The evolution and functionality of the branch development project Biogas Väst

– an innovation system approach

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Abstract

In order to cope with increasing environmental degradation and global warming, there seems to have developed a consensus of that the energy system of today most be changed, or at least, radically modified. To reach such changes, initiating projects of different kinds to support the development and establishment of environmentally friendly technologies is a powerful tool. Several political initiatives, such as funding of research and development, and demonstration and branch development projects, have been carried out in Sweden in resent decades. The Biogas Väst project is a branch development project, carried out in the region of Västra Götaland (in the western of Sweden), which aims at promoting the production and use of biogas in the transportation sector.

This thesis will evaluate the design of the Biogas Väst project and describe the functionality of the regional biogas system. Innovation system theory will be used as a theoretical background in order to derive a set of design criteria, which will be used in the analysis of the Biogas Väst project. The derived criteria differ depending on the state of development the innovation system under study has reached. A survey of the actors, networks and the institutional framework that constitutes the regional biogas system has been done, mainly through interviews of important actors.

The Biogas Väst project has supported formation of networks between actors involved in the biogas system. In addition, an *advocacy coalition* on a local scale has formed and influenced the institutional framework. However, based on the design criteria, no niche market has been identified and explored in the Göteborg region, and some, perhaps crucial, actors have not been induced to participate. The practice of the *green gas* principle could benefit the natural gas industry as much as the biogas industry.

Acknowledgements

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1. Introduction

Due to an extensive use of fossil based energy, the global environmental degradation continues and no significant decrease of greenhouse gas emissions is yet to be seen. Fossil based fuels dominate the global energy supply and accounts for approximately 80 % of the total energy use (STEM, 2002a). In the late 1990s, there seems to have developed a scientific and political consensus of that the energy system of today must be replaced, or at least radically modified, to cope with the climate issues. At local and regional levels political initiatives such as branch development, research/development and demonstration (RD&D) and cooperative projects of different kinds, are becoming more and more important to promote environmental-friendly technologies.

In the region of Västra Götaland in the western of Sweden, local politicians and the regional industry initiated a branch development project called Biogas Väst in the beginning of 2001. The project aims at promoting the production and use of biogas as motor-fuel in the transportation sector. Primarily, this should be achieved through joint marketing and formation of networks between firms, politicians and municipal authorities.

The main purpose of this thesis is to investigate and describe the evolution of the branch development project Biogas Väst and, from an innovation system approach, determine the functionality of the biogas system in the region of Västra Götaland. Interviews with relevant actors have been the main method for gathering information.

A theoretical framework of the functionality of innovation systems, developed by Jacobsson and Johnson (2000), will be used to determine a set of design criteria that could be taken into consideration when designing a project of this kind. The design of the project and the functionality of the regional biogas system will be evaluated on the basis of these criteria and the innovation system theory. The analysis will be delimited to explain the system by, mainly, endogenous factors, i.e. measures carried out by actors participating in the project and the regional biogas system. Naturally, several other events, both national and international, have influenced the development but these will not be examined in this thesis.

The report is structured as follows: first, the theoretical framework is outlined in a, for this thesis, suitable form. Thereafter, some technical aspects of biogas are presented, such as production and distribution methods, potentials of biogas production, and some information regarding the vehicles. The Biogas Väst project and the actors participating in it are described in detail, and the course of events that led to the initiation of the project is investigated. Finally, the functionality and design of the biogas system and Biogas Väst is evaluated and discussed.

2. Theoretical framework

In order to derive a conceptual framework with the purpose of evaluating the performance of, in the case of this thesis: a *regional branch development project* within the field of alternative fuels (more specifically: biogas), a theoretical background has to be introduced. First, the concept of *innovation system* and *functions* will be presented and thereafter followed by a section that deals with technology evolution and characteristics in the development of industries. These will finally be put together in a, for this thesis, suitable form. Note that the theory will be limited to projects carried out in a relatively early state of development, at least before the industry to be supported has reached a self-sustained period of growth.

A branch development project is defined, in the context of this thesis, as a project that aims to support the development of an industry. Several sub-projects may be carried out during such a project, research and demonstration projects (R&D), demonstration projection etc.

2.1 The innovation system approach[1]

In the resent decades several system approaches for studying technological innovation and development have evolved. These vary in both geographical and physical limitations; some are technology specific, others focus on regions or nations (Freeman, 1988), and some on entire industries (Hughes, 1987). A common feature for several of these system approaches is that, in contrast to traditional economic analysis, in which perfect markets and fully informed agents select the optimal technology, other factors must be taken in consideration to describe technology evolution. Such factors are, for example, *path-dependency*, *increasing returns to adoption* (Arthur, 1988), the importance of well-established networks, *dominant designs* (Abernathy & Utterback, 1978) and institutional factors of different kinds.

A common understanding in the innovation system approach is that the determinants of industrial development and growth are not only found within individual firms; firms are embedded in innovation systems that aid and constrain the individual actors within them (Johnson & Jacobsson, 2001a). The innovation system approach is based on the concept of *technological system* (Carlsson & Stankiewicz, 1991), and the definition of such:

"... network(s) of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse and utilize technology"

(p. 111). Through this definition, three types of elements that define the system and its borders can be drawn. These are:

(i) *Actors* and their competence, which are the "operative" element within the system. Actors can be of both technical nature (producers,

[1] The majority of this section is based on Johnson and Jacobsson, 2001a.

developers, repair men etc.), as well as consumers, politicians, universities, banks (providing venture capital) and others that in one way or another acts within the system. A particularly important type is the *prime movers* (Jacobsson & Johnson, 2000) or system builders (Hughes, 1983) that posses such a power within politics, finance or technology that they can, by them self, initiate a development and/or a diffusion of a new technology[2].

(ii) Between these actors, *networks* of different kinds are likely to evolve in an emerging system. Networks are the prime channels for knowledge and information transfer, as for example: user-supplier networks, informal networks and problem-solving networks that can be said to define the nature and the boundaries of the system (Carlsson et al., 2002). Hence, the identification and formulation of problems, both technical and institutional ones, and, in some cases their solutions, is diffused through these. For firms, being involved within a network broadens the flows of information and knowledge, and, often, dramatically increases the possibilities of gaining influence on the institutional framework. A particularly important type of networks, in the context of technology management, is *advocacy coalitions* that consist of a range of actors that together form a unit, powerful enough to gain influence over institutional factors.

(iii)*Institutions* play an important role of setting the environment for a technological system to evolve within. Institutions in this context are a broad range of factors: legislation, regulation, culture, education and such. The culture in a region affects consumer demands and behaviours, and therefore, also indirect affects the legitimacy for different technologies. Institutional organs govern the legislations, educational systems and incentive-structures, and thereby, so to say, setting the rules of the game.

[2] Note that, in contrast to a prime mover, an actor with such a power can play the role of a *prime blocker* for the system instead (Jacobsson & Johanson, 2000).

These elements vary between regions and are, by no means, independent of each other. For example, advocacy coalitions may influence the institutional framework, in which turn may affect the range of actors that are willing to participate in the system, and, hence the networks that may evolve as well. (Johnson & Jacobsson, 2001a)

In order to study an innovation systems performance a number of *functions* can be applied. These functions describe the system through several different aspects and are useful for defining the borders of the system, which in general is a difficult task (Carlsson et al. 2002). Johnson and Jacobsson point out five functions:

- creation of new knowledge,
- guide the directions of search,
- supply of resources,
- creation of positive external economies and
- formation of markets.

At an early stage, an identification of a problem (with a technological solution) that needs to be solved could be the initiation of a new innovation system.[3] In order to solve this problem, in the case of technological systems, a creative phase of experimentation takes place, with the aim of *creating new knowledge* (an innovation of some kind, for example). This function will probably last throughout the whole lifecycle of the system and, perhaps, will be the source of several new systems.

In this experimental phase, it is of great importance to *guide the directions of search* amongst firms and other actors, in order for potential participants to deploy resources within the system. This can be accomplished in a numerous of different ways, but generally speaking, a growth potential of some kind will have to be recognised (technical or economical). This is closely related to the legitimacy of a new technology, which is an important issue for an evolving industry.

[3] However, the initiation of a system does not have to be demand-pulled. In some cases, a somewhat "vague" feeling of a problem that needs to be solved could be enough. (Bergek, 2002)

In a stage where the industry is about to enter a period of growth, the *supply of resources* of different kinds is crucial, not only capital and raw materials, but also competence in the form of skilled labour, technological competencies and much more. In a later stage of development, resources, to ensure the development of complementary products to the new technology, may be required to broaden and strengthen the system. Such resources are vital in the competition with other technological alternatives in becoming the dominant design for the industry.

Positive external economies (spill over effects) in different shapes are likely to emerge through, for example, the evolvement of complementary products. Such economies often functions as an inducement for additional network formation, and, in the long (successful) run, even changes in culture. The up-come of such economies increases the strength and further establishing the innovation system as an industry.

The last function, which for many actors (and, perhaps, the industry in general), is considered as the most important one, is the *formation of markets*. Through particularly this function, the system is able to evolve from the take-off phase to the growth phase, but markets are seldom created in spontaneous manners. Instead, market creation often requires the removal of legislative and political obstacles, as well as an increasingly legitimacy of the technology. (Johnson & Jacobsson, 2001a)

In order to develop a fully functional innovation system, all these functions must be served in one way or another. A self-sustaining period of market growth will only be reached when positive feedback mechanisms have emerged, connecting the functions in self-inducing virtuous circles (Johnson & Jacobsson, 2001a). However, the order they may be served in and the importance of a specific function at a given time varies in the evolutionary process.

A wide range of *blocking mechanism* may yet hinder the formation of the functions. Such could be: lack of legitimacy for the technology, lack of skilled labour, poorly articulated demands from costumers, superior incumbent technologies (in terms of price/performance ratios), to mention a few. In contrast to these, *inducement mechanisms*, as strong networks, the establishment of standards, increasing returns to adoption, scale economies may benefit the development of the system. Taking all these in consideration in the design of a branch development project is essential for the outcome.

2.2 Issues concerning the evolution of innovation systems

The growth and stabilisation process of technology systems is often explained through cyclical models of innovation. Central for such models are the fact that a dominant design can be locked-in through path-depended processes (Abernathy & Utterback, 1978); moreover, it has been argued that the best technology not necessarily becomes the "winner", i.e. the dominant design.

The process towards a dominant design is influenced by several sources, such as *learning by using*, *network externalities*, *scale economies, informational increasing returns* and *technological interrelatedness* (Arthur, 1988). Especially learning by using and scale economies are factors that, in a direct way, affect the price/performance ratio for a product.

Cyclical models of innovation are generally described as consisting of two main phases: a formative period followed by a market expansion. The change of adoption of the technology during these phases often describes an s-curve, as indicated in figure 1. In addition, these phases differ in terms of technological invention: from radical to incremental (Abernathy & Utterback, 1978).

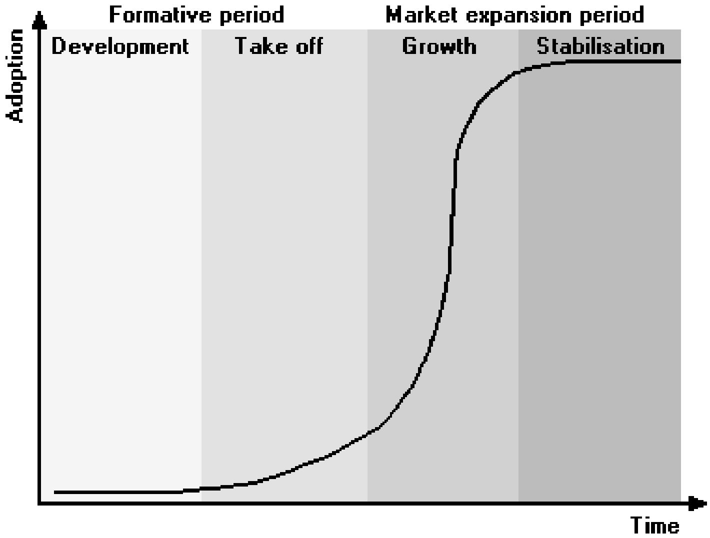

Figure 1: *The two main phases in the evolution of an industry. These two phases can, in addition, be divided into a development phase, diffusion phase, growth phase and stabilisation phase.*

The formative period starts in a stage where numerous technological designs (alternatives) are formed to meat a consumer demand, though, not always a well-articulated one. At some point, a specific design or set of designs[4] is likely to capture a critical mass of the market and thereby become the dominant design, a standard for the industry. The industry then enters the market expansion period, where a shift of the activity within the system normally occurs: from product innovation to process improvements. (Abernathy & Utterback, 1978)

In addition, these two phases can be further divided into four sub-phases (se figure 1) along the lines of Kemp and Rotmans (2001) statement: *"although* (technological) *transitions are characterised by non-linear behaviour, the process itself is a gradual one"*. These phases are the *development phase*, the *take off phase*, the *growth phase* and the

[4] For example: an infrastructure constituted of a range of linked sub-technologies supporting a prime technology; i.e. production and distribution facilities, refilling stations and such supporting a car.

stabilisation phase.[5] Considering the purpose of this thesis, and that the "goal" of the development process could be said to be "reaching a self-sustaining growth phase", the characteristics of the two first phases will be described.

Development phase

The development phase is characterised by broad range experimentation, firm entry, small markets and a high uncertainty regarding technological, regulative and market issues (Johnson and Jacobsson, 2001b). The system is mainly constituted of actor types associated with invention, development and production of technology. Several technological designs, or set of designs, are competing, not as much for market shares in this early phase but to acquire resources in terms of technical competence and finances for further product improvement. Therefore, creating and sharing knowledge and learning is central. This is mainly achieved through the formation of problem-solving networks.

Since the development of innovation systems seldom occurs without the influence of other systems, new products have to face the challenge of competing against incumbent technologies. Direct actions from competitive actors (lobbying etc), and competitive disadvantages for not having undergone processes of increasing returns, such as scale economics, hinders the development process (Arthur, 1988). This is closely related to the legitimacy of a new technology, which often is low due to uncertainty and lack of knowledge in this phase.

Take off phase

The main difference between the take-off phase and the development phase is the increased adoption of the technology, i.e. a market begins to emerge. The technology has developed to a state where it, at least in some aspects, is competitive with incumbent alternatives and could, thereby, be utilised in niches or protected market spaces. Such markets are either

[5] The name and characteristics of these phases are based on Unruh, 2000; Johnson & Jacobsson, 2001a; Kemp & Rotmans, 2001.

based on performance factors such as mobility, low emissions, or "created" through, for example, governmental subsidies. Thus, the take off phase is characterised by the exploitation of niche markets, additional firm entry, an increased adoption of the technology and emerge of commodities.

In pace with an increased recognition of growth potentials within the industry, other actor types than inventors and developers are likely to enter as well. Primarily actors that bring resources to the industry in terms of mass-production capabilities, venture capital and such, but even others as politicians, universities, media etc. The problem-solving networks are complemented with networks that aim to strengthen the competitiveness of the industry against other industries, mainly advocacy coalitions that aim at influencing the institutional framework at guiding the direction of search by, for example, identifying growth potentials.

At the shift from the take off phase to a market growth, a dominant design is expected to emerge, either as a specific product design or as a "standard procedure" in a production/distribution-chain.

2.3 Design criteria for a branch development project

Due to the high uncertainty and unpredictability of technology evolution and the emergence of markets, it is a difficult task to *a priori* determine which functions or measures that should be taken in consideration, and in which order, when designing a branch development project that aims to establish an innovation system.

Though, in a general perspective, the functions have different roles to play in the development phase and the take off phase.[6] As indicated in figure 2, the importance of a function in a given phase may vary as well. The functions are arranged in an order that is based on the characteristics of the phases described earlier; a plausible order to create such characteristic features in the evolving industry.

[6] The statement is based on Johnson & Jacobsson (2001b). However, not the explicit order of the functions in relation to the state of development indicated in figure 2.

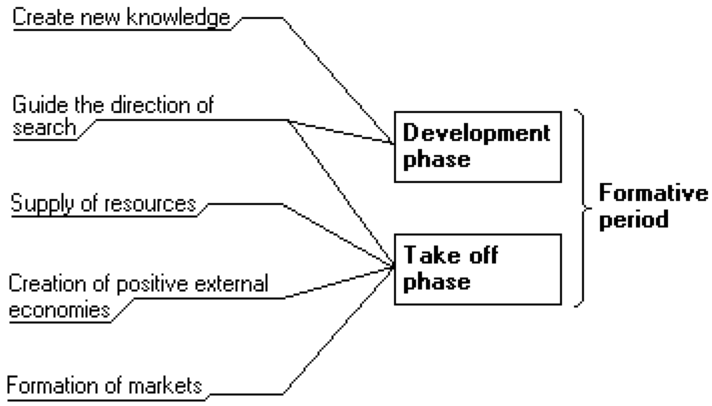

Figure 2: *The importance of the five functions varies depending on the state of development for the industry.*

Considering this order and the different characteristics of the two phases, a branch development project would have a different design depending on the state of development the industry is situated in (i.e. the development phase or take off phase). For example, different type of actors should be induced to participate; different actor types would constitute the networks to be created; different institutional issues should be focused on, depending on which phase the project is about to be carried out in. Therefore, an important step is to determine whether the industry is situated in the development phase or the take off phase. To do this a survey of the industry is necessary. In such a survey, certain "key-factors" could prove useful, such as the number of firms active in the field and current production volumes in relation to competing industries, furthermore, which type of markets are explored (if any) and the institutional settings. In addition, several other questions will need to be answered as well: uncertainties and legitimacy regarding prime and sub-technologies; what have already been done within the particular field (in terms of already established networks, demonstration projects etc); identify actors that operate in the technological field (or actors that are willing to do so); identify institutional factors of importance and, if possible, identify (future) blocking mechanisms and bottlenecks.

A summary of important measures to be considered in the design of a branch development project is presented in figure 3. Though, the figure should not be interpreted as that the objectives to be carried out in the two phases are necessarily bound to each phase. Several of these objectives could be served continuous by the whole development process, but may be specifically important during these phases.

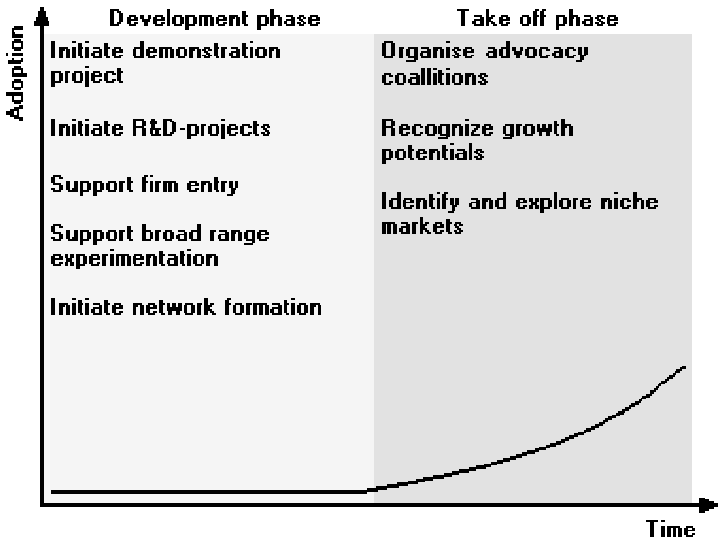

Figure 3: *Measures to be taken in consideration when designing a branch development project.*

Development phase

The main task for a branch development project in this phase is to support a development towards technological readiness[7] (Karlström & Andersson, 2003), from invention to innovation, i.e. to support improvement of the price/performance ratio of the technology, or set of technologies, to a state where it becomes competitive in some respect.

[7] Technological readiness is a somewhat vague term; there are no explicit measures that indicate when such a readiness has emerged. Readiness should be interpreted as that the technology has reached a state of competitiveness in some aspect in comparison with other technological alternatives.

As indicated in figure 2, two functions may be served in such a process: create new knowledge and guide the direction of search. The creation of new knowledge, both explicit new knowledge and the spread of knowledge amongst actors, is vital. Primarily, to ensure broad range experimentation, hence knowledge is the prime source for generating different technological designs as a solution to a (technological) problem of some kind. That will reduce technological uncertainties and may increase the legitimacy for the technology. The uncertainty of the outcome of technological competition and since that the formulation of a problem (or a consumer demand) may vary over time, the creation of variety in the knowledge base is important.

Demonstrating the technology to certain actors and initiating R&D-projects could to some extent achieve this.[8] Either, a single technology can be demonstrated, or a whole system of interrelated technologies. A demonstration project may, in addition, act as an arena for network formation where several important actors of both technical and political nature may convene.

To induce product improvement, resources in terms of competence and capital must be stimulated, via the function "guide the direction of search", to be deployed in the industry. Such resources are mainly found within firms or supplied through governmental agencies. Therefore, growth potentials within the industry must be recognised through, for example, demonstration projects and networks.

The formation of problem-solving networks is generally important in this phase. Technological systems often consist of several interrelated technologies (in the case of biogas: biogas production facilities, distribution system, filling stations and vehicles), hence; it is necessary for a strong network to have actors representing all these links.

[8] It is not always preferable to have a wide spread diffusion of the experiences and results gained from a demonstration project. If the goals of the project are of technical nature, such "open door" policy could prove counter productive. (Karlstöm & Andersson, 2003) Therefore, a selection of which actor types that will participate and share outcomes of the demonstration project is recommended.

Take off phase

In the take off phase, measures should be taken to induce an increased adoption and diffusion of the technology. This requires the function "formation of markets" to be served, which, accordingly, requires a stimulation of the function "supply of resources". Thus, additional firm entry is necessary in this phase. Though, in contrast to the development phase, not only firms with technical competencies regarding experimentation and product improvement, also firms with mass-production capabilities and actors that could constitute networks for institutional influence. Such influence (on tax policies, value systems, market regulations etc) are to be considered as "the heart" of the process whereby new technology gain ground (Jacobsson and Johnson 2000). As mentioned in section 2.1, markets seldom emerge in a spontaneous way, they will often have to be stimulated or even created. To achieve that, formation of an advocacy coalition, a set of actors with a common belief, is essential (Johnson and Jacobsson 2001b).

The advocacy coalition tries to influence policy and attitudes in the line of this belief. More concrete, such a coalition may change tax-systems and affect the creation of protected market spaces via regulations; affect the public views of the technology and thereby its legitimacy, all in favour of the industry. Commercial and non-commercial actors, universities, politicians, media amongst others, could play crucial roles in such a coalition.

Kemp et al. (1998) suggest that a mass-market formation will only be achieved if the system has gone through a formative period with niche market exploration. Though, the processes and circumstances whereby mass-markets evolve are far from well understood. As mentioned in section 2.1, several blocking mechanisms may hinder such a development, as well as inducement mechanisms could support one. Such niches could be any kind of "market space" where the technology in some aspect is superior, in terms of technological characteristics (mobility, efficiency, CO_2–neutrality etc), or where it is economically supported through, for example, beneficial tax-policies or subsidies. In such markets, the product could benefit from scale economies, learning by using and learning by doing effects.

Market expansion requires new resources to the industry, such as (venture) capital, raw material, skilled labour and mass-production competencies. Therefore, it is important to guide the direction of search in this phase as well.

As pointed out earlier, the shift into the growth phase is often characterised by the selection of a dominant design. In such a selection, standardisation may emerge and the system may benefit from *technological interrelatedness*, which means that several complementary technologies become a part of an increasing infrastructure (Frankel, 1955). Such could be: refilling stations, third-part software, spare parts of different kinds and other complementary products. This is closely related to emergence of positive external economies that may arise in the form of a highly skilled labour force, specialised suppliers, or in a more abstract variant: as an informational "out-flow" from problem-solving networks. This will, however, require new firms to enter via further niche market exploration and supply of resources (Johnson and Jacobsson, 2001b).

As stated in the beginning of this section, these design criteria should only be regarded as guidelines in the design of a branch development project. Several concerns affect the development of an industry and, thereby, complicate the management of a branch development project. An innovation system evolves under the influence of several societal factors, many which are difficult to affect.

3. Biogas as a fuel

In order to survey the state of development for the biogas system, this chapter provides background information of biogas and biogas vehicles: technical issues regarding biogas as a fuel, production and distribution methods, production volumes and some economical aspects. Some facts of biogas powered vehicles and the availability of such will be presented as well.

3.1 Production and distribution methods, and production volumes

Biogas is a so-called alternative fuel, meaning that it is produced from renewable resources and the net output of carbon dioxide decreases from a system perspective (STEM, 2002b).

Biogas is produced from anaerobic digestions of organic substances. Such milieus are usually created in digestion chambers, sewage treatment plants or waste decompositions, but can also be found naturally in swamps, refuse dumps etc. As raw materials, sewage wastes (sludge), wastewater or waste products from grocery firms, industry or agriculture can be used. Depending on which raw material being used, the emissions from biogas vary, but are generally considered as low. Biogas produced from sewage wastes is in several reports pointed out as the most environmental-friendly fuel of today (STEM, 2002b, see SOU, 1996). Emissions of nitrogen oxides (NO_x), sulphur dioxides (SO_x) and particulate matters (PM) are considerable lower than from petrol and diesel. Natural gas has the same emission characteristics as biogas but with one important difference: natural gas is a fossil fuel and, thereby, not carbon dioxide neutral. (SOU, 1998)

Both producing (deposition and digestion) and distributing biogas are based on quite well known techniques. Even though, there are several issues that must be dealt with when developing such a system. First of, biogas is a compound of primary methane and carbon dioxide (and to some extent nitrogen and sulphur). Depending on the raw materials, the ratio between these substances varies and thereby the quality.[9] To be used as a fuel in vehicles, the amount of methane must be at least 96 % (Sveinsson and Helgadottir, 2000). Since no known production technique gives such high quality gas, the gas must be upgraded. This is, however, a rather expensive and undeveloped process, and considered by many as

[9] Quality in this context is the same as the ratio of methane in the gas; since it is from the methane molecule energy is extracted. Generally it can be said that the more orderly the production - the better the quality of the gas.

unreliable (SOU, 1998). To be profitable, an upgrade facility has to reach a certain size in terms of production capacity. This size varies amongst the literature, but somewhere between 10 GWh/year and 40 GWh/year (SOU, 1998) has been mentioned. Upgrade facilities are currently used in a small scale in several municipals: Uppsala, Göteborg, Trollhättan, Linköping and Bromma, to mention a few.

Secondly, establishing a distribution system for biogas is expensive. The main option is using a pipeline system, but with the current magnitudes of biogas, such system would not be profitable (SOU, 1998). Instead, the biogas industry has developed a method comparable to the *green electricity* principle, which may be used in regions where there is a distribution system for natural gas. Due to the fact that biogas and natural gas has the same chemical characteristics[10], they could, either, share the same distribution system, if the biogas were to be upgraded, or the biogas could be used in other sectors (heat and electricity production, for example) and natural gas would be used as fuel for vehicles instead. Though, the latter naturally requires that the amount of natural gas sold as a vehicle fuel would be replaced in another sector by the same amount of biogas, otherwise the environmental benefits would be lost. This is called the *green gas* principle and is practiced in Laholm and partly in Göteborg. By using this principle, the natural gas functions as a back up for the somewhat fluctuating production volumes of biogas. However, the amounts of biogas used indirectly as a vehicle fuel are limited to the capacity of receiving biogas in other applications. An alternative to this is to distribute the gas via tank lorries, which is an expensive solution, although practiced in some regions in Sweden. In addition, lately there has been an increased attention to leakage of methane gas that may occur during both production and upgrading of gas and from the waste products from the production. To what extent is poorly investigated and, thereby, also what environmental affects this may have.

The total biogas supply in Sweden is approximately 1.4 TWh/year produced by 220 plants, which of 150 is municipal sewage treatment plants and another 15 facilities uses grocery and industry wastes as raw

[10] I.e., both natural gas and upgraded biogas could be used in the same type of engine.

materials (see table 1). 40 GWh (an increase with 10 GWh since 1997) is used as fuel and the rest is primarily used for district heat and electricity generation (Sveinsson and Helgadottir, 2000). On a long time perspective this figure could increase to approximately 17 TWh/year (SOU, 1998). The majority of biogas produced has yet been from municipal sewage treatment plants, but there is a growing belief on the potentials of using agriculture and grocery wastes, primarily through grows of pasture plants. The Federation of Swedish Farmers (LRF) has estimated such a potential for region of Västra Götaland to be approximately 8.4 TWh/year (Johansson, 2001).[11]

Tabel 1: *The amount of biogas produced in Sweden from different production methods. Of the total volume biogas produced (1.39 TWh/year) only 25 GWh/year are used as transportation fuel in Västra Götaland.*

Type of production method	TWh/year
Sewage treatment plants	0.81
Landfills/digestion chambers	0.43
Industrial sewage	0.09
Waste decomposition	0.03
Agriculture	0.01
Pilot installations	0.01
Total	1.39

Source: www.sbgf.org

In the region of Västra Götaland, currently two plants are producing biogas accessible for vehicles: Gryaab in Göteborg and Tekniska Verken in Trollhättan. The production volumes have been quite constant since the facilities were taken into use (1991 in Göteborg and 1996 in Trollhättan, se figure 4). In total, an average of 46.6 GWh/year (see figure 4), which has been more then adequate to meet the current consumer demand. Though,

[11] This figure is based on the assumptions that 510 hectare, in a region within Västra Götaland called Västra Älvdalen, will be available for grow of pasture plants. Every hectare of cultivated land gives 7.0 tonne dry substance (DS) of raw materials, but due to energy loses 6.3 tonne DS will be available for biogas production. With a calorific value of 2.6 MWh/(year·DS), the total biogas production will then equal to, approximately, 8.4 TWh/year.

the gas produced in Trollhättan is the only one used directly in vehicles (via an upgrade facility). In Göteborg, the gas is distributed to the town gas system (10-11 GWh/year) and the rest for heat and electricity generation as a replacement for natural gas that Göteborg Energi AB would use in these applications otherwise. However, only the biogas distributed to the town gas system replaces natural gas for the transportation sector. The gas used up in the combined heat and power plant would be utilised there regardless of a demand from the transportation sector or not. Therefore, approximately half of the volumes of gas sold to vehicles in the Göteborg area (10 GWh in 2002) consist biogas; the other half is natural gas. The gas used in the transportation sector were in 2002 approximately 25 GWh in the region of Västra Götaland, which of 15 GWh biogas (5 GWh from Trollhättan and 10 GWh from Göteborg).

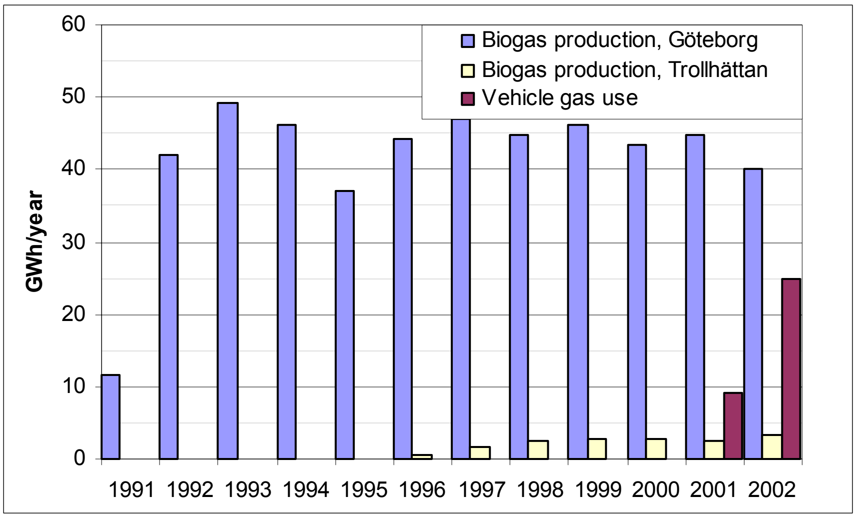

Figure 4: *The biogas production in the region of Göteborg, where Gryaab in Göteborg produces an annual average of 41.4 GWh and Tekniska Verken in Trollhättan 2.3 GWh. The gas consumption in the transportation sector was in 2002 25 GWh, which of only 15 GWh are biogas.*

3.2 Biogas powered vehicles

The technique for gas-powered vehicles is quite well developed and several of the incumbent car manufactures produce such vehicles. Despite that, only Volvo could offer cars for sale on the Swedish market until the year of 2001. Though, both Volvo and Scania have, in cooperation with municipals (Göteborg and Trollhättan), developed gas-powered buses for public transports that were available in the early 1990s. Due to the limited range of different vehicle types, Gatubolaget in Göteborg has had difficulties in finding small and medium sized environmental friendly vehicles for transportation utilities, which would fit the stated demands. This has been solved by a slight modification of Opels Zafira CNG model, as a result of a partnership with Bilstudion (Opel dealer in Göteborg). However, in recent year, several car manufactures have introduced models to the Swedish market: Opel, Volkswagen, Mercedes, to name a few, and even more will be introduced in the near future. In the beginning of 2003, a total of 2500 cars were active within Sweden. This can be compared to the 1400 cars that were active in the beginning of 2001, an increase of approximately 55 %. In Göteborg, the same figures are 670 at the beginning of 2001 and 1350 at the beginning of 2003, an increase slight under the national level by approximately 50 % (see table 2). (www.miljofordon.org, 030315)

Tabel 2: *The amount of gas-powered vehicles active in Sweden and the region of Västra Götaland at the year of 2001, 2002 and 2003. Biogas Väst has a goal of 2500 gas-powered vehicles in the end of 2003. Note that the figures equal the quantity of vehicles in the beginning of each year.*

	Sweden			The Göteborg region		
	2001	2002	2003	2001	2002	2003
Light vehicles	1410	1640	2530	670	670	1350
Heavy vehicles	330	420	550	80	115	140
Total	1740	2060	3080	750	785	1490

Source: www.miljofordon.org

Due to the rather low energy content in biogas[12], the gas has to be compressed to a pressure of roughly 250 bar. Most of the vehicles are of a type called *hybrid*, which means that they are equipped with two types of injection systems and, thereby, can be powered with two types of fuel (biogas or natural gas, in combination with petrol). The vehicles have to be equipped with two tanks, which slightly reduce the luggage space. With the possibility of running the vehicle on petrol, the distance a driver could get on one tank is doubled (from about 300 km to 600 km), which can be quite useful considering the low density of refilling stations for gas. 29 stations are currently situated in Sweden, none of them north of Stockholm, where of 11 in the region of Västra Götaland. Some of these are none-public and others only provide natural gas. A few firms dominate the market: Fordonsgas Väst is the only provider of refilling stations in the Göteborg region and Sydkraft Gas dominates the south and southwest regions.

In the year of 2000, the Swedish government changed the car taxes in favour for environmental friendly vehicles. The tax for a gas-powered car (both biogas and natural gas) should be based on the purchase price for a corresponding conventional car, which often is approximately 15 % lower (and, thereby, a lower tax). The estimated tax may, in addition, be reduced with 20 %, or at the most with 8000 SEK annually.

3.3 Production costs and market prices for biogas

Biogas is totally exempted from fuel tax. The market price is in general lower than petrol, but costs about the same as diesel. Though, according to Svate Englund (SOU, 1998), the production cost of biogas could optimally be at the same level as petrol, but never as low as diesel. Of existing production methods, sewage treatment plants are believed to be the most cost effective. The production cost is estimated to be approximately 0.70 SEK for each produced kWh of biogas. The corresponding figures for petrol and diesel are 0.74 and 0.50 SEK/kWh respectively (carbon dioxide

[12] 9.72 kWh/m^3, which can be compared to 8722 kWh/m^3 for petrol.

tax included). The distribution cost for biogas is estimated to be 0.56 SEK/kWh, where upgrading and storing/backup is assumed to be the highest posts, 0.10 and 0.27 SEK/kWh respectively. The total cost for the production and distribution of one kWh biogas would equal a price of 10.96 SEK/l petrol (Euro 95); where 8.7 kWh biogas equals one litre petrol. It is therefore believed that biogas would be more competitive with petrol than diesel. (SOU, 1998)

Due to factors as production and distribution methods, production volumes and policies, the market price of biogas varies strongly between regions, for example: 5.50 SEK/m^3 in Trollhättan and about 9 SEK/m^3 in Stockholm (see table 3). All the biogas is, to some extent, subsided on a municipal level (Mats-Ola Larsson). That would serve as a good explanation to the low price in Trollhättan. The local authorities have agreed on a fixed price during an introduction period; which easily could be done since the whole production-chain, including the refilling station, are owned by municipal firms. Stockholm has an expensive distribution system of tank lorries, where the gas is distributed to three commercial refilling stations (Shell, Statoil and OKQ8).

Tabel 3: *The table shows factors that, in addition to local subsidies, contribute to the different price of gas in the two regions of Trollhättan and Stockholm.*

	Trollhättan	Stockholm
Raw material	Industrial and grocery wastes	Sewage wastes
Upgrading facility	Yes	Yes
Distribution method	Pipeline	Lorry trucks
Actor types (production, distribution and refilling stations)	Municipal Municipal Municipal	Municipal Municipal Commercial
Price policy	Fixed price	Supply and demand
Price (SEK/m^3)*	5.50	~ 9

* *Current prices in April 2003.*

4. Biogas Väst and the biogas system in the region of Västra Götaland[13]

This chapter will explore and describe the biogas system and Biogas Väst. At first, a general description of the project itself will be delivered, followed by a detailed investigation of the course of events that eventually led to the initiation of Biogas Väst. Thereafter, the biogas system and the actors within it will be presented.

4.1 Aims and purposes with Biogas Väst

Biogas Väst is a project that brings municipalities and companies together in order to promote the production and use of biogas as a vehicle fuel. The project is mainly carried out to increase employments and trades in the region. According to Göran Värmby (Business Region Göteborg), supporting local and governmental environmental goals is considered as secondary. The official start was in March 2001 and will continue to the end of 2003.

The general purpose of the project is formulated as "…stimulate and impel the increase and development of production and distribution of biogas, and increase the use of methane powered vehicles in the region of Västra Götaland", furthermore to "…promote an establishment of a market through the cooperation with natural gas" and to "…contribute to a sustainable environmental and economical development". In a wider time perspective to "…in a long-term establish a self-sustaining market". A number of quantitative goals, which evolved during a pre-study carried out in 2000, were stated as a complementation to these. The quantity of refilling stations should increase from 5 to 25, methane powered vehicles[14] from approximately 800 to 2500 and the biogas use in the transportation

[13] The information presented in this chapter is gathered during several interviews (see appendix) and various public reports published by actors.
[14] Note that the statement regarding the quantity vehicles is formulated as methane powered and not biogas powered.

sector from 9 GWh to 120 GWh. All these goals were to be accomplished within the time period of the project: from the beginning of 2001 to the end of 2003. Succeeding with these goals should establish the region of Västra Götaland as a leading region for biogas use in the transportation sector. Additionally, the project would contribute to accomplish the regional environmental objectives concerning the decrease of hazardous substances and green house gases emissions.

Business Region Göteborg (BRG) manages the project in cooperation with a working group where all the financers are represented. These financers are (in addition to BRG): Volvo Cars, Volvo AB, Göteborg Energi AB, FordonsGas Väst, Göteborg Transport Office, the Västra Götaland region, the municipalities of Borås and Trollhättan, and co-financed by the Federation of Swedish Farmers (LRF).

The general strategy is stated as "…continue a powerful increase of the infrastructure primarily within the region, and increase the amount of vehicles on the roads and streets". Focusing on network formation, joint marketing of biogas should accomplish this; establish cooperation between the five sub regions in Västra Götaland (Trestad, Göteborgsregionen, Sjuhärad, Skaraborg and Bohus-Dal). In a wider perspective: to induce collaboration with actors in the south regions of Sweden and even Norway, where biogas is expanding as well. In order to meet a growing demand for biogas and ensure a long-term supply of raw materials, various types of actors from the agriculture sector would be necessary to influence.

4.2 The development of Biogas Väst

At first, it should be pointed out that Biogas Väst has coevolved with other regional biogas system, which have emerged both in the south and the central parts of Sweden. These events have, naturally, influenced the development process and, later, the functionality of Biogas Väst. Though, which affects this co evolution has had will be dealt with in the analysis section.

In the creation process of Biogas Väst, no important main actor or *prime mover* can be identified, instead, a numerous of crucial events that mainly took place during the 1990s, which were carried out by different actors, eventually led to the initiation of the project. Some of these events can be regarded upon as independent, whilst others are a part of a “development path” as indicated in figure 5.

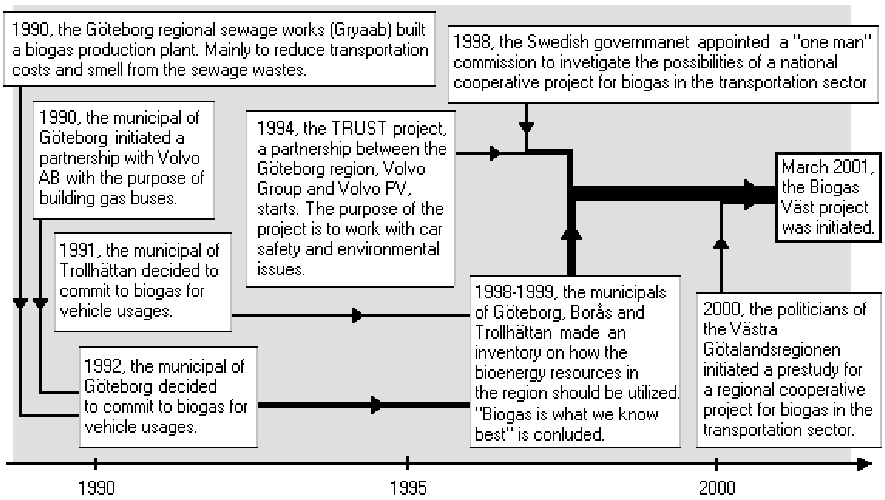

Figure 5: *The figure shows the somewhat intricate course of events during the development of Biogas Väst. A few development paths, which connect some of the events, eventually led to the initiation of the project.*

In the beginning of the 1990s, the politicians of Göteborg wanted to increase the environmental profile of the city’s public transportation system. A partnership with Volvo AB was initiated with the purpose of building gas buses. One year later (1991), this resulted in an investment of two gas busses, and the fleet was further increased the year after with additional 17 busses. Despite technical problems and complains about lack of power, further investments was carried out in the late 1990s and in the beginning of 2000, and today there are in total 57 gas busses active in the public transportation system.

Parallel to this, the Göteborg regional sewage works (Gryaab) built a biogas production plant (at the Ryaverken) that mainly would use sewage wastes as raw materials. Initially, the main function of the plant was to lower the fairly high transportation costs and reduce the odour form the sewage wastes.[15] In 1992, a small-scale upgrade facility was built where less than a percent of the biogas was upgraded and used as fuel for 5 of Gryaabs cars (although the amounts of gas upgraded would be enough for at least 13-15 cars). A couple of years later (1994), a gas engine was taken into use for heat and electricity generation. Through that installation, all Gryaabs need for heat was covered and roughly 50 % of its electricity demands.

In 1992, the politicians of Göteborg decided to take the biogas commitment one step further. Through different actions, the biogas production and the biogas-powered vehicles in the area should increase. As a first step in that direction, the sewage treatment plants biogas production capacity was to be expand. Mainly through an increase of raw material flows to the production facility[16], but also through a coordination of the municipal actors involved (Renova, Gryaab and Göteborg Energi AB).

Approximately at the same time, the municipal of Trollhättan decided to commit to biogas for vehicle usages. This eventually led to a local biogas project was started in 1996 in cooperation with Vattenfall and the regional buss company (amongst others). A local infrastructure along with a biogas production plant was built to, initially, support 12 biogas-powered buses, but was later expanded and now supports over 100 vehicles. In the late half of the 1990s, Trollhättan was the second largest municipal regarding biogas usages in the public transportation sector, next to the municipal of Linköping.

Another event, that later in the development process would prove important, was the TRUST project (transportation development in big city), which is a cooperative between, primarily, Volvo, Volvo AB and the city of Göteborg.[17] The aim of the project was to improve safety and environmental issues regarding the transportations in a big city area. The project has, amongst others, been a contributing factor of influencing the Swedish tax system in favour for gas-powered vehicles (see section 3.2),

[15] The rotting process decreases the volume of the sewages wastes by approximately 50 %.
[16] These raw materials consisted of wastes (mainly fat) from grocery firms and a chips and an ice cream manufacture.
[17] Additional members are Fordonsgas Väst, Göteborg Energi AB, Göteborg Transport Office and Business Region Göteborg.

and thereby increased the incentives for a costumer to purchase one. However, even more important when focusing on the development of Biogas Väst, is the early state of network establishment between actors that Biogas Väst probably would not manage without.

Next important step towards the creation of Biogas Väst was taken by the municipals of Göteborg, Borås and Trollhättan. These municipals had initiated an informal inventory, from a trade and industry developing perspective, on how the regions bio-energy resources best should be utilized.[18] The inventory was settled in 1998, and the conclusion drawn from is was that "biogas is what we know best". Mostly due to Trollhättans earlier progresses in the biogas field (and the knowledge generated thereby), an already existing distribution system for natural gas[19] and the large potential for the Ryaverken to produce biogas.

During this period, the Swedish government had initiated a commission to investigate the possibilities of utilize biogas on a national scale. Several negative aspects of biogas was brought up in the report (SOU, 1998), most of them concerning economical aspects of developing a production distribution system and potentials for biogas production, even though, an inquiry concerning possible interests of initiating regional cooperative projects was made. The politicians of Göteborg, Borås and Trollhättan (the same group of politicians that initiated the above mentioned inventory) decided to answer this proposal, but since that group was more or less unofficial, they answered through the already existing TRUST. Furthermore, TRUST took the responsibility of being the head of a regional cooperative biogas project in the region of Västra Götaland. One year later (2000), the politicians of Västra Götaland, together with TRUST and the municipals of Borås and Trollhättan, financed a pilot study on how a biogas project would be formed; regional production potentials of biogas, possible actors within such a project, technological issues etc. The conclusions drawn from the pilot study indicated great possibilities on such a project. A satisfying number of actors had responded positive, as

[18] The inventory was carried out by Göran Värmby, employed by Business Region Göteborg, and would later be the project manager for Biogas Väst.
[19] There was a consensus on that biogas system had to coexist with natural gas due to the heavy investments in developing a distribution system.

well as issues of more technical nature; production of biogas (Gryaab) and cars (Volvo), distribution of gas (Göteborg Energi AB) and fuelling stations (Fordonsgas Väst), all seemed viable. Due to the earlier gas bus projects (in both Göteborg and Trollhättan), the TRUST project, the inventory of bio-energy utilization and the fact that the region of Västra Götaland has since decades been a frequent user of natural gas, there was a well established belief in gas as a transportation fuel. In addition to that, network between current actors had to, a certain degree, already evolved. Thus, the pilot study did not only function as an inventory of potentials and possibilities, in fact, this was the actual initiation of the project.

4.2 The biogas system and the actors within it

There is a huge mix of different actors involved in the biogas system; political authorities at both municipal and regional levels (and to some extent national level), commercialised and none-commercialised municipal firms, and business companies; all with different interests and level of involvement. This section will clarify which actors are involved and to what extent, the relations between them and what interests and motives they have. Some actors, which could prove important to the biogas system, have as yet chosen not to participate or not being offered a possibility due to special circumstances. This has had different affects on the system and they will therefore be included as well.

The actors that constitute the physical part of the biogas system (producers, distributors etc) could be divided into two geographical sub-systems. The gas produced for vehicles are carried out and distributed on a local level in Göteborg and Trollhättan with no sharing of components in the production/distribution chain. Though, the actors share the same network and act within the same national institutional framework and, hence, are a part of the same innovation system. The sub-systems will be described further in the coming section, and the actors participating within them will be described on the basis of these sub-systems.

4.2.1 The biogas system in Göteborg and the actors within it

The biogas in Göteborg is produced by Gryaab's sewage treatment plant using sewage wastes and, to some extent waste products from restaurants and school kitchens in the region, as raw material. The gas is sold to Göteborg Energi AB and used instead of natural gas as a fuel in, both, a combined heat and power generator and distributed to the town gas system.[20] With the exception of a small-scale upgrade facility that provides gas to 5-10 of Gryaab's own vehicles, no biogas is used as fuel for vehicles; only natural gas is. However, Fordonsgas Väst pays Göteborg Energi AB a sum for each unit of natural gas that is sold in Fordonsgas Väst's refilling stations. This is officially stated as a green gas principle, but since the biogas that Göteborg Energi AB uses would be consumed in the combined heat and power application even without the existence of gas usage in vehicles, the biogas could only be claimed to replace approximately 10 GWh (used in the town gas system) out of the 20 GWh of natural gas used in vehicles (see section 3.1). Figure 6 shows the actors participating in the production/distribution-link in Göteborg.

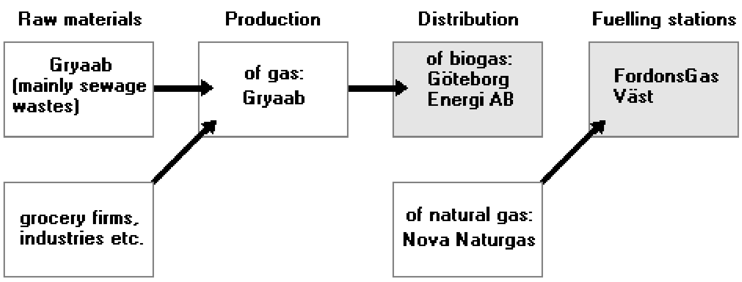

Figure 6: *The figure shows actors that operate within the biogas system in the Göteborg area. Actors marked with a grey area are also actors within Biogas Väst.*

[20] The trade of gas between Gryaab and Göteborg Energi AB is regulated via a contract (see appendix). Since both firms are municipally owned, the contract is designed in a way that a minimum of profit is gained for both parts.

As described in section 4.1, actors participated in the evolving biogas system at different times and stages. One of the first and, perhaps, most important actors is the municipal of Göteborg.

The municipal of Göteborg

As seen in figure 7, Göteborg municipality's involvement in the biogas system is multi-faceted. Partly, as a political organ serving political issues, such as local environmental objectives and, primarily, trade and industry matters. And partly, through the indirect involvement of being the owner of Göteborg Energi AB (who owns a third of Fordonsgas Väst), Business Region Göteborg, Göteborg Transportation Office and part owner of Gryaab. These actors, with the exception of the Göteborg Transportation Office, are considered to be independent with a minimum of political influence.

The Göteborg region has a strong culture of industry; several major firms are located in the region, such as Volvo, SKF, Ericsson and Hasselblad. A pro-industry type of political climate has thereby emerged that are willing to withhold a frontier position within industrial fields. The politicians of Göteborg had in biogas found what, hopefully, would become a growth market to explore, and thereby a possibility of developing a market leading industry. The economical aspects along with a clear environmental profile must be regarded as strong political motives for a participation in a project of this kind.

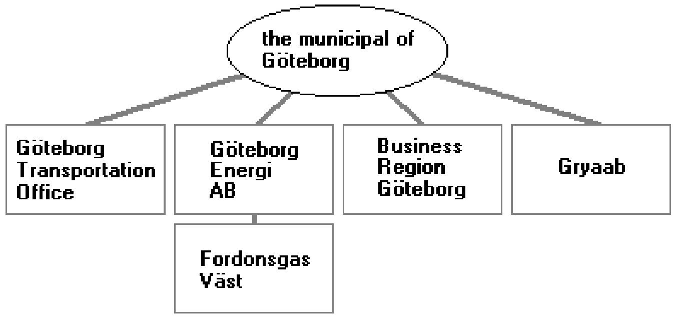

Figure 7: *A schematic illustration of the multi-faceted involvement of the municipal of Göteborg. Göteborg Energi AB owns a third of Fordonsgas Väst, the other two thirds are split equally between Nova Naturgas and Norsk Hydro.*

Business Region Göteborg (BRG)

BRG is a non-profit firm owned by 13 municipals in the region of Västra Götaland. BRG is responsible for promoting and developing trade and industry in the region of Göteborg. The main objective is to increase the level of employment in the region, and work with economic growth, development and diversification of the industry. The prime methods are initiating several branch development projects in different industrial sectors and helping to create a positive climate for firms to settle down in. Network formation between different actor types, such as firms, authorities and researchers, is a central part in such projects. Hence, they functions as a natural head of Biogas Väst.

BRGs prime task is to arrange meetings between actors, lobby biogas issues against (national) authorities, induce advertising campaigns and connect new actors to the project. As head of the project, they have the outermost responsibility for financers and investments made within the frame of the project. Since the start of the project, BRG has had a full time employee working as a project manager. A work group was initiated, which all the financers were represented in.

Gryaab

Gryaab is crucial for the biogas system since they are the only one producing biogas in the Göteborg area. Despite that, they do not participate in Biogas Väst but within the informal networks of the biogas system. Thus, they participate in meetings and discussions regarding the future of biogas production.

Gryaab treats sewages wastes from six municipals in the Göteborg area (Ale, Göteborg, Härryda, Kungälv, Mölndal and Partille)[21] by the motto "a cleaner ocean". This, and the fact that Gryaab is a non-commercialised firm, affects its interests and actions within the system. The main reason for Gryaab to produce gas is, as mentioned in section 4.1, to lower transportation costs and reduce odour of the wastes. This means that Gryaab would, for example, support but not finance the construction of an upgrade facility for biogas, since gas refining is not considered as a part of their business field. But should there be a need for an additional anaerobic digester, via a significant increase of raw materials, they would finance it. As long as there are external interests and needs of the gas, they are willing to meet the demands, but there are no incentives of developing the production process further.

Göteborg Energi AB

Göteborg Energi AB plays an important role in Biogas Väst since they own and manage the gas distribution system in the region, and provide natural gas and biogas. In addition to the direct involvement in Biogas Väst, they participate through the ownership of Fordonsgas Väst (a third share). Göteborg Energi AB is convinced in that biogas has a future as a vehicle fuel; assuming that the production and upgrading technologies will be more cost effective and reliable (personal communication with Anders Larsson). By participating in Biogas Väst, they are able to affect and speed up the development of technologies regarding biogas production/upgrading and distribution, by sharing and taking part of knowledge and networks.

[21] These six municipals plus the municipal of Lerum owns the company.

The prime business field for Göteborg Energi AB is to offer energy-services, broadband internet connection, district heating, cooling, natural gas and electricity transmission.

Fordonsgas Väst

Fordonsgas Väst is the only commercial actor in the production-distribution-chain of gas, and they alone provide and runs refilling stations in the Göteborg area. However, by them this is considered to be a weakness of the industry, and they would therefore welcome additional actors (personal communication with Gunnar Ingelman). According to Gunnar Ingelman (Fordonsgas Väst), this would give rise to competition and increase the strength of the industry (both in terms of reduced costs of biogas and increased availability of refilling stations).

Since the only source of income for Fordonsgas Väst is the sales of gas they, perhaps more than anyone, are anxious to make Biogas Väst a success. Fordonsgas Väst therefore promotes gas as an alternative to petrol and diesel very actively by several advertising campaigns. For example, the building of a new refilling station is often announced through campaigns directed to households in the area.

Fordonsgas Väst believes strongly in methane gas as a vehicle fuel. They consider the technologies in both production/distribution and in vehicles to be sufficiently developed to establish a market based on gas use in the transportation sector. Branch development projects are therefore necessary and preferred over R&D-projects and demonstration projects. Being involved in Biogas Väst gives an opportunity of influencing governmental authorities (the institutional framework) and, thereby, increased possibilities of getting hold of subsidies. Fordonsgas Väst is also involved in other projects and organisations that promote the use of alternative fuels in vehicles, such as “Miljöfordon i Göteborg”, Biogas in vehicles (“Biogas i fordon”, a national branch development project for biogas in vehicles) and the Swedish Biogas Association (“Svenska biogasföreningen”).

4.2.2 The biogas system in Trollhättan

In the Trollhättan sub-system (see figure 8), the biogas is upgraded and distributed via a pipeline to a refilling station situated in the central part of Trollhättan. As in the case of Göteborg, the main raw material for biogas production is sewage wastes, but waste products from local grocery firms and a fish and an alcohol industry contributes with significant amounts.

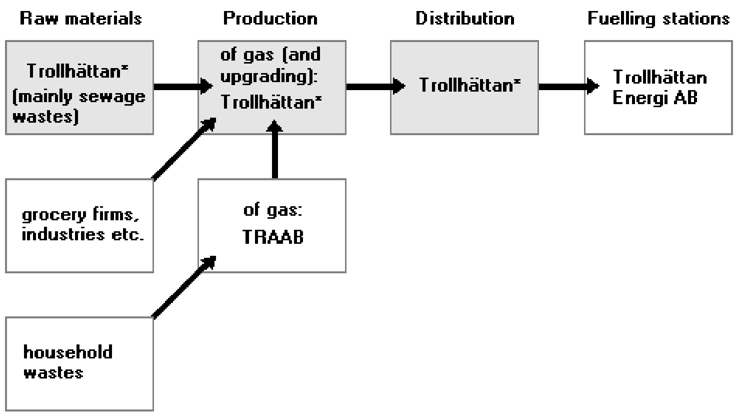

Figure 8: *The figure shows actors that operate within the biogas system in the Trollhättan area. Actors marked with a grey area are also actors within Biogas Väst.*

* *The municipal of Trollhättan*

The municipal of Trollhättan

As owner of both the main production plant, the pipeline for distribution and Trollhättan Energi AB, which runs the refilling station, it is no understatement to point out the municipal of Trollhättan as a crucial actor for the sub-system in the Trollhättan region.

Trollhättan has been an environmental progressive municipal through out the latest decades. Being a part of Biogas Väst was considered as a natural step to increase the environmental profile of the municipal even further.

4.2.3 Additional actors

The Swedish Energy Agency (SEA)

Amongst others, The Swedish Energy Agency distributes governmental subsidies and funds to projects/firms/municipals/researchers that are active within the energy sector. Therefore, SEA acts as an important link between governmental organs and the actors within Biogas Väst.

SEA has so far co-financed several projects, on both firm and municipal level, that aims to develop and increase the performance of biogas associated technology.

The actors within Biogas Väst can apply for governmental finances partly through applications directed to SEA (the LIP-program), or via the Swedish Biogas Association that distributes funds from SEA amongst actors operative within the biogas field. A majority of such subsidies has yet been granted for R&D and demonstration projects; projects that primarily aim to develop technology. Though, according to Bengt Blad (STEM), biogas would, from a societal perspective, be used as a fuel in heat and power generation.

Volvo/Volvo AB

Volvo and Volvo AB produce cars and heavy vehicles respectively, mainly for conventional fuels (petrol and diesel). Though, in the recent decade there has been a growing demand for gas-powered vehicles, mostly from governmental and municipal authorities, and both Volvo and Volvo AB can offer such vehicles. Until the year of 2001, they were the only one providing gas-powered vehicles in the region of Västra Götaland.

The Swedish Biogas Association

Actors from the majority of the evolving regional biogas systems (not only those related to the transportation sector) have instituted the Swedish Biogas Association (SBA). The SBA deals with diffusion of biogas related information, arrange seminaries and meetings, and establishing networks between biogas related actors throughout the whole Sweden. The Swedish Biogas Association also functions as a platform for actors to influence the government and apply for subsidies. Therefore, SBA functions as an advocacy coalition for the national biogas industry.

A wide range of firms, municipals, organisations etc, constitutes the SBA (85 in the year of 2000), where of Gryaab, the municipal of Trollhättan, Fordonsgas Väst and Volvo.

5. Analysis

Analysing a project of this kind that has not yet been finished (not until the end of 2003) is associated with a number of difficulties. First, the majority of information that this analysis is based on has been gathered from interviews with several actors within the system. There are reasons for these persons not to speak as “freely” as they perhaps would in a later stage, when the project has ended. Prestige, high stakes in this early state and lack of distance etc, are factors that might constrain information sharing. Secondly, the results and consequences of the project may not be possible to fully identify and understand until several years after the ending. Finally, measures are still carried out by the project management and, therefore, to get a complete analysis of the project will not be possible until the project has ended. Though, this analysis will be based on what have been accomplished so far and what strategic were chosen during the design of the project.

The biogas system in the region of Västra Götaland has coevolved with several other regional systems. Naturally, there has been a sharing of knowledge between these systems, both regarding technical issues (production and distribution methods) and know-how of, for example, institutional character (how to increase legitimacy for the technology, how to affect local and national authorities etc). Measures carried out by actors in one regional system may later on benefit actors in others. Hence, analysing the biogas system as an isolated system is not fully possible. Not withstanding these limitations, this analysis will focus on the events implemented by the project management of Biogas Väst in order to investigate what affects that the project has had on the biogas system in the region of Västra Götaland. In the analysis, the design criteria formulated in section 2.3 is used, and the functionality of the system is described by using the five functions. First will, however, the state of development of the biogas system be determined since the design criteria is based on an evolving industry that is situated, either, in a development phase or take off phase.

5.1 Development phase or take off phase?

The project was designed in the year of 2000, based on a pre-study carried out the same year (mentioned in section 4.2).

In the beginning of 2001, approximately 750 gas-powered vehicles were active in the region supported by seven refilling stations (which of five public) and the vehicle gas use was 9 GWh/year. Compared to the rest of Sweden, the ratios were approximately 45% (of total 1740 vehicles), approximately 25% (of total 30 refilling stations) and approximately 25% (of total 40 GWh/year). Compared to conventional fuels in Sweden, the number of vehicles and refilling stations and fuel production volumes were lesser than one in a thousand. The number of firms and other actors involved in the biogas system have an equally small share. Only seven firms, where of four municipally-owned, constituted the production/distribution-chain. Three that produces biogas, two that distributes gas and two that runs refilling stations, where of one also builds stations.

The technological uncertainty was considered as high, especially regarding upgrade facilities, which were expensive and doubted because of an increasing insight of leakage problems of methane gas.

A number of different designs of infrastructures were competing, both regarding what sort of raw materials to be used, but also regarding the distribution. The three main options for distribution were, either, to upgrade the gas and use it directly as fuel in vehicles, or upgrade the gas but co-distribute it with natural gas as green gas, or use unrefined biogas in other applications as a substitute for natural gas and use natural gas in vehicles. However, there seemed to have established a consensus regarding the type of engine to be used. Mostly due to a low number of refilling stations through out the country, the hybrid type (both petrol and gas-powered) was the dominating design at the time (and still is).

Some networks had already been established in the region, though, none with an explicit problem-solving character (to work with technical issues). These were the TRUST-project, which incorporated Volvo, Volvo AB, Göteborg Energi AB, Fordonsgas Väst, BRG and the municipal of Göteborg, and some informal networks between municipals in the region.

Considering all this, the biogas system in the beginning of 2001 could be said to be in a shift from the development phase to the take off phase. The technologies that constitute an infrastructure, together with the vehicle technology, had reached a technological readiness for being increasingly adopted, though, mainly in niche applications. An industry had begun to grow, although on a small scale and supported by subsidies and a beneficial tax-system (both regarding biogas and gas-powered vehicles).

5.2 The functionality of the biogas system

All the functions described in section 2.1 needs to be served, even though not necessarily at the same time, for a new industry to evolve and perform well (Johnson & Jacobsson, 2001a). To reach a self-sustaining growth, a state where the functions are connected in cumulative self-inducing circles (positive feedback mechanisms) will have to emerge. Influencing the functions can be achieved through different measures carried out by different actors, which of especially those carried out (or not) of Biogas Väst will be dealt with in the next sub-section.

The functionality of the biogas system in Västra Götaland is visualised in figure 9. As indicated, all functions have not yet been served, and the Biogas Väst influence has mainly been restricted to the function guide the direction of search.

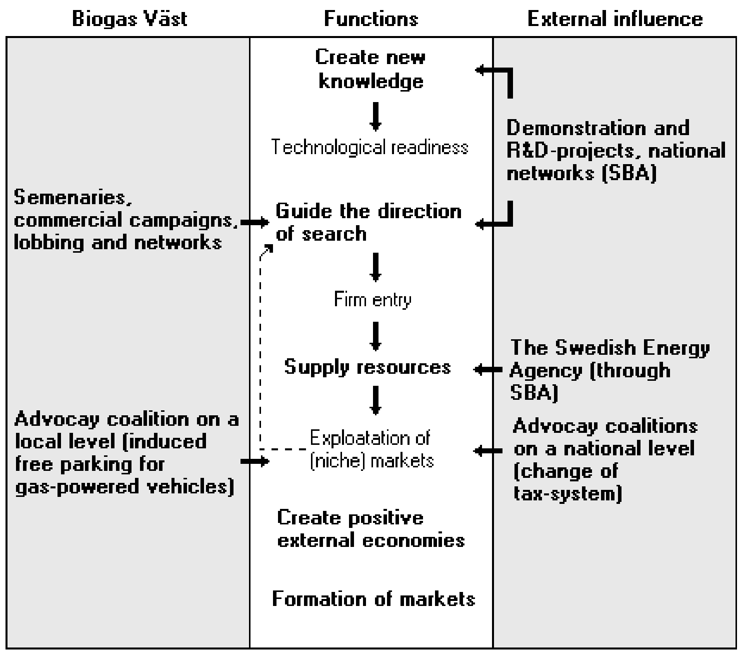

Figure 9: *Measures carried out of both Biogas Väst and other external influences have affected the functionality of the biogas system in the region of Västra Götaland.*

During the late 1980s and early 1990s, both R&D-projects and demonstration projects were carried out in several regions in Sweden, intending to create new knowledge regarding biogas production technology for the transportation sector. Most of them co-financed of the Swedish Energy Agency. Even a number of upgrade facilities were built, though all on a small scale. This gradually resulted in an increased technological readiness for biogas as a vehicle fuel, but not to a level sufficient to compete with the conventional fuels.

Biogas Väst has actively (and successfully) guided the direction of search among regional actors to participate in the project: several firms, municipals and the regional political organ (Västra Götalandsregionen). Though, in this guiding process, it is inherently important to recognise the "right" kind of growth potentials and to have a clearly stated system goal ("increase the biogas utilisation in the vehicle sector" instead of "increasing the vehicle gas utilisation in the vehicle sector"). If not doing so, there is a risk of attracting the wrong type of actors. Due to the composition of the technological system in the Göteborg region, i.e. firms and technical artefacts linked to the biogas industry, there are some alternative systems that could be generated instead of the intended one (see figure 10).

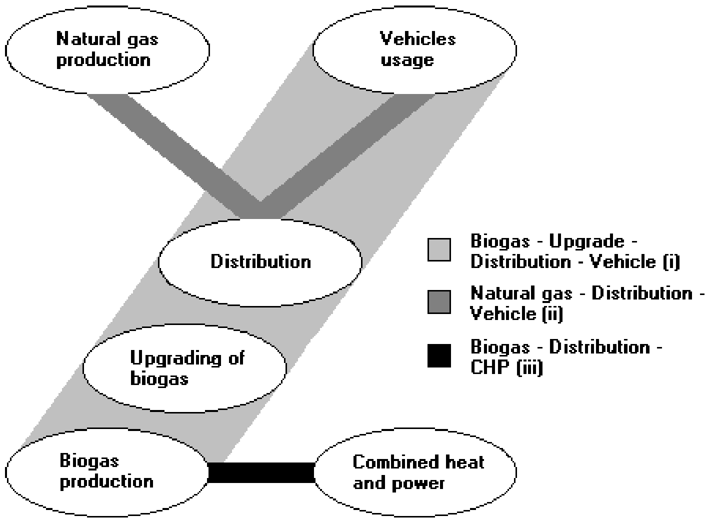

Figure 10: *Different actors may have different interests within Biogas Väst and, thereby, promote the establishment of other production/distribution chains instead of the indented one.*

Considering the actors that are involved in Biogas Väst, there are primarily two competing production/distribution-chains that are closely related, in addition to biogas used as fuel in vehicles (i). First, natural gas used as fuel in vehicles, indicated as (ii) in the figure. The natural gas is significant cheaper than biogas and is sold and distributed by Nova Naturgas, which owns a third of Fordonsgas Väst. Secondly, biogas used in heat and power facilities, indicated as (iii) in the figure. Due to the high upgrade costs of biogas (when it is to be utilised as a vehicle fuel), it is more economical to use it in combined heat and power facilities. Until the cost of upgrading is lowered, both Englund (SOU, 1998) and STEM (personal communication with Bengt Blad) believes that the optimal use of biogas from a societal perspective would be in such applications. Since

Göteborg Energi AB has the sole right to all the biogas produced in Göteborg, they also determine where the gas should be utilised. The practice of the green gas principle is beneficial to both Nova Naturgas and Göteborg Energi AB. Because of the limited amounts of biogas that could be sold as green gas, which is limited to the town gas systems potential of receiving biogas (10-11 GWh/year), a demand for natural gas is assured. Göteborg Energi AB powers a CHP-plant with the rest of the biogas, and thereby replaces natural gas, which gives environmental benefits to the heat and power sector, but not to the transportation sector.[22] If the explicit goal for the innovation system is to establish the biogas-to-vehicles production/distribution chain (i), the involvement of Nova Naturgas may hinder the development of that in favour for the naturgas-to-vehicles (ii) instead.

The increased firm entry, as a result of the guide the direction of search process primarily performed by Biogas Väst, has drawn resources to the industry. Primarily as capital (co-financers as the Västra Götalandsregionen and LRF) and knowledge and capacity of building refilling stations (Fordonsgas Väst), vehicles (Volvo, Volvo AB). This has strengthened the industry in general, but also through the network formation that has occurred between these actors.

Advocacy coalitions promoting the use of biogas has emerged. Partly through the national SBA, but also on a local scale in Göteborg through the TRUST-project and to some extent Biogas Väst. To determine which actors or coalition of actors that has affected the institutional framework is difficult. The tax-system for environmental-friendly cars has been changed in favour of such vehicles, which could be considered as the "sum" of several advocacy coalitions. Both from the TRUST-project, projects as Biogas Väst, the SBA, Volvo etc., have contributed to this institutional change. Though, on a local scale in Göteborg, the Biogas Väst project has been an important factor to accomplish free parking on the municipally owned parking slots throughout the city.

The functions create positive external economies and formation of markets has not yet been served (or stimulated). These functions are

[22] According to Göteborg Energi AB, the biogas should have been used in the CHP-plant regardless of a demand from the transportation sector (i A.L).

related to the size of the industry and the activity within it, and may emerge in a more spontaneous way than the other functions, when the industry grows. The biogas industry has not reached such a state yet.

5.3 Evaluation of the design of Biogas Väst

As stated in the section above, the biogas system was, at the beginning of 2001, in a shift from the development phase to the take off phase. At this state, designing a branch development project would focus on, both, objectives associated with the development phase, but mainly on those from the take off phase (see figure 3 in section 2.3).

No demonstration projects or R&D-projects of any kind have been initiated of the project management of Biogas Väst. Though, several have been carried out in other regions of Sweden, which of a majority have been financed (or co-financed) by STEM.[23] Due to the policy of STEM[24] and the existence of a national biogas network (SBA, se section 4.2.3), which ensures diffusion of information and knowledge, a demonstration project would not only be expensive to implement, but with none or little new knowledge gained from it.

With the aim to establish a functional production/distribution-chain, a number of significant actors have participated in Biogas Väst. Gryaab in Göteborg, Traab and the Tekniska Förvaltningen (a municipal organ) of Trollhätttan are the prime producers of biogas in the region. Either Gryaab or Traab are members of Biogas Väst, but a part of the biogas system since they have chosen to allocate their gas for vehicle usage. In the distribution link, Göteborg Energi AB is vital since they own the distribution system for natural gas in Göteborg, and Fordonsgas Väst is the only one building refilling stations in the region. Volvo and Volvo AB provide gas-powered vehicles to the system and are, naturally, important actors because of that. But, their participation is, perhaps, even more important due to the

[23] About 400 million SEK of governmental funds have been distributed via the so-called LIP (Local Investment Program) to R&D and demonstration projects through out Sweden (Sveinsson & Helgadottir, 2000).
[24] Not support the demonstration of a technology more than one time.

increased legitimacy they bring to the industry. Only through the involvement by them in the project guides the direction of search for other actors, and might, furthermore, act as a sign of a growth potential. Volvo has such a well-established reputation in Sweden that they could play the role of a prime mover for the whole biogas system and, furthermore, a significantly important role in an advocacy coalition. Though, that would require Volvo to be strongly committed to biogas as a vehicle fuel.

The actor types that are missing in Biogas Väst are, partly, the ones that produce and develop biogas production and upgrade facilities, and partly car salesmen. For example, the firm Bystaden AB has developed a competing concept for establishing local biogas systems. This is done by working closely to both local firms that provides raw material and to builders of production facilities, a concept that has led to a cost effective way of establishing a local biogas system. Supporting actor types with competing technological designs, i.e. supporting broad range experimentation, is essential in a state of technological uncertainty.
The car salesmen of gas-powered vehicles in the region also sell conventional cars. Naturally, these actors have a huge opportunity to affect customers, and especially doubtful ones. Through an involvement in Biogas Väst, these actors could be induced to promote gas-powered cars more actively. In addition, car salesmen provide spare parts and repair services for the vehicles. To have a wide range of complementary products and services may be crucial in the choice of a vehicle type for a customer.

One of the prime tasks for Biogas Väst would be to identify and explore niche markets. An exploration of such markets benefits the industry in several ways and learning by doing and using, and increasing returns to adoption are some effects that may arise. Such niches could, for example, be firms, municipal organs and public transportations that want to establish an environmental profile for their business. A program for identifying suitable niches (specific category of customers), and how to stimulate or create these, should have been a part of the pre-study for Biogas Väst. By clearly investigate current and future demands, with, for example, forms distributed to plausible buyers, could recognise growth potentials for other actors. Then it would, for example, be easier to affect car manufactures to introduce their gas-powered models to the Swedish market, and thereby increase the range and avoid bottlenecks as shortage of vehicles.

The organisation of powerful advocacy coalitions, which could act on municipal and/or governmental level, has to some extent been achieved as mentioned in the above sub-section. Such requires powerful actors, which, of curse, are limited in a region. Considering the circumstances, Biogas Väst has, by connecting primarily Volvo to the project, induced a network powerful enough to affect the local institutional framework and in cooperation with others even the national.

6. Discussion and conclusions

To create a self-sustained market growth is inherently difficult; there is no easy step-by-step guide to follow. However, some measures can be taken into consideration in such tasks, which aims to create the right circumstances or conditions for a market expansion to take place. The Biogas Väst project is such an effort, induced by politicians and firms, to establish a market based on the use of biogas as a fuel in the transportation sector. Depending on the design of such a project, it will have, a priori, different possibilities in succeeding in its task.

Generally concluded, the Biogas Väst project could be said to have reached its most important objectives: the formation of networks between important actors. The quantitative goals will most surely not be accomplished, but is of a more insignificant nature. If a period of market growth would emerge, the production of biogas and use of biogas-powered cars would increase as a result.

However, the Biogas Väst project has some characteristics that are quite “typical” for projects of this kind. It will be active in a strictly limited time period, and managed by an actor with no further responsibility than to gain the highest profit of the capital that has been invested until the project ends. These two aspects are, perhaps, the weakest points of the design. Though, to indirectly indicate a clear growth potential within the industry, by stating optimistic goals for the project, acts as an inducement for firms and other types of actors to participate. However, the time period associated with establishing a self-sustained growth is by far more than the two years the project is about to last. Networks must gain strength to survive on their own, which primarily is a matter of trust between the actors participating in the networks. If the project were clearly regarded upon as a *step* towards the establishment of an industry, with a follow-up planned, the stated time period would be adequate. But, due to lack of momentum (or a prime mover/system builder), the industry needs further support, or it might collapse.

Another "typical" aspect of Biogas Väst is that mainly actors from the region of Västra Götaland have been induced to participate. The project manager BRG, which works with regional trade and industry issues, naturally prefers actors situated in the region. Though, considering the shortage of gas-powered vehicles that occurred in 2001/2002, other car importers than just Volvo should have been induced to participate. This could have removed such a bottleneck for the industry.

Due to the somewhat unclear statement of what type of gas that actually should be promoted (vehicle gas or biogas), the industry that is about to develop in Göteborg might benefit more than just firms related to biogas (as pointed out in section 5.2). The practice of the green gas principle is possibly not as beneficial for biogas as been argued. First, the amounts of biogas that could be sold as green gas in the refilling stations is limited to the town gas system's capacity of receive biogas (see section 5.2). The alternative would be to, despite high costs, promote the construction of an upgrade facility. This would give an actual increase of biogas use, increase the knowledge (through learning by doing), which could lower future costs in the construction of such facilities and making biogas more competitive, and reduce technological uncertainty.

The regional biogas system in the region of Västra Götaland is still situated in the take off phase. Additional efforts, as projects a long the lines of Biogas Väst, will be necessary for the industry to progress further and reach a period of self-sustained growth.

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Appendix: the interviewees

Interviewee	*Firm/organisation*
Bengt Blad	The Swedish Energy Agency
Gunnar Ingelman	Fordonsgas Väst
Lennart Ekefjord	Gryaab
Torsten Jansson	Bystaden AB
Anders Larsson	Göteborg Energi AB
Mats-Ola Larsson	Miljofordon.org
Bernt Svensén	Business Region Göteborg
Göran Värmby	Business Region Göteborg