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SUMMARY .......................................................................................................................... 5

1. INTRODUCTION ........................................................................................................... 7
   1.1 Role of natural gas ......................................................................................................... 7
   1.2 Bio-energy and green gas ............................................................................................... 8
   1.3 Green gas technology .................................................................................................. 9
       1.3.1 Digestion ................................................................................................................. 9
       1.3.2 Gasification ........................................................................................................... 10
   1.4 Opportunities for entrepreneurs ............................................................................... 11
   1.5 Present barriers ......................................................................................................... 11
   1.6 Gasunie ....................................................................................................................... 12
   1.7 Research proposal ....................................................................................................... 13
   1.8 Structure of this report ............................................................................................... 14

2. THE DIFFUSION FRAMEWORK OF GREEN GAS TECHNOLOGY .................................. 15
   2.1 Innovation system ........................................................................................................ 15
   2.2 Elements of innovation systems .................................................................................. 16
   2.3 Functions of innovation systems ................................................................................ 17
   2.4 Technology diffusion process ..................................................................................... 18
   2.5 The mechanisms for green gas technology ................................................................ 20

3. ANALYSIS OF THE DUTCH INNOVATION SYSTEM FOR GREEN GAS TECHNOLOGY ...................................................... 23
   3.1 The long term strategy ................................................................................................. 24
   3.2 The historical trajectory of Dutch green gas technology .............................................. 26
       3.1.1 The trajectory of biomass digestion technology (1976 – 2004) ............................. 26
       3.1.2 The trajectory of biomass gasification technology (1990 – 2004) ......................... 27
   3.3 Current Dutch policy instruments for renewable energy .............................................. 28
   3.4 The potential failure of current innovation system for green gas technology .............. 31
       3.4.1 The short/medium term VS long term energy strategy ...................................... 31
       3.4.2 The failure of current renewable energy policy ................................................... 32
       3.4.3 Lacking national business climate for innovation ............................................... 32
       3.4.4 Weak connectivity ............................................................................................... 33
   3.5 The evaluation of the feasibility level ......................................................................... 33
   3.6 Entrepreneurial activity ............................................................................................. 35

4. CASE STUDY – THE SEARCHING STRATEGY FOR N.V. NEDERLANDSE GASUNIE IN GREEN GAS DEVELOPMENT ............................................................... 37
   4.1 External drivers ........................................................................................................... 38
       4.1.1 Policy requirements .............................................................................................. 38
       4.1.2 Financial drivers .................................................................................................. 39
SUMMARY

Considering the security supply of natural gas and related severe environmental problems, SenterNovem has set a “New Gas” platform with the ambition of 15-20% natural gas replacement by green gas in 2030, which will mainly come from bio-SNG. This transition route can take full advantage from the present Dutch natural gas networks: the existing dense pipeline infrastructure, and gas trade and supply network. Bio-SNG generation, upgraded biogas with a natural gas quality and the green gas injection to the natural gas networks, are the most important gas related innovation technologies of renewable energy. However, currently, the bio-SNG generation and injecting upgraded biogas into the natural gas networks are in the R&D stage. The policy ambition seems always to have a distance with the real feasibility level, and the real involvement of incumbent and new starts energy enterprises in this long-term strategy, may be limited. Thus, the first research question of this report is “whether is it feasible to develop a substantial generation level of green gas in the Netherlands?”. Meanwhile, giving the access for green gas to the natural gas infrastructure is another transition target. Gasunie as the biggest Dutch natural gas transmission company, will face a chance and challenge in implementing green gas in its own networks. Therefore, the second research question focuses on the case study – “Whether is it a business chance for Gasunie to engage in implementing green gas?”.

Based on the problem setting above, it is necessary to understand the energy innovation system, in order to evaluate whether in the future the green gas technologies can be implemented successfully in this system. First, we have drafted a description of the general innovation system. It has multiple actors, including government, research institutes, enterprises, market parties, etc, and includes complex interactions among those actors. It is crucial to consider that the innovation technology is just a part of an innovation system. A fundamental condition for a successful diffusion of an innovation technology, is the existence of a well functioning innovation system, which we can evaluate by five specified innovation functions in an innovation system. The energy innovation system has a mostly similar framework as the general innovation system. However, it has its own features, which makes the energy innovation technologies different from other innovation technologies, like ICT and automation, especially for renewable energy technologies. There features include: a small deployment of the renewable energy; the relative market is not easily formed in a short time; this sector is locked into a fossil fuels based energy system. That means that these technologies may not diffuse spontaneously by the initial involvement of energy enterprises, but mainly depend on the stimulation from the institutional framework (policy orientations and financial supports).

The dynamic of innovation, which is defined as the diffusion with the market penetration, is an important aspect of innovation system. Considering the diffusion chain of Dutch green gas technologies, it seems that the small-scale biomass digestion and gasification are on the pre-commercial stage, after about 30 years and 17 years diffusion, respectively. The trajectory analysis, combined with the evaluation by using five system functions, demonstrates that the past inconsistent and changing Dutch policy had been the main barriers resulting to this low diffusion rate after a long period. The technologies of bio-SNG generation and upgraded biogas injection are just in the R&D stage. Theoretically, it is necessary to pass successfully crucial transition points in the formative period for innovation technologies by attracting sufficient financial support. Both the small-scale and large-scale green gas generation technologies will face such transition points in the coming future. Understanding the potential failures effected by “blocking mechanisms” in the formative period, is important to make a rational prediction for the real development. The strength of “blocking mechanisms” can be reduced by inducement mechanisms with increasing their relative strength.

Positive entrepreneurial activities in developing green gas may not easily appear in a spontaneous way. From the system point of view, the functioning of entrepreneurial activities as an inducement mechanism is limited in this specific situation, and the feedback from market formation is also more depending on the policy stimulation. In other words, the government has to increase the strength of its own mechanisms to develop a protective environment for the involvement of entrepreneurial activities. However, from the current Dutch energy system, the long/medium term natural gas energy policies will be a blocking mechanism for implementing green gas. Beside, current renewable energy subsi-
dies are not sufficient to surpass the transition points for the diffusion of green gas technology. Generally, there also lacks a business climate for innovation, by lacking venture capital, weakness of knowledge transfer, etc.

The lack of success in the past diffusion of digestion/gasification and the current problems to introduce green gas in the energy system increase the uncertainty of a future supportive environment. This uncertainty can not be solved by one enterprise itself, even when some drivers seem to be favourable for the deployment of green gas – A future green gas market may be developed because of a long term energy transition strategy; a green gas market may be facilitated because of the forthcoming legislation about providing access for the green gas in natural gas networks; focus on green gas may improve a “Green Company Image”.

Gasunie may expect a higher business chance of offering access to bio-SNG in high pressure transmission lines, compared to small-scale biogas in a cost-benefits point of view. However, because of the potential problems in the energy innovation system, the expected potential of bio-SNG can not be guaranteed. The Netherlands has a separate and complex gas trading system, and the gas transmission company shall draft the quality requirements. However, the current ambiguous entrepreneurial agenda about setting criteria for green gas quality may become a barrier for injecting green gas into the natural gas grid as expected. As an incumbent based transmission company, Gasunie’s business is mainly influenced by the demand of suppliers and shippers, which means that the lack of supportive environment may directly limit suppliers’ involvement, and the substantial involvement at current and short term stage may not be necessary for Gasunie. An incremental strategy coping with the policy orientations, will likely be the direction for the Gasunie sustainable strategy searching for green gas. The current careful involvement is mainly by increasing the competitive advantage with a green image.

The enterprise may not spontaneously develop the green gas technologies. A successful diffusion of green gas technologies, especially, requires a protected environment from government policy, enough financial support, etc. However, the system is dynamic. Although the policy is important, the successful diffusion of green gas technology can be stimulated by many other functions, e.g. the collaboration among enterprises. Thus, it would be wise to remain optimistic about the long term feasibility, but with a sensitivity to the potential barriers in an energy system.
1. INTRODUCTION

1.1 Role of natural gas

In the Netherlands annually almost 3,300 PJ of primary energy is consumed for the production of electricity, heat, transportation fuels, and chemicals and other products. In 2004, Natural gas consumption represents about 46% of the Dutch (primary) energy consumption (Figure 1.1). The main applications of natural gas are chemistry (7%), electricity generation (23%), and – by far the largest application – the production of heat (70%), of which 40% is consumed by households (more than 400 PJ) (Statistics Netherlands, 2006). Outside industry, essentially, all heat is produced from natural gas (Zwart et al., 2006). Meanwhile, about 51% natural gas was exported (IEA, 2004)\(^1\), which contributed 0.3% points to the Dutch economic growth in 2004 (CBS, 2004). Obviously, natural gas plays a very important role in the energy consumption of industries and households sectors, also contributes to the national economic growth.

Figure 1.1 The share of total primary energy supply in 2004, the Netherlands (2006, IEA)

In the World Energy Outlook 2004, it is predicted that the consumption of natural gas will increase (in absolute numbers) over any other energy source. The global consumption of natural gas will be doubled in 2030. In the period till 2020, the European demand for natural gas will increase with annually 2-3%, as a result of changing feed-stocks in the electricity sector (IEA, 1999). The global reserves seem large enough to accommodate the growing demand in natural gas. Currently, the EU covers approximately 60% of its own consumption, mainly from the production in the Netherlands and the United Kingdom (approximately 50%) (Zwart et al., 2006). Although the dependency on import in EU is considered as a problem, the situation for natural gas is much more positive compared to coal and oil. However, in 2004, UK already became a net natural gas importer for the first time since 1998 (DTI, 2006). The production of natural gas in the Netherlands, will reach its maximum in medium time and will gradually decrease later on. Due to the increasing demand for natural gas and the decreasing resources, the import dependency on natural gas in EU will increase to approximately 70% in 2020. Furthermore, the gas will have to be imported from outside EU, e.g. Russia, Africa and the Middle East. A part of the required gas will be imported in liquid form (e.g. Liquefied Natural Gas or LNG), from more distant locations. However, both higher costs and risks are associated with these developments and the dependency on some politically less stable countries (Zwart et al., 2006).

1.2 Bio-energy and green gas

Considering the security supply of natural gas and related severe environmental problems, renewable energies are considered to be essential contributors to the energy supply portfolio as they contribute to reduce the dependency on fossil fuel resources. Especially, biomass accounted for 90% of the renewable energy supply in the Netherlands in 2001 (Figure 1.2). Bio-energy as a substitution for the fossil fuel energy is already on the policy agenda. Dutch government has ambition to implement at least 30% replacement of fossil raw materials by biobased raw materials in 2030.

Figure 1.2 Total Dutch renewable energy supply and policy timeline (2004, IEA)

Dutch government is considering the measures to reducing CO₂ emission, and foresees market penetration of small-scale systems (gasifiers, anaerobic digestion) in new, green, CO₂ neutral, sustainable dwellings or industrial areas. The substitution of natural gas by a renewable equivalent is an interesting option to reduce the use of fossil fuels and the accompanying greenhouse gas emissions, as well as from the security supply point of view. The renewable alternative for natural gas is the so-called “Green Gas”, e.g. gaseous energy carriers produced from biomass comprising both biogas and bio-SNG. This route can benefit from the advantages of natural gas, like the existing dense infrastructure, trade and supply network, and natural gas applications (Zwart et al., 2006). The Netherlands has an excellent position to play an important role in the implementation of Green Natural Gas in Europe, because of its logistic infrastructure (harbors for biomass import and the Dutch natural gas infrastructure), biomass and natural gas knowledge positions, already widespread application of biomass in the power sector. Meanwhile, the existing natural gas infrastructure has the potential to transmit green gas to the fuel stations as one of the alternative transport fuels.

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2 Bio-energy is defined as the energy from the organic content from waste and biomass (Kwant et al., 2003).
4 Synthetic Natural Gas (SNG) from biomass.
1.3 Green gas technology

The definition of green gas in this report, is the gas produced from biomass by different technologies: First, the biogas is produced by biomass digestion; landfill gas; Bio-SNG is “Synthetic Natural Gas” produced from biomass gasification and methanation (Figure 1.3). Meanwhile, biomass from high temperature (>1200°C) or catalytic gasification can become bio-syngas (“Synthesis Gas”), which consists of H₂ and CO (CO₂, H₂O) (Zwart et al., 2006) (Figure 1.4).

1.3.1 Digestion

Anaerobic digestion of biomass to get biogas has been demonstrated and applied commercially with success in a multitude of situations and for a variety of feedstocks such as organic domestic waste, organic industrial wastes, manure, sludges, etc. In the anaerobic conversion of biomass and waste, organic materials are microbiologically converted to methane, carbon dioxide and water, which can be used to generate heat and/or electricity via secondary conversion technologies like gas engines and turbines (Negro et al., 2007).

This process occurs in nature on all places, where air is excluded from the organic materials. The exclusion can be caused by submersion in water. The methane rich swamp gases are produced by anaerobic digestion. Depletion of oxygen is another trigger for the anaerobic digestion. The production of methane from landfill starts as soon as all environmental oxygen is used by the aerobic conversion of the organic content. In the anaerobic conversion the sulphurous components are converted to hydrogen sulphide and the nitrogenous components are converted to ammonia. Also some traces of hydrogen cyanide can be produced. The rate of the anaerobic digestion is determined by the composition of the reaction mixture and the temperature. The rate of reaction increases with higher temperatures. This increase of the reaction rate is limited by the stability of the microbiological agents in this process. Temperatures to about 55 °C are however feasible (Hagen et al., 2001).

Digestion has a low overall electrical efficiency (roughly 10–15%, strongly depending on the feedstock) and is particularly suited for wet biomass materials (Faaij, 2006). Based on the conventional application of the produced biogas for heat production, the more attractive ones are for combined heat
and power (CHP) and upgraded to natural gas quality. Right now, it is a well-established heat technology for waste treatment, and generally available on a commercial basis.

Another specific source of biogas from digestion is landfills. The production of methane-rich landfill gas from landfill sites makes a significant contribution to atmospheric methane emissions. In many situations, the collection of landfill gas and production of electricity by converting this gas in gas engines is profitable and the application of such systems has become widespread. The benefits are obvious: useful energy carriers are produced from gas that would otherwise contribute to a build-up of GHGs in the atmosphere. This makes landfill gas utilization in general a very attractive GHG mitigation option and is widely adopted throughout the EU (Faaij, 2006).

1.3.2 Gasification

Gasification as a thermo-chemical process converts a diversity of solid fuels (biomass) to combustible gas consisting mainly of hydrogen and carbon monoxide, which can be used for heat and/or power generation, or syngas in chemical industry. It can also be used to produce liquid fuels or hydrogen (after additional reforming and shifting process steps), or be upgraded to substitute natural gas (after additional methanation/gas conditioning process steps), and may be distributed through the existing gas infrastructure (Mozaffarian et al., 2003). Figure 1.4 shows the current types of biomass gasification technologies.

![Diagram of biomass gasification types](image)

**Figure 1.4 The types of biomass gasification (Boerrigter et al., 2005 and Mozaffarian et al., 2003)**

For biomass gasification, the only units that are commercially developed are the circulating fluidised bed (CFB, typically 900°C). In larger-scale (CFB) biomass gasification, larger gasifiers (e.g. over several 10s MWth capacity) are generally associated with (Circulating) fluidized bed concepts. At atmospheric pressure (ACFB) gasifiers are used for production of (raw) fuel gas and process heat but not in very large numbers. Biomass integrated gasification/combined cycle (BIG/CC) systems combine flexibility with respect to fuel characteristics with a high electrical efficiency. Electrical efficiencies around 40% (lower heating value (LHV) basis) are possible on a scale of about 30MWe on shorter term (Faaij, 2006). BIG/CC are preferred in which the gas is fired on a gas turbine. Meanwhile as a gas turbine requires a pressurised feed gas, the biomass gasification should be carried out at the pressure of the turbine (typically 5-20 bar) or the atmospherically generated product gas must be pressurised. After low temperature (800-1000°C) biomass gasification, in the methanation section, the cleaned and conditioned product gas with carbon monoxide and carbon dioxide, are converted to SNG – containing mainly CH₄ (Zwart et al., 2006).
1.4 Opportunities for entrepreneurs

“Technology Specific Innovation System” indicates that a new technology is not only determined by technological characteristics, but also by the social system that develops (Negro et al., 2007). It is necessary to understand the key activities, which influence the system functioning and are the requirements for the technology to be developed and widely diffused (Negro et al., 2007). As one of these, entrepreneurial activities are essential. The role of the entrepreneur is to turn the potential of new knowledge development, networks and markets into concrete actions to generate and take advantage of business opportunities (Negro et al., 2007). Besides, entrepreneurial activities are stimulated by many other factors: finance, policy, market and etc. Under the long term energy transition strategy, Dutch enterprises have the opportunities to implement green gas technology.

The Netherlands spent a total of US$ 4.88 billion on government energy R&D between 1974 and 2001. In this period, 15.4% of the total energy R&D budget was allocated to renewable energy R&D (IEA, 2004). Prior to 2000, the Ministry of Economic Affairs managed 25 technology-specific multi-annual programmes covering short and long-term research and development, as well as demonstration and market introduction. The programmes and the specific projects fund were determined by the SenterNovem. SenterNovem reviewed the programmes annually, and an external evaluation was held upon programme completion (IEA, 2004). Thus, industrial R&D can get the financial support for subsidy. Besides, government also provides different subsidies for renewable energy (see Section 3.2).

Directive 2003/55/EC adopted by European Parliament, calls for an admission to the gas network for biogas, which wants to grant a non-discriminatory access to the gas system (European Commission, 2003). In the Dutch Ministry of Economic Affairs, six energy transition platforms are formed that concentrate on different sectors in energy system. One of the transition platforms is dedicated as new gas options. This transition Platform “New Gas” has defined the ambition to replace about 15-20% natural gas by green gas in 2030, and large-scale bio-SNG generation will contribute over than 80% (~240 PJ). Thus, accessing green gas to the Dutch natural gas networks will be another important task of energy transition in the future. The long term policy strategies, the coming regulations and potential financial support will be the incentives for the involvements of energy enterprises.

Meanwhile, green gas not only benefits for EU’s home-market as an energy substitution, the technology transfer and technology collaboration will also be a future business choice. The defined “Clean Development Mechanism” (CDM), is an example. Technology cooperation between entrepreneurs in western and developing countries will improve the development of green gas technology, by the financial incentive from technology trade (Bakker, 2006).

1.5 Present barriers

Even though the social requirements and potentials of green gas are clear, that does not imply that the implementation of green gas will be easy. In the Netherlands, the current realization of national goals regarding the use of biomass energy seems already far behind schedule. Considering the availability of resource, investment for generation and market demand, combined with the 2030 target 30% replacement by biobased raw material, the feasibility for increasing green gas in the future is still a doubt.

Green gas technologies, which can be called “innovation technology”, normally may not offer direct benefits for the individual buyer or investor, instead it can reduce the environmental cost (Jacobsson et al., 2004). Furthermore, it is argued that industrial economics has been locked into fossil fuel-based

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5 The success of a new technology is not (only) determined by technological characteristics but (also) by the social system that develops, diffuses, implements or rejects new technologies. This socio-technical system is labelled as “Technology Specific Innovation System”. (Negro et al., 2007)

6 It was in 2002 prices and exchange rates.

7 Ministry and the Netherlands Agency for Energy and Environment
energy systems through a process of technological and institutional co-evolution, which are driven by path-dependent increasing returns (Unruh, 2000). Thus, government policy is a major inducement mechanism, which influences the diffusion of renewable energy technology (Jacobsson et al., 2004). The gap between government strategies and real financial supports to entrepreneurs is existing, which may block entrepreneurial activities, by lacking the strategy making, knowledge transfer, employee education and investment. Meanwhile, other conventional energy policy may block the implementation of renewable energy technologies. For instance, the Dutch small fields policy and medium term LNG import, although solving the short and medium term supply security issue of natural gas, impacts the development of renewable energy.

Without enough stimulation from policy, the present high uncertainty from market and suppliers gives a negative feedback to policy makers, which may further limit the positive policy making. The still existing technological problems – the influence of adding green gas to natural gas grid, the hazards to gas networks and the safety issues for end user are the other technology uncertainties (MARCOGAZ, 2006), and the not fully available cost data for green gas technology, will be increased by a negative policy. Based on a recent research, the slow diffusion of biomass technology in the past, is caused by the incoherent guidance from the government and a shortage of financial resources (Negro et al., 2007). The future supportive level from government, currently, is ambiguous. Combined with the past unstable policy, a blind optimism seems not realistic. Therefore, this technology may not develop as well as expected in such unsure institutional environment.

It is vital that society continues to develop the various technologies, and gains experiences in their operation as a step towards the future sustainable growth, because of the social responsibility and potential attractiveness from technology itself. It is necessary to understand the innovation system well, and analyse the implementation barriers over technical, economic and political aspects, as it will be helpful for developing green gas technology.

1.6 Gasunie

Entrepreneurial activity has led to the creation of new knowledge, the supply of resources and the development of different types design within each technology field (Jacobsson et al., 2000). In the other word, the activities of entrepreneurs, finally, may influence the diffusion of an innovation technology. For the successful diffusion of green gas technology, different entrepreneurs should be involved in, including suppliers, transmission companies and distribution company, and this success has depended on the collaboration among these entrepreneurs. Green gas has been expected to be an apart in the existed natural gas infrastructure in the future, so the gas transmission company will play an important role in this transition.

N.V. Netherlands Gasunie is the largest natural gas transmission company in the Netherlands, which wants to maintain its strong position in the European market as an independent supplier of gas transport services. For the sustainable development, Gasunie R&D already plays a leading role in a large undergoing international research project of the European Committee. The so called “BONGO” project aims to define quality specifications for biogas and all other types of non-conventional gases, which can be accessed to the gas transmission and distribution system. By the external and internal drivers, Gasunie has the desire to contribute to the NEW GAS transition. However, assessing the state of industrial R&D and making sustainable strategy are particularly problematic in current stage. Even with the potential policy support, it seems still lacking a feasible market, which means that the feedback from the current markets demand is low. Thus, the energy system may not gain enough critical mass to overcome the technological problems (Negro et al., 2007).

8 Areas of expertise. Gasunie Engineering & Technology. [http://www.getgasunie.nl/eng/GET/What%20can%20GET%20do/areas.htm](http://www.getgasunie.nl/eng/GET/What%20can%20GET%20do/areas.htm)

9 “BONGO” is defined as biogas and others in natural gas operations. Here, “Biogas” includes gas from biomass digestion), landfill gas and bio-SNG (from biomass gasification) (Burgel et al., 2006).
In the other hand, the innovation system and market for green gas are dynamic. A proper strategy searching is necessary for enhancing Gasunie’s competitive advantage, by balancing between ambition and feasibility level of the potential market. The financial support, energy policy orientation, potential market and the competition with other entrepreneurial parties will influence company’s strategy making. Therefore, what are the drivers and barriers in a firm level? What can Gasunie learn and do? How does Gasunie balance the short term and long term strategy?

1.7 Research proposal

Research aim
Based on the above problem setting, the aim of this research is to investigate current energy innovation system for green gas implementation, combined with the political and market potential, in order to explain the entrepreneurial activities. The case study will focus on Gasunie’s strategy searching in green gas development.

Research question
Whether is it feasible to develop green gas in the Netherlands, and whether is it a business chance for Gasunie in implementing green gas?

Sub-questions:
- How does the innovation system for green gas technology work, and what are the inducement and blocking mechanisms to this system?
- What were the problems of the biogas technology trajectory in the past?
- What are the performances of current energy innovation system?
- How does the policy influence the market and entrepreneurial activities?
- Whether is it a business chance for Gasunie in implementing green gas?
  - What are the drivers for Gasunie to develop green gas?
  - What are the uncertainties in firm’s level?
  - What can Gasunie learn from the energy innovation system to make the strategy analysis?
  - Where are the directions of current strategy searching?

Boundaries
This research mainly focuses on green gas as a substitution for natural gas. I will use an innovation system framework to investigate the national climate of implying green gas technology, with the theory of technology diffusion. In the case study, this part focuses on Gasunie. The proper strategy analysis will be till 2030, following SenterNovem’s long term strategies.

Research methods
First, literatures research is one of the main resources for this research. The related energy data, policy and market information from the official websites (e.g. IEA, EZ, CBS, ECN, SenterNovem, etc) are other authoritative resources. A well built framework of energy innovation technology system is required. In this established system which is specified for green gas technology, we should evaluate the effective position of different players (government, research institutes, firms, etc), and investigate the inducement and blocking mechanisms in specific diffusion stages.

In the background study, an evaluation of historical system functions can investigate the failure of past innovation system. Meanwhile, based on these, we can evaluate the present national climate for the green gas development. In the case study, the annual report and R&D situation are the first hand information from Gasunie. I will combine the system performances to guide Gasunie making a competitive searching strategy at the firm’s level.
1.8 Structure of this report

Chapter 1 is the general introduction about green gas technology, implementation barriers and the research proposal for this report. In Chapter 2, the theory of innovation system is used to explain how to evaluate the system functioning, and then, an energy innovation system is specified for the diffusion of green gas technologies. Based on the technology diffusion process, in Section 2.5, the inducement and blocking mechanisms in the formative period, are used to investigate the possible failures in this system. Chapter 3 is the evaluation of Dutch energy innovation system for green gas. From the past failures of digestion and gasification diffusion, with the current features of energy innovation system for green gas technologies, the limitations of energy sector and the failures of current national system are discussed. An evaluation of feasibility level is discussed in Section 3.5. In the last Section 3.6, it is important to figure out how the entrepreneurial activities are influenced in this specified innovation system. The next one, Chapter 4 is the case study. The first two sections (Section 4.1 and 4.2), present the external and internal drivers for Gasunie involving in green gas transmission. Section 4.3 lists the current uncertainties for Gasunie. The last two sections, the learning from the innovation system helps Gasunie to make effective strategy searching for implementing green gas, balancing between the drivers and uncertainties. Chapter 5 gives the final conclusion of this research and the general recommendations for the government.
2. THE DIFFUSION FRAMEWORK OF GREEN GAS TECHNOLOGY

Technology is commonly thought of in terms of individual artefacts. However, energy technologies can be better understood as part of large technological systems. Here, the technological system can be considered as the inter-related components connected to a network or infrastructure, which include physical, social and informational elements (Unruh, 2000). In other words, the success of a new technology is not only determined by technological characteristics, but also by the social system that develops, diffuses, implements or rejects new technologies. This socio-technical system is labelled as “Technology Specific Innovation System” (Negro et al., 2007). Meanwhile, changes in technological systems occur at all scales and are often conceptualized in an evolutionary framework with the “dominant design” as basic theory for the establishment of a technological system (Nelson, 1995). In contrast to purely economic arguments, in which perfect markets and fully informed, optimizing agents select the optimal technology, a superior technological variant does not necessarily win out in dominant design framework (Unruh, 2000). Thus, a well understanding on the functions of innovation system is the precondition for developing an innovation technology.

Based on the theory of technology innovation systems, we know that innovation system is a dynamic network with various economic agents. The market penetration shows the maturity stages of technology, which can be called technology diffusion. Since there are differences in terms of the character of technical change and priorities, it is necessary to identify the diffusion stage in market penetration, which we can go beyond these features and understand the diffusion of innovation technology. However, a new technology system may consequently develop very slowly or in a stunted way by many reasons, especially in the early stages of market penetration. The incumbent technology system and some other blocking mechanisms may lock the functions of innovation technology (Figure 2.3). Then, an innovation system failure has occurred. To identify the diffusion stage and investigate the related inducement/blocking mechanisms, are in order to overcome them. In this chapter, I will establish a system framework for green gas, based on the theory of innovation system, to discuss the diffusion and system mechanisms of green gas technology.

2.1 Innovation system

The defined innovation system is: “a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion and utilization of technology” (Carlsson, 1995). As an interaction among production, diffusion, use of new knowledge, innovation system is rather than categorised as a one-way, linear flow from R&D to new products. It is seen as a process of matching technical possibilities to market opportunities, involving multiple interactions and types of learning (Freeman et al., 1997). In Figure 2.1, we can simply find the actors and relationships in a typical technology innovation system. Different elements and their activities of this innovation system influence the system functioning. However, some of these activities are easily locked by some factors in the system, which will block the diffusion of an innovation technology. Furthermore, if we want to un-lock the system, a well understanding of these activities will likely help us to create an insight of the diffusion and the dynamic development of the innovation system. The coming Section 2.2 and 2.3 will be based on the system framework in Figure 2.1 to explain three main elements in technology innovation system, and five functions among these elements.
2.2 Elements of innovation systems

There are many technological systems in a country or a region, and that many actors are involved in several of them. Each of technological systems is seen to be unique and they vary in their ability to develop and diffuse new technology. When the focus is a competition between various technologies, the technology-specific features of the system make this technology specific attractive. Thus, it is necessary to study the characteristics of the specific system associated with an emerging technology (Jacobsson et al., 2000). Three key elements, below, constitute a technological system:

- Actors and their competencies are formal structures with an explicit purpose and they are consciously created (Edquist, 1997). A particularly important actor is a “prime mover” or system builder (Jacobsson et al., 2004).
- Institutions are defined as a set of common habits, routines, established practices, rules, or laws that regulate the relations between individuals and groups. Compared with organization, institutions may develop spontaneously and are often not characterized by a specific purpose (Edquist, 1997).
- Networks constitute important modes for the transfer of tacit and explicit knowledge. In the other words, the knowledge is exchanged between actors by networks.

Actors are technical, financial and/or political, and so powerful, which can initiate or strongly contribute to the development and the diffusion of a new technology, e.g. users, suppliers or venture capitalists or other organization (Jacobsson et al., 2000) (see Figure 2.1). The importance of actors for innovation is obvious. For instance, most formal research and development activities are carried out in organizations such as universities, research institutes, and R&D departments of firms. Entrepreneurs are the most important actors. Entrepreneurs are the main vehicles for technological change in that they carry through innovations. Innovation is often an important precondition for making profit, and therefore a large portion of diffusion and innovation processes in a market economy mainly occur through entrepreneurs. Thus, in addition to production, firms must be able to have a good overall in-
novation performance (Edquist, 1997). Besides, government also plays a vital role in stimulating and formatting an innovation system.

Institutions, by their very nature, regulate the relations between people and groups of people within as well as between and outside the organization. This means that the pattern and the content of communication and interaction in the economy are affected by the institutional set-ups. Institutions affect innovations. Connections between institution and innovation, exist at the level of the entrepreneurs where institutions affect the relations between R&D, production and marketing. They also exist at the level of the market, e.g. the relations between entrepreneurs and between entrepreneurs and households. Feedback mechanisms from consumer’s reaction on new products, durable and selective user-producer relationships, and network relationships are essential to many types of innovation processes. Relations between government agencies and entrepreneurs and stable forms of technology policies are examples at a third level (Edquist, 1997). However, if we want to be more precise about the channels of influence between institutional set-ups of the economy, it may be useful to take the point of departure in various specific functions of institution.

A network is for an identification of new problems and development of new technical solutions, and more general information diffusion networks. It influences the perception of what is possible and desirable, and constrains the individual firm and sets limits to its technology choice (Jacobsson et al., 2000). It is a channel for the transfer of tacit and explicit knowledge (See the flow lines in Figure 2.1).

Technological innovation is here regarded as the introduction into the economy of new knowledge or new combinations of existing knowledge, which means that innovation is looked upon mainly as the result of interactive learning processes: Interaction does not only take place in connection with R&D but also in relation to normal and everyday economic activities such as procurement, production, and marketing; the interaction occurs within entrepreneurs (between different individuals or departments), consumers, and other organizations like public agencies (Edquist, 1997). Thus, the defined elements above have their interactive functions, which contribute to the innovation system.

2.3 Functions of innovation systems

Be aware of the characteristics of innovation system elements, the innovation is both an individual and a collective act (Jacobsson et al, 2000). Innovation systems can be all represented as sets of institutional actors and interactions, having as their ultimate goal – the generation and adoption of innovations at some level of aggregation (country, region, industrial sector, technology, etc). A successful innovation technology means it should be developed and widely diffused. Thus, the positive activities of these system elements are required, which can be called “Functions of Innovation Systems” (Negro et al, 2007).

The concept of system functions was developed by Jacobsson and Johnson (2000), who defined it as “a contribution of a component or a set of component to a system performance”. Technology specific innovation system may be described and analysed in terms of its “functional pattern”, and the below key functions are set for Technology Specific Innovation System (Hekkert et al, forthcoming; Jacobsson et al, 2004; Johnson, 2001 and Negro et al, 2007).

Function 1: Creation and diffusion of new knowledge
The initial creation of knowledge is the essential start for innovation. Then mechanisms of learning are the heart of an innovation process. According to Lundvall “the most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning” (Lundvall 1992). This function includes “learning by searching” and “learning by doing”. The knowledge diffusion by networks is related to co-ordination with different actors, which promotes the co-operation between them (Johnson, 2001). During the knowledge diffusion, it may be important to get feedback from the performance of innovation system and goals by network. The network will consist of the structure of the innovation system, which can be considered as an intermediate form of organization
between different market levels. A network also allows policy decisions based on the latest technological insights, and information leading to changing development directions.

**Function 2: Guidance of the search**
This function refers to those activities within the innovation system, which can positively affect the visibility and clarity of specific wants among technology users. For instance, the government announces a goal to aim for a certain percentage of renewable energy in a future year. This event grants a certain degree of regulation or legitimacy to develop the sustainable energy technologies and stimulate the allocation of resources for the development (Negro et al, 2007). Note that guidance of the search is not a sole matter of market research; it is often an interactive and cumulative process of exchanging ideas between technology producers, users, and many other actors, in which the technology itself is not a constant but a variable (Hekkert et al, forthcoming).

**Function 3: Resources mobilisation**
Resources, both financial and human sense, are necessary as a basic input to all the activities within the innovation system. For a specific technology, the allocation of sufficient resources is necessary to make knowledge diffusion possible. In this sense the function can be regarded as an important input to function 1, although obviously the basic supply of ‘skills and riches’ is important to other functions as well. Of course the ubiquity of resources can only be a fact where knowledge (function 1) and confidence (function 2) are sufficiently far developed (Hekkert et al, forthcoming).

**Function 4: Markets formation**
New technology often has difficulty to compete with embedded technologies (Negro et al, 2007). A new innovation is relatively recognized as crude and inefficient, therefore it is important to create protected environment for new technologies. One possible is the formation of temporary niche markets for specific applications of the technology (Kemp et al., 1998). Another possibility is to create a temporary competitive advantage by favourable tax regimes or minimal consumption quotas, which are the support from governmental policy.

**Function 5: Support from advocacy coalitions**
In order to develop well, a new technology has to become part of an incumbent regime, or has to even overthrow it. Parties with vested interests will often oppose to this force of ‘creative destruction’. In that case, advocacy coalitions can function as a catalyst: they put a new technology on the agenda (function 1), lobby for resources (Function 3), favourable tax regimes (function 4) and by doing so create legitimacy (function 2) for a new technological trajectory. If successful advocacy coalition grows in size and influence, it may become power enough to brisk up the spirit of creative destruction. The scale and success of coalition is directly dependent on the available resources (function 3) and the future expectations (function 2) associated with the new technology (Negro et al, 2007).

These functions above provide a tool for setting system borders; can be used as a tool to describe the present state of a system; may be useful for investigating the dynamic innovation system (Johnson, 2001). We also have to be aware that the system functions are not independent from each other but interact and influence with each other. A function fulfilment can lead to positive cycles of processes that strengthen each other, and lead to the building up of momentum to create a process of creative destruction within the incumbent system (Jacobsson et al, 2004)

### 2.4 Technology diffusion process

Technology diffusion is the innovation technology to expand the opportunity set for various economic agents. The success of the new technology is determined by its diffusion (Carlsson, 1991). The process of technological diffusion, first, is a process of variation, selection and retention. It is necessary to understand the inertia of established technology. The second is that it is a process of unfolding, creating “new combinations”, resulting in paths and trajectories (Geels, 2002).
In conceptualisation, TT (Technological Transitions or technology diffusion) consists of a change from one socio-technical configuration to another, involving substitution of technology, as well as changes in other elements. Such reconfiguration processes do not occur easily, because the elements on a socio-technical configuration are linked and aligned to each other. Radically, new technologies have a hard time to break through, because regulations, infrastructure, user practices, maintenance networks are aligned to the existing technology (Geels, 2002). A new technology often requires a long period of nurturing and diffusion, before it becomes an attraction to a larger segment in the market.

Normally, we can use a form of S-curves to describe the diffusion process. This curve indicates how the familiarity with and application of a technology develop over the time. After a hesitant start (the formative period), it comes to a breakthrough stage or a market expansion period, which stands for the knowledge, use of the technology and so on mature enough (Dieperink et al., 2004 and Jacobsson et al., 2004). During the formative period, the S-curve can create indeterminacy in the competitive outcome. Increasing returns in this competitive period are most influential, when positive feedback can give a technology with the right timing or favourable historic conditions, advantages, and than it can lead to market domination (comes to the market expansion period) (Unruh, 2000). Meanwhile, the diffusion process can also be defined as a process with the commercial maturity of a technology by more detailed stages, which may be used to identify the system failure/ gaps and assess the successful commercialisation. The stages of commercial maturity of a technology are defined as below (Foxon et al., 2005) (Figure 2.2):

- Basic and applied R&D includes both university institutes and industry R&D.
- Demonstration includes early prototypes, and is intended to refer up to the point where full scale working devices are installed — but only in single units or small numbers, and financed largely still through R&D related grants. This is often the preserve of small spin outs or research subsidiaries.
- Pre-commercial is for capturing a fairly broad stage of development, one where multiple units of previously demonstration-stage technologies are installed for the first time, and/or where the first few multiples of units move to much larger scale installation for the first time. Larger players begin to move in or spin outs and grow rapidly, so investment risks are high at this stage.
- Supported commercial is the stage where, given generic technology supporting measures technologies are rolled out in substantial numbers and by commercially oriented companies.

Figure 2.2 A simple S diffusion flow of the commercial maturity of technology (Foxon et al., 2005; Unruh 2000 and Jacobsson et al., 2004)
• Commercial technologies can compete unsupported, within the broad regulatory framework.

Apparently, combined with the presented system theory above (Section 2.2 – 2.3), these stages should not only be interpreted as a one-way linear flow in Figure 2.2. The technology progress and related market growth are dynamic, which are derived by more determinants, such as government policy, availability of risk capital, customer demand, etc. A successful formative period is one of the preconditions for the final diffusion of a technology. In the formative stage, it is thought that system failures likely appear to happen in two transition points: from the demonstration to the pre-commercial stage; from the pre-commercial stage to the support commercial stage, which may lead the failures of diffusion by different “blocking mechanisms” (Foxon et al., 2005) (see Figure 2.2). Thus, during this period, we have to understand how the system functions are locked, in order to explain why sometimes a technology diffuses slowly.

We need to go beyond the functions in the formative period and understand the process combined with inducement mechanisms, which may be more helpful for our limited understanding about what the new system is. The conception of dynamic diffusion is helpful for analysing the conditions under which blocking mechanisms have been overcome, when a process of formative period started, or how the diffusion of new technology has been stunted (Jacobsson et al, 2004).

2.5 The mechanisms for green gas technology

In this section, we can use the theoretical mechanisms to figure out the inducement and blocking mechanisms. These mechanisms may induce or block the diffusion of green gas technology in the formative period, and may also influence the functions mentioned in the Section2.3. In Figure 2.3, it shows how the mechanisms and functions interact for green gas technologies. New technology often has cost drawback compared with incumbent technologies, which may not offer direct benefits in short-term for the individuals or producers, instead it reduces environmental cost. Furthermore, the incumbent energy technology still gets subsidies (Jacobsson et al., 2004). These may block the system functions for the renewable technology. For instance, the Dutch primary energy mainly depends on natural gas, and the related new or efficient technology still can get financial support/investment both from government and enterprises, which means that these technologies will compete with green gas technology with high cost advantages.

<table>
<thead>
<tr>
<th>Inducement mechanisms</th>
<th>System functions</th>
<th>Blocking mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government policy</td>
<td>Creative and diffusive of new knowledge</td>
<td>High uncertainty</td>
</tr>
<tr>
<td>Entrepreneurial activities</td>
<td>Challenge of the market</td>
<td>Lack of regulation and legitimacy</td>
</tr>
<tr>
<td>Feedback from market formation</td>
<td>Resource mobilization</td>
<td>Weak uncertainty</td>
</tr>
<tr>
<td>Market formation</td>
<td>Support from advocacy coalition</td>
<td>Ambiguous behavior of established entrepreneurs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>government policy</td>
</tr>
</tbody>
</table>

*Dark lines show the main influences between inducement/blocking mechanisms and functions

**Figure 2.3** The interactions between inducement/blocking mechanisms and functions in the formative period for green gas technology (Unruh., 2002; Jacobsson et al., 2004)
Compared with many other conventional energy technologies, the diffusion of green gas technology is not spontaneous, and requires a well-designed system. Firstly, the government policy is a major inducement mechanism, which is firstly involved in the initial innovation R&D. Then, policy instruments such as R&D funding, demonstration programmes, investment subsidies and legislative changes can stimulate the formation of market (Jacobsson et al., 2004). Meanwhile, the government policy will influence the entrepreneurial activity in an indirectly but a strong way (also see Figure 2.1) by the formed market, I will discuss the relationship further in Section 3.5.

Entrepreneurial activity is another important inducement mechanism in innovation system, which is essential to convert the potential of a new technology to generate and earn business benefits, and to help the market formation. They may help to shape the new technology system by bringing knowledge and resources, enlarging the technology system (e.g. by becoming specialist supplier and developing new application). They also may help to stimulate the positive external economics, e.g. the division of labour (Jacobsson et al., 2004). The entrepreneurial entrants also have an important role in the process of legitimization for a new field. Thus, active entrepreneurial activities will stimulate the system functions. However, a good climate for stimulating entrepreneurial activities seems the precondition for green gas technology, which requires an effective collaboration among different actors or organisations, especially the support from government.

From Figure 2.1, we can find that the feedback from the market will influence many other system elements. Here, it also influences the functioning of system. In current gas market, the biggest player, right now, is still the natural gas with a deep market penetration, by a lower price and stable supply. The feedback from the consumers for green gas is not strong, and the initial market has not been formatted. That means that in present stage, the feedback from market seems not a strong incumbent mechanism compared with the other two mechanisms.

In the other side, some main blocking mechanisms will lock the performance of the system. The first blocking mechanism is the high uncertainty in different sources. It directly or indirectly influences the functions as an obstacle, like the diffusion of knowledge, guidance of the search, markets formation and advocacy coalitions. Because of that, the entrants may be away from the field of new technology. Right now, the uncertainty of green gas generation and injection technology, the quality, the safety issues, etc (MARCOGAZ, 2006), seems slowing down the energy entrepreneurial entrants and also the involvement of positive government policy. The lack of regulation/legitimacy may lock the guidance of the search, market formation and advocacy coalitions. These two blocking mechanisms will further lead the lack of invest and subsidy, and finally impact the technology diffusion at the early stage. However, they are the basic characters for an innovation technology.

Besides, weak connection in terms of weak learning and political networks between different players in a technology innovation system, may also lock the system functions. For instance, in the middle of 1990s, the Dutch government cut off the subsidies for biomass digestion, and one of the possible reasons is that the government expected to change the R&D stage to the commercial stage. As a matter of fact, the market had not been formed yet. Later on, many plants were shut down because of the technological problems and lacking financial supports (Negro et al., 2005). Thus, the weak connection between the politic network and the technological market penetration locks the diffusion of the biomass digestion technology. Besides, the weak connection between research institutes and enterprises is also a potential barrier for technology diffusion.

We already know the important role of government policy, entrepreneurial activities and feedback from market as inducement mechanisms, but the opposing mechanisms may lock the functions at the same time. For the feasibility analysis of implementing green gas in Dutch future infrastructure, we have to figure out which diffusion stage the green gas technology is in for the first, then combining with the analysis of related current inducement/blocking mechanisms, to evaluate the functioning of the present innovation system for green gas technology. Combined with the features of energy system, it will be easy to emphasize the most important inducement mechanisms to reduce the strength of current blocking mechanisms.
3. ANALYSIS OF THE DUTCH INNOVATION SYSTEM FOR GREEN GAS TECHNOLOGY

In the past 30 years of the Netherlands, small-scale biomass digestion technology was in a slow diffusion. Till now, it has not fully been in the pre-commercial stage, and examples are unknown where upgraded biogas from biomass digestion has been added to the natural gas grid. Also, biomass gasification technology is already developed, but it seems diffusing in the same way with digestion technology. From a trajectory analysis, we will find that the system functions were locked by some blocking mechanisms, especially by the inconsistent and changing policy, insufficient financial support and weak connectivity among those actors. Although the Dutch government has the ambition to achieve 15-20% total natural gas replacement by green gas, and bio-SNG will contribute over than 80%, because of the limitation of energy system (Section 3.4.1), a spontaneous market penetration seems impossible for renewable energy. Thus, entrepreneurs may be inevitably hesitating in involving in related projects. From the lesson of past trajectory in the energy innovation system, and the analysis of potential system failures may predict the future diffusion of green gas technologies in a specified energy innovation system.

**Figure 3.1** The current commercial maturity of green gas technology in the Netherlands (Mozaffarian et al., 2003, Zwart et al., 2006 and Raven, 2004)

Before starting the system evaluation, firstly, it is important to figure out the diffusion stages where the current technologies are in, which may help us understand when and where the system failure may happen. The green gas technologies are mainly divided to two types: biogas from small-scale biomass digestion or landfill gas, and SNG from large-scale biomass gasification/methanation. Based on Figure 2.2 and recent researches (Mozaffarian et al., 2003, Zwart et al., 2006 and Raven, 2004), Figure 3.1 presents an approximate assessment of the current stages of commercialisation, for a number of green gas technologies in the Netherlands. In the future, both of two types technologies will face the transition points discussed in the former chapter, which are crucial and sensitive points to a successful diffusion. There are kinds of policy instruments for renewable energy in current situation, which provide different subsidies for different diffusion stages. However, these policies seem still insufficient to stimulate the entrepreneurial entrants and protect the niche markets, which increase the uncertainty of the future protective environment.
As one of the important mechanisms, entrepreneurial activities will finally influence whether an innovation technology succeeds. However, for energy enterprise, this involvement in renewable energy technology is highly limited by the level of external support. The last section focuses on the dilemma for positive entrepreneurial activities in implementing green gas.

3.1 The long term strategy

In 2005, SenterNovem had a biobased raw materials platform – biobased raw materials is estimated by supplying at least 30% replacement of fossil raw materials in 2030 (The ambition level see Table 3.1). In order to implement this platform, the steps including an established certification system, coalitions between government and market, established institutions, jointly cooperation, positive market feedback are required. From a technological perspective, government wants to stimulate the development and implementation of various forms of large-scale and small-scale biorefining, biomass gasification, methanation and synthesis gas production in the future (SenterNovem, 2006).  

Table 3.1 The contributions of biomass to the Dutch energy infrastructure in 2030

<table>
<thead>
<tr>
<th>Application</th>
<th>Consumption (PJ)</th>
<th>Ambition</th>
<th>Feasibility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Replacement by Biomass (%)</td>
<td>Saving fossil energy (PJ)</td>
<td>Replacement by Biomass (%)</td>
</tr>
<tr>
<td>Heat</td>
<td>1090</td>
<td>17</td>
<td>185</td>
</tr>
<tr>
<td>Electricity</td>
<td>810</td>
<td>25</td>
<td>203</td>
</tr>
<tr>
<td>Transportation</td>
<td>540</td>
<td>60</td>
<td>324</td>
</tr>
<tr>
<td>Raw materials</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal industry</td>
<td>65</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chemistry natural gas</td>
<td>123</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chemistry petroleum</td>
<td>315</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Others</td>
<td>57</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total raw materials</td>
<td>560</td>
<td>25</td>
<td>140</td>
</tr>
<tr>
<td>Total</td>
<td>3000</td>
<td>28.4</td>
<td>852</td>
</tr>
</tbody>
</table>

Based on the 30% replacement by biobased raw materials, bio-SNG is estimated to replace 9% (120 PJ) of the total natural gas consumption\(^{11}\), which is almost 18% of the amount of natural gas which is not being used as primary energy or for the production of electricity (Rabou et al., 2006). Table 3.1 shows the comparison between 2030 ambition level and the results of feasibility analysis, by the contribution of biomass to different energy sectors. Even if the existing distance is mainly due to the energy consumption of electricity and transportation, biomass still can contribute about 22% replacement of fossil raw materials in 2030. Clearly, the bioenergy may contribute to the electricity sector with the 12% replacement, instead of 25% ambition. Table 3.2 shows the further details in the feasibility level – the deployment of different biomass technologies contributes to heat and electricity sectors. The bio- SNG will be the direct and biggest contributor to the heat sector, as the replacement of natural gas in 2030.

Table 3.2 The contribution of biomass for Dutch heat and electricity in 2030 (Rabou et al., 2006)

<table>
<thead>
<tr>
<th>Application</th>
<th>Consumption (PJ)</th>
<th>Ambition</th>
<th>Feasibility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Replacement by Biomass (%)</td>
<td>Saving fossil energy (PJ)</td>
<td>Replacement by Biomass (%)</td>
</tr>
<tr>
<td>Heat and Electricity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central electricity production</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>WPI</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Small-scale CHP</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Direct combustion</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SNG</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total heat and electricity</td>
<td>1900</td>
<td>21</td>
<td>388</td>
</tr>
</tbody>
</table>

\(^{a}\) The yield of electricity production can be 40% to 45% through combustion and 50% through gasification with usage in STEGs (Steam and Gasturbine) (Rabou et al., 2006).

\(^{b}\) The saving fossil energy in feasibility level is only approximate calculation.

\(^{c}\) SNG is used as the direct contributor to the heat sector by replacing natural gas.

11 It refers from Platform – Groene Grondstoffen: Biomass in the Dutch energy infrastructure in 2030 (Rabou et al., 2006)
12 In 2030, the 1340 PJ consumption of total natural gas is estimated.
Meanwhile, the government is clear about the dependence on the future import of residue products, semi-manufactured and final products in the future. Table 3.3 shows the prediction of the availability of biomass in 2020. In the period between 2030 and 2040, the expected turnover for biomass imports will be € 2-3 billion (about 70PJ/year biomass import). The positive consequences of biomass import are the following: increased diversity of the primary raw materials for our energy supply, lower prices over the long term for products from biomass than those from fossil oil, lower expenditures for energy imports and reduced expenditures on the trade in CO$_2$ emissions that can amount to € 1-1.5 billion per year (SenterNovem, 2006$^{13}$).

Table 3.3 The availability of domestic biomass for the Netherlands, 1999 and 2020 (De Noord et al., 2004)

<table>
<thead>
<tr>
<th>Type of biomass</th>
<th>1999 PJth</th>
<th>2020 PJth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indigenous energy crops</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Biomass residues</td>
<td>15</td>
<td>25-41</td>
</tr>
<tr>
<td>Biomass waste</td>
<td>19</td>
<td>57-100</td>
</tr>
<tr>
<td>Import from EU</td>
<td>-</td>
<td>Included above</td>
</tr>
<tr>
<td>Import from rest of world</td>
<td>-</td>
<td>Included above</td>
</tr>
<tr>
<td>Total</td>
<td>34</td>
<td>87-146</td>
</tr>
</tbody>
</table>

As a special platform for “New Gas”, its first transition period is from 2007-2010. The government plans to invest € 405 million in total till 2010 for this platform. One of these transition paths is green gas generation from biomass. The replacement of natural gas by green gas is the central in this transition path. In 2030, the contribution of green gas with a higher ambition will replace 20% (300 PJ) natural gas$^{14}$. The potential of (upgraded) biogas and landfill gas in the Netherlands is maximum 60 PJ/year (4% replacement) due to the limited availability of suitable digestible feedstock materials in 2030. To reach this ambition level, bio-SNG production is required at least 240 PJ (Zwart et al., 2006). Because of its higher potential, this transition path has set the priority indications for bio-SNG in a long term transition: develop a technological infrastructure for including bio-SNG in the gas grid and monitoring gas quality; create a level playing field by promoting bio-SNG; develop a market demand (SenterNovem, 2006)$^{15}$. The involved members are from the gas sector and the energy companies (e.g. Gasunie), research institutes (e.g. ECN, university institutes), governments (e.g. EZ, SenterNovem) and other organizations (e.g. CE Delft, the Netherlands Society for Nature and Environment and the Expertise Centre for Sustainable Entrepreneurship)$^{16}$.

Currently, digestion is an available and seems commercially proven technology with widespread implementation on farm scale in recent years, however the bio-SNG generation as mentioned above is under development and realisation, and the first plant would not be expected till 2010. Thus, upgraded biogas will be considered as the first generation of green gas, and used directly for power production, mobility, or injection to a local low-pressure natural gas grid (charged by local distribution companies), with the expected generation of 9.6 PJ/year in 2010. Bio-SNG will be the second generation implemented in a later phase, and the large amounts of SNG would typically be injected to the high or medium pressure national gas grid (charged by Gasunie). Based on a latest research, after 2010, the potential of green gas in the long term is about 5,000 million m$^3$/year (about 160 PJ$^{17}$), which is composed by 1,500 million m$^3$/year upgraded biogas from co-digestion and 3,500 million m$^3$/year bio-SNG (Welink et al., 2007).

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$^{14}$ Green gas will replace 20% natural gas, which is based on current natural gas consumption level (about1500 PJ/year).

$^{15}$ SenterNovem, 2006. Energy transition task force


$^{17}$ 1 m$^3$ green gas = 8.8 Kwh; 10$^9$ Kwh = 3.6 GJ
Obviously, the government is increasing the ambition level on this sustainable energy transition. However, one of the distinct problems seems that there is no benchmarking for these ambition numbers, and some of the information is ambiguous. As a matter of fact, the feasibility level may not be so optimistic. Furthermore the theories of innovation system and functions discussed in Chapter 2, the specified diffusion chain and mechanisms for green gas technologies, can be used to evaluate the historical trajectory and current system performances. It is in order to make a proper evaluation – whether is the current Dutch energy system ready for the successful diffusion of green gas technology in the future.

3.2 The historical trajectory of Dutch green gas technology

The diffusion of innovation technology depends on what it can offer to the existing technological regime. The whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures and institutions and infrastructures that make up the totality of a technology is called a technological regime (Kemp et al., 1998). This phenomenon can be further specified into system barriers to explain a slow diffusion in preferable technologies. Explanations for a slow diffusion can be found by focusing on technological factors, government policy and regulatory framework, cultural and psychological factors, demand and production factors, required infrastructure and maintenance and the undesirable societal and environmental effects of technologies.

In the evolution of innovation technology, the formative period, including R&D, demonstration and pre-commercial stages, normally includes a range of competing designs, small markets, many entrants and high uncertainty in terms of technologies, markets and regulation (Kemp et al., 1998; Jacobsson et al., 2004; Figure 2.2). Furthermore, this period is more important for the successful diffusion of an innovation technology, however many factors seem impeding the development of innovation technology in this period. The uncertainty in terms of technologies, markets and regulation, makes the required investment of this period in a highly risky (Jacobsson et al., 2004). Meanwhile, the industrial economics also have been locked into fossil fuel-based energy systems through a process of technological and institutional co-evolution driven by the path-dependent increasing returns (Unruh, 2000). The infrastructure is based in favour of incumbent technological systems, which blocks the development of a renewable energy technology – a system failure may occur.

System functions (Section 2.3) contributing to the performance of system will be the proper indicators. Positive functions, such as many initial R&D projects, related conference/workshops, governmental explicit targets, subsidies, specific tax regimes, legislation, etc, will contribute to the diffusion of the innovation technology. We can use the functions to evaluate the past performances of energy innovation system, figure out the significant blocking mechanisms and the interactions among them. Finally, we would expect the powerful inducement mechanisms to trigger these functions and overcome the range of potential blocking mechanisms.

3.1.1 The trajectory of biomass digestion technology (1976 – 2004)\textsuperscript{18}

After the past 30 years of development, the current biomass digestion technology can likely be defined as “the existence of a range of competing designs, many small scale entrants and high uncertainty in terms of technologies, markets and regulations”. It had experienced a substantial fluctuation with a low diffusion. Manure digestion had been experimented since the 1970s, and it had become a mature technology in a technological sense. However, the implementation of projects was problematic, probably because of a mismatch between design rules and inconsistent institutions. Furthermore, the unfamiliarity with the technology among governments and entrepreneurs had slowed down the projects.

\textsuperscript{18} Based on a literature research, mainly Negro’s publications about Dutch digestion (Negro et al., 2005 and 2007).
At the beginning, in 1980s, there were some R&D projects and many entrants including the research institutes, governmental institutes, farmers involved in biomass digestion because of the application of digestion in waste regime. At that time, government also operated some platforms and regulations to promote the development of biomass digestion, such as “National research programme for recycling of waste” (NOH), “National Coordination Commission for Waste Policy” (LCCA), Energy production from waste and biomass” (EWAB). This technology was thought likely as an alternative energy production by the gradually mature technology and positive feedback from government policies (a positive guidance of search). Many plants were set up by the advocacy coalition: the collaboration between research institutes and entrepreneurs, between government and entrepreneurs. This beginning showed a positive functioning of an innovation system.

However, later on, a cut back of governmental subsidies aborted these projects/plants. This cut of budget could be an attempt of the government to change from R&D to market instruments. Actually, at that time, there was still some serious technological uncertainty, and the niche markets for biogas seemed not well formatted. First, it was proved to be technically difficult to digest organic waste flows from households, because of the contained much woody material. Second, the composting of waste proved to be much cheaper then digestion, leaded composting plants to be more successful in organising sufficient feedstock from the market. Finally, it was problematic to find enough end-uses for the digestion. Thus, this subsidy cut back appeared in the first transition point (see Figure 3.1) directly leading to the system failure, which stunted the diffusion of digestion. Meanwhile, we can also probably consider that, here, a weak connectivity between government and market feedback locked this technology. Beside, the size of investments and the number of policies was very broad, and the technical potential was still small because of the relatively high costs.

Around the 2000s, energy companies and research institutes involved in digestion plants again, however the development and application of digestion was till delayed due to inconsistent policies and regulations (Negro et al., 2005 and 2007). After a couple of years of ambiguous policy directions, the “Environmental Quality Electricity Production” (MEP) regulation was introduced in order to reduce the unfeasible economic aspect and provide ten-year investment security. However, a 10-year subsidy is no longer enough for digestion plant construction, which normally requires an earning back period of 6-9 years. Thus, the financing of biomass projects would be in danger. This policy, here, has its short coming and is also likely a blocking mechanism, as will be discussed further in Section 3.4.2.

After the re-development of co-digestion plants from 2004, still, the development of biomass digestion faces lots of problems. Additionally, biomass digestion is not seen as a promising technology for large-scale energy supply (>50 MWe), because of its limited origins (wet organic residues) and low efficiency compared with other biomass technologies. Meanwhile, the further technology of upgrading the biogas to the pipeline quality natural gas has a technological uncertainty, so the feasibility of biogas injection to natural gas networks will be limited both by the small-scale supply of biogas and unknown quality requirements. Meanwhile, CHP application and combustion strongly compete with green gas generation; the large-scale bio-SNG production from biomass gasification has been considered as a future highlight (Zwart et al., 2006). Thus, a successful diffusion of digestion will face lots of challenges, and more requires a power enough legislation and financial support in future to stimulate the market formation, and further the entrepreneurial activities in the Netherlands.

3.1.2 The trajectory of biomass gasification technology (1990 – 2004)

Gasification technology also experienced a back up trajectory like digestion technology. When the gasification began to get attention in the Netherlands in 1990s, there were several critical voices that warned against following the hype without first solving technical problems and obtaining consistent support from the government. For instance, there were no clear national programmes. Some projects were being prepared, but mainly for the biomass co-combustion in coal plants. An additional problem was the lack of market formation by the Dutch government, to attract more research funds and get

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Based mainly on Negro’s publications about Dutch gasification (Negro et al., 2006).
entrepreneurs interest. At that time, there were no subsidies, feed in tariffs, launching customer activities from the government.

In 1993, a project of large-scale gasification plant in North-Holland was planned by the coordinator of the national energy companies, several energy companies, and researchers from ECN. The first phase (1993-1997) of the North-Holland project therefore boosts several functions in the biomass gasification innovation systems. However, one year before the construction was supposed to start, experiments demonstrated that the economics of the project was not economically profitable. In addition, there was no suitable wood delivering company to provide long-term contracts (10 years), due to the uncertainty of wood prices. Meanwhile, the liberalisation of the energy market\textsuperscript{20} started to interfere with the project plans, which boosted the development of conventional energy. Here, the governmental policy became a blocking mechanism. Furthermore, energy companies became reluctant to invest in high-risk projects. The fact that biomass gasification was an unproven technology resulted in insurmountable technological uncertainties. Finally, the province of North-Holland and the energy company decided to abort their ambitious gasification project in 1998 (Negro et al., 2006). It was the same happening to another large-scale project named Amer-plant because of the economic unfeasibility of using waste wood. Clearly, these showed the blocking mechanisms: high uncertainty of resource, weak connectivity. In the following two years, the further research and development almost paused. Since 2002, new financing research programmes started, but it still showed a fluctuating governmental guidance of the search.

Even with a high-energy efficiency and wide variety of applications, biomass gasification has not been successfully implemented in the Netherlands. Until now, large-scale gasification is only rooted in Dutch research on coal gasification and the development activities of small-scale biomass gasification are the units for developing countries. The technology itself has problems, but the arising blocking mechanisms, including government policy, lack of legitimacy, ambiguous entrepreneurial behaviours, limit the development of this technology.

Meanwhile, probably because of the small scale and low efficiency of biomass digestion, the Dutch government plans to stimulate large scale R&D and demonstration projects of biomass gasification and methanation, first by making local use of bio-SNG, then injecting to regional networks with a limited variety of end users as the second generation of green natural gas till 2030 (Senternovem, 2006). However, the technology for integrated bio-SNG production is on the R&D phase. A recent research by Zwart also describes that the planned project will aim at the demonstration of the technical feasibility in integrated bio-SNG production in 2010 (Zwart, R.W.R. et al., 2006). It is thought that system failures may appear to happen in the coming transition from the R&D/demonstration to the pre-commercialisation stage, if there is no a supportive environment. The strength of inducement mechanisms (government policy, entrepreneurial activities and feedback from market formation) should be increased the reduce strength of blocking mechanisms (Section 2.5).

3.3 Current Dutch policy instruments for renewable energy

Dutch government already provides many kinds of subsidies for renewable energy development. Figure 3.2 shows the current policy instruments for sustainable energy, divided by technology diffusion stages and policy types. For R&D and demonstration stages, there are three subsidies available. DEN\textsuperscript{21} is a tender programme for renewable energy projects, which is a follow-on programme from the former NOVEM programmes for specific renewable energy technologies. In 2001 SenterNovem started the Energy Research Subsidy (EOS) programme, which aims to initiate and support innovation and research in the fields of energy efficiency and sustainable energy\textsuperscript{22}. Its four subsidy schemes pro-

\textsuperscript{20} The liberalisation of the energy market was started in 1998 for the entire electricity sector.
\textsuperscript{21} In Dutch: Duurzame energie
\textsuperscript{22} EOS: Energy Research Subsidy- Stimulating research into sustainable energy systems. http://www.senternovem.nl/english/products_services/towards_sustainable_energy/eos_energy_research_subsid y.asp
vide the support in different technological researches (e.g. generation, convention, storage, efficiency and renewables); different players including universities, research institutes and entrepreneurs; different phases (R&D, demonstration and pre-commercial phases)\(^{23}\). It has specific research fields for biomass and new gas. WBSO (Promotion of R&D act) is a tax incentive scheme designed for every entrepreneur in the Netherlands who undertakes research into technological innovations and in the process comes up against technical problems and solves them himself, from SMEs\(^{24}\) to multinationals, from starters to family businesses\(^{25}\). SUSPRISE is an acronym for the European Sustainable Enterprise project, which seek to expand co-operation and co-ordination among research activities in the field of sustainable industrial production by promoting networking of relevant national research programmes\(^{26}\).

Besides EOS-UKR (Unique Opportunity) subsidy scheme for demonstration and pre-commercial stages, green fund scheme aims to encourage investment that supports nature and environment, i.e. environmental-friendly projects that are innovative and have a low market penetration. This often means that the financial return for investors is lower than that generally available in the market-places, and that these projects are therefore in need of extra support. Thus, this scheme is primarily aimed at projects that are still in the initial phase of their technological development, and mainly concentrates on the following phase of development, i.e. pre-commercial stage\(^{26}\). The above four policy instruments are mainly used as the subsidies for supporting the development of renewable energy technology in R&D, demonstration and pre-commercial stages.

The other policy instruments are mainly applied to the pre-commercial stage and higher market expansion phase. Energy Premium Regulation (EPR) and Energy Performance Advice (EPA) are subsidies to encourage consumers using energy efficiency technologies and renewable energy. Environmental-friendly projects that are innovative and have a low market penetration.

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\(^{24}\) SMEs: Micro, small and medium-sized enterprises


\(^{26}\) The SUSPRISE brochure. [http://www.susprise.net/pub/data/doc/a00/b27.pdf](http://www.susprise.net/pub/data/doc/a00/b27.pdf)

\(^{27}\) The information refers from the Sustainable Profit of Green Funds Scheme and 2007 SenterNovem website. [http://www.senternovem.nl/mmfiles/sustainable_profit_tcm24-196677.pdf](http://www.senternovem.nl/mmfiles/sustainable_profit_tcm24-196677.pdf)

\[^{20}\] An overview of the environmental benefits generated by the Green Funds Scheme [http://www.senternovem.nl/mmfiles/sustainable_profit_tcm24-196677.pdf](http://www.senternovem.nl/mmfiles/sustainable_profile_tcm24-196677.pdf)
mental quality of Electricity production (MEP)\(^{29}\) is another important subsidy for domestic electricity producers from renewable resources and CHP who feed-in to the national grid (IEA, 2004). The level of the MEP feed-in-tariff is fixed at the level of the tariff in the first year that the MEP tariff was requested for a duration of maximum 10 years following the start of operation of an installation. The tariffs are different in renewable energy technologies and sources. From Table 3.4 we can see how the MEP feed-in tariff changes since 2003. Till 2007, pure biomass will get 6.6 €ct/kWh subsidy, and small scale bioenergy (<50 MW\(_e\)) will get 9.7 €ct/kWh subsidy. That means that it will be more attractive for the small-scale farm digestion plants.

### Table 3.4 MEP feed-in tariffs for renewable electricity from 2003 to 2007 (€ct/kWh)\(^{30}\)

<table>
<thead>
<tr>
<th>MEP categories</th>
<th>2003</th>
<th>2004 to 2005</th>
<th>2006 up to 2007</th>
<th>2008 after 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>REB exemption</td>
<td>2.9</td>
<td>2.9</td>
<td>1.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Sludge</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Land fill gas</td>
<td>0.0</td>
<td>0.0</td>
<td>0.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Mixed biomass</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Meat and bone meal</td>
<td>-</td>
<td>0.0</td>
<td>0.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Pure biomass</td>
<td>4.8</td>
<td>4.1</td>
<td>5.5</td>
<td>7.0</td>
</tr>
<tr>
<td>Wind onshore</td>
<td>4.9</td>
<td>4.9</td>
<td>6.3</td>
<td>7.7</td>
</tr>
<tr>
<td>Wind offshore</td>
<td>6.8</td>
<td>6.8</td>
<td>8.2</td>
<td>9.7</td>
</tr>
<tr>
<td>Small scale bioenergy</td>
<td>6.8</td>
<td>6.8</td>
<td>8.2</td>
<td>9.7</td>
</tr>
<tr>
<td>Hydro power</td>
<td>6.8</td>
<td>6.8</td>
<td>8.2</td>
<td>9.7</td>
</tr>
<tr>
<td>Solar-PV, wave and tidal energy</td>
<td>6.8</td>
<td>6.8</td>
<td>8.2</td>
<td>9.7</td>
</tr>
<tr>
<td>Levy per connection</td>
<td>34.0</td>
<td>39.0</td>
<td>39.0</td>
<td>52.0</td>
</tr>
</tbody>
</table>

\(^{a}\) Mixed biomass: biologically degradable materials and municipal solid waste
\(^{b}\) Pure biomass >97% biologically degradable material
\(^{c}\) Small scale bioenergy < 50 MW\(_e\)

TechnoPartner encourages and supports anyone wanting to start a business that is based on a technological invention. Such “techno starters” are seen as pioneers who have the guts to bring new technological development to market\(^{31}\). The Environment & Technology Programme (ETP) stimulates the development and services that benefit environment, which aims to improve the environment through technical innovation, researched and improved market introduction. The last two schemes environmental investment allowance (MIA) and energy investment allowance (EIA) mainly apply to the supported and fully commercial stages, which are under the Green Funds Scheme\(^{32}\). The EIA scheme offers entrepreneur a fiscal advantage in investing in energy-saving company assets and sustainable energy\(^{33}\).

These policy instruments above provide the subsidies to different diffusion stages, also stimulating renewable energy development from biomass at a certain level. Some R&D subsidies (e.g. EOS-LT) are the direct financial incentives for a long term research of green gas. One of the further investment subsidies for the fully commercial stage, EIA, may provide a fiscal advantage (maximum 44% of €110 million investment deduction) to biomass gasification and biogas upgrade installation in the 2007 EIA energy list (SenterNovem, 2007)\(^{34}\). Besides, a similar subsidy like MEP is needed for giving the

\(^{29}\) In Dutch: Milieukwaliteit van de Elektriciteitsproductie


\(^{31}\) http://www.senternovem.nl/english/products_services/encouraging_innovation/technopartner.asp

\(^{32}\) An overview of the environmental benefits generated by the Green Funds Scheme

http://www.senternovem.nl/mmfiles/sustainable_profit_tcm24-196677.pdf

\(^{33}\) http://www.senternovem.nl/mmfiles/EIA%202007%20engels_tcm24-216436.pdf (SenterNovem, 2007)

\(^{34}\) Biogas upgrade installation means for: producing gas of natural gas network quality, whereby only gases from biomass or fertilizer are used as energy input, and consists of facilities to upgrade the biogas to gas that meets natural gas network quality standards, (possibly) gas cleaning equipment, (possibly) compressor.

Biomass gasification plant means for: producing biogas through gasification of biomass, and upgrading the biogas to natural gas quality, whereby the gas is then included in the natural gas network. (SenterNovem, 2007).
sufficient financial support for green gas generation, which will be important to improve its price completeness. They may improve the maturity of biogas upgrading technology, which may also directly guarantee the green gas quality for adding to natural gas networks. However, the feasibility of green gas generation seems far away from the current situation, since the green gas technologies are on the R&D stage (see Figure 3.1) and the formative period always requires a long time.

3.4 The potential failure of current innovation system for green gas technology

The successful diffusion of green gas technology should be depending on a well designed innovation system with positive functions. Although current renewable energy policy environment seems promote the development of green gas technology, with kinds of subsidies and long term strategy orientations, there seem still existing limitations and failures in current energy policy. The consequences are that the uncertainties from different sources are increased, which may lock different system functions (Figure 2.3). By specifying the source uncertainties, the uncertainty is discussed further in Section 4.3, which are significant barriers in implementing green gas in entrepreneurial level. The next section (Section 3.6) will explain why the entrepreneurs may hesitate on implementing green gas technologies. Below are the discussions of three potential failures in the current energy innovation system for green gas:

- The failure of current policy instruments in the subsidies for the diffusion chain;
- Lacking national business climate for innovation in innovation culture and financial support
- Weak connectivity between research sector and the business sector and other parties

3.4.1 The short/medium term vs long term energy strategy

Since the role of natural gas in Dutch energy supply will become increasingly important in the decades to come as well as during the transition to a sustainable energy economy. Some short/medium term policies are still important to confirm the position of natural gas in the energy market. The small fields policy is that gas production from small field is encouraged by using Groningen field as a swing producer. Approximately two thirds of the total gas currently produced comes from small fields. Furthermore, it is not the case that there will be no gas left in the Netherlands in 25 years time. However, it is expected that most gas from the small fields will have been produced by them. The Groningen field will not have been depleted either by that time, but the reservoir pressure will no longer be high enough for the field to act as swing producer. To ensure an adequate gas supply in the long term, to meet gas demand, the Netherlands will increasingly depend on imports from outside the EU, e.g. from Russia, Algeria, and Iran and on liquefied natural gas (LNG). The preparations for large-scale imports of gas from Russia are partly bilateral, for instance by Gasunie entering into contracts with the Russian company Gazprom (EZ, 2005)

The small fields policy and LNG import has contributed considerably to the security of supply in the Netherlands. However, they confirm the position of natural gas, and on the other hand, impact the entry of renewable energy. Especially because of the LNG import in the long term, the gas infrastructure will likely still be mainly occupied by natural gas, which may block the introduction of green gas into the gas infrastructure. Meanwhile, the energy efficiency technologies applied in generation and consumption, also uphold the absolute position of conventional energy and are the strong competitors with renewable energy technologies, by attracting funding and policy attentions.

3.4.2 The failure of current renewable energy policy

We know that current renewable energy policy drivers and long term strategy may stimulate the development of green gas, however it seems that there are still existing some failures, both in the subsidy itself and the subsidy system. The well known “Environmental Quality Electricity Production” (MEP) regulation is introduced in order to reduce the unfeasible economic aspect and provide ten-year investment security to the electricity generation from renewable energy. Although the subsidy is amended annually, and the overall subsidy level increases, a 10-year subsidy seems not long enough for renewable energy plants, e.g. digestion plant construction, which normally requires an earning
back period of 6-9 years. Thus, the financing of large biomass projects would be in danger. This policy, here, has its shortage and is also likely a blocking mechanism on stimulating the involvement of entrepreneurial entrants.

Present policy instruments mentioned in Section 3.3 and Figure 3.2, can be categorised into four quadrants, based on the direction of their support to market. Policies can be directed towards consumers (demand-side) or producers (supply-side). They can also be directed towards capacity (i.e. the facility and/or its capital costs) or generation (i.e. the product and/or the associated price to the customer) (IEA, 2004). Dutch government provides more support to supply-capacity (Figure 3.3). It is clear that the government has a strong desire to improve sustainable energy R&D, and also has the intention to invest in renewables, relatively, in a more expanded market. In other words, the protection environment for demonstration and pre-commercial stages seems insufficient. However, the development of green gas is on R&D stage and will face the transition to demonstration and pre-commercial stages, and this insufficient policy, especially the limited financial support will be a barrier for expanding the green gas market.

![Figure 3.3 Market deployment of Dutch renewable energy policy instruments (exclude the policy instruments for R&D)](image)

3.4.3 Lacking national business climate for innovation

Based on the 2003 EIM research, the Netherlands improves the entrepreneurial activity, relative to other Western countries, and the Dutch business climate is adequate considering general competitiveness. However, the Dutch culture, the labour market are less favorable for innovation start-ups: The Dutch culture seems to be still not very supportive to entrepreneurs who actually failed; the labour market is characterized by little flexibility that puts forward the alternatives to entrepreneurship, thus (innovative) entrepreneurship is less attractive (Bosma, 2003).

The financial system seems also less favorable. From a 2006 research, it said the Dutch innovation in sustainable energy still concerns about relatively large capital requirements, long investment periods, dependence on regulations and subsidy support, and an increasing number of leading venture capitalists. However, the Netherlands does not have sufficient venture capital for sustainable energy innovation, especially in the early prototyping and piloting development stages (demonstration/pre-commercial stages) right after the conceptual R&D phase. Partly this is driven by lack of a clear and consistent long term strategy and policy of Dutch Government on innovation in sustainable energy; partly this also seems to be driven by an insufficient need or incentive for Dutch R&D in general to push its ideas effectively further into the innovation pipeline towards actual market introduction (Bain&Company, 2006). The allocation of current subsidies in sustainable energy mainly goes to the mature companies, which is discussed in Section 5.3.2. Besides, Dutch subsidy levels (about 10% on investment) are uncompetitive relative to some other European countries, e.g. Germany about 30 - 40% on investment (Bain&Company, 2006).
Bio-SNG technology is on the R&D stage, so that the system gap will likely appear in the next transition stage. The niche market for green gas has not formed, and the green gas generation still requires the financial support. It is clear that the less favourable business climate (innovation culture and financial incentives) for innovation will likely lock the diffusion of green gas generation in the future.

3.4.4 Weak connectivity
Lacking favorable national business climate for innovation may be a consequence from a low degree of interaction between the research sector and the business sector, which stands for the serious weakness of knowledge transfer (weak connectivity). Government expenditures on R&D are relatively high in the Netherlands, however the business expenditure R&D is lagging far behind the averages in the EU and the OECD. Meanwhile, the degree of public-private collaboration seems low. About 10% company patents were realised in partnerships with Dutch universities. Only the enterprises seem to collaborate more frequently than smaller sized enterprises. Besides, based on the benchmarking innovation start-up ratio, it appeared that the dynamism of innovation entrepreneurship in the Netherlands is also lagging behind compared to Germany, US and UK (Muizer, 2003). Generally speaking, there exists problem for knowledge transition from fundamental research into new products and services.

A success diffusion of green gas technology requires an effective collaboration among different players. The knowledge and information transfer and reaction from suppliers to transmission companies, consumers, and the government also results from the knowledge and information. In the historical failures of biomass digestion and gasification (Section 3.2), the weak connectivity in terms of weak leaning and political networks, knowledge transition already exists.

3.5 The evaluation of the feasibility level
Before to make a evaluation to the feasibility level based on the performances of past/current system, it is important to understand the features of energy sector where it plays in, and how these features possibly limit the deployment of green gas in energy sector, which can help the involved actors to figure out the basic climate for green gas development. Firstly, we have to notice that energy system is huge. Even with the continued high growth rates over the past and next decades, the replacement of conventional energy by renewable energy is only a small part or will start in the future. Thus, the energy transition will be a long term perspective.

Second, for several reasons, new markets are not easily formed. If we focus on the green gas, we will clearly find that its related technologies have cost disadvantage compared with natural gas generation technology. The natural gas price in the current Dutch market is still cheaper than green gas, even with the eco-tax. On the other hand, consumers have the free choice on the liberalized energy markets, which further confirms the main role of natural gas. Meanwhile, recent Dutch policies, e.g. small field policy and LNG import, which try to support the short/medium term supply security of natural gas, also confirm the natural gas market. Besides, the deployment within the renewable energy market itself competes among different technologies. In the Netherlands, the first competitor with biomass is wind power. Then, other biomass technologies, e.g. combustion, co-firing, fermentation, CHP, compete with green gas technologies. The actual market for green gas seems not easily formed in short time.

Third, the industrial economics probably have been locked into the established (fossil fuel-based) energy systems through a process of technological and institutional co-evolution driven by the path-dependent increasing returns (Unruh, 2000), which include established institutional framework, re-investment in incumbent technologies and physical infrastructure. The government plays a central role in starting the initial projects, stimulating the formation of niche markets and increasing the attraction of green gas. Thus, the diffusion of green technology is more sensitive to the policy orientations. Fourth, the green gas technologies, like other new technologies, may not offer direct benefits to current buyer and investor, but reduce the environmental costs. Therefore, the government has the major

35 There features of energy sector are quoted from Jacobsson and Bergek (Jacobsson et al., 2004).
responsibility to induce the market counting the external costs by different policy instruments, which increases the governmental intervention in the diffusion of green gas technologies again.

The number of landfill plants increased to sixty-four in 2000. Together, the landfill sites produced 3.1 PJ landfill gas in 2002\textsuperscript{36}. Digestion technologies were also diffused in other sectors in the 1990s. Digestion of industrial waste waters was increasingly applied in food processing industries, whose biogas production increased to 1 PJ in 2002\textsuperscript{37}. Digestion was also used in stabilising the sludge that remained in sewage treatment plants after purification. Total biogas production from waste water and sludge was 2 PJ in 2002\textsuperscript{38}. Finally, anaerobic digestion was applied in a few plants that processed organic household waste, but biogas production remained limited (0.07 PJ in 2001) (Raven, 2005). Till 2002, there was less than 6 PJ biogas generation from landfill and digestion.

Although the total average waste will arise 20\% towards 2030, more MSW will be recycled (about 50\%). Besides, the higher attraction of waste incineration and a zero landfill policy (see Table 3.4) in the future will lead to the decrease of landfill gas from about 3 PJ in 2002 to 0 PJ in 2030 (de Noord et al., 2004). Including the farm scale plants, the energy potential from digestion will be 10 PJ in 2020 from an older research (Kwant, 2003). Because of the co-digestion development in 2004-2005, till the end of 2006, 40 new co-digestion plants with the scale 20 MWe installed and 200 plants scale from 40 – 60 MWe are in planning (see Appendix Figure 1) (Asselt, 2007). The available energy potential from biogas may be higher than 10 PJ, however the availability of pure upgraded biogas may be smaller than the total potential of biogas generation. Digestion is an available and seems commercially proven technology with widespread implementation on farm scale recent years, but the generation price still does not have the competitive advantage. Although MEP can provide sufficient subsidies, a10-year duration seems not long enough for digestion plant construction, which normally requires an earning back period of 6-9 years (Section 3.4.2). A stable generation level may not be guaranteed. Thus, till 2010, about 1,500 million m\textsuperscript{3}/year (48 PJ) generation of upgraded biogas may not be reached. Besides, the criteria setting for the required quality of upgraded biogas in the natural gas grid, is just on the research agenda, so that the adaptation level in the local natural gas grid is unknown. The actual replacement of natural gas in the first green gas generation period will be lower.

The first generation period by upgraded biogas, is expected as the formation period of niche market for green gas, then transfer to a larger market by bio-SNG. However, the expectation may highly be limited as discussed in the former paragraph. Another problem is that the bio-SNG generation is under development and realisation, and the first plant would not be expected till 2010, which means it will face more barriers during the diffusion from an initial stage to a higher stage. The first barrier will be the insufficient support for the transition from demonstration to the pre-commercial stages (see Section 3.4.2). Since the green gas market may not be formed as expected, the second generation period by bio-SNG will face a high risk. In the energy sector, there are already some inherent limitations for renewable energy. The competition with conventional energy and other formation renewable energy exists, and the general national innovation climate seems not favourable. Green gas technologies as a part of this system, actually, are limited by many inner factors. Bio-SNG highly dependence on biomass import, so the uncertainty of resources is increased (see Section 4.3.5). Thus, a 300 PJ replacement ambition by green gas in 2030, without a high level protection environment, may be hard to reach.

\textsuperscript{36}The landfill gas was used for the production of 0.5 PJ electricity and 0.15 PJ heat and another 16 million m\textsuperscript{3} gas was supplied without conversion (e.g. in industrial processes).

\textsuperscript{37}The biogas was converted to 0.07 PJ electricity, 0.6 PJ heat and another 7 million m\textsuperscript{3} gas was supplied without conversion.

\textsuperscript{38}The biogas was converted to 0.4 PJ electricity and 0.8 PJ heat and another 13 million m\textsuperscript{3} gas was supplied without conversion.
3.6 Entrepreneurial activity

“Technological innovations are regarded as the introduction into the economy of new knowledge or new combinations of existing knowledge. Through interactions in the economy differ, pieces of knowledge become combined in new ways or new knowledge is created and, sometimes, this results in new processes or products. Such interaction does not only take place in connection with R&D but also in relation to normal and everyday economic activities such as procurement, production, and marketing.” (Edquist, 1997)

Entrepreneurial activities are essential for the economic penetration of an innovation technology. The role of the entrepreneur is to turn the potential of new knowledge development, networks and markets into concrete actions to generate and take advantage of business opportunities (Hekkert et al., 2007). In Figure 2.3, as one of the inducement mechanisms, entrepreneurial activities stimulate the market formation. Meanwhile, strengthened entrepreneurial activities may reduce the strength of blocking mechanisms, such as lacking the uncertainty of technology, increasing the connectivity among different actors and pushing government to improve the policy making, by collaboration, industrial R&D, etc. For instance, the Dutch government had been reluctant to give tax exemptions for biofuels, but several entrepreneurs collectively lobby for the exemption. Meanwhile, entrepreneurs can compete for collecting R&D resources and emphasize the benefits of this specific technology, which also induce the technology diffusion. Thus, from the innovation system point of view, enterprises have the corporate responsibility with other organizations to stimulate the diffusion of renewable energy technologies.

Even with the social and policy pressure, the boosting “corporate image” for enterprises and the potential market, many incumbent interests still exist. For entrepreneurs themselves, they want to be really involved, when there is a positive financial feedback both from increased market demand and cost effectiveness (See Figure 3.4), because they are benefits oriented. Lack of financial incentive, combined with high level of uncertainties in technology, resource, and government policy, lead to the hesitation of the entrepreneurial activities. In other words, for the strategy making, enterprises should be able to see beyond that which currently exists to what is possible in the future; has to perceive the future need; identify the necessary ingredients; secure the resources that may be missing initially; communicate their vision to the relevant agents – capitalists, suppliers of raw materials, knowledge people, etc (Carlsson et al., 1991).

Figure 3.4 Virtuous cycle in a support environment for enterprises (IEA, 2003)
Incumbent energy entrepreneurs, who aim to diversify their business strategy, have the advantage in fulfilling system functions than the new start-ups. For instance, they know their customers, and they are perceived to be trustworthy and they can organize a switch to green at minimum efforts for the customer (van Dijk et al., 2003). As mentioned before, the carbon-saving technologies have the external barriers (cost disadvantage and lock-in incumbent fossil fuel infrastructure), and over these barriers more depends on the governing institutions with the organizational, social and institutional changes. However, the trajectory of biogas technology in the past history was limited by the fluctuation in government policy. The long term strategy with an attractive ambition may not be guaranteed, because of the lack of effective policy instruments in current stage and an increasing uncertainty of the future market for green gas. Thus, incumbent energy entrepreneurs should pay attention to the uncertainty of policy and predict the dynamic potential of market for the sustainable strategy making. In the next Chapter, I will use a case-study to analysis the sensitivity for a Dutch energy transmission company – Gasunie for implementing green gas in a firm level, combined with the governmental policy and market performance.
4. CASE STUDY – The searching strategy for N.V. Nederlandse Gasunie in green gas development

N.V. Nederlandse Gasunie\textsuperscript{39} as a natural gas infrastructure company, has 12,000 kilometres of high pressure and regional natural gas pipelines, numerous installation and around 1,100 custody transfer stations, which is one of the biggest in Europe (Gasunie, 2006\textsuperscript{40}). It wants to maintain its strong position in the European market as an independent supplier of gas transport services by safety, reliability and efficiency. Gasunie is also committed to responding swiftly to new demand for transport and related services from customers and consumers.

Meanwhile, it has a desire to contribute to the transition towards sustainable energy supply, which creates economic and social value in its activities. Gasunie has its priorities in sustainable energy transition by its knowledge, experience and existing physical infrastructure. Based on the national energy transition strategy\textsuperscript{41}, it already takes an active role and as a member of the task force on New Gas Platform. It also plays a leading role in a large international research project under the European Committee regarding the conditions for the blending of sustainable produced gases into the existing gas infrastructure\textsuperscript{42}, for instance a under development project “BONGO”, which aims to develop quality specifications for accessing biogas and all other types of non-conventional gases to the gas transmission and distribution system\textsuperscript{43}. From EU gas directive (2003/55/EC) to Dutch government’s future policy strategy for green gas and the potential market, combining the internal and external drivers, it seems that Gasunie will get business benefit and positive image in getting involved in green gas transmission, and also can collaborate with fuel stations to supply the biofuels in the future (Schouten et al. 2006).

However, assessing the real strategy is particularly problematic. The existing uncertainties will be the barriers for Gasunie’s strategy making. For the short term oriented benefits, Gasunie need not enter substantially in this long term transition and current insufficient markets. In the energy innovation system, entrepreneurial activities are not an isolated mechanism in the diffusion of green gas technology. Although the policy strategies predict the potential market, lacking enough financial support is still the biggest barrier. The failures of current policy environment and future policy uncertainty increase the uncertainty level of market formation and suppliers, which may further limit the activities of entrants.

Therefore, learning from the system may help Gasunie to figure out which uncertainties are the critical ones and balance between the drivers and uncertainties, in order to get a proper strategy for implementing green gas. Besides, an incremental strategy may help to Gasunie keep the sensitivity to the policy and market, and have a competitive image.

I will use the below entrepreneurial framework conditions\textsuperscript{44} to discuss the drivers for Gasunie making positive reaction. They are:

- Government policies
- Government programs
- Financial support
- Market openness

\textsuperscript{39} In the below text, it is simply called “Gasunie”.
\textsuperscript{40} N.V.Nederlandse Gasunie. Annual Report 2006. \url{http://www.nv nederlandsegasunie.nl/JV/2006/Gasuniejaarv.2006.GB.pdf}
\textsuperscript{41} SenterNovem. 2007. Energy transition. \url{http://www.senter novem.nl/EnergyTransition/}
\textsuperscript{42} Areas of expertise. Gasunie Engineering & Technology. \url{http://www.getgasunie.nl/eng/GET/What%20can%20GET%20do/areas.htm}
\textsuperscript{43} “BONGO” is defined as biogas and other non-conventional gas operations, including biogas from biomass digestion, landfill gas and bio-SNG (from biomass gasification) (Burgel at al., 2006).
\textsuperscript{44} They are from the definition of Bosam’s nine entrepreneurial framework conditions (Bosma et al., 2002).
• R&D transfer
• Access to physical infrastructure
• Commercial and professional infrastructure
• Attitudes, cultural and social norms

Government policies, programs, financial support and market openness can be considered as external drivers. I will use R&D transfer, access to physical infrastructure, commercial and professional infrastructure and attitudes, cultural and social norms, to discuss the internal drivers of Gasunie. Then, the definition of source uncertainties will be used to specify the uncertainties for Gasunie. The rest sections will present how learning will help Gasunie making current strategy analysis, and which kind of searching will be fit for current situation.

4.1 External drivers

4.1.1 Policy requirements

From the evaluation of biogas technology trajectory in Chapter 3, we already have the impression how the government policies were involved in and influenced the technology diffusion. As one of the inducement mechanisms (Figure 2.3), positive government policy has very special role in stimulating the formation of market and entrepreneurial activities for biogas technology. The EU directive and Dutch “Gas Act” already mention the possible position of biogas in the future gas infrastructure and energy supply system. Different national policy instruments, such as production tax systems, tax exemptions and tradable certificates etc, may financially support the development of biogas technology and improve the technological penetration in market.

EU Directive 2003/55/EC establishes common rules for the transition, distribution, supply and storage of natural gas, which shall also apply to biogas and gas from biomass or other types gas in so far as such gases can technically and safely be injected into, and transported through, the natural gas system. Meanwhile, it requires:

“Member States should ensure that, taking into account the necessary quality requirements, biogas and gas from biomass or other types of gas are granted non-discriminatory access to the gas system, provided such access is permanently compatible with the relevant technical rules and safety standards. These rules and standards should ensure, that these gases can technically and safely be injected into, and transported through the natural gas system and should also address the chemical characteristics of these gases.”

The transmission requirement has been implemented in 2000 Dutch “Gas Act”. Based on that, Gasunie shall draw up draft conditions stipulating the minimum requirements for biogas, applicable to the technical design and operation of pipelines and installations with a view to the connection of such pipelines and installations to its gas transmission network, with objective and non-discriminatory conditions (Section 11, Gas Act). If the biogas does not fit the quality requirements or the network capacity is not available, then Gasunie may reasonably refuse. Besides, in 2003 Dutch Minister of Economic Affairs established a national regulation for guaranteeing the origin of biomass.

Even there is no obligation/regulation for Gasunie providing access to green gas in natural gas network right now. The Netherlands intends to be the cleanest and most innovative gas-producing coun-

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47 EZ. 2000. Rules in respect of the transmission and supply of gas (Gas Act).
48 Minister of Economic Affairs, 2003. No WJZ 3073206. Regulation on guarantees of origin for renewable electricity
try in European (SenterNovem, 2006). With the long-term ambition of new gas transition (see Section 3.4), the relative regulations about accessing the natural gas grid for green gas will likely be operated. As the largest natural gas transition company, Gasunie will be required to make a reaction.

4.1.2 Financial drivers

The formation of niche biogas markets experienced lots of fluctuations, and its deployment in current Dutch energy market is still very small. However, the supply and demand of renewable energy market are more influenced by the policy instruments. The long-term ambition – In 2030, the contribution of green gas will be 20% of the total natural gas consumption, so the potential of the future green gas market is significant. Although upgraded biogas is estimated to having a part deployment, it will focus on the first generation period before the bio-SNG fully commercial (around 2015). Besides, upgraded biogas seems as the local utilisation, which may be more cost-benefit by accessing into the local natural gas grid and distribution lines. In other words, it does not have the potential benefits by going into Gasunie’s high and middle pressure lines, even if the injection technology is mature enough.

At laboratory scale, bio-SNG has already been demonstrated that can be produced in the same composition with natural gas by means of gasification followed by methanation. With the feasibility of technology, the expectation is that the entire conversion chain, from biomass to synthetic natural gas, can be scaled up to the level of commercial production within 10 years (SenterNovem, 2006). With the current technology, the market price for bio-SNG (8.5-8.9 €/GJ) will be 10 to 40% above natural gas, but with up-scaling and process optimization—aided by the increased gas price—this route can quickly become competitive. Table 4.1 shows bio-SNG production costs and subsidy requirement in different scales and gasification conditions. The current Dutch MEP feed-in tariffs provides 6.6-9.7 €ct/kWh subsidies for electricity generation from biomass (see Table 3.4). Thus, a similar subsidy on bio-SNG to MEP will supply the implementation of the fully commercial bio-SNG plant (Zwart et al., 2006). In the future 10 years R&D/demonstration stage, the generation guarantee from subsidy may be operated based on the current high ambition level.

Table 4.1 Bio-SNG production costs in different scales and gasification conditions (Mozaffarian et al., 2003 and Zwart et al., 2006)

\begin{tabular}{|c|c|c|c|}
\hline
 & 10MWth & 100MWth & 1000MWth \\
 & atmospheric & atmospheric & \\
 & 7 bar & 7 bar \\
\hline
Capital charge (M€/year) & 3.0 & 11.6 & 11.5 & 52.8 \\
O&M costs (M€/year) & 2.3 & 7.4 & 7.3 & 33.8 \\
Biomass costs (M€/year) & 0.5 & 10.8 & 10.8 & 108.0 \\
Total SNG production costs (€/GJ) & 30.8 & 15.3 & 14.8 & 9.3 \\
Required subsidy (€ct/kWh) & 8.5-8.7 & 2.9-3.1 & 2.8-3.0 & 0.8-1.0 \\
\hline
\end{tabular}

*The required subsidy is calculated with the natural gas price for small consumers (6.6-7.1 €/GJ)*

With a formed market, Gasunie will have a business chance. With the expected 500-1000MWth/plant generation of bio-SNG, bio-SNG can be compressed from 7 bar to 66 bar, which gives the possibility for bio-SNG injection to the high transmission lines (HTL: range from 43 to 66 bar). In HTL, there are blending facilities available, which guarantee the transported gas into G-gas pipelines by mixing high calorific gas and low calorific gas or diluting high calorific gas with nitrogen, so it enhance the attraction for SNG injection to HTL than RTL (regional transmission lines) (Zwart et al., 2006). Once the quality requirements are available, which may guarantee the quality of bio-SNG in the entry, it will be possible to inject bio-SNG to RTL as well. Thus, the future potential market will be the main financial driver for Gasunie involving in this new gas transition.

49 SenterNovem, 2006. Energy transition task force


51 The pure market price of bio-SNG = 2.7-3.2 €/GJ (natural gas price for large consumers) + 3.9 €/GJ (ecotax for small consumers) + 1.8 €/GJ (the ecotax-transfer) (Mozaffarian et al., 2003)
Besides the potential market mentioned above, the government and financial market parties jointly establish a public-private venture capital fund for a period 10 years with an annual budget of € 500 million, which invests in projects that are compatible with the selected energy transition paths. Although the project investment from this fund is not known specifically in advance, the commercial and sustainability criteria for such projects are known beforehand (SenterNovem, 200652). It is an important incentive for R&D and the initial market formation. If Gasunie involves in the new gas transition task, it may get the specific financial support for the initial R&D of injecting green gas to the natural gas grid. Besides, the new gas transition is also under kinds of current R&D subsidies (see Section 3.2). For instance, Gasunie can apply the EOS-ES/LT for the long term R&D.

4.2 Internal drivers

4.2.1 R&D transfer
The involvement in different biogas R&D cooperation is one of the important initial steps for green gas technology diffusion. On 29th June 2004, Gasunie and other local distribution companies (ENECO, Essent and NUON, NAM) signed a manifest, which they announce their plans for the development of “Green Gas” experimental applications and other sustainability of gas usage in the Netherlands53. The under development project “BONGO”, which is set up from a EC fund and collaborated with different parties (research institutes, university, gas company and gas organization), aims to develop the quality specifications of biogas and all other types of non-conventional gases, for accessing to the gas transmission and distribution system. The national energy transition platform, which requires Gasunie involved in developing “New Gas” in Dutch infrastructure. The R&D cooperation will help Gasunie obtaining the necessary knowledge about the quality of green gas, and they improve the knowledge transfer and form the initial network, which is the important function of starting an innovation54.

Besides, the knowledge centre – Gasunie Engineering & Technology, which includes the fields of research, technology development, energy studies, training and engineering, with many leading facilities and knowledgeable people, is the advantage for Gasunie learning the innovation knowledge of green gas. Since 2006, Gasunie Engineering & Technology centre actively contributed to innovation in sustainability and the new sustainable strategy for implementing green gas is on the agenda. Besides, as a biggest Dutch natural gas transition company, Gasunie has the financial advantage in R&D investment compared with less research – intensive firms.

4.2.2 Business advantage
The future energy transition will depend on the existing natural gas infrastructure. Gasunie has 12,000 kilometres of natural gas pipelines network, including high transmission lines and regional transmission lines. The high transmission lines with blending facilities will be the attraction for transporting the expected large generation of bio-SNG (about 16% or 240 PJ replacement of natural gas in 2030). Obviously, Gasunie’s future business may be involved in adding green gas to natural gas network and transporting. Meanwhile, it has the mature knowledge in transmission technology, which will help to develop the green gas transmission in the natural gas infrastructure.

Gasunie also has the priority in gas commercial and professional infrastructure, which refers to the presence of commercial, accounting, and other legal services and institutions that allow or promote the emergence of businesses (Bosma et al., 2002). Gasunie possesses the mature gas transport services in the liberalized market, which means that it may help the green gas to enter the liberalized green market and enhance the its cost competitiveness. Gasunie has the advantage that they know their customers (suppliers and shippers), they are perceived to be trustworthy and they can organise a switch to

54 The function “creation and diffusion of new knowledge” (Section 2.2)
green at minimum effort. Clearly, it will have these priorities to transport green gas, and play an important role in future green gas market.

4.2.3 Business image and culture

Firms’ strategies are strongly constrained by their current position and by the specific opportunities open to them in future, which means that they are path-dependent (Tidd et al., 2005). However, the business culture will also influence entrepreneurial strategies making. Here, business culture refers to the extent to which existing social and cultural norms encourage, or do not discourage, individual actions that may lead to new ways of conducting businesses or economic activities and may, in turn, lead to greater dispersion of personal wealth and income (Bosma et al., 2002).

Nowadays, the stimulation to implement green gas is firstly as one of the options in the field of environment related to reducing emissions and climate change, and secondly for the energy diversity and security supply in the future. It is especially important for the Netherlands, which consumes about 50% primary energy from natural gas. Green gas as the alternative energy for natural gas has its priorities in heat, electricity and maybe transportation sectors. The boosted conception so called “corporate social responsibility” also directly influences a business company’s strategy making. A related environmental image will help Gasunie to promote its competitive capability.

Gasunie reacts to the liberalized natural gas market, and liberalization may lead to a focus on short-term benefits (van Dijk et al., 2003). Therefore, Gasunie is more depending on short-term benefits by transporting natural gas, which is the main business mission. However, GTS develops its network by reviewing demand for transport capacity and other services over the long term, and it has a desire to contribute to the transition towards sustainable energy supply. The sustainable development is its long term perspective. Under this, Green gas is an attraction for Gasunie’s long-term sustainable development.

4.3 Existing uncertainties

![Figure 4.1 The influences of uncertainties to green gas transmission](image.png)

Uncertainty is a significant character in the diffusion of an innovation technology, and also an important blocking mechanism to the functions of technology system. For entrepreneurs, high level uncertainty is the external barrier that the entrepreneurs hesitate in the development of this innovation technology. Although the drivers from different aspects as we mentioned above, may stimulate that Gasunie could have a business chance by positive activities, the related risk and uncertainty from policy, market, supplier, etc, are still the inevitable barriers. The business strategy making in implementing
green gas seems not easy. This section, the existing uncertainties for Gasunie in implementing green gas are discussed (Figure 4.1), based on the typology of uncertainty source\textsuperscript{55}.

Clearly, uncertainties, such as policy, resource, supplier, etc, directly influence the gas transmission company, and the market demand indirectly may influence the Dutch transmission company. Besides, the existing interactions are important to figure out the relations among these uncertainties. Green gas technologies are configuration technologies, which require a highly designed protective environment to help overcome the inherent limitations in energy sector (see Section 3.5) and the potential failures in current energy innovation system. Government plays a major role, so that the policy uncertainty is the most risk for Gasunie involving in by its direct/indirect ways. Below is the discussion of these uncertainties by the influence strength. Balance between the external/internal drivers and the uncertainties may be the realistic way of sustainable strategy making.

4.3.1 Political uncertainty
Although EU has the directive about accessing biogas to the gas network, and Dutch government also shows its desire for this adaptation, there are still no legal regulations or clear descriptions about the adaptation level. Secondly, since Dutch gas infrastructure is fully designed for natural gas, the still available natural gas resources have absolute advantage in cost benefits by the incumbent technologies. In the current Dutch policy instruments and long term strategy (Section 3.1 and Section 3.3), we can not find clear subsidies for Gasunie to carry out related researches, which can obtain the knowledge for adding green gas to natural gas network with an acceptable level. Also the possible subsidies for future injection maintaining have not been available yet. Although the task of “New Gas” platform mentions the setting of green gas quality standard (SenterNovem, 2006\textsuperscript{56}), a clear schedule still has not been known yet. The lesson from the past policy – inconsistent and changing (see Section 3.2), increases the uncertainty level for the future policy. Thus, the ambiguous policy orientation and financial support will be the barrier for implementing the green gas in natural gas system.

From Section 3.4.2, we know that the potential failures of current policy instruments may impact the diffusion of green gas technology to a high market penetration level. In other words, the insufficient subsidies for demonstration and pre-commercial stages might be the future barrier for the formation of green gas niche markets, which will directly limit the green gas generation. Thus, a more supportive and clear policy in the future for green gas diffusion is required. In the current situation, only a long term transition strategy is not power enough to support Gasunie involving in.

4.3.2 Market uncertainty
Market uncertainty will indirectly influence Gasunie, by increasing the policy uncertainty, supplier uncertainty (Figure 4.1). Because the direct contact parties with GTS are the suppliers and shippers\textsuperscript{57}, the market formation influence the suppliers’ involvement in green gas generation. Although the green gas digestion and gasification technology already have appeared for a long time, a mature green gas market and clear consumers have not been formed yet. This might be resulted from the past inconsistent and changing policy, which did not stimulate the niche formation (Section 3.2), and it also might be resulted from the market itself. The un-formed market and uncertain demand limit the involvement of entrepreneurial entrants in green gas generation. Besides, the decision of a player to invest in a new technology is highly influenced by the uncertainty of their consumers. Thus, without a mature market, there will be no further investment in the development or distribution of green gas technology.

\textsuperscript{56} SenterNovem, 2006. Energy transition task force.
\textsuperscript{57} Shipper: a company that uses the national gas transmission grid to have gas transported based on a transport contract with GTS.
Supplier: a company that supplies gas to end users and needs transport capacity to do this.
Firstly, in the liberalized gas market, the preferences of consumers will determine whether or not they will accept green gas, which is related with consumers’ expectations regarding its prices, quality, safety and so on. The green gas shows a disadvantage in market price compared with present natural gas price (Section 3.3), which will influence the choice of consumers and further influence the involvement of green gas supplier.

Secondly, uncertainty may rise with respecting to the characters of consumers. A prerequisite of successful innovation is the technological compatibility with the consumer characters (Meijer et al., 2005). For energy technology, the size of the energy demand is one of the important consumer characters. Although the total Dutch energy demand will increase in the future, other formations of resources and technologies, e.g. LNG, wind power, biomass combustion, energy efficient technology (CHP), also will be the alternatives. Although government has the ambition to replace about 20% natural gas by green gas in 2030 (Section 3.3), the future actual demand of green gas can not be easily predicted. Thus, the implementation of this ambition should depend on a well designed policy environment. Obviously, the discussed uncertainty of policy (see Section 4.3.1) reduces the ambition level. Thirdly, in micro-economic point of view, the uncertainty about the development of the green gas demand – when the demand will stabilize and how much the networks should be set for green gas, increases the market uncertainty. The actual market deployment by green gas may be not an optimistic number as expected.

Market uncertainty has interactions with many other uncertainties, as we can see in Figure 4.1. Market directly influences the gas suppliers/shippers and policy, so that Gasunie have to be careful about the uncertainty level of market during a sustainable strategy making.

4.3.3 Supplier uncertainty
When the dependency on a supplier is high, supplier uncertainty becomes increasingly important; when the dependency on a supplier is high, suppliers have more bargaining power and can create uncertainty on their actions (Meijer et al., 2005). Although green gas supplier currently is not the business parties with GTS, once Gasunie involves in the green gas transmission, the quantity and quality supply of green gas will directly influence its business. Beside, the supplier uncertainty will increase a negative feedback to the policy making and market formation.

The uncertainty of green gas suppliers is determined by different factors, such as the shortage of financial support, the uncertainty of generation technology, market demand, policy and returns time, etc. In the past decades, the biogas generation projects/plants experienced ups and downs, and then the generation of biogas showed a huge instability. The current entrants in green gas generation might get negative influence from that.

With certain quality standards, although it will be possible to transport the biogas from small scale co-digestion plants in a long distance, it seems not cost-beneficial in a small market deployment. The scattered and small scale of present digestion plants (< 50 MWth) probably can not provide the quantity guarantee for Gasunie’s green gas transmission (see Appendix Figure 1). Unless, there will be large scale co-digestion plants. The contradiction is that the past failure experiences of digestion may limit the generation scale of biogas and there is no further plan for large scale digestion plants. Thus, the future supplier will be the large scale bio-SNG plants, however bio-SNG technology is still on the R&D stage, so the future suppliers are actually unknown. Furthermore, the lacking of a general favourable business climate may limit the involvement of the innovation entrants. In other words, it will influences how many entrepreneurs will actual involve in an innovation (Section 3.4.3). Thus, the unpredicted actual amount and scale of the green gas generation, by the supplier uncertainty may influence Gasunie making a proper deployment of green gas in its business.

4.3.4 Technological uncertainty
Besides the uncertainty of green gas generation technology itself, technological uncertainties may rise in connecting the new technology to the existing technological infrastructure (Meijer et al., 2005). Green gas has to meet a certain quality standard, otherwise green gas would not be accepted by natu-
ral gas networks. The current problem is that this standard has not been set yet, so whether and when it is possible to accept green gas in natural gas network is unknown.

The biogas from digestion and land fill normally may contain halocarbons, ammonia, biological agents, siloxanes and polyaromatic hydrocarbons (PHAs), which may corrode the gas networks and transmit pathogens and disease. For bio-SNG, the carbon monoxide, PHAs and hydrogen may also threaten the health and corrode the transmission facilities. The consequences, for instance direct toxicity of leak in a semi-confined environment, indirect toxicity by combustion products, water pollution of injection in subterranean storage and air pollution, clogging the pipelines and safety devices and undue change of combustion properties because of the different components in green gas (See Appendix Table 1), are resulted from current un-mature upgrading technologies and unavailable criteria (MARCOGAZ, 2006). Thus, an un-established risk assessment and specified criteria for green gas quality increase the technological uncertainty for adapting green gas in natural gas networks. GTS has the responsibility for the security supply of gas, so it is important to get the green gas quality requirements.

4.3.5 Resource uncertainty
Resource uncertainty can be described as uncertainty about the availability of raw material, financial resources and human (knowledge people) needed for innovation (Meijer et al., 2005). It can indirectly influence the transmission company, and directly influence green gas suppliers by knowledge people and financial resources.

The uncertainty of financial resources, one is from governmental subsidy, which is already discussed in Section 4.3.1; another is from the general venture capital (Section 3.4.3). Both of them increase the economic risk for green gas generation. There may not be stable green gas resources. Uncertainty of human resources relates to the availability of knowledge and skills required in the green gas projects, and the human resources in the firm-internal level can complement with external resources in the innovation level (Meijer et al., 2005). Based on this point of view, Section 3.4.4 already presents the historic weakness of national knowledge transfer.

The Netherlands does not have enough available domestic biomass for the future requirement, so the optimum way for 2030 Dutch 30% biomass replacement will depend on the import for other EU countries. Increasing the available supply of biomass in future could therefore depend to a greater degree on the local active production of energy crops on surplus arable land, marginal and degraded lands, or plantation forests. However, the production of biomass competes with local agricultural food production, and a poor management will lead to losses of terrestrial carbon and the degradation of biological diversity. Thus, biomass production is more related to local agricultural and land use policy, also the market feedback. Besides, the issue “can the biomass be produced and used in a sustainable manner” makes that the biomass export countries hesitate to expand the biomass supply (OECD/IEA, 2007). For the import country, like the Netherlands, it is difficult to make accurate forecasts about the availability of importing raw biomass. Besides, other competitive technologies exist, e.g. biomass fermentation and combustion. These uncertainties directly increase the uncertainty of supplier, and indirectly influence Gasunie’s future role in the green gas transmission.

4.3.6 Competitive uncertainty
Firstly, competitive uncertainty is related with the size of competitors. The more the number of competitors, the more likely the diffusion of innovation technology is to success. Within these competitors, competitive uncertainty arises from the actions of potential or actual competitors, which may be either “innocent” – A lack of competitor intelligence or awareness about the prospective actions of competitor firms, or “strategic” – Firms deliberately create uncertainty for their competitors in order to gain a strategic advantage (Sutcliffe and Zaheer, 1998).

Gasunie is the only transmission company that links the main network (high pressure/regional transmission lines) to the big consumers and local distribution companies. The local network, which is laid to link small individual consumers to the main network, is owned mainly by local distribution companies. On a national scale, Gasunie does not have an actual competitor for green gas transmission in the
high pressure and region transmission lines. Therefore, the competitors for green gas sources may be the local distribution companies, which can distribute the small scale green gas to local use. This competition may not be a pressure for Gasunie, because of the different level business and the relatively low volumes.

Competing with others for the same business can perceive uncertainty about when the competitor will bring his competing technology to the market and which marketing strategies he will use. Competitive uncertainty can arise about the adoption behaviour of competitors, e.g. can a competitor gain strategic advantage by adopting the technology first (Meijer et al., 2005). In the future, some other transmission companies from outside the Netherlands, might be the potential competitors both in green gas transmission business and transmission technology collaboration. However, it is not clear yet. Besides, other regions, especially electricity, will be huge potential competitor for the transmission of green gas. Making a long term strategy may bring the strategy advantage for Gasunie in this case. However, in the current market, it is not easy to predict the future competitors to Gasunie with a same business.

4.4 Learning from the system

Right now, the drivers (see Section 4.1 and 4.2) from policy, the related potential market and firm itself, which we can call “open innovation”58, may stimulate Gasunie involving in searching new strategies in implementing green gas. However, the current existing high uncertainties in the firm level (see Section 4.3), may influence Gasunie’s decision, realistically. Thus, the related strategy should be made under the multiple dimensions of uncertainty to make a proper risk assessment, and to evaluate whether it is a real business chance. From the system point of view, green gas technologies should belong to the configuration technologies, which require multiple components to work together to establish a favourable institutional environment (Geels and Raven, 2006). Thus, the real problems may be no longer the uncertainty of green gas technologies, but how a favourable environment can be established and substantially contribute to a transformation of the energy sector. As an important player in the Dutch natural gas system, learning from the energy innovation system will help Gasunie to search the proper sustainable strategies related with green gas transmission, especially in the current initial and high uncertainty stage, to forecasting the market trends.

Back to the Dutch innovation system for green gas technologies, the diffusion of green gas technology in the past decades was not as successful as expected. Many blocking mechanisms locked the system functions, including the inconsistent and changing policy, insufficient financial support, weak connectivity among different actors, insufficient entrepreneurial entrants. The consequences were the backing up and stunt in the technologies diffusion, and the still un-formed niche markets for green gas (see Section 3.2). In Dutch energy innovation system, a well designed climate by active functions (see Figure 2.3) is the precondition for implementing green gas technology; relative regulation/legislation and sufficient financial support are the main drivers for energy companies to setting the related sustainable strategy. The governmental intervention in the diffusion of green gas technologies is very important, and the government plays a central role in starting the initial projects, stimulating the formation of niche markets and increasing the attraction of green gas.

Currently, biogas from digestion will be limited in small-scale generation. Accessing Gasunie’s natural gas networks to upgraded biogas in the future seems difficult to predict, because it seems more fitting for the local distribution networks and local use, from the view of policy DG (distributed generation). The present and long term high-light in bio-SNG will stimulate a potential market for Gasunie, because of its expected large scale generation and a 16% (240 PJ) replacement ambition of total Dutch natural gas consumption in 2030.

However, from the analysis of current policy failures (see Section 3.4.2), we know that the policy environment is more favourable for the R&D stage, which lacks sufficient subsidy for the transition

58 The enabling routines for building effective linkages outside the organization in order to identify, resource and implement innovation, have been called “open innovation” (Tidd et al., 2005).
from the R&D/demonstration stage to the pre-commercialisation stage. Currently, bio-SNG technology is just on the R&D stage. Thus, the diffusion of bio-SNG may have the high risk facing the backing up/stunt in the coming future, which may not generate enough bio-SNG as expected. The relative market might be small and not attractive. Beside, the uncertainties to Gasunie (see Section 4.3), are whether there is a significant adaptation level and when there will be a quality criteria. Policy orientations for stimulate and protect the green gas market, play an important role. Therefore, the current strategy making should be sensitive to the policy orientations.

For Gasunie, its main business depending on the short term benefits by transporting natural gas. Because the green gas market is not easily formed and the energy transition period is long, the transfer of business task should not be hurried. In the other hand, although policy plays an important role, there are still many potential contributors, e.g. NGO’s, collaboration among enterprises, stimulating the formation of green gas market. Thus, an incremental strategy might be proper, by coping with the policy orientations and keeping an optimistic view for the system functioning.

4.5 Searching for Gasunie

The strategy analysis – “What could a company do?”, can be effectively answered by scanning the environment and identifying a wide range of potential targets for the innovation (Tidd et al., 2005). The learning from the energy innovation system for green gas technology may help Gasunie to enable effective search before this strategy analysis. Below are some recommendations for the strategy searching of implementing green gas:

- **Defining the possible strategy boundaries**
The current policy environment has long term ambition in the future green gas transition, with sufficient R&D subsidies, but insufficient subsidies for demonstration/pre-commercial stages. The successful diffusion will depend on the further change of institutions. Based on that, Gasunie may start some initial R&D related with bio-SNG injection technology in current situation, and make a flexible and incremental strategy by a possible prediction for the long term development, instead of a substantial involvement.

- **Coping the strategy with business image**
Since the uncertainty mainly comes from the current policy and its future orientations, the strategy will have more utilization for enhancing Gasunie’s environmental image, in order to improve its competitive advantage in current “Green” trends. Thus, the strategy should combine with the proper boundaries.

- **Integrated future search**
Although there are well-proven and useful approaches to forecasting technology and market trends, these often make simplifying assumptions in a wider context in which predicted changes might take place. An alternative approach is to take an integrated view of what different future might look like and then explore innovation triggers within those spaces (Tidd et al., 2005). For instance, some business scenario researches will be helpful for Gasunie to make a prediction. None is necessarily the right answer to what the future energy market will look like by that time, but they do offer an enough description within which to explore and simulate, and to search for the risk assessments and opportunities which might affect Gasunie.

- **Involving in R&D**
As the largest Dutch gas transmission company, Gasunie shall draw up the draft conditions stipulating the minimum requirements for green gas, which means that the R&D of criteria setting is necessary in current stage for the future transition. Gasunie already attends a under developing “BONGO” project to define the quality specifications for green gas. A proper time schedule is necessary. Besides, the possibility of injecting bio-SNG will be to HTL (high pressure transmission lines) (see Section 4.1.2), so another R&D directions probably should be related with the quality requirements for bio-SNG adding to HTL, and the technological requirements for transporting and blending bio-SNG in natural gas networks. The later R&D may be fitting for the long term with gradually increasing investment.
• **Learning from others**
Since Dutch green gas technologies are on the R&D/demonstration stage, learning from other enterprises outside the Netherlands, which are with the similar business, actually, will help Gasunie to carry its particular processes. Beside, involving in kinds of knowledge workshops/conferences is important way to learn and communicate in current period.

• **Collaboration**
Collaboration for Gasunie in current situation is important, which may reduce the R&D cost; get the new knowledge; reduce the development risk; promote the shared learning. For instance, the collaboration between Gasunie and other research institutes will stimulate the new knowledge transfer and help to set a proper criteria for green gas quality. The collaboration with government will get the immediate information about the policy orientations, e.g. the deep collaboration with SenterNovem in energy transition platform (already started); the collaboration with the potential green gas supplier will help Gasunie to figure the possible business chance.

• **Understanding the market dynamics**
Although its market is not easily formed in short/medium term, and the current policy environment has many problems, the potential markets may arise as a consequence of various kinds of change from communication and interactions. On the economical optimisation point of view, the price of natural gas will increase, and the green gas might be an optimum alternative energy with a decreasing cost. Also, the formation of green gas market can be stimulate by some collaborations among the enterprises. Thus, Gasunie would be open the mind to this potential market dynamic change, which will influence Gasunie’s long term business mission. Otherwise, Gasunie might lost the strategy advantage, and the future market.
5. CONCLUSION AND RECOMMENDATION

This research investigates the barriers of implementing green gas in the Netherlands in an energy innovation system and at entrepreneurial level. The main research question is “Whether is it feasible to develop green gas in the Netherlands, and whether is it a business chance for Gasunie in implementing green gas?”

Sub-questions:
· How does the innovation system for green gas technology work, and what are the inducement and blocking mechanisms to this system?
· What were the problems of the biogas technology trajectory in the past?
· What are the performances of current energy innovation system?
· How do the policy and market influence entrepreneurial activities?
· Whether is it a business chance for Gasunie in implementing green gas?
  - What are the drivers for Gasunie to develop green gas?
  - What are the barriers in firm’s level?
  - What can Gasunie learn from the energy innovation system to make the strategy analysis?
  - Where are the directions of current strategy searching?

In this chapter, I would like to draw the conclusions based on the research results from former chapters, and give some general recommendations.

5.1 The performance of Dutch energy innovation system for green gas technology

Innovation — A source of diversity in economic life, may broaden the set of assumptions governing economic decisions. The removal of barriers to communication opens up new possibilities. The merger of firms with different technologies and corporate cultures may generate new ideas, in addition to creating possibilities of exploiting economies of scale and scope. The elimination of trade barriers which result in increased economic integration opens up vast new opportunities (Carlsson et al., 1991). A successful innovation relates with the economic penetration of this innovation, as we called “diffusion”, which is highly impacted by the involved entrepreneurial activities by turning the potential of new knowledge development, networks and markets into concrete actions to generate and take advantage of business opportunities (Hekkert et al., 2007). From some successful diffusion experiences of ICT and automation, we know that the entrepreneurial activities play an essential role in stimulating the market formation, in a more spontaneous way. However, in a specified energy innovation system for renewable energy technologies, that seems another case.  
(Conclusion 1: Entrepreneurial activities are essential for the successful diffusion of an innovation technology, but its functions might be limited by policy in an energy system)

In a large energy sector, which is mainly occupied by conventional energy and its technologies, the energy transition will take a long time and the market formation for alternative energy is also difficult in short term. The incumbent enterprises have benefited from the established energy systems, including a stable and large market, available and protected policy, established networks with other economic parties. The new entrants always face the financial problems, e.g. disadvantage in renewable technology cost and market price, etc. However, cost, by itself, is not sufficient to harness the inputs of distributed actors/players involved in the development of new technology (Garud et al., 2003). In general, the limits on these technologies change do not depend on science and technology itself, which tend to evolve much faster with the organizational, social and institutional changes that allow the diffusion of new technology (Unruh, 2002).
(Conclusion 2: The innovation technology of renewable energy is a configurational technology, which mainly depends on the organizational, social and institutional changes)
In the Netherlands, natural gas is the most important primary energy source. As one of the energy transition paths in the future, green gas seems as a special attraction for the Netherlands, with its high similarity with the natural gas quality, some already mature generation technologies and potential available sources. However, the past trajectory of Dutch biomass digestion and gasification was not successful. The inconsistent and changing policy and insufficient finance increased the risk of enterprise’s investments and stunted the formation of the niche markets, which leaded the draw-back and fluctuating development of these technologies. For example, the government seemed not keeping the sensitivity to the market by a blind budget cut in 1994. Besides, the policy from other sectors also exerted an impact on the diffusion of these technologies. In 1998, the liberalisation of the energy market aiming to introduce competition in conventional energy price, made it hard for green generators to compete in a relative high price. These policies directly/indirectly may lock the diffusion chain. Now, biomass digestion and gasification technologies can be described as “the existence of a range of competing designs, many small scale entrants and high uncertainty in terms of technologies, markets and regulations” after about 30 and 17 years development, respectively.

(Conclusion 3: The past diffusion of digestion/gasification technologies was slow, mainly because of the inconstant and changing policy)

Currently, co-digestion combined with CHP is already seen as DG with small scales (< 50 MWe), and more plants are planned since 2004. Although many kinds of subsidies are available, the well known “MEP” does not have a long enough duration of support for generation (see Section 3.4.2). The actual availability of biogas may not be as expected (48-60 PJ after 2010). As another technology attraction, bio-SNG technology is on a long-term development with the 16% replacement ambition of natural gas ambition in 2030. Bio-SNG technology will be on the demonstration stage till 2010. One of the expectations for the successful generation will be the similar subsidies like “MEP”, which can keep the competitive price for bio-SNG and provide an enough subsidy for generators. However, there are some potential failures in current established energy innovation system, which may be the barriers for the future diffusion of bio-SNG technology.

In the formative period, the system failure may appear to happen in the transition from the demonstration stage to the pre-commercial stage (Foxon et al., 2005). Current renewable energy policy gives insufficient support to this transition point (Section 3.4.2), which means that it may limit the diffusion of bio-SNG technology from the R&D stage to the demonstration-pre-commercial stages in the coming future. Besides, the national innovation climate is not favourable: the national subsidy level seems also insufficient; the interaction between research sector and business sector, is low; the knowledge transfer facing the transition barriers, leads the Dutch national innovation to step a bit away other EU countries, e.g. Demark, Germany (Bain&Company, 2006). Furthermore, the short/medium term natural gas policy may have negative influences. The small field policy and LNG import protecting the security supply of natural gas in a short/medium term, may block the diffusion speed of green gas. Even the other type bioenergy technologies may still strongly compete with the green gas technologies, as we know the biomass fermentation (bio-fuels) and combustion technologies. In the other words, these failures may increase the risk for the entrepreneurial entrants in green gas, and further relative incumbent/new energy enterprises may hesitate. Thus, a blind optimism about the feasibility level of green gas, from the system point of view, seems unrealistic, unless there will be an improved energy innovation system with a balance in short/medium and long term benefits.

(Conclusion 4: The current environment seems unfavorable for the future involvement of green gas suppliers, by lacking sufficient financial support)

Considering another expectation – the future green gas adding into the Dutch natural gas network, letting the green gas in the future infrastructure, the risk is relatively increased by the uncertainty of

59 DG: Distributed generation
60 See Appendix Figure 1 2007 Dutch biogas installation.
policy, supplier and a complex Dutch natural gas trading and transmission system. Thus, in the case study, a specified analysis focuses on the largest Dutch natural gas transmission company, in order to investigate whether it is a business chance for implementing green gas in a firm’s level.

5.2 Case study

From the system point of view, the enterprise has the “corporate responsibility” to transfer the innovation knowledge and stimulate the market formation. Since the renewable innovation being a kind of configuration technology requires more support from the governmental institutions and enterprise is market oriented, the enterprise would not involve in a spontaneous way. In the Dutch natural gas system, it is common practice that the supplier takes all responsibilities on control and measurement activities on the gas supply. As an independent natural gas transmission company, Gasunie supplies natural gas transport services and is responsible for the safe transport. If green gas fits for certain quality requirements, it will be possible adding green gas into Gasunie’s networks. Upgraded biogas from digestion will be limited by its small-scale generation. In Gasunie’s high and middle pressure lines, adding these biogases seems not cost-beneficial instead of local supply. Future bio-SNG may be the business focus of Gasunie in green gas transmission — the large scale generation, about 16% replacement of total natural gas, the possibility of high pressure lines’ injection.

The current main drivers for Gasunie implementing green gas research are the future potential markets and “corporate green image”. However, a success of market introduce is highly influenced by the policy orientations, including the availability of subsidy, the protecting regulations, etc. The adaptation level of green gas in the future infrastructure has not been known yet, and the related entry criteria seems just on the research agenda of government (SenterNovem, 2006).

(Conclusion 5: The ambiguous adaptation level and criteria setting may be the potential limitations for providing access to the green gas in natural gas grid as expected)

Here, the uncertainty is not only the initial character of innovation itself, e.g. the immature technology, unknown demand, etc, which can be overcome by the widely introduce of this innovation, but increased by the potential system failures. It means that this uncertainty interacts in a high level and is more complex, which is difficult to overcome only by enterprise itself. If the current failures and blocking mechanisms may not be overcome, a successful diffusion of green gas may not appear in the future. We can expect a positive environment for the future development, however this system uncertainty implies that the decision making in firm’s level has to be carefully enough.

(Conclusion 6: The policy uncertainty increases the green gas market and supplier uncertainty, which further increases the uncertainty level of Gasunie – The involvement with green gas transmission)

Still, from the boosted “Green Image” conception, and a long term sustainable development point of view, Gasunie can get some competitive advantages for the involvement in implementing green gas research, but it should keep a high sensitivity to the policy orientations. The current natural gas transport is still the main business of Gasunie in the short term. This energy transition will take a long time (maybe 20-30 years), and the feasibility level of green gas might be smaller than the expected governmental strategy. A proper deployment and incremental strategy for implementing green gas seems more reasonable in current situation.

(Conclusion 7: An incremental strategy by coping with the policy orientations and increasing the “Green Image” seems more proper in current stage)

The green gas market in an energy system might be stimulated by other collaborated functions, so it is important to keep an economic optimization about the future market dynamics. Otherwise, once the market is formed, it will be too late for a business involvement. Keeping the sensitivity to the policy orientation, Gasunie could involve in initial R&D of setting the draft for green gas quality requirements and injecting bio-SNG to natural gas networks, combining more collaboration with different parties, in order to learn from others and set a proper incremental strategy.

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61 SenterNovem, 2006. Energy transition task force
(Conclusion 8: From the system point of view, it is also important to keep an economic optimization about the market dynamics, which can be stimulated by the collaborations among enterprises)

5.3 Recommendations for government

Investments in public R&D can initiate and support the development of new energy technologies, but bringing these to market often requires further effort. New technologies, even after these technical feasibility has been demonstrated, face a number of barriers such as cost, infrastructure needs, slow capital stock turnover, market organization, and information and financing constraints. This requires paying attention to the possibility and feasibility of public-sector responses to help overcome these barriers (Sagar et al., 2006). It is the same with green gas development.

- Promotion of the deployment of emerging green gas technologies to help overcome initial cost barriers by anticipating, and taking advantage of “learning”. A major set of policies has involved government-mandated purchase of green gas by utilities. Governments can also promote the deployment of energy technologies through their procurement programs.
- Protect niche markets for the low to moderate penetration levels of green gas. In other words, green gas can work outside the main market at the demonstration/pre-commercial stages. Priority access and obligatory purchase schemes, such as feed-in tariffs may be the most efficient way to incorporate green gas in the physical infrastructure. However, as the penetration of green gas rises, the efficiency of such schemes is likely to diminish and participation in energy and ancillary services markets may be warranted (ECN, 2003).
- In order to build a more productive sustainable innovation pipeline in the Netherlands, financing and incubation support by the Dutch state can obviously help to close the early stage venture capital gap in a short term. The state can provide loan guarantees to project financing banks and by doing so attract venture capital with a more attractive risk/return profile of the leveraged innovation projects. First assessment indicated that this loan guarantee option can provide the most flexible and quickest transition to the ultimately optimal solution, which is better availability of commercial venture capital. Estimated total required funds to close the most urgent early stage venture capital gap (Bain & Company, 2006).
- Provide sufficient financial support to the demonstration/pre-commercial stages to overcome the diffusion gaps appearing in this transition period. Both the biomass digestion and bio-SNG require more support.
- Collaboration with different parties to get the effective information and feedback. Government should be sensitive to the dynamic change in the market, which can help the policy making and prevent the “policy failure”.
- Education in university and enterprise is important to increase the innovation knowledge people and innovation willingness in individual level.
- Effective risk management and establishment of demonstration plants could help to reduce these perceived barriers and thereby lead to an increase in the number of willing investors. This would result in more competitive financing opportunities.
- Overcoming infrastructural barriers. The main barrier for green gas adding into the natural gas network is the unknown quality requirements. Government should play the leading role in the involvement of criteria research, with other institutes, transmission companies and green gas suppliers.

Sustainable energy transition will take a long time. During this period, a gradually improved institutional environment may finally guarantee a successful diffusion of green gas technology as expected right now.
ABBREVIATIONS AND DEFINITIONS

BIC/CC: Biomass integrated gasification/combined cycle

Bio-energy: The energy from the organic content from waste and biomass.

Biogas: It is produced by biomass digestion or landfills, contains mainly CH$_4$ and CO$_2$.

Bio-SNG: Synthetic natural gas is produced by biomass gasification and methanation, contains mainly CH$_4$.

Bio-Syngas: Synthesis gas is produced by biomass high temperature gasification (>1200°C) or catalytic gasification, contains H$_2$ and CO.

BONGO: Biogas and others in natural gas operations

CBF: Circulating fluidized bed

CBS: Centraal Bureau voor de Statistiek (Statistics Netherlands)

CDM: Clean development mechanism

CHP: Combined heat and power

DEN: Duurzame energie (Sustainable energy)

DG: Distributed generation

DTI: The Department of Trade & Industry, UK

ECN: Energieonderzoek Centrum Nederland (Energy research centre of the Netherlands)

EIA: Energy investment allowance

EIM: EIM Business & Policy Research

EOS: Energy research subsidy

EOS-LT: Energy research subsidy scheme for long term

EOS-UKR: Energy research subsidy scheme for unique opportunity

EPA: Energy performance advice

EPR: Energy premium regulation

ETP: Environment & technology programme

EWAB: Energy production from waste and biomass

EZ: Ministerie van Economische Zaken (The Ministry of Economic Affairs)

GC: Green certificates

GHGs: Green house gases
Green Gas: It is the general term for both bio-SNG and upgraded biogas or landfill gas, which is suitable and specifies for utilization as natural gas substitute.

GTS: Gas Transport Service of Gasunie

HTL: High transmission lines

IEA: International Energy Agency

LCCA: National coordination commission for Waste Policy

LHV: Low heating value

LNG: Liquefied natural gas

MEP: Milieukwaliteit van de elektriciteitsproductie (Environmental quality of electricity production)

MIA: Environmental investment allowance

NOH: National research programme for recycling of waste

OECD: Organisation for Economic Co-operation and Development

PHAs: Polyaromatic hydrocarbons

R&D: Research and development

REB: The regulatory energy tax or ecotax

RTL: Regional transmission lines

SenterNovem: An agency of the Dutch Ministry of Economic Affairs.

SUSPRISE: European sustainable enterprise project

TT/TD: Technological transitions or technology diffusion

WBSO: Promotion of R&D act
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### APPENDIX

Table 1: Indicative composition/properties of natural gas and different raw gases from biogas (SNG) (MARCOGAZ, 2006)

<table>
<thead>
<tr>
<th>Composition/Properties</th>
<th>Units</th>
<th>Natural gas (typical North Sea H)</th>
<th>Biogas</th>
<th>Anaerobic digester</th>
<th>Landfill</th>
<th>O₂-fired</th>
<th>Air-fired</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td></td>
<td>88.8 (86.6 - 88.8)</td>
<td>65.0</td>
<td>45.0</td>
<td>15.6</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td></td>
<td>8.3 (8.3 - 8.5)</td>
<td>-</td>
<td>-</td>
<td>1.5</td>
<td>5.8</td>
<td>(0 - 5.8)</td>
</tr>
<tr>
<td>Hydrogen</td>
<td></td>
<td>-</td>
<td>0 - 2</td>
<td>0 - 2</td>
<td></td>
<td></td>
<td>(0 - 2)</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td>(0 - 2)</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td></td>
<td>2.3 (1.9 - 2.3)</td>
<td>35.0</td>
<td>40.0</td>
<td>12.2</td>
<td>20.0</td>
<td>(10 - 25)</td>
</tr>
<tr>
<td>Nitrogen</td>
<td></td>
<td>1.1 (0.9 - 1.1)</td>
<td>0.2</td>
<td>15.0</td>
<td>0</td>
<td>approx.</td>
<td>50.0</td>
</tr>
<tr>
<td>Oxygen</td>
<td>mol%</td>
<td>&lt; 0.01</td>
<td>(0 - 1)</td>
<td>(0 - 10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td></td>
<td>1.5 (0 - 5)</td>
<td>&lt; 600</td>
<td>&lt; 100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonia</td>
<td>mg/m³</td>
<td>-</td>
<td>100</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total chlorine</td>
<td>mg/m³</td>
<td>-</td>
<td>(0 - 100)</td>
<td>(0 - 5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total fluorine</td>
<td>mg/m³</td>
<td>-</td>
<td>0.5</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siloxanes</td>
<td>mg/m³</td>
<td>-</td>
<td>0 - 50</td>
<td>0 - 50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tar</td>
<td>g/m³</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0 - 5</td>
<td>0.01 - 100</td>
<td></td>
</tr>
<tr>
<td>Gross calorific value</td>
<td>MJ/m³</td>
<td>40</td>
<td>32</td>
<td>17</td>
<td>14</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Net calorific value(1)</td>
<td>MJ/m³</td>
<td>35</td>
<td>22</td>
<td>21</td>
<td>13</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Wobbe Number (1)</td>
<td>MJ/m³</td>
<td>50</td>
<td>26</td>
<td>27</td>
<td>29</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Relative Density (1)</td>
<td>kg/m³</td>
<td>0.6</td>
<td>0.9</td>
<td>0.7</td>
<td>0.2</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Methane Number (2)</td>
<td></td>
<td>76</td>
<td>135</td>
<td>144</td>
<td>64</td>
<td>77</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1 2007 Dutch biogas installation, excl. landfill gas and digestion of sewage sludge (Asselt, 2007)