about the general organization of supply, transportation; organizational setup transportation and distribution company, organizational setup of transportation company, members and conditions of the partnership of the heat company, agreement on organizational setup and conditions of distribution role: integration of network operation and delivery of heat; agreement on execution of responsibilities of heat company, definition of property rights (CO2 and heat), definition of transactions and coordination mechanisms, conditions for emergency supply

Agreement 4.
All parties agree that the main requirements for the institutional design are that the design has to match with the institutional environment (requirement 4), the design has coordinate transactions efficiently (requirement 5) and the design has to deal with appropriate definitions of actors and games (requirement 6). A detailed explanation of these requirements is described in Appendix 3.

Round 2. General layout of the system

Agreement 5.
The transport and distribution of heat will be separately organized. Eneco will be the distributor and deliverer of heat and cold. A transportation company will be the transporter of the heat.

Agreement 6.
The transportation company will be a public private partnership, called 'Heat company'. This heat company will consist of members of Delft municipality, DSM, Delfluent, housing corporations, Eneco. The shares of the heat company are divided between them according to the capital supplied. New parties (e.g. other heat suppliers in the future) may enter the heat company. The responsibilities are ownership and maintenance of the infrastructure, operator of the transportation network.

Agreement 7.
The distribution and delivery of heat and the network operation will be integrated within the activities of Eneco. Eneco is issued a 10-year license for heat and cold delivery and distribution. After the expiration of this license, the delivery and distribution will be organized differently; competition will be introduced or there will be a public procurement procedure. This decision will be made by the heat company and the residents. The level of service provision by Eneco uring the license period will influence this decision. In case a public procurement procedure will be chosen, Delft municipality will be responsible for this tendering.

Agreement 8.
The residential heating system has a transport and a distribution component. The transport system holds a water loop, connecting the sources via Heat Supply Stations (HSS) to a Main Delivery Point (MDP). Heat is distributed to the households using a similar water loop. This loop connects the Main Delivery Point to the Heat Delivery Stations (HDS) placed in residential areas.

Agreement 9.
Connection of sources and sinks to the network is done according to the metaphor of ‘stringing together beads’. The first phase is the creation of the beads. The second phase entails the stringing together of the beads, thereby creating a string of sources and sinks (Rom-Rijnmond, 2004).

Agreement 10.
The design, construction and maintenance of the infrastructure is the responsibility of the heat company. A building contractor will execute these activities. This will be done through a DBM PPP partnership between the building contractor and the heat company. A building contractor shall be selected based on an open tendering procedure.

Round 3. Property rights, transactions and technical layout

Agreement 11.
Property rights for heat belong to the facility that sells them. For waste water, part of the heat originates from households. Therefore, a part of the value of the heat from AWZI Harnaschpolder belongs to the household and another part belongs to Delfluent. The percentage division of this parts are to be determined by research. 100% of the value of the heat from DSM belongs to DSM. Property rights for cold are determined in the same way.

Agreement 12.
Property rights for CO_2 credits are determined as follows: heat becomes a product for DSM and Delfluent (and in the future other heat suppliers). As for electricity production, thermal heat production will then also be associated with CO2 emissions. When an industrial company becomes a heat supplier, the cap increases accordingly. This solution requires implementation in national or even European laws and regulations. Delft municipality, EZ and VROM commit themselves to lobbying for this to be arranged.

Agreement 13.
Transactions and coordination mechanisms are defined as presented in Table 5 of this report.

Agreement 14.
Warm and cold water will be stored in an aquifer in two separate chambers. The net heat put in the ground (i.e. the energy balance) should be close or equal to zero and a hydro-geological investigation is necessary in order to get a license from the Province.

Agreement 15.
The pipelines of the main transport system are (as much as possible) placed next to the railroad track, since this railroad will be replaced underground in the coming years. The other pipelines are placed next to roads. Three MDP’s are placed; one MDP for Harnaschpolder, one MDP for the districts Spoorzone and TU Noord and one for Poptahof, Voorhof and Buitenhof. In a MDP the heat is exchanged and upgraded by a heat pump to the necessary temperatures and there is room for the necessary expansion that occurs in the pipes and possibly for storage of heat. The transportation network will consist of two ring structures. Both connect the sources to the MDP’s, one transporting hot water, the other cold water. The layout of the distribution networks depends on the structure of the residential area, but will probably consists of a combination of a ring and a tree layout: one for hot tap water, one for heating and one for cooling.

Round 4. Emergency and initial supply

Agreement 16.
The TU Delft will be connected to the system to act as an initial and emergency supplier. The option of connecting greenhouses in Westland as an emergency sources in a later stage is kept open.

Agreement 17.
There will be three phases of connection to the network. First the separate residential areas will be connected to a close-by source or a backup source and will form small stand-alone systems. Then these small systems will be connected to each other in such a way that the back up sources are needed only in cases of a failure at DSM or the Harnaschpolder.

Agreement 18.
For possible future expansion some real options are included in the design. These are a possible connection to other sources Botlek area, greenhouses and other residential areas.

Round 5. Resident participation

Agreement 19.
Inside the houses, a low-temperature heating system will be installed. The in-house system can be switched from heating to cooling.

Round 6. Specification of the design

Agreement 20.
The agreed temperatures are depicted in Figure 14. DSM is allowed to drain off water at higher temperature than they are now. This is a driver for DSM to participate.

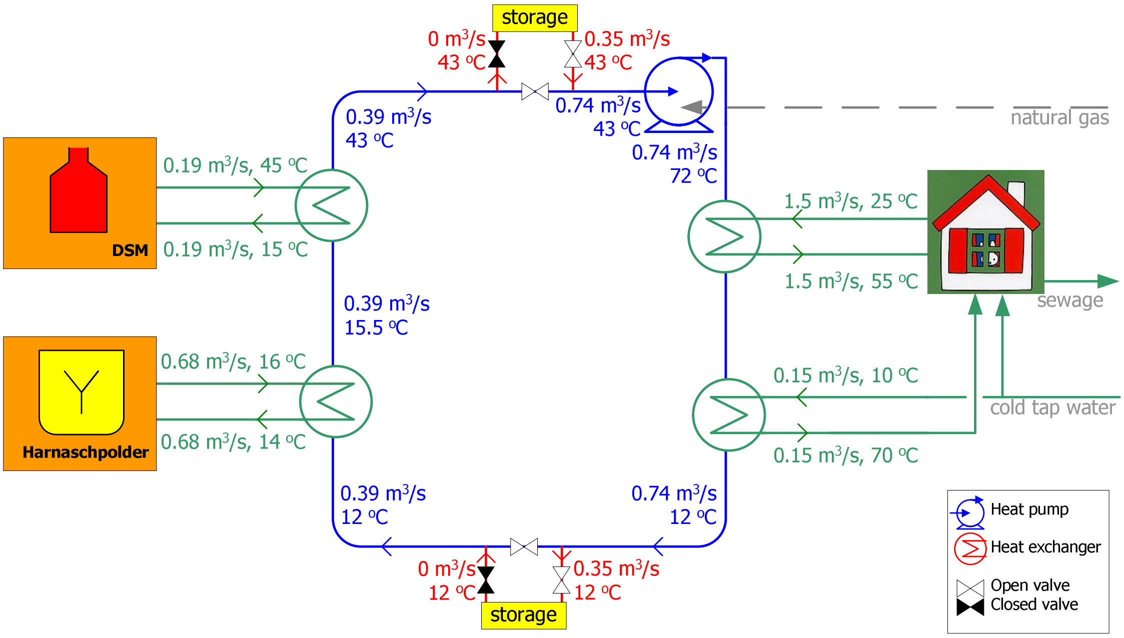

Figure 14. System diagram with temperatures and volume flows at maximum capacity (winter peak).

Agreement 21.
The determination of the tariffs will be based on the new regulation of DTe. A time period for the supply of heat should be fixed. The time period for the supply of heat by DSM and Delfluent will be ten years, as after these ten years competition might be introduced.

Agreement 22.
The times of delivery must correspond with the restructuring periods. The connection of households to the network is divided in different phases, as specified in Table 10.

Table 10. Phases of connection to the network.

Period	**Households connected in this period (# w.e.)**	**Total households connected at end of period (# w.e.)**
until 2010	8,500	8,500
2010-2015	5,500	14,000
2015-2020	2,000	16,000
from 2020	3,000	19,000

Round 7. Evaluation

Agreement 23.
Delft municipality, DSM, Delfluent, Eneco, the housing corporations Vidomes, Woonbron and Duwo agree upon a go decision for implementation of the design.

Round 8. Implementation

Agreement 24.
Implementation of in-house equipment is the responsibility of the housing corporation. The housing corporation is free to find a building contractor according to a self-designed tendering procedure.

6.2 Recommendations

In addition to a technical, institutional and process design of the city heating system, there are some recommendations we would like to make to Delft municipality.

A first recommendation relates to conducting additional research regarding certain design aspects. We recommend some further testing and elaboration of the technical design. It may be possible to further optimize the design. If Delft wants to extend the system to include more heat suppliers and more energy sinks, we also recommend to investigate the compatibility of this design with the specifications of the heat suppliers from the Rotterdam Harbour. Since the they deliver heat at higher temperatures, operating temperatures and capacities of the transportation system should be carefully considered. Both research activities should be followed by a sensitivity analysis, in order to determine the sensitivity of the performance of this design to the above mentioned additions and / or improvements. The most relevant performance criteria to take into account in the sensitivity analysis are the costs of the system and the amount CO_2 emissions avoided.

A second recommendation is that Delft municipality should monitor emerging opportunities for introducing competition. Competition in generation and retail of heat is not possible at present, because there is no market price for heat (it is currently considered waste). However, increasing scarcity and price of fossil fuels, in addition to the establishment of a trading scheme in CO_2 emissions, may increase the value of heat, and allow for a market price to be established. If this is the case, competition can and should be introduced in the system, because this reflects government regulation with regard to energy policy.

Finally, we would like to recommend Delft to keep an open mind during regarding the substantial (technical and institutional) design throughout the decision making process. Although Delft can enter the decision making process with our conceptual design, the design process carried trough with stakeholders may yield some unforeseen opportunities and solutions, that can add to the quality of the design.

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8 Appendices

Appendix 1. Requirements from the Basis of Design

The requirements for the technical design consists of:

The energetic system of Delft must increase sustainability (requirement 1):

a) The system should at least in part use energy, which is currently unused.
b) The energy used should replace the current demand for fossil fuels partly.
c) The system's energy sinks must contain at least one form of city heating for Delft.
d) The system must perform with maximum energy efficiency.
e) The system must emit as few greenhouse gas emissions as possible.
f) The system should have minimal negative local, regional and global environmental impact.

The city heating should be in compliance with the user's needs (requirement 2):

a) The size of the energy system must be at least 5% of the yearly energy demand of Delft (while the goal of Delft is to achieve 15% of the energy demand in a sustainable way and this project must be of significance we assume 5% of the energy demand is a reasonable minimum).
b) The supply of energy should be flexible in the way that it is robust with respect to the daily, seasonal and long-term fluctuations in demand.
c) Because of b, the system should use more than one source in order to be robust
d) Because of b, a minimum reserve margin of 20% above current peak demand for expected and unexpected growth of demand must be implemented. Because heat autonomous demand has declined over the past years (see Energie in Nederland, 2005) and the system will be designed for a selected amount of houses, an increase in peak demand is not expected. Therefore, we assume that a reserve margin of 20% of current peak demand is sufficient.
e) The system should have a reliability of at least 99,5% (general assumed figure, which equals a maximum of 44 hours of non delivery per year)
f) The system should have maximum reliability
g) The system must deliver heat at the correct temperature, depending on the technical solution. For hot tap water, this temperature should be at least 66.5 ^{o}C. For low temperature heating, this should be 55^{o} C and for radiator heating, this should be 90 ^{o}C (Novem, 2002).

The system has to be technically and economically and legally feasible (requirement 3):

a) The system must be safe enough to at least meet the law for individual risks and the norm for group risks (see Ministry of VROM, 2005 for details on how this should be done in practice).
b) The systems lifetime must be secured for a minimum of 35 years (35 years is used as technical lifetime for heat system for glass houses by Kempkes and De Zwart (2002)).
c) There needs to be an arrangement to secure heat delivery after the systems lifetime expiration.
d) The system should have the highest profitability possible to lower the costs for citizens.
e) The energy costs increase for citizens who use the system must be below 15% (15% seems reasonably defendable in achieving support by customers).
f) The system should use as much as possible potential financial incentives of governmental organizations that support the development of sustainable energy systems.
g) The system must contain at least one energy source (this requirement is however redundant because of requirement 2c).
h) The system must contain at least one energy sink.

i) The system must fit to current households equipment with minimal additional costs (fixed, applications, maintenance), hinder and downtime.

The requirements for the institutional design consists of:

The design has to match with the institutional environment (requirement 1):

a) contribute to the reduction of green house gasses, thereby following the regional, national, European and global laws, directives and protocols, as described in Appendix 5;
b) be in accordance with the existing values and norms in our society, as described in Appendix 5;
c) be in accordance with all national, European and global laws;
d) be in accordance with the goals and expectations written down in the Delft municipal 3E plan which in total reduce the CO_2 emission reduction with 33500 ton per year in 2012.

Based on Original Institutional Economics:
The design has to take into account that trust and competence building are important to this project (requirement 2);

a) utilize knowledge present with different parties;
b) contribute to the creation of trust between parties;

Based on layer three from the model of Williamson the following requirements were derived:
The design has coordinate transactions efficiently (requirement 3):

a) include governance structures to coordinate the interactions between actors in the most efficient way (keeping in mind Transaction Costs Economics);
b) take into account the possible subsidies available to support the costs of implementing such a design;
c) reconsider the way the tariffs are set up;
d) make sure that the design fits with the liberalized energy market;

Based on level four the following requirements are important:
The design has to deal with appropriate definitions of actors and games (requirement 4):

a) deal with problems arising from unclear sewage water and CO_2-credit property rights;
b) use the advantages of PPP to create a base for support among stakeholders;

The requirements for the process design consists of:

Critical actors must participate during the whole decision-making process (requirement 1).

The process should have low entry and exit barriers (requirement 2).

The core values of a future network operator, the housing association, the heat supplier and the developer must be protected (requirement 3):

a) Improvement and maintenance of construction and technical quality and/or the lettability of the buildings for the housing association
b) Continuity and making profits for a future network operator
c) Continuity and making profits for the heat supplier
d) Continuity and making profits for the developers

At the beginning of the process a process manager must be selected. The choice for this process manager must be based on consensus within the group of critical actors (requirement 4).

Depending on the group of critical actors, experts must be consulted in order to guarantee the substance of the process; the actors must agree upon the choice for these experts (requirement 5).

The process must consist of different steps: the process design must explicit the deliverables, actors and roles, rules and structure of each step (requirement 6).

Appendix 2. Stakeholder analysis from first phase

	Problem perception				**Interests**	**Goals**
Actor	*Norm*	*Core of the problems*	*Opportunities*	*Influential instruments*		
Public actors						
EU	No deterioration of welfare in the EU	Creation of city-heating system based on waste heat, contributing to cleaner environment, but that has to fulfill directives	Possibilities for implementing this system in other EU countries when it turns out to be a success	Decision-making authorities Regulation and Rules Subsidies	Maximum welfare in the EU	A sustainable and efficient city heating system, fulfilling the EU Directives
Min VROM	No deterioration of living environment	Restructuring process of districts, with the use of waste heat	Possible improvement of the living environment	Decision-making authorities Regulation and Rules Subsidies	Maintenance of cities, a vital countryside, sustainable development of society, healthy and safe living environment, sustainable consumption en freedom to choose.	A city-heating system that contributes to a better living environment
Min EZ	No deterioration of economic position	The creation of a city-heating system with waste heat from industry water, that probably needs subsidies from the government	Possible improvement of the lettability of certain districts, improving the position of the housing corporations	Decision-making authorities Regulation and Rules Subsidies	Market in which entrepreneurs can prosper, in which there are equal chances, in which consumers have optimal freedom to choose and in which public interests are safeguarded.	An energy system which is economically efficient
Min V&W	No deterioration of the Dutch waterways and highways	The creation of a city-heating system with the use of waste heat		Decision-making authorities	Protecting the Netherlands against the negative influences of water and	A city-heating system based on industry water, that

		from industry water		Regulation and Rules	providing it with safe, world-class connections (www.venw.nl)	efficiently uses this water
NEa (part of VROM until 2006)	Reduction of greenhouse gas emissions in The Netherlands	The creation of a city heating system which will probably emit less CO_2 and NO_x than the conventional system	Possibilities for implementing this system in other municipalities when it turns out to be a success	Supervision (monitoring, sanctioning)	Compliance of the Dutch firms to the rules and regulations for trade in NO_x and CO_2 emission rights	A sustainable and efficient city heating system, fulfilling part of the reduction targets
Province Zuid Holland	No deterioration of the position of Zuid Holland	Efficient use of waste heat from industry and other sources in Zuid Holland for city-heating	Possibilities for implementing the same system in other municipalities when this system turns out to be a success	Decision-making authorities Regulation and Rules	Maximum welfare in the province of Zuid Holland	A sustainable and efficient city heating system that creates satisfaction for stakeholders
Delft municipality	A sustainable city: a city that gives a central position to the future value of the city, that handles space, resources and energy in a sensible way, a city that unequivocally chooses for sustainable urban development (Delft municipality, 2004)	Creation of a city heating system that has to fulfil the requirements of sustainability and has to satisfy the inhabitants	Possibilities for implementing the same system in other districts when this system turns out to be a success Improvement of the municipality's reputation as a sustainable city	Decision-making authorities Regulation and Rules License allotment Subsidies Participation / Agreement	Maximum welfare of Delft	A sustainable and efficient city heating system that creates satisfaction for inhabitants
Rotterdam municipality	No deterioration of economic position of Rotterdam	Creation of a city heating system in Delft with the use of	Possibilities for implementing the same system in Rotterdam when	Decision-making authorities	Maximum welfare of Rotterdam	Optimize economic activity Botlek area

		heat from Botlek	this system turns out to be a success More income from taxes	Regulation and Rules License allotment Subsidies Participation / Agreement		
Midden Delfland municipality	No deterioration of economic position of Midden Delfland	Creation of a city heating system for Delft with the use of heat from the AWZI Harnaschpolder	Possibilities for implementing the same system in Westland when this system turns out to be a success More income from taxes	Decision-making authorities Regulation and Rules License allotment Subsidies Participation / Agreement	Maximum welfare of Midden Delfland	Optimize the economic position of AWZI Harnaschpolder
Westland municipality	No deterioration of economic position of Westland	Creation of a city heating system for Delft with the use of waste heat. This system may possibly also supply the greenhouses.	Possibilities for supplying the greenhouses in Midden Delfland with the city heating system	Decision-making authorities Regulation and Rules License allotment Subsidies Participation / Agreement	Maximum welfare of Westland	Optimize the economic position of Midden Delfland greenhouses

HHD (Body of surveyors of dikes of Delfland)	No deterioration of quality of Delfland waters	The creation of a city-heating system with the use of waste heat	Improvement in efficiency of the use of waste water Improvement of the reputation of HHD	License allotment	Improvement and maintenance of the water barrage, water management and water quality in Delfland (www.hhdelfland.nl)	Efficient and maintaining use of Delfland waters
Heat company Rotterdam	No deterioration of operational flexibility No deterioration of profits	The creation of a city-heating system with the use of waste heat	Possible cooperation with a future heat company in Delft	Market knowledge Technical knowledge	Optimal use of waste water from companies in the Rotterdam port area, waste processing industries and power plants for the use of city heating	Making profits form possible future cooperation
TU Delft	No deterioration of TU Delft education and research	The creation of a city-heating system with the use of waste heat, where the CHP of the TU Delft can be used as an emergency supplier	More income by functioning as an emergency supplier	Technical knowledge	Optimal quality of education and research	Making profits from functioning as an emergency supplier

Private actors						
Distribution network operator	Limited additional costs from maintaining the network	Creation of a city-heating system with the use of waste heat and the need for technical restructuring Possibility of income loss due to higher energy efficiency	Gaining experience with the construction the new system, thereby improving their competitive advantage Enlarging market power on energy	Market knowledge Technical knowledge Blocking power	Continuity	Making profits from the implementation of the new system

			generation market			
Eneco	No decrease of profits	Creation of a city-heating system with the use of waste heat, where the current gas network will become useless in the restructured area. The new system requires a network operator. This network operator may be different from the current.	Vertical integration	Market knowledge Technical knowledge Blocking power	Continuity	Remain the network operator, from the electricity network as well as the new network
Other energy companies	No reduction of profits (no income loss caused by higher energy efficiency)	Creation of a city-heating system with the use of waste heat and the need for technical restructuring Possibility of income loss due to higher energy efficiency	Gaining experience with the construction the new system, thereby improving their competitive advantage Enlarging market share	Market knowledge Technical knowledge Blocking power	Continuity	Making profits from the implementation of the new system
Project Developers	No reduction of profits	Creation of a city-heating system in restructuring projects, with the use of different technologies than usual	Gaining experience with the construction of buildings with the new system, thereby improving their competitive advantage	Blocking power Market knowledge Technical knowledge	Continuity, profit	Obtaining an attractive contract for building a city heating system
Housing corporations	Increase of lettability of the buildings that are to be restructured	The creation of a city-heating system in districts that are to be restructured	Improvement of the lettability of the buildings	Ownership rights Blocking power	Improvement and maintenance of construction and technical quality and/or the lettability of the buildings (see	Energy savings and comfort improvement in restructuring projects in order to fulfil the construction, technical and architectural quality (see

					Waals, et al., 2000)	Waals, et al., 2000)
DSM	No reduction of profits, no increase of costs	Waste heat of DSM has to be used for city heating	Possibilities for a better overall efficiency and therefore possibilities for higher profits Image improvement	Blocking power Market knowledge Technical knowledge	Continuity, profits	Making profit out of a city-heating system Achieving CO_2 credits in order to expand activities No distortion of the operational flexibility
Delfluent	No reduction of profits, no increase of costs No additional costs for breach of contract	Waste heat of the AWZI has to be used for city heating	Possibilities for a better overall efficiency and therefore possibilities for higher profits Image improvement	Blocking power Technical knowledge	Continuity, profits	Making profit out of a city-heating system No distortion of the operational flexibility
Botlek area	No reduction of profits, no increase of costs	Waste heat of the Botlek has to be used for city heating	Possibilities for a better overall efficiency and therefore possibilities for higher profits Image improvement	Blocking power Market knowledge Technical knowledge	Continuity, profits	Making profit out of a city-heating system Achieving CO_2 credits in order to admit new companies to Botlek area No distortion of the operational flexibility

Interest groups						
MKB (Association of Dutch middle and small business)	No deterioration of the position of the entrepreneurs	Creation of a city-heating system with the use of waste heat from industrial firms	Image improvement of the Dutch middle and small business	Advising	An entrepreneur-friendly environment in The Netherlands	Development of a city-heating system to the satisfaction of participating Dutch middle and small business
IPO (Inter provincial consultation)	No deterioration of working conditions of provinces and sustained cooperation between provinces	Creation of a city-heating system	Possibilities for cooperation and learning between provinces when the city-heating system will be implemented in other provinces as well	Advising	Optimise working conditions of provinces and stimulation of provincial restructuring processes (www.ipo.nl)	Development of a city heating system
VNG (Association of Dutch municipalities)	No deterioration of the power and quality of local authorities, enough participation of local authorities in decision making process	Creation of a city-heating system within a municipality, upon initiative of the municipality	Possibilities for implementing the same system in other municipalities when this system turns out to be a success Example setting by Delft municipality	Advising (pro-active and on request) during consultations with government, provinces and HHD	Improvement and maintenance of the power and quality of the local authorities	Development of a city-heating system with enough involvement of the local authorities
Platform Bewoners en Duurzaam Bouwen	Increase of number of houses built with sustainability in mind	Creation of a city-heating system with the use of waste heat	Improvement of the sustainability of the construction of buildings and living	Advising	Sustainable construction and living	City heating system implemented in the most sustainable way
LTO	No deterioration of the position agricultural and	Creation of a city-heating system in Delft, which	Possibilities for achieving CO_2 credits when the greenhouses	Advising	A strong economic and social position for farmers, and a	Achieving CO_2 credits when greenhouses are

	horticultural industry.	possibly also will function as heat supplier for the green houses in Westland	are added to the city heating system		sustainable agricultural and horticultural industry in The Netherlands (www.lto.nl)	added to the city heating system
Energiened	No deterioration of the functioning of the energy sector	Creation of a city-heating system with the use of waste heat and the need for technical restructuring	Improvement of image of energy companies	Market knowledge Advising	Creation of a liberalized balanced energy market that functions effectively, a healthy, socially acceptable energy sector, operating in fruitful business climate. (see Energiened)	Implementation of an energy system that contributes to a healthy energy sector
Consumers	No deterioration living environment No increase in costs Reliability of heat supply	Creation of city-heating system which demands adjustments of current systems and takes time	Improvement of the living environment	Blocking power	A highly qualitative and reasonably priced house Maximum reliability of heat supply	Improvement of the comfort and quality of the houses Minimal hinder during implementation Minimal cost increase (energy costs, switching costs, rent increase and additional costs) Maximum reliability of heat supply

Appendix 3. Clarification of covenants

In each part of the process design, different decisions are to be made. Therefore, we first list the decisions that need to be made in the design of the process design and in the decision-making process itself, and the deliverables of these decisions. We identify the actors whose participation is required to make each decision. In order to guarantee speed and substance of the process, we identify catalysts that can be used to motivate actors to participate. Finally, we group decisions in different phases or decision-making rounds.

In our description, when we refer to the participants in a round, we do not name the process manager explicitly, because he is not a stakeholder in the decision making process. However, the process manager is always present.

Clarification start-up covenant

The design of the start-up covenant, containing agreements on the decision making process, is considered the preliminary round in the process. Before any decision making regarding the city heating system can start, there needs to be an understanding of the sense of urgency felt by the different participants, of a problem statement and of process agreements.

The start-up covenant must meet the following requirements:

- It must contain the deliverables mentioned in Table 11.
- It must be convincing for subscribers (Delft municipality, DSM, Delfluent, Eneco, the housing corporations Vidomes, Woonbron and Duwo, SenterNovem and Prof. dr. J.P.M. Groenewegen).
- Considering the new and uncertain nature of the system to be designed, it is important that the decision making process promotes trust and provide opportunities for learning. This must be reflected in the process arrangements.
- The goal of this covenant is to commit parties to the process and to promote trust and learning. Therefore, the agreements must create prospects of gain and thereby protect the core values of participants. For the start-up agreement, this aspect of process quality is more important than progress, substance and openness.

We have designed the start-up covenant based on these requirements and on the deliverables mentioned in Table 11. Below, we provide an explanation of the chosen agreements.

The process manager can be chosen in a discussion between participants. We have chosen Peter Rommens from Delft municipality, department of Programs and Projects (Programma's en Projecten). As mr. Rommens has talked to many of the participants, he has a good understanding of their interests and core values. He also has enough substantial knowledge to lead the process well. It is imperative that the participants I in the process see mr. Rommens as an independent and trustworthy process manager. Therefore, the interests of the municipality must be served by someone other than mr. Rommens, preferably from another department.

An agreement of entry and exit has been added to the covenant. In principle, none of the critical actors should leave the process. The rule has been added however to give parties the feeling that they can always retreat. The process manager must make sure that no one makes use of the right to exit the process. The process should be kept interesting to all parties and their core values must be protected. An agreement about how decisions are reached (i.e. by consensus) is added to convince parties to participate in the process. If decisions are made in consensus, their participation will allow them to influence the outcome of the process. If it is difficult to reach consensus, the progress of the process must be protected by postponing the decision or coupling it with other issues. Another solution may be to transformation the difficult decision into a process agreement. It is the responsibility of the process manager to intervene if decisions cannot easily be made by consensus. Because the district heating system is relatively new, information sharing and learning must be encouraged. In order to remove reluctance to share information, an agreement has been added that parties can protect proprietary information while still bringing it into the process.

Table 11. Decisions, rounds and deliverables start-up covenant.

Decision	Phase / round	Deliverable
Start-up agreement about who feels a sense of urgency, who will be involved	0	1.Creation of sense of urgency 2.Selection of parties and creation of plan: the initiator and a selection of actors that will get involved in the decision-making process 3.Assignment allotment 4. When to involve Botlek 5. When to involve emergency suppliers
Start-up agreement about the problem statement (→ goals and constraints for the decision making process; design space of the decision making process)	0	4.Problem-identification: process manager identifies problem definitions for different stakeholders 5.Formulate design requirements of the decision-making and implementation process 6.Operationalize design requirements
Process agreements (agreements on the use of experts, on the way of discussing (GDR), process manager, rules of the game	0	7.Designing the process: process architect will make some proposals (incl. Planning) 8.Prototyping 9.Commitment to design of decision-making process and implementation process 10.How to deal with the process design in practice 11. Who will be the process manager 12. Go/no-go decision

The before mentioned stakeholders should be convinced of participation in the project. Delft municipality can come up with several reasons to convince them. DSM can be convinced of participation by the prospect on revenues by CO_2 emission permits. Another reason for DSM to participate are the financial rewards they receive for the supply of heat and the image improvement obtained by involvement in the project. For Delfluent the prospect on financial rewards for the heat delivered and image improvement are reasons for participation. Housing Corporations will see advantage in the city heating system since at first it will lead to improvement of the comfort of the buildings. Also, it will give them access to new knowledge and possibilities for learning about such heating systems which may give them an competitive advantage. For the housing corporations as well, image improvement can be another reason to be involved. Eneco will be faced with a loss in demand for gas in the districts where the residential heating system is introduced. Eneco will be compensated for this loss, when participating in the project. Furthermore, Eneco will be given the prospect of making profits from delivering heat and the prospect of realizing integrated energy supply and distribution.

Group sessions only discuss process. Identification of problem statements can be done by the municipality in bilateral meetings. Substantial matters that are to be discussed in the group are postponed to the decision making process.

Clarification of the covenant for the utilization of waste energy for residential heating in Delft

In order to create a covenant decisions are to be made on the technical and institutional design. In Table 13 and Table 12 these decisions, their deliverables and the round the decision should be made in, is represented.

Table 12. Decisions, rounds and deliverables for the technical design.

Decision	Phase / round	Deliverable
Analysis		
Formulation of goals and constraints (= requirements) for technical design	1	List of goals and constraints for the institutional design
Formulation of design space for the technical design	1	Description of design space for the institutional design
Conceptual design		
Decision about which sources and sinks to connect to the network	0	List of sources and sinks
Decision about the general layout of the network	2	General layout of the network
Decision about storage of warm and cold water	3	Definition of storage facilities for warm and cold water
Decision about the location of the pipelines	3	Overview of locations of pipelines
Decision about the placement (location and number) of heat pumps (at MDP or HDS's)	3	Overview of location and number of heat pumps
Decision about when to connect which residential area to the network	4	Overview of phases of connection to the network
Decision about real options: which ones are acceptable?	4	Information about what to do with real options
Decision about which emergency / reserve capacity sources to use (= real options)	4	Emergency and reserve capacity sources
Decision about the type of in-house heating system	5	Type of in-house equipment
Specific design (Technical issues, necessary adjustments heat suppliers)		
Decision about the type of heat pump	6	type of heat pump
Decision about the type of pipelines	6	Type of pipelines
Decision about the type and size of heat exchangers	6	Type and size of heat exchangers
Decision about the type and size of in-house equipment	6	Type of low temperature heating system, additional boilers, etc.
Decision about the maximum connection capacity	6	Definition of the maximum connection capacity
Evaluation		
Decision whether to start the implementation of the project	7	Go/no go decision

Table 13. Decisions, rounds and deliverables for the institutional design.

Decision	Phase / round	Deliverable
Analysis		
Formulation of goals and constraints (= requirements) for institutional design	1	List of goals and constraints for the institutional design
Formulation of design space for the institutional design	1	Description of design space for the institutional design
Conceptual design		
Decision about the general organization of supply, transportation	2	Start-up agreement about the general organization of supply, transportation

Decision about who will be responsible for distribution and transportation	2	Agreement on organizational setup transportation and distribution company
Decision about the organizational setup of transportation company	2	Agreement on organizational setup of transportation company
Decision about who will be the members of the consortium, the conditions for this consortium.	2	The members and conditions of the partnership of the heat company (Warmtebedrijf)
Decision about the organizational setup of relation between building contractor and heat company	2	Agreement on organizational setup of relation between building contractor and heat company
Decision about the distribution and delivery of heat; integrated or not?	2	Agreement on organizational setup and conditions of distribution role: integration of network operation and delivery of heat
Decision about the division of property rights	3	Definition of property rights (CO2, cold and heat)
Decision about the transactions and coordination mechanisms	3	Definition of transactions and coordination mechanisms
Decision about the emergency suppliers and the conditions for emergency supply	4	Definition of emergency suppliers and the conditions for emergency supply
Specific design		
Determining the tariffs and responsibilities	6	Tariffs and responsibilities
Determining the times of delivery	6	Definition of times of delivery
Evaluation		
Decision whether to start the implementation of the project	7	Go/no go decision
Implementation		
Tendering for in-house equipment	8	Definition of selected building contractor for in-house equipment

Per round, the requirements, the decisions, the involved actors, the ways to convince the actors and the needed knowledge will be described. Although important throughout the whole decision making process, some of the design principles mentioned by De Bruijn (2002) will be mentioned here explicitly per round, because of their great importance in that round. What should be noted here is that the fact that decisions are grouped into rounds does not mean that a choice is fixed after the round is closed. In later rounds, decisions may be recalled if this improves the progress or substance of the decision making process.

Round 1. Analysis

During round 1, the following parties should be involved: Delft municipality, DSM, Delfluent, Eneco and the housing corporations Vidomes, Woonbron and Duwo.

The requirements for this round are:

- Being careful with company sensitive information (like profit numbers) in order to protect the parties' core values .
- In order to guarantee the speed and the substance of this round, the process manager should invite an expert as a third party.
- Parties opinions should be fully taken into account by formulating requirements and design space.

During this round the requirements and the design space for the institutional and technical design are formulated. It's obvious that the above mentioned actors are willing to participate in this round, since the formulation of requirements and the design space are determinative for the final designs. For establishing well-defined requirements and a clear design space , we advise to use brain storm sessions and creativity techniques.

Round 2. General layout

During round 2, the following parties should be involved: Delft municipality, DSM, Delfluent, Eneco, Housing corporations Vidomes, Woonbron and Duwo, and the heat suppliers from the Botlek area.

The requirements for this round are:

- In order to guarantee the speed of this round, the process manager should emphasize the importance of keeping this round at a high abstraction level and not to go too deep into details.
- Maps should be used for the visualization of the areas that are to be restructured.
- In case of conflict arising during this round, the process manager should propose package deals and coupling with other decisions.

During this round, the technical decision of the general layout and institutional decisions on organizational set-ups are made. The technical decision of the general layout of the network is substantially coupled with the institutional decision about the general organization of supply, transportation. This decision will be made simultaneously with definition of roles and responsibilities at the conceptual level. To make this set of decisions, the following actors need to be involved. Obviously, Delft municipality needs to be involved as a problem owner. Eneco needs to be involved in this round because its roles and responsibilities will be dealt with. Eneco has an incentive to cooperate because an advantageous organizational and physical setup of the system can compensate for the loss of demand for gas that would occur upon introduction of the system. Eneco is also a potential member of the heat company. First, Eneco has a lot of knowledge as an energy network operator. Second, it will create trust between Eneco and the municipality. We expect that Eneco will want to participate in the heat company because it will give them more control over upstream activities. DSM and Delfluent need to be involved in this round. First of all, the heat suppliers consent with the general layout because they may withdraw from the process. They will want to be involved in this round because the decisions made will determine whom they sell their heat to. Making them a member of the heat company will increase their commitment to the city heating system and will them to keep delivering heat. The ROM Rijnmond project shows that heat suppliers were interested in becoming a member of the heat company. The incentives have to do with a better relationship with the municipality, with an improved image and with an increase in power. Another advantage lies in the longer term. When competition develops among suppliers of heat (due to increased scarcity of fossil fuels for instance), they will have a favorable competitive position because trust has already been established. Heat suppliers from the Botlek area may be involved in this round for strategic purposes. Their heat is currently not necessary for a functioning system. However, it is interesting for Delft to have them involved to allow for future expansion of the system and to diminish the power of DSM and Delfluent. If Delft waits too long, heat suppliers from the Botlek area may be involved in other projects (Rotterdam, The Hague, greenhouses, etc). Another reason for their participation is their previous experience with the ROM Rijnmond project. This will enhance learning during process. The incentive for heat suppliers from the Botlek area to participate in this round and in the heat company is similar to the incentives for DSM and Delfluent. Housing corporations should be involved for several reasons. First, if they decide not to connect houses to a city heating system during restructuring, they may endanger the process. Although their participation in the heat company could be useful for learning, there is insufficient reason to involve them. First of all, the decisions that are relevant for them are made during design and implementation, and not during the operational phase. Housing corporations will want to participate in round 2 because it increases their influence on the design. Decisions in this round can be supported by visualization for the general layout and negotiations in separate rooms for the decisions on organizational set-up.

Round 3

During round 3, the following parties should be involved: Delft municipality, DSM, Delfluent Eneco, the housing corporations Vidomes, Woonbron and Duwo, the selected building contractor for infrastructure, the heat suppliers from the Botlek area, the Platform Warmtetarieven and the Ministries of Economic Affairs and VROM.

The requirements for this round are:

- The participants of this round should be up to date with the laws and regulations that are to be applied.
- Due to the complexity of the decisions that are to be made in this round, openness is very important is this round. Therefore the process manager should guarantee the transparency of this round, clearly explaining the process course.
- The experts conducted in this round may not become participants in the process.
- The process manager should be aware of possible strategic behavior and should watch out for non-substantial discussions (de Bruijn et al, 1999).
- The process manager should keep track of the winners and the losers in this round and take this into account for the future decisions.
- The process manager should be aware that actors are participating in this round as themselves as well as members of the heat company, which might lead to strategic behavior.

In round 3 technical decisions on locations and institutional decisions on property rights and transactions are made.

The property rights for heat, cold and CO_2 credits need to be defined. Because this is a strategic issue, concerning the parties' prospects on making profits, this decision cannot easily be made. By coupling it to other decisions, it will be easier to find a satisfying solution.

Besides defining property rights, the definition of transactions and coordination mechanisms is crucial. The appropriate allocation of CO_2 credits however also depends on the chosen technical solutions. For instance, the way storage is executed, and the location of pipelines and heat pumps determine the energy and CO_2 savings. Therefore these issues will be dealt with in the same round. The result is a set of negotiations between transaction members, i.e. Delft, DSM, Delfluent, heat suppliers from the Botlek area, Eneco (as members of the heat company and as themselves), housing corporation and Platform Warmtetarieven. In this negotiation round, all parties except Platform Warmtetarieven have the prospect of making profits. As long as this is the case, there is no need for a another specific catalyst to enhance progress. Platform Warmtetarieven have a clear incentive to participate. They want decisions to be made such that households will not be paying more for their energy than they would with a conventional system.

CO_2 credits are a way to commit DSM and Delfluent (and in the future other heat suppliers) to the project. Obtaining CO_2 credits is a reason for heat suppliers to participate in the project and therefore also in this round. Therefore, the allocation of the property rights for CO_2 is considered critical to the process design. Delft should consider involving the Ministries of Economic Affairs and VROM to achieve this. Therefore, in our design, EZ and VROM will be invited to discuss property rights and allocation of CO_2 credits.

In order to make qualitative decisions on the technical issues, additional expertise will be necessary. Therefore, a technical advice center should be conducted as independent expert.

Round 4

During round 4, the following parties should be involved: Delft municipality, DSM, Delfluent Eneco, the housing corporations Vidomes, Woonbron and Duwo, the selected building contractor for infrastructure the emergency suppliers TU Delft, Greenhouses Westland and the heat suppliers from the Botlek area if they decide to become members of the heat company.

The requirements for this round are:

- In order to guarantee the openness of this round, the new participants should be given the necessary information about the design so far.
- The emergency suppliers TU Delft and the greenhouses should share the necessary technical information in order to make sure that connection is possible.

During round 4 decisions are made about the phases of connection to the network and about emergency and initial supply. The decision about the phases of connection to the network (which residential area when) should be made between the members of the heat company and the housing corporations. Along with this, arrangements should be made for emergency or temporary supply between potential emergency suppliers, Delft municipality, and members of the heat company (Eneco, DSM, Delfluent, heat suppliers from the Botlek area and Delft). According to our technical design, TU Delft and greenhouses in Westland are the most appropriate emergency sources. Once emergency suppliers have been identified, arrangements should be made between them, Delft municipality, and members of the heat company. For the emergency heat suppliers, there is a disincentive for participation. Both parties have or are developing own heating systems. When they supply heat to another system, this will lead to inefficient operation of their own, closed system. However, they can be convinced by providing adequate (financial) compensation for being emergency supplier. Conditions for emergency supply as well as compensation need to be negotiated.

Round 5

During round 5, the following parties should be involved: household representatives, housing corporations, Eneco and Delft municipality.

The requirements for this round are:

- The residents should be provided sufficient information about the different possibilities for in house equipment.
- In the letter they receive as well as in the decision making process, the residents should be made aware that their opinion is of great importance.

In this round, the type of heating system to be placed in households is chosen. This round will be executed with resident participation, after announcement by letters to residents in the areas to be restructured. The incentive to participate is obvious. Eneco wants a choice that will lead to increased consumption. Delft municipality wants the most energy-efficient system. The inhabitants want a system that is comfortable and cheap. The goals of the housing corporations reflect the goals of the inhabitants. The communication process to the residents can be supported by visualization in flyers, media coverage and meetings in the residential areas.

Round 6

During round 6, the following parties should be involved: Delft municipality, DSM, Delfluent, Eneco, Housing corporations Vidomes, Woonbron and Duwo, the selected building contractor for infrastructure, the heat suppliers from the Botlek area if they decide to become members of the heat company and the Platform Warmtetarieven.

The requirements for this round are:

- A clear overview of the technical options should be provided by the experts.
- The experts conducted in this round may not become participants in the process.
- Up-to-date information from the government on tariff-setting should be provided.

In this round the details of the design should be agreed upon. The institutional detail design issues concern the determination of tariffs and responsibilities and the times of delivery. The technical detail design issues concern the operating temperature in different parts of the system. Tariff setting will be done based on the new DTe directive. Here, the 'niet meer dan anders' (not more then otherwhise) principle will be used. A decision about the times of delivery will be made in mutual agreement between Eneco, members of the heat company, Delft and the housing corporations. It depends on the restructuring schedule and the lead times for equipment supply.

Round 7

During round 7, the following parties should be involved: Delft municipality, DSM, Delfluent Eneco, Housing corporations Vidomes, Woonbron and Duwo, the selected building contractor for infrastructure, the heat suppliers from the Botlek area if they decide to become members of the heat company, SenterNovem and Prof. dr. J.P.M. Groenewegen.

The requirements for this round are:

- The experts conducted in this round may not become participants in the process.
- All the participants should agree upon the test used for the evaluation and should commit to the results of these tests.
- The evaluation round should be considered as part of an iterative process.

In this round, the final design is being tested after which the participants decide upon a go/no go decision for the project. SenterNovem will verify and validate the technical design as independent expert and Prof. dr. J.P.M. Groenewegen, Professor of Institutional Economics at TU Delft, will verify and validate the institutional design as independent expert.

All the abovementioned actors are willing to participate in this round, since this round will be the determinative round for the go/no go of the project.

Round 8

During round 8, the following parties should be involved: Delft municipality, DSM, Delfluent Eneco, Housing corporations Vidomes, Woonbron and Duwo, the selected building contractor for infrastructure, the heat suppliers from the Botlek area if they decide to become members of the heat company and the selected building contractor for in-house equipment.

The requirements for this round are:

- The European and national laws and regulations for tendering procedures should be taken into account.

During this round, the tendering of a building contractor for in-house equipment will take place.

Appendix 4. Technical calculations

The technical calculations are made in Excel. An overview of the made calculations is presented in this appendix. The calculations are also the basis for testing the system.

Overview of demand

The calculations of numbers of w.e. (house equivalents) are derived from data from Delft municipality. They are aggregated from street information. We have listed the amounts of w.e. per area and the amounts of w.e. which will be connected over time. This is summarized in Table 14 and Table 15.

Table 14. Numbers of households per residential area.

Residential Area	**Number of households** (w.e./area)
Harnaschpolder	1,200
Spoorzone (including Centre area)	5,759
Poptahof	2,681
TU Noord	1,754
Voorhof	1,652
Buitenhof	5,954

Table 15. Numbers of households connected over time.

Year of connection	**Number of households** (w.e./area)	**Cumulative households**
Now-2010	8,500	8,500
2010-2015	5,500	14,000
2015-2020	2,000	16,000
From 2020	3,000	19,000

With the information of Energiened (Energie in Nederland, 2005) on the average use per w.e. for hot tap water and house heating we calculated the estimated demand, which equals 531 GWh per year. To get a first impression on the balance between demand and supply we calculated 61 MW demand (with a constant demand level). This is used for the back-of-the envelope calculation.

Overview of supply

Supply is delivered by DSM and Harnaschpolder. Flows of DSM are assumed to have a temperature of 45 ^{o}C. Momentarily the temperatures are between 28.6 and 35 ^{o}C, but this is caused by regulated limitations on the temperatures of the effluent of DSM. Process conditions are higher and therefore an average temperature of 45 ^{o}C is assumed. The maximum flow of DSM is 0.34 m^3/s, which is one third of current flow, because two third of production is possibly moving away to China.

The effluent of Harnaschpolder has a temperature of 16 ^{o}C and a flow of 10 m^3/s. These streams are assumed to be at constant temperature and flow throughout the year. The flow of DSM can cool to 15 ^{o}C and Harnaschpolder can cool to 14 ^{o}C. This is assumed to be able to pass energy to the colder streams.

To get a first impression on the balance between demand and supply we calculated 126 MW supply (with a constant demand level).

Back-of-the-envelope-calculation

When comparing the estimated demand of heat of 61 MW with the estimated supply of the sources of 126 MW, it is clear that in principle enough heat is created by the sources DSM and Harnaschpolder. It is still not sure that all of this energy is usable. We will determine this with more detailed calculations.

Reserve capacity

On basis of data of Energiened (Energie in Nederland, 2005) we estimated the needed reserve margin for the capacity of the city heating system. We therefore incorporated 2 trends in the change of demand of heat. The first trend entails the total amount of households. It can rise from 19,000 to 24,000 by connecting more areas than suspected or monotonous increase households per area. The second trend is the decreasing demand for gas for heating and tap water we have seen the last 25 years. We assume the declination of demand has been at a constant rate (which equals 3.25%) and this trend will continue for 10 more years. Than demand will be constant. These trends predict a *decrease* in needed capacity in 40 years of 1.9%. Therefore we assume no reserve capacity is needed.

Capacity of distribution pipelines

On basis of entry capacity (the standards used for end user capacity of gas pipes and electricity lines from Essent (Essent, 2005) the needed capacity of pipelines for house heating and hot tap water is estimated. The estimated needed capacity of individual house pipelines for house heating is 0.61 L/s and for hot tap water 0.20 L/s. The different areas with different amounts of w.e.'s result in the needed capacity presented in Table 16.

Table 16. Needed capacity of distribution pipelines.

Residential Area	Needed capacity distribution pipelines (m^3/s)
Harnaschpolder	0.069 for house heating 0.007 for tap water
Spoorzone (including Centre area)	0.330 for house heating 0.032 for tap water
Poptahof	0.154 for house heating 0.015 for tap water
TU Noord	0.100 for house heating 0.010 for tap water
Voorhof	0.095 for house heating 0.009 for tap water
Buitenhof	0.341 for house heating 0.033 for tap water

Maximum flow in winter peak

The first assumption in this section is the peak demand, which equals two times the average demand in the months house heating is used (8 months per year).
On basis of the temperatures given, chosen and assumed, and the demand calculated, the flows in the distribution system are calculated: 1.09 m^3/s for house heating and 0.11 m^3/s for hot tap water. The system as described here is presented in Figure 15.

With this information the right sub system can be used to calculate an energy balance.

$$\Delta Q = Q_{in} - Q_{out} = 0 \rightarrow Q_{in} = Q_{out}$$

$$\begin{aligned}
&Q_{in} = (C_{p,water}\varphi_v \rho_{water} \Delta T)_{Transpor\_right} = Q_{out} = (C_{p,water}\varphi_v \rho_{water} \Delta T)_{Heating} + (C_{p,water}\varphi_v \rho_{water} \Delta T)_{Tapwater} \rightarrow \\
&C_{p,water}\rho_{water}(\varphi_v \Delta T)_{Transpor\_right} = C_{p,water}\rho_{water}(\varphi_v \Delta T)_{Heating} + C_{p,water}\rho_{water}(\varphi_v \Delta T)_{Tapwater} \rightarrow \\
&\varphi_{v,Transport\_right}\Delta T_{Transport\_right} = \varphi_{v,Heating}\Delta T_{Heating} + \varphi_{v,Tapwater}\Delta T_{Tapwater}
\end{aligned}$$

The temperature of the transport system is estimated to be 43 ^{o}C. This is caused by the temperature of DSM (45 ^{o}C). In this calculation the flow of the transport network is the only unknown figure and can therefore be calculated. Incorporating losses the flow of the transport system is calculated to be 0.74 m^3/s. Assumed is that 5% of the energy gets lost in the transport pipeline.

A heat pump needs to be installed to get the stream in the transport pipe from 43 to 72 ^{o}C. With an energy balance over the heat pump it is calculated that 89 MW of additional energy (of gas) is needed to operate this heat pump. Losses of 10% are assumed in the heat pump and incorporated. While the delivered amount of energy is known to be 163 MW, the Coefficient of performance (COP) of the heat pump can be calculated:

$$COP = \frac{\text{heat supplied}}{\text{energy used}} = 1.83$$

The storage facility is estimated to be able to pump 0.35 m^3/s into the transport pipeline at 43 ^{o}C (the same temperature as in the transport network). This leaves 0.39 m^3/s to be supplied by DSM and Harnaschpolder. With a second energy balance over the left sub system we can calculate flows of DSM and Harnaschpolder:

$$\Delta Q = Q_{in} - Q_{out} = 0 \rightarrow Q_{in} = Q_{out}$$

$$\begin{aligned}
&Q_{in} = (C_{p,water}\varphi_v \rho_{water} \Delta T)_{Harnaschpolder} + (C_{p,water}\varphi_v \rho_{water} \Delta T)_{DSM} = Q_{out} = (C_{p,water}\varphi_v \rho_{water} \Delta T)_{Transport\_left} \rightarrow \\
&C_{p,water}\rho_{water}(\varphi_v \Delta T)_{Harnaschpolder} + C_{p,water}\rho_{water}(\varphi_v \Delta T)_{DSM} = C_{p,water}\rho_{water}(\varphi_v \Delta T)_{Transport\_left} \rightarrow \\
&\varphi_{v,Harnaschpolder}\Delta T_{Harnaschpolder} + \varphi_{v,DSM}\Delta T_{DSM} = \varphi_{v,Transport\_left}\Delta T_{Transport\_left}
\end{aligned}$$

Harnaschpolder is limited in its amount of energy that can be delivered to the cold stream, because it can only heat it up to 15.5 ^{o}C. The low temperature of 16 oC of the stream causes this limitation. With the energy balance this results in a flow of 0.68 m^3/s. The rest of the energy is delivered by DSM. This results in a flow of 0.19 m^3/s, which is within the possibilities of DSM (which has the maximum of 0.34 m^3/s).

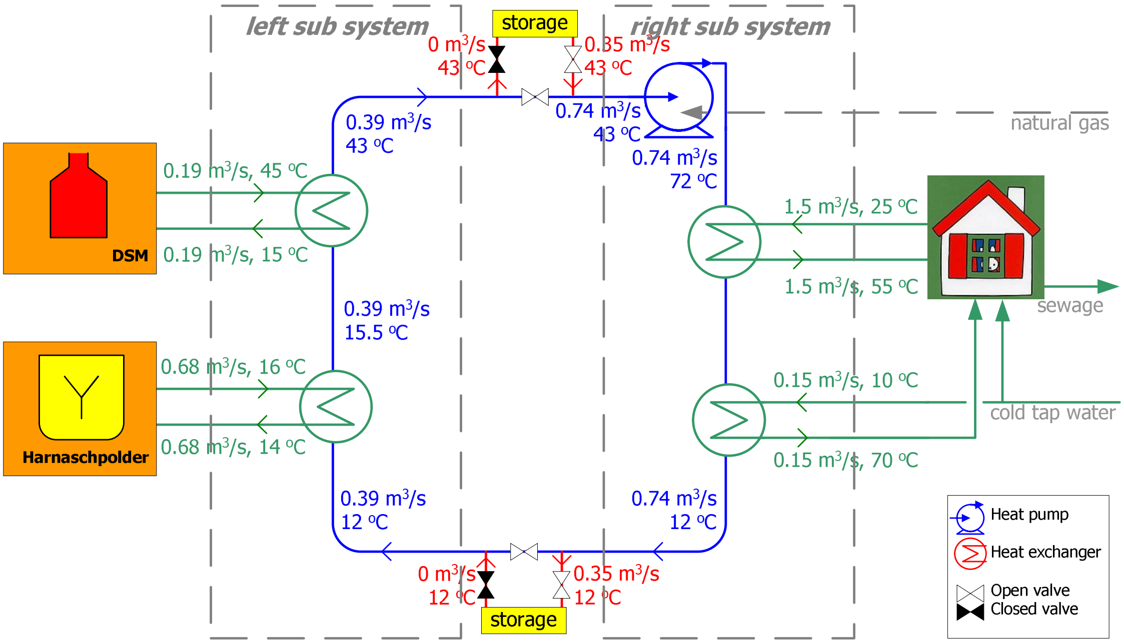

Figure 15. System diagram with sub systems.

Comparison with regular system

The system with a heat pump is compared to a regular system with all individual house heating and tap water systems on gas. The heat pump energy demand is estimated on the average demand, which is 30 MW. This is realized by reversing the assumption for the peak demand. (Two times the average energy demand during the 8 months that house heating is enabled). This results in 261 GWh of energy use by the heat pump per year. The use of energy in a gas system is estimated based on the data of Energiened (Energie in Nederland, 2005). This figure is made comparable with the one for the heat pump and equals 532 GWh. This proves that the city heating system saves energy. The energy saved is estimated to be 270 GWh, and represents 49.1% of the energy used in the regular gas system.

Dealing with fluctuations in demand

Fluctuations in demand can be displayed in a load duration curve. A load duration curve for natural gas demand is displayed in Figure 16. We assume this is comparable to the Dutch situation. VREG (2003) states that the profiles for cooking and heating are similar so we assume the profile is shaped equally for heat demand in the Netherlands.

In the figure line A is the yearly average natural gas demand for house holds in Flanders. B represents the difference between peak demand and average demand. C represents the average demand. In our calculations we assumed that the peak demand of heat in winter will not be larger than two times the average demand. To validate this figure, we compare this with natural gas demand found by VREG (2003). *R* represents the ratio of the peak demand over average demand. For Figure 16 *R* is defined as:

$$R = \frac{B + C}{C}$$

R is estimated to be 1.9. This is smaller than 2, so our assumption holds.

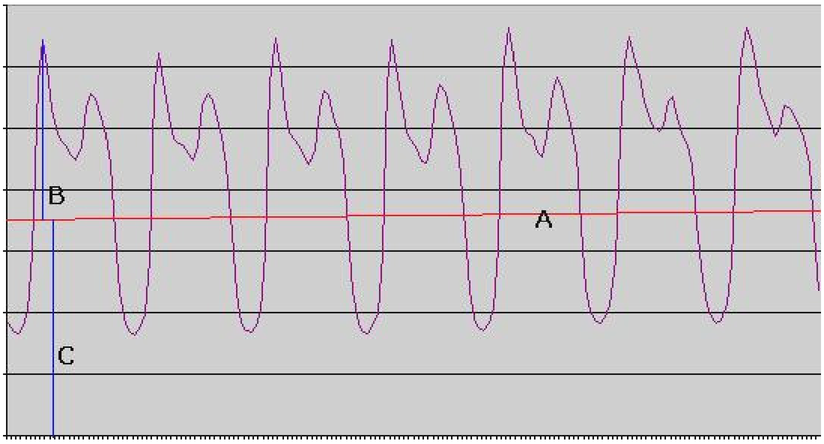

Figure 16. Yearly load duration curve for natural gas demand (VREG, 2003).

Appendix 5. Four layer Framework

Table 17 Four-layer framework, based on Williamson (1998).

Four-layer framework	
Level 1 Culture and values	Environmental concern, taking responsibilities Conscience of limitation of resources Value of image; giving the right example Innovativeness is rewarded Poldermodel
Level 2 Laws and formal policy	Kyoto protocol 2003/87/EG: Greenhouse Gas emission trading 2004/17/EC: Public procurement procedures NMP 4 (national environmental policy) Beleidsplan Milieu en Water (provincial environmental policy) New policy on heat tariffs (Dte) 3E: Klimaatplan Delft (municipality's environmental policy)
Level 3 Institutional arrangements	Contacts, negotiations and agreements between Delft municipality, DSM and the HHR Delfland Subsidies, Tariff structures Governance: Public procurement procedures, ownership structures, governance structures
Level 4 Actors and games	Public parties: EU, VROM, EZ, V&W, NEa, Province Zuid-Holland, Delft municipality, municipalities around Delft (Rotterdam, Westland, Midden Delfland,), HHD, Warmtebedrijf Rotterdam, Private parties and interest groups DSM Gist, Delfluent, Botlek area, Project developers, Housing associations, Energy companies and network operator, TU Delft, EnergieNed, IPO, VNG, MKB Nederland, LTO Nederland, Platform Bewoners en Duurzaam Bouwen Research institutions ECN, Senter Novem, Infomil, RMNO