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Feasibility of Biogas as Transportation Fuel in China

- Implications for the Policy Makers in China

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ABSTRACT

The purpose of this thesis is to assess the desirability and feasibility of biogas as an alternative fuel and to identify the key policy issues for realizing its potential in China.

It, thus, aims at providing lessons for Chinese policy makers with respect to biogas as an alternative transport fuel. In order to reach that goal, the thesis first analyses the desirability of biogas from two dimensions: environment and potential. The result is that biogas is attractive as a substitute to fossil fuels.

Secondly, the Swedish and Chinese cases of Biogas Technological Innovation System (TIS) are described and later analyzed by Functional Analysis (FA). To better understand the Chinese situation, the specific case in Chongqing City follows later, indicating the feasibility of a pilot project for biogas as transport fuel in China.

Thirdly,, key lessons extracted from Swedish case, combined with the analysis of China, highlight the blocking factors and associated key policy issues in China. It serves to help Chinese policy makers focus their efforts to realize the large potential for the biogas in transport sector.

ACKNOWLEDGEMENTS

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1. Introduction

The pressure from the shortage of fossil fuel has recently forced the world to accelerate the development of alternative fuels and improve the energy structure. Biogas is one of the best fuel alternatives at the moment when considering its impact on the environment. Sweden is the leading country in utilizing such fuel in the transportation sector. The development of biogas is also driven by a search for a suitable solution for the agricultural residuals and civil waste which are not attractive for other industries. The interest in biogas is increasing also developing in countries. In China, a Biogas Technological Innovation System (TIS) has been developing for quite a long time and has obtained significant results, especially in rural areas. Even though it is currently restricted to heating and electricity, there is a huge potential also in the transport sector. But there are a lot of problems that need to be solved before a mass market will accept this new technology. Policy makers, thus, must identify the key policy issues that need to be addressed.

As pointed above, the development of biogas fuel in Sweden is quite advanced. As both of the authors come from China, we are eager to understand how biogas fuel can scale up in China as well. Even though the biogas TIS in strong generally, in the transportation sector, it is almost non-existing. So the purpose of our thesis is to **assess the desirability and feasibility of biogas as an alternative fuel and to identify the key policy issues for realizing its potential in China.** In order to reach the purpose, several sub questions are necessary to answer.

As a relatively new alternative, biogas needs to be regarded as desirable by the main actors influencing its development and use. So the first sub question is to *assess the desirability of biogas in China*. It will be explored in two aspects, a) from the environmental point of view and b) from the potential of biogas production.

According to some analyses, biogas is the most environmental friendly alternatives at the moment. From a calculation of main raw materials in China, we consider that the potential is high enough to attract actors. The details will be discussed in the following chapters.

Sweden is one of the leading countries for biogas fuel utilization, so understanding the conditions in Sweden would be helpful for us when we analyze the development in China. There exists a biogas innovation system in China dating back decades, but it mainly aims at heating and electricity. The application of biogas for transportation use is relative new to China. Yet, in exploiting this application, the strength of the current TIS can be used. The second sub question therefore is "What is *the dynamics of the Biogas Innovation Systems in Sweden and China*"

In order to provide suitable suggestions and recommendations, we need to identify the strength and weakness of the biogas IS in China. The comparison between the Swedish and Chinese cases is made to extract the key lessons from the Swedish case and to see if these lessons could be applied to China. The third sub question is "*What are the key issues to stimulate the growth of biogas as a transport fuel in China?*"

The thesis is structured in the following way. Section 2 introduces the technology and discusses the desirability of biogas in China. Section 3 outlines the analytical framework and section 4 describes the methods used during the study. Section 5 contains an analysis of the dynamics of the biogas innovation systems in Sweden and China. Finally, Section 6 identifies the key policy issues for China.

2. The technology and its potential

There are currently two major technologies that could be used to generate biogas. The most widely used one is anaerobic digestion. Most of the sewage treatment plants use this technology to generate biogas in the process of cleaning sludge. A new technology to generate biogas involving biomass gasification has recently been applied in several countries, e.g. Austria. If successful, more gasification plants will be built and the potential for biogas will be expanded with the new sources. The utilization of biogas as transportation fuel also needs the development of complementary support such as the improvement of gas engines and control equipment. The filling station is also vital to market expansion even though the price of the pumps in the filling station is still too high. These technologies will be outlined below in section 2.1 and 2.2 whereas section 2.3 addresses the desirability of biogas. In short, we assess the environmental friendliness of biogas and the potential of biogas in China.

2.1 Biogas technology

The most important part of a biogas digest plant is the anaerobic digester. The sources for digestion include animal manure, household organic waste, residuals from the food industry, sludge etc. Before adding the sources into the digester, they must be pre-treated, cleaned and stored for a while. There are three different process temperatures: 10° C to 25° C, 25° C to 35° C and 49° C to 60° C respectively, depending on the sources put into the digester (Jönsson and Persson, 2003).

Sometimes, different sources have to be mixed in order to yield more biogas. These mixtures are stored in the digester in the absence of oxygen for a period of ten to thirty-six days depending on the sources and process temperature. During the process, microbes and enzymes convert the manure in three steps (hydrolysis, fermentation and methane formation) into biogas. The yields of biogas vary depending on the sources added to the digester and the conversion temperature.

The residual of the digester can be used as organic fertilizer to replace chemical ones. However there is strict standard for utilizing organic fertilizer from digestion in order to reduce the risk of pathogens spreading. When considering the contents of the fertilizer, the biogas plants prefer to use the waste from the food industry because of its stable contents and its easy quality control. However, wastes from the food industry are limited so the digestion plants have to balance the quality of the residual and the availability of the sources.

Digestion plants can be divided into farm-scale plants and community plants (or centralized plants). In a farm-scale plant a single farmer utilizes own sources to digest manure, household organic waste and sludge. The biogas generated is used as energy for cooking and heating within the family. The farm-scale plants are widely used in many developing countries, (China, India etc.) because of its low investment and high feasibility. In a centralized plant, sources from all over a city need to be separately collected with a complex logistic system. The centralized plants are mainly found in the industrialized countries where there are complete recycling mechanisms. The centralized plants have higher efficiency and usually have the ability to better pre-treat the sources before digesting them.

Upgrading Process

After the digestion process, the biogas contains almost 55% of methane, 44% of carbon dioxide and other small amount of pollutants such as hydrogen sulphide (H_2S). Several post-treatment steps eliminate impurities to reduce the emission of greenhouse gas during the combustion process for generating energy later. What's more, if biogas is utilized as transportation fuel, further upgrading processes need to be followed. There are three European countries today that have the approved standards for biogas as a transportation fuel. These are Switzerland, Germany and Sweden (Jönsson, 2004). As one of the leading countries using biogas as transportation fuel in the world, only Sweden has a national standard at the moment. The standard biogas fuel contains 98% of methane. Under such standard, the upgraded biogas almost has the same quality as natural gas and can be distributed through the natural gas grid, but the cost to upgrade biogas is almost 1/3 of the total cost to produce biogas fuel (Persson and Nilsson, 2006).

Gas upgrading is normally performed in two steps. The main step is the process that removes the CO_2 from the gas. Minor contaminants (e.g. sulphur compounds) are normally removed before the CO_2-removal. The water dew point can be adjusted before or after the upgrading (depending on the upgrading process).

There are different technologies used in this process such as Water scrubber technology (single pass absorption or regenerative absorption), PSA (Pressure Swing Adsorption) technology and other membrane technologies. The principle of the process is that the carbon dioxide and other impurities are dissolved or absorbed during the process while methane does not. The basic steps in this process can be seen from Figure 2.1 which shows how the biogas is generated from the raw sources to the final product.

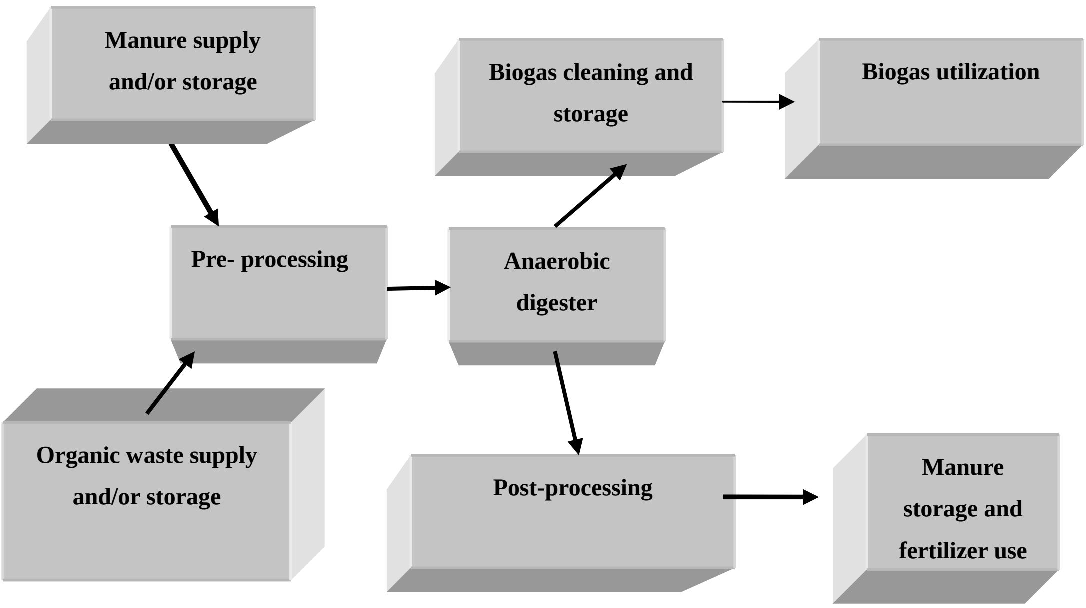

Figure 2.1 Basic layout of a biogas plant

2.2 Complementary technologies

Sewage Treatment

The currently most feasible way to produce biogas is from sewage treatment plants. The absolute quantity of waste water per person (per capita) is 4 liters per day, having a dry solid content in excess of 10% (Persson and Nilsson, 2006). Biogas generation can not only reduce the total volume of the sludge, but also raise the quality of the nitrogen, which could be converted into organic fertilizer. According to research, the residual from the biogas production can be better absorbed by that is a better fertilizer (Persson and Nilsson, 2006). The principle of biogas production in sewage treatment plants is to convert the organics to organic acids, carbon dioxide, water and energy. This process is a biological process where the settled sewage enters a specially designed reactor where, under aerobic conditions, organic matter in the solution is oxidized or incorporated into cells. Later, the organic acid (existing in the cells) is converted to methane, carbon dioxide and energy with the help of methane forming bacteria (Gray, 2004). The energy generated during these processes could be used to sustain the energy consumption of the plants per se. The recycling energy usage reduces the energy assumption of the plant, which not only reduce the cost of the plant but also contribute to sustainable development.

Gas Vehicle

The feasibility of biogas utilization in the cars depends on the efficiency of the gas engines. Over time, lots of efforts have been put into improving the fossil fuel engine. According to the theory, the power generated by methane is greater than that by petrol. However, in order to enhance the efficiency of the engines, more advanced technology is required (Rutledge, 2005)[1]. One of the leading companies in Sweden is Volvo Car Cooperation. Volvo put at least 100 Million SEK per year into research to

[1]At the moment, there are two types of gas engines: open-loop system and closed-loop system. The stoichiometric burn engines including feedback controls that process information from the exhaust to aid in engine operation is called a closed-loop system and the engines without feedback controls are called open-loop system. In general the closed-loop systems are more tolerant of changes in fuel composition

improve the relevant technology. Until now, when using their technology, the biogas engine performance is almost the same as petrol one (Wahlén and Gustavssan, 2006).

However, the gas engines require a high quality of the fuel. The biogas must contain more than 95% of methane in order to be injected as a transportation fuel. What's more, there are other limits of the impurities in biogas in order to make sure that the emission will be under control. Currently, Sweden is the only country that has a national standard for biogas fuel (See Table 2.1). Other following countries such as Germany, Switzerland is in the process of making the standards.

Table 2.1: Excerpts from the Swedish standard for biogas as vehicles fuel (SS 15 54 38)

Component	Unit	Standard A	Standard B
Methane, CH^4	vol-%	96-98	95-99
Water content	mg/Nm^3	<32	<32
Oxygen, O^2	vol-%	<1	<1
Total sulphur	mg/Nm^3	<23	<23

Source: Persson (2006), *Biogas – a sustainable fuel for the transport sector*, Swedish Gas Centre (SGC)

Another important index to analyze the engine performance is the exhaust emissions. The residual CO_2, NO_X from the combustion during the driving process should be absorbed before emitted in order to meet the standards. Euro III is the current standard and was phased in from 1st January 2000. A further tightening of the emissions standards, known as Euro IV, begins on 1st January 2005 and will be in force for all new cars by 2007[2]. The acceptance of EU standard is important for the car manufactures to invest in R&D because they don't need to redesign the components in other countries.

Filling Stations

One of the most important parts a biogas industry is the filling station. It is the only

[2] The website of Vehicle Certification Agency (VCA), http://www.vcacarfueldata.org.uk/eurostandard_help.asp

way for the end user to access the biogas. In Sweden, Fordonsgas is the main provider of filling stations focused on biogas. Due to their efforts, the public in the southwestern part of Sweden can easily access cheap biogas fuels. However, compared to the petrol companies, Fordonsgas is relatively small and it is sponsored by the government. They themselves cannot satisfy the whole needs within the country. With the market expanding in Sweden, larger firms have become interested in the biogas business, such as E-on. But unlike Fordonsgas, they prefer to make short-term profits which cause a higher price of the biogas.

Recently, the Swedish government has required all the large filling stations to provide alternative fuels. However, due to the ten times higher cost of the biogas pumps, most of the stations will choose ethanol instead. Hence, the provision of filling station may remain a problem.

The equipments for the biogas filling stations are mainly imported from Spain and Italy. Even though Swedish companies have the ability to produce these high-quality required equipments, the limited market makes them reluctant to invest in the business (Persson and Nilsson, 2006). If more filling stations will be built in the future, the local Swedish companies can provide compressors or pumps which may reduce the costs.

2.3 The desirability of biogas in China

The desirability will be analyzed in two dimensions, one is the environmental aspect and the other is the biogas potential in China. The benefits from the environment are the biggest advantages to utilize biogas fuels and the potential decides the possibility to accept it.

Environmental Indicators

According to the Tokyo Protocol, which was signed in 1997, the amount of gas emission should be under control. The quota of the CO_2 emission is limited to all the participant countries. In order to achieve the target, replacement of fossil fuel is inevitable. Even though the alternatives, such as ethanol or DME, can also help to reduce emissions, the combustion residual of CO_2 emission from those alternatives is higher. According to one calculation, biogas can reduce the emission by 55% (Ingelman, 2006), which is considered as the most environmental friendly alternative at the moment. The Weststar Project carried in California compared the environmental indicators for different alternatives. From Figure 2 we can see the environmental effects from different alternatives at the moment and biogas is the best one according to the greenhouse gas emission and air pollution.

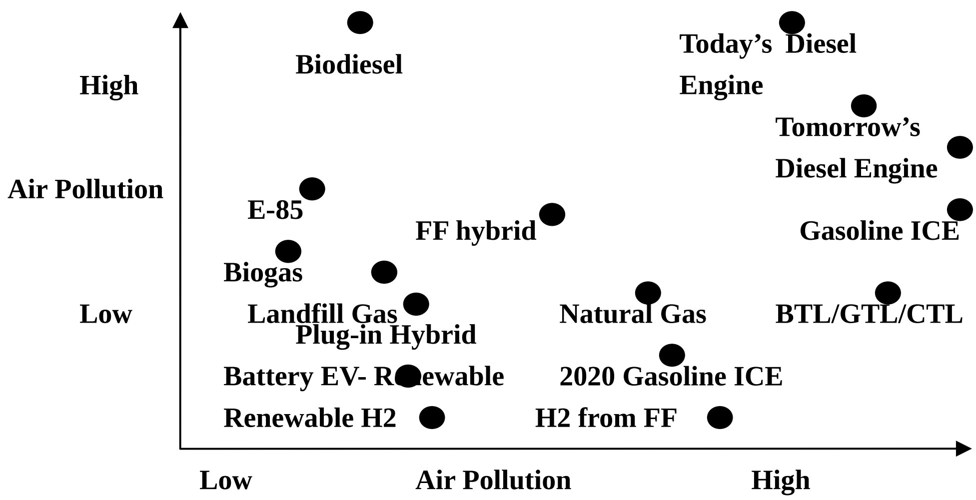

Figure 2.2 Environmental indicators of different alternatives

Source: WesterStar and California Report (2005)

The utilization of biogas also helps to deal with the potential of waste and residuals. The sewage and the organic waste treatment are world wide problems. According to the World Bank the amount of waste is increasing, especially in developing countries. Biogas production can utilize these wastes as resources. That is why the Waste Treatment Association drives the biogas utilization in many industrialized countries (Jönsson, 2006). As for the developing countries, with the arable land per person decreasing and the volume of the wastes increasing rapidly, there is an urgent need to find out ways to treat these wastes. What's more, when biogas production capacity has been expanded, it could use agricultural residuals as well which is another pollution source in China.

Biogas Potential

The calculation of the potential of a given technology is one of the most complicated problems for researchers. There are different methods used to estimate the potential of the biogas production, however, none of them is perfect. They are questioned from the choice of sources, the availability of the sources, the yield of the sources, the technology used to generate biogas and even the efficiency of the gas collection etc.

There are dozens of raw materials that could be utilized in generating biogas and it is almost impossible to calculate the potential from all the sources. Considering the practical conditions and feasibility, only the major sources are included in calculations, usually the amount of sewage, sludge, organic waste, agricultural residual etc. The size of raw material sources in the form of agricultural residuals is usually based on assumptions. In Sweden, it is assumed that 10% of the set aside land will be used to plant energy crops (Jönsson, 2006). However, nobody knows for certain if it is possible. There may be competition of land utilization between food and energy crops so 10% is just the base of assumption and need to be verified in the future (Persson and Nilsson, 2006).

The availability of the sources is another dilemma. In some calculation, the total amount of the source is utilized, but 50% is the most widely used ratio of the source available (Batzias et al., 2004). However whether this ratio is correct or meaningful requires further verification. In different countries the availability of the sources also differ depending on the clustering of villages, the distance to the production plant etc. So, the available rations are hard to choose.

The biogas yield from different sources is also a hot debate topic. The amount varies in different environments and the data from laboratory cannot be applied in the calculation of the biogas production in commercial companies. There are so many factors affecting the final yield, thus it is difficult to find a benchmark. In different countries or even in different organizations, different yield ratios are used, which makes it very difficult to compare different calculations.

Most of the researchers or scholars get the result from the digestion technology. Even though the anaerobic digestion is the most common used technology, other technologies cannot be ignored. As mentioned above, the gasification technology has been developed to commercial application. This new technology will enrich the sources for biogas production and expand the biogas potential hugely. Take the Göteborg Energy for example, where the new (planned) gasification plant can reach 100 MWh/year in capacity (Knutsson, 2006). The utilization of biomass as new sources will expand the biogas potential in Sweden quite a lot.

The process of biogas production per se has lots to be discussed. The efficiency of the plant decides the total biogas production. From pre-treatment to digester and finally post-treatment, there will be biogas and energy loss. The more loss there is, the less the potential will be. What's more, the size of the plant affects the efficiency of the biogas production. Better control systems and closed-loop design can reduce the loss (Xiong, 2006). The availability ratio will certainly be raised in the developing process and loss will be further controlled with the knowledge development.

When calculating the potential in China, we need to take the Chinese conditions into consideration. China is a big country with a high-density population. The volume reduction of sludge and sewage in the cities is one of the critical problems that need to be solved. The sludge and sewage could be categorized as municipal organic waste or industrial waste. Sewage treatment systems haven't been yet invested in all cities, but the amount of municipal organic waste involved is enormous. Similarity, there is big potential from industrial organic waste output in China and it is feasible to utilize those as biogas source since the central government had emphasized the construction of large-scale biogas plants. So far there are about 3 000 industrial scale biogas plants nationwide and will be more built in the future. (Gu, 2004)

What's more, the organic waste from households in most of the municipals has not been utilized. The recycling conception hasn't been accepted by most of the citizens at the moment in China. With the huge population in China, the potential of the organic waste is massive, which makes it a promising source for biogas production. However, it takes time to educate persons and spread knowledge about the proper separation of organic waste from other wastes.

According to the method of Gray (2004), the potential from sludge in China exceeds 1751 TWh and if 5% of the organic waste could be recycled as the input for the biogas generation; the potential might reach 3,350 TWh. However, these are the minimum data in the calculation due to the range of the contents and the available ratios we used. (See the details in the Appendix Ⅰ)

The large agriculture sector contributes the biggest amount of manure in the world. The availability of manure depends on how the animals are raised. In Western countries, only the manure from the central raising plants is considered as available. In China, most of the manure is from household raising stocks; there is small amount of central livestock farms, mainly located close to big cities, such as Shanghai. This type of feeding farms for sheep, pigs, and ducks had increased dramatically these years (Li et al., 2001). According to the calculation from Li et al., (2001) the potential of biogas from concentrated feeding farms is 60.1 TWh. We also consider the total amount of manure in China including those from the countryside and central raising farms. As the common methods, 10% of the total manure is considered available for the biogas production.

The biggest sector in China is still agriculture today. Around 60% of the people in China still live in rural areas (UN Database), thus how to solve the agricultural problem is vital in China. The proper way to treat the agricultural residual not only reduces the pollution in rural areas as most of them are directly burned after the harvest, but also can increase the income of the farmers if they are collected and recycled. From the results calculated by Li et al., (2001), the potential energy value from agricultural residues would reach to 10482 PJ, equivalent to 2911 TWh.

The forest source in China is not rich and has been over exploited. Even though China has leading technology in the gasification area, we will not consider the potential from gasification technology, as there is a high competition for the wood materials from different industries.

Table 2.2 summarizes our estimates of the potential in China. The total potential of the biogas production is thought higher than the results from major resources mentioned before, but it is impossible to take all raw materials into consideration. The details of the calculation are described in the Appendix Ⅰ. But the data we used is quite conservation as biogas fuel is relatively a new technology in China and hasn't been widely accepted today.

Table 2.2 The potential of the biogas in China

Raw Materials	Biogas Potential (TWh)
Sludge	1,752
Organic Waste	3,350
Manure	240
Agricultural Residual	2,911
Total	8,253

This potential of more than 8000 TWh is promising enough to start the business. The most mature generating technique is from sludge and manure. The utilization of organic waste will take longer time as it requires education of people in how to separate the household wastes. Even in Sweden, after 10 years of experience, only a few cities e.g. Uppsala have succeeded in using organic waste (partly because most of the citizens in Uppsala are those in universities which makes it easier to educate them)

There are two most feasible ways to produce biogas fuels in China considering the situation at the moment: one is to utilize the sludge and the other is from manure. The former utilizes the sewage treatment facilities in the cities and build more biogas generation plants in the cities especially in those haven't been covered by the current treatment system. The manure is one of the best sources to produce biogas in rural areas. The new application of the manure in rural areas will certainly provide the farmers an opportunity to increase their income by selling the manure to the plants.

There will be two options to realize the potential of the biogas-centralized and decentralized. The number of the biogas plants in China ranks first in the world, however, most of them are household with low efficiency. Considering the post-upgrading processes, it is impossible to utilize these household scale plants. Instead, raw materials are better for collection and transportation. The centralized plants also can have better pre-treatment processes which will generate better by-product (fertilizer). However, the centralized production of biogas will waste the initial investment of the household plants. Considering the complexity and broadness in China, we suggest both options can be taken in different areas.

3. Analytical framework

3.1 Technological innovation system

There has been extensive research around the innovation system approach by researchers and policy analysts who are interested in the processes underlying innovation, industrial development and economic growth (Bergek et al., 2006). Freeman inspired the concept of innovation system in the 1980s and after the joint effort from various researchers, this concept had been developed in order to better assess development and performance of systems centered on new technologies or new product area. However the main idea of innovation system remains-that is the creation, innovation and diffusion is both an individual and collective act (Edquist and Hommen, 1999; Hekkert el al., 2004).

Following other innovation system researchers, Carlsson and Stankiewicz (1991) proposed the concept of technological innovation system which aimed to define the boundaries of the systems on one core product or technology (Bergek and Jacobsson, 2003). The central thought of Technological Innovation System (TIS) is defined as follows (Carlsson and Stankiewicz, 1991)

> “It is the network(s) of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse and utilize technology.”

Accordingly, there are three components in a TIS, actors, networks and institutions. The underlying concept of TIS means that in order to stimulate the development, diffusion and utilization of one specific technology, the actors will interact through the networks that connected them, within an institutional infrastructure that includes culture, regulations and laws.

Several actors could be found within a TIS. They appear in the system in the form of firms, organizations and universities. In the case of biogas TIS, the range of actors includes, biogas production plants, upgrading plants, energy companies, equipment providers, central and local government, relevant scientific and industry associations etc.

The networks appear in two different forms, the first one, as defined in innovations system literature, is called learning networks. Such network has different styles such as user-supplier networks, co-operations between related firms, networks between competitors and university-industry networks (Jacobsson, 2004). The functionality of this type of networks is to transfer knowledge shared by various actors (Bergek et al., 2006; Jacobsson and Bergek, 2004).

Another type of network refers to those that influence the political agenda (Jacobsson, 2004). Normally it exists in the name of “advocacy coalitions” proposed by several political science researchers. The focus of this network is to contribute to the stimulation of a technology specific system by advocating it in wider political debates (Jacobsson, 2005).

Institutions refer to legal and regulatory aspects as well as to norms and culture (Jacobsson, 2004). They regulate the interaction between actors and specify the value base for different segments in the society. Also institutions could refer to beliefs that influence firms’ decision in the form of frames (Geels and Raven, 2006). More specifically, institutions can be viewed as product standards, benchmarking, laws, regulations, relevant policies and so on (Geels, 2004; Bergek et al., 2006).

3.2 Analytical model

The innovation system approach has recently been developed by several Swedish scholars, aiming to provide an analytical framework for the identification of inducement and blocking mechanisms in the development of a TIS (Johnson and

Jacobsson, 2001). In the latest paper, six consequent steps were brought up in order to help policy makers to identify key policy issues and policy goals. The central idea of this scheme of analysis is based on the concept of functional analysis (Bergek et al., 2006).

In our analytical model, five consequent steps are determined on the basis of a functional analysis. The first step is to trace the history of an innovation system. The main purpose of this step is to study the trajectories, in other words, the historical development of one emerging technological innovation system, especially in its initial stage.

The second step in our analytical model is to identify the current structure of systems. As described before, a technological innovation system comprises three structural components, i.e. the actors, networks and institutions (Carlsson and Stankiewicz, 1991). These include not only firms along with the whole value chain (up and downstream), universities and research organizations, but also public bodies, venture capitalists, etc (Bergek et al., 2006). Several methods will be used to identify the actors in this paper, e.g. interviews, literatures reviews, which will be explained in the following chapter. In addition to the actors, the identification of informal and formal networks should be involved in this step. Compared to formal networks, the informal ones are more difficult to identify because it may require discussion with industry experts or other actors, or analysis of co-patenting, co-publishing or collaboration (Bergek et al., 2006). What's more, institutions such as culture, norm, laws, regulations and routines need to be identified (North, 1994) as it is important to adjust, or "align" the institutions to a new technology. The process of institutional alignment will not be fulfilled automatically. It requires the effort from various actors to actively form a beneficial environment for the development, diffusion and utilization of new technology.

The use of functional analysis to map the functional pattern of TIS is the third step.

After the review of the history and the definition of the structural components of systems, the deeper analysis of the emerging innovation system's performance is conducted by functional analysis. Normally, the systems comprise several components, which contribute the final "goal" of overall system (Jacobsson, 2004). It is of great importance to evaluate the contributions of those components to the systems. These functions constitute a set of key processes in the evolution of a TIS and functional analysis is an analytical method to evaluate those key processes or functions. These processes are: 1. knowledge development and diffusion; 2. influence of the direction of search; 3. entreprenenurial experimentation; 4. resource mobilization; 5. market formation; 6. legitimation and 7. development of positive externalities. As for our analytical model, the first six functions will be taken into consideration since the last one-development of positive externalities is dependent on the joint discussion of other six functions, it is still not clearly articulated in the theory of TIS.

As argued in the technological innovation system literature, the advantage of functional analysis is to separate what is being achieved from structure. This will facilitate for policy analysts to understand how they need influence the components at a TIS so that its functionality is improved. It focuses on the "what is really being achieved in the systems" in terms of key processes that have a more direct and immediate impact on the ultimate" goal" of the systems (Jacobsson, 2004).

As is pointed out in the latest paper by Bergek et al., (2006), the assessment of performance in a TIS is based on two methods, industrial life cycles and system comparisons. For the latter method, system comparisons may be analysed from two perspectives. The first is to compare the development of the focal TIS with other TIS. In the case of biogas industry, an example can be a comparison between biogas and other alternative fuels, ethanol for example. Another perspective is to compare the development of one identical TIS between different countries which is the comparison of China and Sweden in our report. From the Swedish case, we can draw the key lessons learned in Sweden over the last decades. These key lessons indicates how to form the positive cycle in the process of biogas development and give the Chinese officials indications of what to do and how to do it.

The final step is to specify the inducement and blocking mechanisms and the associated policy issues that have a direct impact on the development of emerging innovation system. The relevant key policy issues are extracted and the policy makers can better understand the consequence of the policy. The figure 4.1 presents the analytical model that forms the basis of whole thesis.

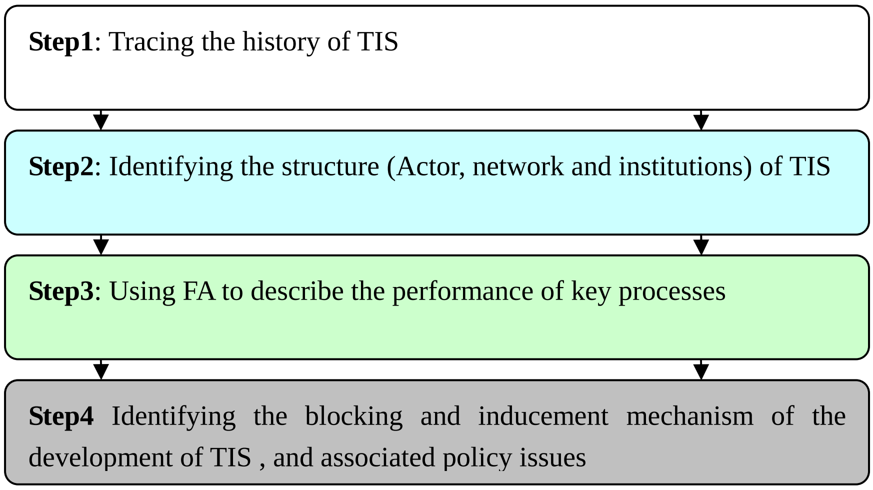

Figure 3.1 Analytical model by the use of FA

4. Methodology

4.1 Literature review

In the study for our thesis, collecting the relevant literature and reading through the related articles was one important task for us. Since both of us in some way lacked the specific knowledge regarding biogas, pre-studying was necessary to enrich our capabilities in order to be able to analyse the specific biogas technological innovation system and how it may diversify into the transportation sector. The extensive literature review also offered us the latest information within this area from other scholars and researchers. It helped us to understand the current trend of biogas development from technological and policy point of view. The literature included printed material, books, articles, reports, papers, essays etc as well as database such as GUNDA (Electronic library at Gothenburg university), CHANS (Electronic library at Chalmers University of technology) and other environmental journal databases. The papers and articles are from relevant academic organizations and government report.

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4.2 Interviews

Interviews were essential to complement the literature. They served to validate the data and information collected from other sources, e.g. research institute papers, company brochures, doctoral dissertations and master theses. By comparing the data from different sources, the originality and development of knowledge can be underscored. As biogas is a relative new business, the actors in the network know better or more than others. Thus, it is of importance to interview actors such as biogas firms, policy makers, research institutes and even some customers.

Because of the scope of this study, the interviews were conducted both in China and

Sweden (See Appendix Ⅳ). Considering the structural components of this specific TIS, interviews were related to all actors involved in the whole value chain, including biogas production plants, upgrading plants, energy companies, vehicle manufactures, central and local government, relevant associations and universities, etc. In all, we made 15 interviews for this thesis (see Appendix Ⅳ).

5. Dynamics

The evolution of the biogas TIS varies a lot in Sweden and China due to different situations and trajectories. In order to map the functionalities of two systems, the dynamics of the biogas TIS in these two countries will be analyzed by FA model. The Chongqing case in China, specifically, provides the Chinese officials with the image of a pilot project to utilize biogas fuel in the beginning phase.

5.1 The Dynamics of the Biogas TIS in Sweden

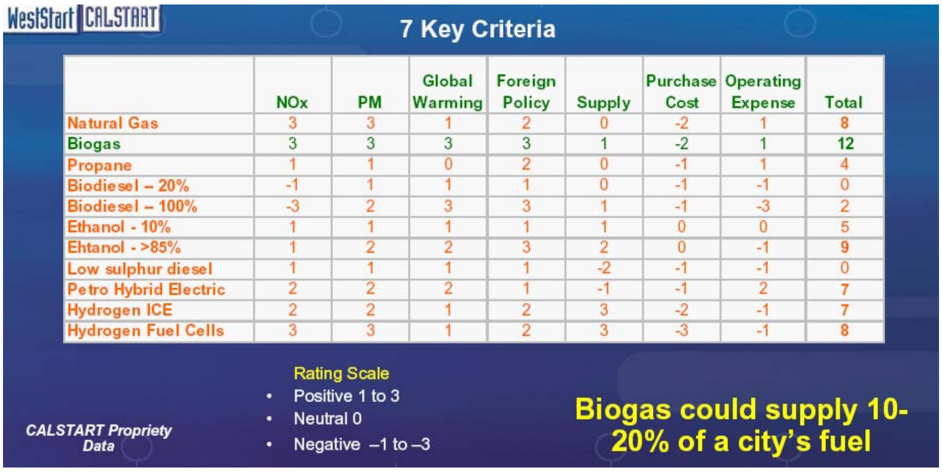
5.1.1 A brief historical overview of the biogas TIS

The development of a gas industry in Sweden could be traced to the beginning of last century, when the utilization of natural gas began. In the 1920's the Swedish Gas Association was established to coordinate the actors in the whole industry (Ekman and Grönstedt, 2006). The immature technology and the limited application at that time inhibited the development of the gas industry. The turning point appeared during the Second World War. Due to the shortage of the petroleum and restrictions in importing oil, the government had to find out new alternatives to fuel the buses and cars. Gas was the best choice at that time and a new application was found for gas as a transportation fuel. In several northwestern cities pipe grids were introduced to transport the gas for public buses and private cars. However, after the Second World War, the price of oil remained low for almost half century, which slowed down the pace of gas utilization. The government stopped building pipe grids in cities. Meantime, the sewage treatment association in Sweden tried to find out a suitable solution to deal with the waste and sludge, and the technology to produce by-product-biogas from the sewage treatment emerged. The most feasible way to utilize the commercialized biogas was for direct heating and cooking. As upgraded biogas has almost the same quality as natural gas, some cities injected the upgraded biogas into the pipe grids.

The experiment to use gas as a transportation fuel in Sweden has started quite early. When the gas technology was still in the process of development in the 1980s, there were several pioneering projects around the country. In 1986-1987, Malmö introduced the first 3 gas buses in the city. These three buses were hand-made with the cost around 720 KSEK each. The extra cost of the infrastructures such as the compressor and cleaning system made the usage of gas buses quite expensive. However, the excellent environmental performance encouraged more experiments. In 1990, the first 5 hand made biogas buses were introduced in Linköping at the cost of 620 KSEK each. Following in 1992, another 20 buses were introduced in Göteborg at a cost of 520 KSEK. At the same time, Volvo put emphasis on the commercialization of biogas buses. And finally in 1995, commercialized buses were available for South Sweden, with a price of 350-400 KSEK each, almost half of the initial price. In 1997, Linköping introduced its second-generation biogas buses (Strateco, 1997). With the continuous effort for decades, today, all of the city buses in Linköping are driven by biogas. It has also been proved that the biogas production and the upgrading is economically sustainable.

Biogas development has accelerates in recent years. The Tokyo Protocol, Rio Summit, etc. have pushed the whole world to reconsider their environmental policies. Among them one of the most important tasks is to replace petrol with cleaner energy. The leading experiment in terms of the biogas utilization in Sweden has attracted attentions from several countries, such as US and Germany. Indeed, biogas produced in Linköping will be exported to California in next year (Jönsson, 2006). Comparing to other alternatives, it is seen as the most environmentally-friendly fuel available (see Figure 5.1, the 7 key criteria).

What's more, biogas production benefits relevant industries such as the sewage treatment industry. The agricultural sector, to some extent, also gets benefits from biogas development. The value of energy crops is increased which will give incentive to farmers growing these crops. It will increase the farmers' income and may reduce expenditure for governmental subsidies, too. With knowledge diffusion, people will also cultivate the habit of the recycling of the waste.



	NOx	PM	Global Warming	Foreign Policy	Supply	Purchase Cost	Operating Expense	Total
Natural Gas	3	3	1	2	0	-2	1	8
Biogas	3	3	3	3	1	-2	1	12
Propane	1	1	0	2	0	-1	1	4
Biodiesel – 20%	-1	1	1	1	0	-1	-1	0
Biodiesel – 100%	-3	2	3	3	1	-1	-3	2
Ethanol - 10%	1	1	1	1	1	0	0	5
Ehtanol - >85%	1	2	2	3	2	0	-1	9
Low sulphur diesel	1	1	1	1	-2	-1	-1	0
Petro Hybrid Electric	2	2	2	1	-1	-1	2	7
Hydrogen ICE	2	2	1	2	3	-2	-1	7
Hydrogen Fuel Cells	3	3	1	2	3	-3	-1	8

Figure 5.1 The 7 key criteria of different alternatives

Source: Boesel, *(2005)*

5.1.2 The structural component of biogas TIS

From this overview of biogas development in Sweden, it is clear that the structure of the innovation systems has evolved for some time. These will now be reviewed in more detail.

Actors of biogas TIS in Sweden

1. Biogas production plant

Biogas generation plants have developed for decades in Sweden. At the moment, most of biogas is produced form sewage treatment plants. Almost 80% of the sewage treatment plants generate biogas in Sweden, which makes the number exceed 250 (Berglund, 2005). There are also centralized plants testing other sources such as household organic waste (in Uppsala) and energy crops (in Västerås). The digestion plants utilizing the waste from food or fishery industry also contributes to biogas business in Sweden. Mainly, biogas from the plants is applied to support central heating system for the cities. Only 20% of the biogas is transported to the upgrading plants at the moment (Ingelman, 2006).

2. Biogas upgrading plants

Göteborg Energi owns the biggest upgrading plant in Sweden currently. In addition to buying raw biogas from Gryab, it also buys raw biogas from other places such as digestion plants and organic recycling plants. The new upgrading plant in Arendal will be the biggest upgrading plant in the world. After it starts operation in November 2006, it requires new sources of biogas to satisfy the production capacity. So Göteborg Energi plans to build a biomass gasification plant to produce methane-rich gas to expand their source supply (Knutsson, 2006). After the upgrading process, the biogas can reach natural gas quality and can be directly injected into the pipe grid. There are also other centralized biogas production plants that integrate the upgrading process into the generating process, such as Växtkraft (in Västerås)[3]. From Table 5.2, we can see that for a small city, a centralized plant can utilize the household waste and municipal sludge to generate power for the city. It reaches sustainable development. What's more, the centralized plants can not only offer better pre-treatment but also reduce the cost of the biogas production.

Table 5.2 The key data of biogas plant in Västrås

Key data:

Incoming substrates to the biogas plant per year	
• Source-separated organic waste from households and institutional kitchens with a dry matter content of 30 %	14 000 tonnes
• Liquid waste (grease trap removal sludge), with a dry matter content of 4 %	4 000 tonnes
• Ley crop from a contracted acreage of 300 hectares with a dry matter contents of 35%	5 000 tonnes
Production per year	
• Biogas from the biogas plant	15 000 MWh
• Biogas from the sewage treatment plant	8 000 MWh
• Up-graded biogas to fuel quality	
Energy	23 000 MWh
Equivalent to petrol	2.3 Million litres
• Digestion residuals	
solid part with a dry matter content of 25-30%	6 500 tones
liquid part with a dry matter content of 2-3%	15 000 tonnes

[3]Växtkraft conducted a project lasting for 10 years and in the sponsor of EU from 2003 for the treatment of source separated household waste, ley crops and other suitable organic waste. Different from Götebory Energi, it also contracted with the local farmers for growing ley crops (ensilage) as an energy crop feedstock for the digester. However, in order to meet the increasing demand of the biogas, how to find the right resources is one of the most important things to consider in Västerås. (The key data of the project in Västerås is in the Table 5.1.1)

Source: The Växtkraft-project in Västerås, May 2006

3. Filling Stations

Another important actor in the network is Fordonsgas (owned by Dong Sverige AB and Göteborg Energi AB). Fordonsgas distributes the gas, builds and owns the refueling stations. With its past successes and increasing demand, the company is planning to expand their filling stations in other cities. However, in different cities, the cost for transporting the biogas varies. So how to decide the price for the biogas in different cities is still discussed, but in order to attract more customers, the price of biogas will need to be 3-5 SEK lower than petrol for a long time. The most expensive investment for the filling station is the compressors. In order to use it more efficiently, the buses and the cars are sharing the same compressor. Most of the buses are filled at night and during the daytime the private cars utilize the compressor capacity.

4.Equipment suppliers

The development of biogas is accompanying with the development of equipment in different steps. The basic equipment for generating biogas has been used for decades. However, for the upgrading process, the high price is mainly caused by high investment. The compressor and pumps needed in this step require extremely high quality, thus only a few companies in the world can offer those components. In Sweden, such equipments have to be imported from Italy, Spain and Denmark (Persson and Nilsson, 2006). Even though in Sweden some companies may have the ability to produce such equipments, the relatively small market hasn't attracted them.

5. Vehicle manufactures

Several vehicle manufactures started research on biogas cars in the beginning of the 90's. Among them, Volvo is the leading player in Europe. They are involved in developing more efficient passenger and goods transportation systems designed with the environmental issue in mind (Portfolio 21, 2005). The company has put lots of money into R&D in the relevant technologies. But the huge R&D investment cannot be shared within the whole cooperation which makes the cost of biogas cars still high

(Wahlén and Gustavsson, 2006). Even though Volvo hasn't made profits from biogas cars, the increasing demand drives them to expand the capacity to 6,000 units in 2006 (Göteborgs-Posten, 2006). But the company is still waiting for the production of such cars to be more profitable. That requires that gas vehicles are accepted by more end users. However in order to realize this, the current infrastructure needs to be upgraded and other problems be solved.

6. Research organizations

Scholars and researchers in universities and institutes are always involved in the latest technology and help such technology to be commercialized. The results from academic research are of great help for industrial development in this field. Lund University is one of the top universities in Sweden and is very active in environmental research and focuses their studies on 3 particular areas: Biogas processes, Biogas conversion and Biogas system analysis[4]. Tight collaboration has also occurred between Swedish universities and foreign universities and other NGOs (Non Governmental Organizations), especially with the Californian ones that show great interest in this expanding and innovative field (Berglund and Nordqvist, 2006).

7. Industrial association

A shortage in the supply as transportation fuel has occurred in several cities. During the interview with the industry association-SGA (Swedish Gas Association in Stockholm) and SGC (Swedish Gas Centre in Malmö) they both worried about biogas supply (Ekman and Grönstedt, 2006). The current bottleneck is in the form of upgrading plants. The associations have been working on promoting the upgrading capacity national wide. They try to persuade the local governments to use more biogas as transportation fuel as its source for heating and electricity can easily be replaced (Svensen, 2006). The SGA was established around 1920's to diffuse the use of natural gas at that time and they began to be concerned with biogas in the 1990s. It aims to help its member companies to not only transfer knowledge and techniques but also to

[4] http://www.china-biogas.cn/CN/B/B01/B01B/200308/20030827174335.html

be an advocate of biogas (Ekman and Grönstedt, 2006). SGC, on the contrary, has focused on biogas development from the beginning. Their members have done a lot of work to search for and diffuse knowledge in relevant areas as well as to create a better cooperation between universities and industries. 60% of SGC's budget comes from the commercial companies and 40% from government funding (Jönsson, 2006).

8. Government departments and associations

The government departments are the most important player in the network. Without government support, it would have been impossible for the biogas TIS to emerge. The tax-reduction policy and the free parking rules all encourage the consumers' interest in biogas. The unique characteristics in Sweden is that the government support initially came from local governments and when the niche grew big enough, the central government started a national support of TIS. There is special funding for the alternative fuels development in Sweden today and biogas development gets almost 40% of the total funding every year (Ekman and Grönstedt, 2006). What's more, the biogas plants building are also co-funded by the government via its national policy support.

Network of biogas TIS in Sweden

Sweden is a small country and the players in the biogas innovation system have close relationship with each other. Most persons know others well and the informal communications among the persons help to strengthen the interaction of the players (Ekman and Grönstedt, 2006). The dynamic information exchange in the innovation system encourages the expansion of the TIS. As the biogas TIS in Sweden has become more mature, product standards have been defined and the regulatory framework has developed . These components in turn accelerate the formation of network.

The support of biogas development for Swedish government was driven from bottom to top. The municipal governors were interested in biogas development at a region level, partly due to the need to treat waste. For example, Biogas Väst, aims to work as a catalyst in western Sweden and Västerås is a part of a European network, financially supported by the European Union.

Institution of biogas TIS in Sweden

In addition to codified knowledge (standards) which is easy to express and transfer, institutions also relate to the culture, norms and routines etc. that can not be codified easily *(*Asheim and Coenen, 2005*).* The alignment of institution takes longer time and efforts. The early adopters of the product, to some extent, can influence others and express the norms (Moore, 1998). The persons involved in the networks are the best candidates to spread such knowledge. In Sweden, they are the first generation to buy a biogas car and these early adopters have exerted lots of efforts to scale up the utilization of biogas fuel (Svensen, 2006).

After the experimentation in several cities and the performance of biogas production was proved to be favorable, the central government started to establish national rules and regulations. One is a deduction of 40% of the tax for a company car using alternative fuels and another is the local fuel taxes on biogas. (Svensen, 2006).

Sweden in leading countries in the world to utilize biogas as transportation fuel and is the only country has a national standard for biogas fuel. In order to be distributed, the biogas from the upgrading plants must satisfy the national standard. What's more, the SGC has certificate system to make sure the production plants as well as the filling station satisfy the standard. (Details of the standard items are in the Appendix VI)

5.1.3 The functional pattern of the biogas TIS

1. Knowledge development and diffusion

Gas knowledge has existed for decades. However, without an emphasis on further knowledge formation, the efficiency of the technology would still be low and could not have satisfied the requirement for the transportation application. After 1980s, biogas knowledge has been developed broadly in particular in Technical Microbiology and Chemistry Center at Lund Universitet[5], SGC and some commercial companies such as Göteborg Energi etc. Although it is hard to define the volume of biogas research, it is clear that Volvo alone has invested at least 100 Million SEK per year (Wahlén and Gustavsson, 2006).

With a rising interest in biogas in recent years, cross-national cooperation projects (several are funded by the EU Commission) are conducted in order to realize the potential of biogas as transportation fuel. Research centers and business companies all over the Europe work together. The efforts so far have reduced the price of relevant equipments to almost half of the original price (Persson and Nilsson, 2006). The amount of biogas produced is climbing every year.

2. Influence on the direction of search

In Sweden, the driving force of the initial biogas development came from the sewage treatment association (RVF) in order to treat municipal sludge properly. When biogas utilization was proved to be a good way to solve local air pollution, more plants have been built in Sweden to increase the capacity. As a result, extra biogas supply during summer initiated the formation of biogas vehicle market. What's more, Swedish government pushes biogas utilization so that biogas vehicle market expanding rapidly which attracts more actors to enter the business.

With the experience of biogas production, the farmer association Lantmännens RiksFörbund (LRF) also got involved in the industry. Different from the biogas development in Germany which was driven by the agriculture sector in the beginning, the farmer association in Sweden was not interested in pushing the biogas development (Jönsson, 2006). However,, there are some farmers attending the biogas production chain (in Västerås for example). As it is not feasible for the farmers to cultivate ethanol-producing plants, the ley crops for the biogas production may be one

[5]http://www.china-biogas.cn/CN/B/B01/B01B/200308/20030827174335.html

of the alternatives in the future. But at the moment, with high subsidy from governments, farmers prefer to choose setting aside their lands instead.

With the expanding market, the profit-driven companies have the incentives to enter the new industry. The long-term vision from EU has indicated that the biogas fuel has huge potential in the future. Even though it might not be profitable business, the first-mover advantages still impel the new actors. The Biogas Väst is a famous project in southwestern Sweden to coordinate all the actors involved. The WestStar Project in California has attracted more than 115 actors (Boesel, 2005).

3. Entrepreneurial experimentation

Biogas development in Sweden has been going on for several decades. The experimentation of natural gas buses during the Second World War proved the feasibility of gas as a fuel. After the gas pipe building was suspended, the cities without the coverage of such infrastructures (e.g. Linköping) still continued research in this field**.** Then the biogas utilization became the choice for their experimentation. Linköping city has done lots of pioneering entrepreneurial work such as the reduction of odor during the biogas production, the operation of biogas buses etc. These experimentations benefit all the follower cities and push the development of biogas development in the whole country (Svensen, 2006). The trial in other countries such as Netherlands and German also give Sweden useful lessons. The entrepreneurs from different industries and the collective work from all value chain actors have contributed to the diffusion of biogas. The uncertainties of the biogas were reduced in a rather short time and the cost of producing biogas also decreased due to economies of scale.

4. Market formation

The gas market originates from 1920 when the SGA was established to coordinate all the actors in the natural gas industry. The gas market kept expanding after the Second World War due to its multiple applications. The introduction of the tax for carbon dioxide in Sweden in 1991 provided incentives the formation of a biogas niche market. (McCormick and Kaberger, 2005). Governmental pushes later helping to expand the market by advocating public transportation to adopt the biogas. The expanding niche market provided opportunities for the biogas technology improvement and at the same time reduced the risks and costs.

Göteborg Energi plays an important role in the development of biogas TIS in Sweden. They entered the biogas business quite early and the production capacity has been increasing by the establishment of new plants. The government has also instituted a law that petrol stations selling more than 3000 m^3 petrol or diesel annually have to provide renewable energy as ethanol or biogas[6]. At the same time, the local government also provides extra incentives such as free parking in the city of Gothenburg, and liberation from the road toll tax in Stockholm.

The market for biogas has expanded rapidly especially in the recent three years, mainly from private users. Taken Western Sweden for example, biogas utilization is expanding rapidly when looking at statistics of production and sales (Figure 5.2). The continuous incentive from the government accelerates the formation of the niche market. However, when crossing the chasm from niche market to the mass market, there will be new problems emerging (Moore, 1999), e.g. the current shortage in the supply of biogas. If biogas production capacity cannot expand in line with the demand, the biogas market will be blocked and it will take years for the market to reaccept the biogas. At that time, it may have missed the window of opportunity.

[6] http://www.miljofordon.se/nyheter/main.asp?iNewsID=554&iMenuID=413&iParentMenuID=&iLanguageID=1

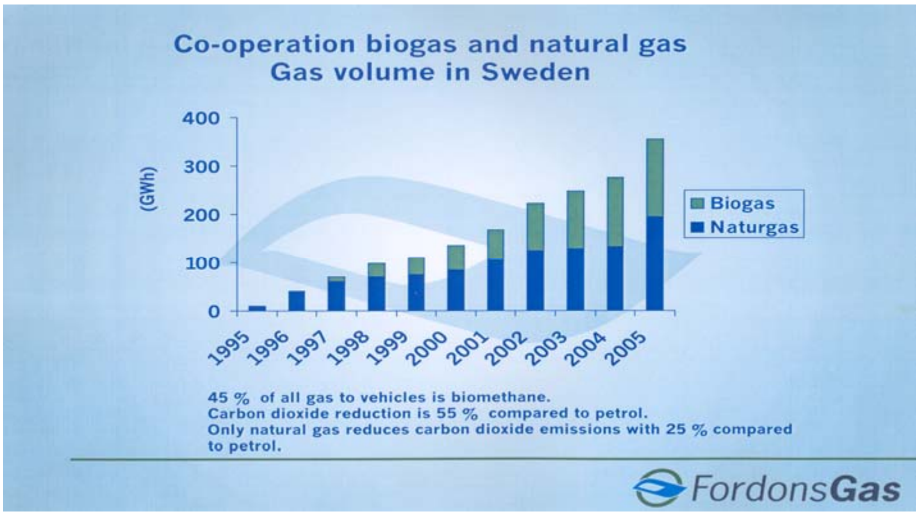


Figure5.2: The data of the market for the gas business (*Source: FordonsGas, 2006)*

The interviews in Sweden clearly indicate that the initial actors in the industry have had success in their lobbying for government support to the biogas TIS. With favorable policies such as tax exemption and free parking, the price of using a biogas car is in southern region lower than using fossil fuel at the moment. It could be predicted that the low biogas price and the incentive policies will last at least for another 6 years (Svensen, 2006). The sustainable policies and the environmental friendly characteristics make biogas cars popular. The niche market is on the verge of becoming a mainstream market.

5. Legitimacy

Today environmental thinking has become a major issue. Sweden, for example, has a party in the parliament named Miljöpartiet focusing on environmental issues. The debate about greenhouse gas is a major concern and as the Kyoto Protocol, established by the United Nations in 1997[7] aims at reducing the emissions of CO_2. Consequently, many countries feel a pressure for new energy sources to be developed. Health concern also pushes the biogas development and change the whole structure of the gas market.

[7]http://europa.eu.int/comm/environment/climat/kyoto.htm

Today biogas cars are very well socially accepted. According to car dealers in Gothenburg, one third of the customers ask about biogas cars (Svensen, 2006). However some people are still skeptical to use gas as fuel and do not trust the technology. They feel that there might be problems with safety and that the gas tank can explode. Other customers are concerning about the availability of gas.

6. Resource mobilization

For the biogas development some of these resources are hard to measure. There are few figures of the volume of capital available. Biogas Väst has a budget of five million SEK from the government every year (Svensen, 2006). In 2004, Fordonsgas had a turnover of 49 million SEK and had 7 employees but is growing rapidly[8]. Volvo Cars recently announced they will put a cap on expenditures on development of biogas engines. Yet there are other car manufactures offering gas-cars, such as VW, Fiat, Mercedes and Opel. The other car producer in the region, Saab, has no gas cars and put their resources into ethanol instead. A reason for this could be that the owner GM also owns Opel and thereby have technology in house ready to integrate in short time if demand rises. Goteborg Energi has invested in upgrading plants but has no budget for research. All their cars are environmentally friendly and they are one of the owners of Fordonsgas.

The government also set aside lots of budget to support the biogas development. According to Ekman and Grönstedt (2006), almost 40% of national environmental budget is utilized on biogas these years. The EU Commission and the World Bank are also concerned about this alternative, which give financial support in several pioneering projects.

[8] www.affärsdata.se

5.2 The Dynamics of the Biogas TIS in China

5.2.1 A brief historical overview of the biogas TIS

Compared to Sweden, the biogas development and utilization in China is quite different. As China is such a big agricultural country, the resources from the agricultural sector should be properly utilized. However, in the practice the technology only allows for anaerobic digestion of animal manure in rural areas. This kind of biogas is mostly used for the heating, cooking and lighting (Yan, 2005).

This history could be traced to the early 1950s, when farm-scale biogas plants in small villages began an initial experimentation in the eastern and northeastern part (Byrne et al., 2004). In 1980, the national authorities launched a blueprint plan for the development of biogas over the whole country (Shi, 2006). Since then the local governments continued to promote biogas application in undeveloped areas to add to the energy supply capacity. During 1980-1990, several universities and research institutes worked together for developing new technologies. They developed several biogas production models suitable for the situation in China. In the 1990s, Chinese national banks and global organizations such as World Bank and Asia Development Bank entered the TIS by providing investment and loans to thousands of experimentation projects. The result during this period was quite promising. The technology for farm-scale biogas plants is mature and more advanced than other countries (Shi, 2006). The total number of biogas plants is increasing over time. In the end of 2005 there was about 12 million household biogas plants in China and over 3,000 industrial-scale plants, which produced over five billion cubic meters (equal to 550 TWh) of biogas annually (Delaquil, et al., 2003).

However, China has little experience with handling solid waste which is another source for biogas production. The methane generated at open-landfills is leaked into the air and hence accelerates the greenhouse impact. Regarding the sewage treatment, China is leading country in the application and development of wastewater treatment technology (Shi, 2006). By 2000 there were about 45 thousands sewage treatment plants which are able to produce biogas. Due to the fact that China is such a big country, the existing infrastructures are not enough. Therefore the central government has taken actions to push the local authorities to build more facilities. However, because of the requirement of large investment, only eight percent of all cities had followed the decision by 2001. According to the ninth-five year national long-term plan, by 2010, 80% of the cities should have their municipal sewage treatment plants and in some developed cities such as Beijing, Shanghai (Shi, 2006), it is compulsory to install biogas extraction equipments for the sewage treatment process (Ninth-year national long-term Development plan, 2002).

With the development of its economy, China is becoming highly dependent on energy. In 2005, China had become the second largest oil consuming country in the world. Transportation, as the biggest sector for energy consumption, is soaring. Since 1990, the government has realized the importance of oil-dependence reduction and started to encourage the use of natural gas vehicle (NGV). In 1988, the first compressed natural gas filling station was installed in Nanchong city in Sichuan province (Hu, 2006) and by 2005, China has 80 thousands natural gas-driven vehicle and 300 filling stations (Wellinger, 2005). There are, nevertheless, only few cities that have experimented with biogas as fuel, such as the experimentation of extracting biogas at landfills in Anshan City (Zhao, 2006). As for other cities around the country, the required upgrading plants and filling stations are still not implemented (Hu et al., 2005).

5.2.2 The structural component of biogas TIS

Since biogas fuel is quite new in China, the relevant actors, networks and institutions can only be outlined based on information from natural gas in this sector. Like the situation in Sweden, the biogas industry includes generation plants, upgrading plants, filling stations, energy companies, local and central governmental departments, industrial associations and equipment providers (they are providing fuel filling facilities, pumping equipments, compressors and so forth).

Actors of biogas TIS in China

1. Biogas production plants:

China currently has more than 10 million household biogas plants in rural areas and 3,000 industrial scale biogas plants (Gu et al., 2004). They are mainly using sewage and industrial organic waste as raw material. The biogas produced by household plants is supplying energy for farmers who use it for heating, cooking and lightning. The first small household biogas plant was established in Liaoning Province in 1963 (Shi, 2006), and then the diffusions of such kind of plants were accelerated nationwide. The industrial scale biogas plants are mostly located in agricultural dominated regions, like, northeastern, south and the middle part of China, namely, Jiangsu, Hebei, Guangzhou, Guangxi, Chongqing, and Chengdu provinces.

The first large-scale plant was built around 1980 in Jiangsu province, where alcohol and sugar manufactures generate a large amount of biogas during the production process (Shi, 2006). The biogas from industrial scale plants was delivered into power plants located in the city or sub-areas for electricity generation. The utilization of organic waste from central livestock and poultry farms were taken into operation in 1990. An early case can be found in the northern part of China-Dongfang biogas plant in Changchun city, Jilin province, which started to operate in 1992 (Byrne, et al., 2004). However there is little experience with solid waste management. According to the statistic of World Bank, the solid waste output from Chinese cities is currently 140 million tons per year and those waste are pumped and handled directly at landfills (Zhang et al., 2004) Without any collection, the methane (biogas) generated at landfills for whole country was estimated to 1 million tons per year (Zhang et al., 2004). Yet, a very small amount of cities are collecting the methane from their landfill facilities. One experiment is Anshan City in LiaoNing province where the department of municipal solid waste treatment and Environmental protection department worked together to collect the biogas at landfill (Wang, 2006). There was also a pilot project experimenting with biogas-driven refuse collection vehicle in 2005 (Hu et al., 2005).

2. Biogas upgrading plants:

Biogas upgrading technology is quite advanced in Sweden and it takes decades to develop this technology. In China, the gas-driven vehicles are focusing on the application and development of natural gas so not much attention is paid to biogas vehicles. Around the whole country, there are few upgrading plants designed for biogas. The exceptions are some in LiaoNing and Guangxi province where there are some demonstrating projects (Shi, 2006).

3. Fuel filling stations:

The development of compressed natural gas vehicles pushes local authorities building filling stations. The total number of gas stations in China amounts to 300 (Wellinger, 2005) so far, and it is increasing year by year. Taking Chongqing for example, until 2004, the city has 49 filling stations for compressed natural gas (It can be used for biogas); they decided to build 10 more stations during the year of 2005, and 20 more stations in 2006 (Zhou, 2006). The usage of compressed natural gas vehicles are concentrated in ChongQing and SiChuan regions where there is a plenty resource in terms of natural gas.

4. Equipment providers:

The range of equipment providers covers the biogas production equipment manufactures, biogas upgrading equipments providers, and filling stations equipments providers. As for biogas production, the local firms take an important role in this area and have developed several equipments suitable to the situation in China. One example is the project in Jiangsu province, Jiangsu Taicang Xintai Alcohol Corporation. It is the company producing white wine and the wastewater discharge reaches 1.6 thousand tons per day (Gu et al., 2004). The company can now utilize wastewater to produce methane. The facilities and equipments of biogas production in this factory are supplied by Jiangsu Fengyu Energy Company. Foreign equipment suppliers are also involved in the construction of biogas projects in China. In this case, one Japanese company provided equipments and technologies for biogas storage tanks. The varieties of equipments providers are one significant characteristic in the development process. There are hundreds of equipment providers for biogas production (including household and industrial scale plants) existing in different provinces. However, for the local policy makers, they preferred to choose local suppliers which mean that the choice is still limited. Due to the fact that China still lacks key technology, the domestic companies are mainly producing basic equipments such as fermentation, storage tanks. The key components such as upgrading and pumps and compressor in filling stations have to be imported from other countries. In the case in Chongqing City, such key parts for the gas filling stations are from Japan and Germany (Zhou, 2006).

5. Vehicles manufacture

The Chinese automotive industry is developing rapidly. The original automotive companies are scaling up their business by increasing the cooperation with foreign companies, building more factories, reinforcing the investment into new types vehicles research. At the same time, new ones are entering into this business. Currently there are five domestic companies that offer natural gas cars and buses; they are Dongfeng, Yutong, ChangAn, Biyadi, Yiqi (Hu, 2006). Meanwhile, some multinational companies are also expanding their natural gas vehicles in China, such as Volvo, Man, Honda and Toyota. The current targeted customers in China are from public transportation systems like city bus companies and taxi companies.

6. Central and local governments

The increasing concerns of environmental protection and security of energy supply has made the Chinese central government realize the importance of alternative fuel since 2000. Lots of plans and regulations had been implemented to develop sustainable energy from then on. The development of biogas is supported by the National ´Development and Reform commission, Ministry of Agriculture, Ministry of

Communication and Environmental Protection Departments. The local departments are following the central decision by conducting more operational work than the central departments.

7. Industrial associations

There are several industrial associations in the area of biogas TIS. The first one is "China Biogas Association" which takes charge of transferring the knowledge and introducing the projects. This non-profit organization under the instruction from Ministry of Agriculture and Ministry of Energy plays a significant role in this area. The Automotives Association is crucial for the biogas application in transportation. The major responsibilities of other non-official organizations are to help the Chinese automotive companies accelerate the joint research and capital investment.

8. Universities and research institutes

Lots of universities and research institutes are conducting research on biogas technology from biogas producing, upgrading and applying, etc. There are about 10 universities having relevant laboratories over the country (Shi, 2006). The leading one is Tsinghua University where the researchers and scholars are focusing on policy issues and biogas engine problems. In addition, agricultural universities in several provinces have started biogas projects. Other research centers and institutes, concentrate on theoretical and laboratory experimentations in such fields. Chinese Biogas Research Center at the Ministry of Agriculture is a particularly important example.

Network of biogas TIS in China

The associations are responsible for formulating the network to transfer the knowledge. Regarding the biogas production, China has plenty of livestock and poultry farms, producing large amount of animal manure and formulated four basic models for biogas production in agricultural sector after the early experimentation that ranged from northern to southern part, covering most of the agricultural regions (Li et al., 2001). Briefly, under the directive and instruction of central government departments, it is comparatively easy to copy and diffuse such technology in China. The tight connections among different local departments make it possible to “import” the new technologies and experience from other regions. With the help from foreign bank and some international organizations, the learning networks also cover to other countries.

Institutions of biogas TIS in China

The central government, functioning as headquarter of the whole nation, has made up several long-term development strategies to develop sustainable renewable energy and improve the energy structure. The relevant files and documents can be found in the latest Five-year Development Plan (Delaquil et al., 2003). The directive plans inform the related departments who will subsequently establish the specific development plans. In addition, there exist energy and environmental laws to guarantee renewable energy development. Many local departments also have policy-supporting gas both for natural gas and biogas.

Though in some places there are small-scale experimentations, a TIS of centered on biogas industry in transport sector hasn’t emerged in China. The country has, however, established several specific regulations and relevant departments also define the exact rules in CNG vehicles. For example, how to build up the filling stations, the choice for equipments of filling stations, and the locations of natural gas filling stations are all described. The European 3 standard is also accepted in the whole country (Details in Appendix Ⅴ)

However, as a relative new concept in China, Chinese customers are not accustomed to gas-driven vehicles. They may be afraid of gas explosions and leakage during the operations. Furthermore, trying new things is not a tradition in China. One misunderstanding for gas vehicles is that based on the previous perception, the vehicles lack strong power to drive the engine. As a matter of fact, those drawbacks described above are only in the past, for those new and latest gas vehicles, such problems have been tackled.

5.2.3 The functional pattern of biogas TIS

1. Knowledge development and diffusion

The main leading research force for biogas in China are in universities, like Tsinghua university, China Agricultural universities and other research institutes belonging to relevant governmental departments, such as National Biogas Research Institute. Those institutes play important roles in generating and diffusing knowledge. Since the 1960s, the anaerobic digestion technology for small-scale biogas production has been tested. The successful cases can be found in Guangxi province. The household biogas plants in that province was developed in the 1970s, the model of ecological and energy circulation is famous as “3 in 1” and “4 in 1” systems. After the successful implementation in Guangxi province, the technology was diffused to several provinces that have the same properties in terms of geographic characteristics, agricultural structure, and livestock models. What’s more, the technology initiated in Guangxi province also has been diffused to other Southeast Asian countries, such as Thailand, Vietnam (Shi, 2006).

The technology for biogas generation integrated in sewage treatment was developed in 1980, and this technology is advanced in China. The total number of industrial-scale wastewater treatment plant was 3,000 by 2005, and it increases quickly through the support from the government. But the experience in biogas upgrading and filling technology is limited. Even though some institutes are doing such research, the results are not quite optimistic (Shi, 2006). Knowledge exchange with other countries is necessary. In the example of Anshan City, the importance of exchanging experience and technology is shown in the biogas producing process[9].

[9]The city has their own solid waste treatment plant and some researchers are doing the experimentation to inject the biogas into the vehicles. Previously they normally put the produced biogas into power plant for electricity, in 2005, after introduced the upgrading technology from Germany and Switzerland and bought several natural gas/biogas driven refuse collection vehicles, the researchers began to utilize the biogas generated from landfills as

2. Influence on the direction of search

The increasing concerns for protecting environment and the rising oil price in the last two years oblige the officers to reconsider their fuel policies. As the result of China's economic development, lots of people are eager to afford cars. According to the national statistics, the number of vehicles in China amounts to 30 million and by 2020 it will increase to 130 million[10] (Online Source in Wall Street Newspaper, 2006). The emission of those petrol-driven vehicles has a large impact on the environment. Therefore it becomes emergent to use alternative fuel to replace the petrol. On the national level, a proposal to develop the renewable energy has been included in the National Eleventh Five-Plan which describes the government policies in the next five years, detailing the amount of research money, resources and laws, regulations etc. As regulated in the latest National Long-term Development Plan, the goal for renewable energy is that is should amount to 40% of total energy consumption by 2015 in China. Several sustainable energies should be promoted in the next decade.

As for biogas development, China will primarily develop large-scale biogas plants and the build-up of electricity network from biogas plants. Chinese government has also decided to intensify scientific research and investment into biogas for other uses, such as transport fuel (Delaquil, 2003). Such overall planning is important for the scale-up and diversification of biogas. The National Development and Reform Commission has established several specific plans for the biogas TIS. The target is that 80% of the cities should have their own sewage-treatment plants and 20% of them should build relevant biogas collection factories nearby. Subsequently, the local governments will set up similar targets considering the local conditions. The agricultural and industrial departments are working together to promote the application of biogas. These incentives from governments clearly attract companies and capital investors. Currently there are more than 30 big projects and hundreds

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the vehicles fuel, currently there are only 3 refuse collection vehicles are using the biogas, according to their long-term plan, it is expected to replace all public transportation including buses and taxis with biogas vehicles by 2015.

[10]http://finance.creaders.net/newsViewer.php?id=663569

small projects with joint effort from several private companies and local research institutes (Shi, 2006).

3. Entrepreneurial experimentation

The entrepreneurial experimentations by energy and public transportation companies are more or less conducted under the guidance of government. Although there are 3,000 large scale biogas plants in the Liaoning, Guangxi, Sichuan and Chongqing provinces, the technology is, however, still in an experimenting phase. It is not mature enough, which means that during the digestion process, the transforming efficiency is still low. Several technologies are tested to determine the suitable ones. In terms of fermentation processes, there are UASB, CSTR, EGSB, IC, AF, UBF types (Gu et al., 2005), but UASB and CSTR cover 80% (see table 5.2). In the case of Changde City, the World Bank started to subsidize a project in 2002 focusing on small-scale biogas plants in rural areas. After four years, 80% of the farmers' family in Dingcheng district of Changde City owned their farm-scale plants (Eric, 2003). Another case is the investment from French Development Bank, which cooperated with Changsha Municipality in Hunan province to build natural gas grid and filling stations.

Table 5.2 Biogas fermentation processes for industrial organic wastewater

	Type	Number	Percentage
1	UASB	200	49.26
2	CSTR	128	31.53
3	EGSB	14	3.45
4	IC	30	7.39
5	AF	8	1.97
6	UBF	5	1.23
7	Others	21	5.15

Source: Final General Report of National Action Plan for Industrial Scale Biogas Development

Some automotive manufactures are doing experiments in the field of gas-driven vehicles, both natural gas and biogas vehicles. One participant is Chinese Automotive Factory which even focuses on the development of natural gas driven private cars. In the public transportation sector, the leading research and relevant entrepreneurial experimentations are conducted by some multinational manufacturers. For example, the joint pilot project for biogas-driven recycling vehicles and public buses, conducted by Anshan Environmental Department, Landfill Treatment Centers and the Volvo Group. Besides, include some Chinese automotive manufacturers.. The bus producing company Chongqing Yutong finished a pilot project for long-distance biogas and natural gas driven buses in 2005 (Ge, 2006). This type of bus would consume 40 cubic meters per hundred kilometers and its emission satisfies European III Standards.

4. Market formation and resource mobilization

Most Chinese customers and companies haven't heard about biogas-driven vehicles before. Even some researchers in the biogas field are only familiar with biogas applications in electricity and heating. Therefore, the development of biogas as transport fuel is in the beginning stage. The initial market hasn't been formed and relevant resources have not been mobilized. However, it is rather easy in China to mobilize the resource from technology research centers, state-owned energy companies, and public transportation companies. According to the planning and requirements from central and local governments, they could act together in an effective way, drawing on the extensive experiments in China.

5. Legitimacy

The legislative system in China is much different from that in Sweden. First of all, the government agencies are responsible for establishing the plans for renewable energy implementation. They should be approved by the State council and the National People's Congress (NPC) who have the rights to pass all general laws and regulations. Once approved by NPC, those plans and regulations can be regarded as legitimized.

There are no specific regulations and laws to promote the utilization of biogas in transport sector at the moment in China. However the current policies for promoting renewable energy indicate the future trends for biogas utilization. In 1996 state energy technology policies were approved to develop and utilize new energy actively. It is used as the guideline from a technology perspective. But as yet, it doesn't have much connection with biogas utilization in the transportation sector. Policy makers haven't yet realized the possibility to use biogas for vehicles. However, it is clearly stated that the build-up of biogas plants in rural areas and industrial waste should be promoted in short time. This may eventually spread over to the transport sector in the future.

5.2.4 Forming a niche market in Chongqing City

So far China has a complete infrastructure for the general biogas TIS including production, distribution and basic pipes construction. The actors operate within a well-structured network and the potential is rather huge over the whole country. With the development China's economy and living standard of citizens, the country is becoming more dependent on oil and one important pressure is from the usage of petrol in transportation. The situation will be worse if the government do not consider other alternative fuels to reduce the oil-dependence and to protect environment. However, not like some European countries and U.S, the biogas application in transport sector has still not emerged in China. Therefore, studying the possibility and feasibility of a niche market for biogas vehicle in China becomes necessary. From this point of view, Chongqing city, where there was a relative mature market for natural gas vehicles (NGV), was selected as to demonstrate a possible pilot project.

5.2.4.1 General description of City

Chongqing is located between Sichuan and Hubei province. The characteristics of geography decided the importance of the city. It is the crucial transportation spot connecting China's northern and eastern areas. It is the biggest industrial city in the southwestern part of China and is known for its mechanics, chemistry, and fiber industries. Furthermore, the transportation of the city is very constructed. In total there are about 10 bus and tram routes operating inside the city. Moreover the number of taxis has reached 40 thousands and approximate 100 taxi companies are running the business (Wang, 2006).

According to a survey in the year of 2004, the population of city (including sub areas and countryside) amounts to thirty million (Chongqing Municipal statistics, 2004). It implies a large demand for energy, especially when the living standard of citizens is rising and people are purchasing their first own cars. By 2005, the number of private cars has reached 250 thousand with an increase of 50 thousands cars compared to last year (Chongqing Municipal statistics, 2005). It is obvious to that this figure will increase significantly in next years.

5.2.4.2 The development of gas vehicles

The city first developed compressed natural gas vehicles in 1998 (Zhou, 2006). Because of its plentiful natural gas resources, the local government decided to develop gas driven vehicles to reduce the greenhouse gas emission and protect the environment. By doing so the government made several development plans and came up with relevant promoting policies. Chongqing Science & Technology Commission played a very important role in the development of natural gas vehicles. First of all it coordinated the research with some Chinese automotive companies. It also was responsible for the short-term and long-term planning. By 2005 the city had 49 compressed natural gas filling stations, 36 of which are distributed in the major area (Zhou, 2006). Under the directive and requirements from government, the public taxi companies had continuously been involved in the applications of natural gas taxis and by 2005, the city had 20 thousands natural gas driven and hybrid gas/ oil vehicles. Indeed, the percentage of gas-driven taxis reached 65% and buses 60 % (Wang, 2006). However, due to the limited capital, the taxis are currently being transformed from petrol engine to gas engine, which is easily done in garage and automotive factories. The disadvantage of this type of vehicle is the low efficiency. But in 2005, the first single-gas driven taxi began to operate and this was produced by a Chinese automotive manufacture.

With the early development in gas-driven vehicles in China, the city has become the biggest area for natural gas vehicles nation-wide. The whole value along with this industry (including the sale of cars, the maintenance, construction of filling stations, the infrastructure for delivery of the gas) has accumulated to 1 billion Yuan (equal to 1 billion Kr). The funding for scientific research of natural gas vehicles from central and local government had accumulated to 40 million Yuan, the usage of money ranged from the production of gas driven vehicle, engine development, filling stations equipments, CNG delivery, and safety techniques. Under the cooperation with municipalities and Chongqing Vehicle research center, the national gas vehicle engineering research center was established with headquarter in Chongqing City. Furthermore the governments established several promoting policies and technology standards for the natural gas vehicles. For the former, the guideline for the application and use of natural gas vehicles was written in 2003, and by implementing this plan, the government built up a leading team who was responsible for both the strategic and operational issues, meanwhile those persons are taking charge in some departments relating to the natural gas vehicle industry (Zhou, 2006). For instance, some officers from the city planning department, city public transportation bureau, had been involved in this leading team. For the latter, the regulations for building filling stations distance between two filling stations had been established from 2002 to 2005.

5.2.4.4 The assumptions

Since upgraded biogas shares the same properties as natural gas, it could also be utilized in CNG vehicles. Nevertheless, currently there are no upgrading plants in China and most of the produced biogas had been used in rural areas for heating, electricity and lighting. To some extent, it is not practical to use biogas produced in rural areas in the transport sector. First, the farmers themselves need the biogas for their own energy consumptions; second, as there is no existing gas grid around the countryside, the transportation of biogas would be a problem. Hence, in this specific case, only industrial organic waste and municipal organic waste have been included in the calculation.

According to calculation made by Chinese researchers, the potential of biogas output in Chongqing City could reach 600 million (Gu et al., 2005) cubic meters (untreated biogas, methane 55%-65%) per year. The number is estimated based on the total output of industrial organic waste. So far Chongqing has more than 40 industrial scale biogas plants which are located around the city, producing 30 million cubic meters biogas every year and this accounts for the 5% of total potential of the city (Chongqing municipal statistics, 2005). Today, the produced biogas has mostly been utilized for electricity. Some of biogas plants own small gas injecting pipes which are connected to the municipal natural gas grid (Ge, 2006) and some plants were built close to the power generation plants. However, this untreated biogas needs to be upgraded if it is to be used in cars, trucks and buses, which imply new investment and financial support to build new upgrading plants. Normally, as was the case in Sweden, the energy companies will be interested in building upgrading plants and filling stations. Due to Chinese particular situation, we assume that the stated-owned energy companies such as China Petroleum & Chemical Corporation (SINOPEC) would add 3 decentralized upgrading plants. Three upgrading plants are able to support 10 industrial scale biogas production plants for upgrading treatment. Then parts of the gas would be loaded on tanks and the rest will be distributed through the constructed natural gas grid.

5.2.4.5 The size of a niche market

With the consideration of limited investment and support from government, the size of a pilot market was calculated in a conservative way. Nevertheless the result is rather promising. Even though only 10 industrial scale plants were included, the capacity of those still amounts to around 7.5 million cubic meters methane every year. According to interviews in Sweden, 1 m^3 cubic meter of untreated biogas (containing

55%-60% methane) can be converted into 0.579 cubic meters of treated biogas (containing 95% methane) (Persson and Nilsson, 2006). This indicates that the production of purified biogas can reach 4.3 million cubic meters every year. As a result, more than 2000 light-vehicles (including private cars, taxis) could be driven with biogas if the annual driven distance would be 200 thousand kilometers per car (calculation in AppendixⅡ). In the longer term, if the actual biogas output from industrial organic waste reaches 300 million, which is half of the potential in this area, then the number of vehicles can be supplied with biogas would be significantly increase to 80 thousands, which is almost half of the total current cars in this city.

6. Conclusions and key policy issues

The purpose of our thesis is to assess the desirability and feasibility for biogas as alternative fuel and identify the key policy issues to realize its potential in China. In order to reach the purpose, three steps are taken, referring to the three sub questions in this thesis.

The first sub-question in our thesis is to assess the desirability of biogas. This sub-question has been discussed from two aspects: environmental friendliness and its potential. From these two points of view, biogas is considered as a possible and desirable alternative in transport sector.

From the environmental point of view, biogas is the most environmental-friendly alternative at the moment in terms of green gas emissions, especially CO_2. Moreover, from the UN database, we know that transportation fuel occupies more than half of total oil consumption in the world. So biogas fuel will help to both release the pressure on the oil supply and to reach the international environmental protocols.

Considering the Chinese situation, we estimated the potential from four major sources: sludge, organic waste, manure and agricultural residuals. The potential from these four sources is about 8,253 TWh per year. These data are probably on the conservative side but the potential appears to be huge. What’s more, the biogas TIS as a whole is already quite strong in China and the actors involved have already acquired knowledge and information in relevant fields. The recently natural gas development in China also provides an infrastructure, such as filling stations and pipe grids in some cities, which means that pilot biogas projects can be started soon.

The second sub-question: the dynamics of the Biogas Innovation Systems in Sweden and China was analyzed in sections 5.1 and 5.2. The history of the Swedish and Chinese biogas TIS was overviewed and subsequently analyzed using a functional analysis. The biogas TIS historical path in these two countries is quite different and there are key lessons Sweden and China can learn from each other. In particular, China faces the same driving force as Sweden did decades ago: treatment of waste. Biogas TIS was developed from the sewage treatment system in Sweden and the experiments in Sweden are valuable to China.

From the functional analysis, we may see the strengths and the weaknesses of each dimension in the Chinese biogas TIS and they help us to understand the present inducements and blocking mechanisms. In the general biogas TIS, China has strong position. However, biogas application as transportation fuel is almost nonexistent and all the functions are weak. But the component from the broader biogas TIS and the players from the natural gas industry jointly have a strength that can be used to develop biogas in that application. What is required is to coordinate all the components together.

The coordination of the players is the task of the policy makers in China. The third sub question: “What are the key issues to stimulate the growth of biogas as a transport fuel in China?” is designed to make sure that all the strength in the biogas TIS in China can be used to scale up the use of biogas as a fuel in transportation sector. The lessons from the Swedish case and the comparisons between Sweden and China help us to identify the key policy issues. There will be discussed in the next two sections.

6.1 Blocking factors

In order to identify the key policy issues, we need to understand current blocking factors. As the purpose of this thesis is mainly concerned with Chinese biogas development, we will focus on the factors in China. However, it doesn’t mean biogas TIS in Sweden has matured. On the contrary, on some point, China is stronger than

Sweden.

Biogas knowledge is widely spread in China, especially in rural areas. The concept of biogas utilization has been widely accepted by citizens. It is an advantage for the biogas development. However, as mentioned before, the application of biogas is restricted to heating and electricity, specifically in household plants. The knowledge of biogas as transportation fuel should be diffused to the citizens. At the moment only the experts or scholars in the field of relevant research know that biogas can be also used as an alternative fuel. Even though the current policies for promoting renewable energy indicate the future trends for biogas utilization, there are no specific regulations and laws to promote the utilization of biogas fuels at the moment in China. The clear statement to build-up biogas plants in rural areas in short time is considered as the current guideline in China but as yet, biogas TIS development in municipals has not been mentioned.

The central government has regulated detailed plans to support renewable energy and pilot projects have started in several cities. The positive trends encourage more actors to join the business. Entrepreneurial experimentation in China is, however, mainly done by the state-owned companies. There are projects now undertaken with support both from the governmental departments and international organizations. For the private companies, however, the huge initial investment and legal obstacles block them from entering the business.

The market for gas is relatively small in China. The focused customers now are the companies in public transportation systems such as the city bus companies and taxi companies. With the development of the natural gas business, there are gas buses and taxis in some cities. These buses and taxis sustain the initial market for the biogas. However, the prices for gas vehicles are still high, which constitutes blocking factor for biogas development.

In Sweden, the national standards guarantee the quality of biogas and encourage positive development. Nevertheless, standards in terms of biogas quality do not exist in China, which may cause the confusion.

Comparing to other countries, the resource mobilization is the strongest factors in China, due to the political system. The strong dimension will make the development of biogas TIS easier. But for the future realization of the biogas potential there is a challenge in terms of how to mobilize raw materials in large volume.

6.2 Key policy issues

Concerning the weakness of the biogas TIS in the transportation sector, the most important policy issue in China is to **raise the awareness** of biogas as an alternative fuel. This issue will influence *all dimensions* mentioned before. A positive attitude to biogas from government officials will encourage the diversification of the TIS. For the central government, concerns for biogas should rise to the same level as that of other alternative energies, such as solar and hydro energy. If a decision to encourage biogas development is clearly stated in the short-term and long-term national plans, actors involved will have more confidence to invest in research and in the construction of infrastructure.

Biogas is widely accepted in China, especially in the rural areas. What should be done in the next step is to diffuse knowledge of biogas in the transport sector. **Training and promotion policies** from the government can play important roles. The benefits of biogas fuel, the advantages of using this fuel and how to use it should all be spread widely. *Knowledge diffusion* is the prerequisite for the realization of biogas as a transport fuel.

Regions which already have an existing gas infrastructure can actively move to

biogas pilot-projects. We propose that such project needs to be started in a number of locations when a natural gas infrastructure has been established, e.g. in Chongqing city. The demonstration projects are vital in the early phase of the biogas TIS development. The initial experimentation is vital for *knowledge diffusion* and *entrepreneurial experimentation*. The demonstration projects in Sweden were helpful for the followers in the path of biogas development. At the moment, some international organizations have already helped to set up several such projects in different areas in China. For policy makers, they need to think about how to utilize these projects as demonstrations to facilitate the initial experimentation and diffuse the knowledge.

The pilot projects also stimulate the *formation of a market*. However, the biggest blocking mechanism for the expansion of the market in Sweden lies in the limitation of raw materials. In the Swedish case, the sewage, sludge and the organic waste compose the main sources at the moment. But in order to utilize these sources, it takes long time to **educate people** and **find proper solutions**. Also, the formation of a larger market relies on the **ender users' acceptance.** Without the coverage of the distribution channels, the end users cannot access biogas, thus the market will be limited. For the policy makers, ensuring an acceptance from the mass-market is tangled with other policy issues such as the initial experimentation and knowledge diffusion.

From the Swedish experience, it is clear that the distribution channel is difficult to build up. The pump for the biogas filling station is ten times more expensive than the pumps for liquid fuels. The Swedish government provides a subsidy for the pumps but still most of the actors in the system complain about the price of the pumps partly due to the dependence on the importing capital goods. In China, the same situation disturbs the biogas distribution. Even though several demonstration stations have been set up, the commercialization of the biogas needs more **infrastructure and distribution channels.**

In the beginning of the biogas development, the cost of the biogas may be higher than other alternatives. The nursing market, of course, needs protection from the government; however, a sustainable development requires virtues cycles in order for the market to expand. In order to reach the threshold at the beginning, the **co-development of different alternatives** may be necessary. Scientists have already assessed the possibility of co-production of ethanol and biogas. The co-production enhances the utilization of the raw materials, reduces the cost and expands the market for the alternative fuels. The different fuels are not necessary to be in competition.

The *resource mobilization* is the strength in China. However, comparing the driving forces in these two countries, we clearly notice that in the Swedish case, biogas development was initiated from the local level and when the biogas production was proved to be one of the best solutions to the sewage treatment, the local or region departments accelerated the development by a policy push. It was thus pushed from bottom. In contrast, in China, the decisions come from the central government. Thus, **how to utilize resources properly and how to put them work together smoothly** are the questions for the policy makers to solve. In particular, in contrast to Sweden, the large agricultural sector in China provides a huge potential as biogas source. But how to utilize the residual from the agricultural sector requires the officials to **take lessons from other countries** and at the same time **develop new gasification technology.**

As we know, Sweden is the only country in the world setting national standards for biogas, from the content of the biogas fuel to the establishment of filling stations. The details of the Instructions for filling stations of methane gas powered vehicles' in Sweden was set up by SGA several years ago. The standards regulate the location, layout of the filling station as well as the equipment and component requirements, checks and official inspections and operation and maintenance. On the contrary, in China, standard establishment is lagging behind. Without standards, the quality of gas cannot be guaranteed. A low blend with natural gas is very important in the first stage for biogas development because it can share the cost of infrastructure. In order to reach this blend, standards are vital for the quality and for providing safety for the end users. In China, no relevant standards have been established. For the policy makers, the pre-requirements of positive development are the **establishment of standards.** Without the standards, all the functions will be blocked to some extent.

6.3 Conclusion

For the Chinese government, realization of the potential of biogas is just in a beginning stage. For policy makers, it is impossible to copy the successful path from other countries, thus they need to develop suitable policies for China. From the functional analysis of the Chinese TIS and drawing on key lessons learned in Sweden, we have identified blocking mechanism and key policy issues for biogas development in China.

The biogas TIS as whole is quite strong in China. But biogas application as a transportation fuel is almost non-existent at the moment. Each functional dimension is weak compared to Sweden. However, if policy makers can take actions to make the whole system oriented to this application, a diversification of the TIS may develop quickly in China.

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8. Appendix

Appendix Ⅰ: The calculation of biogas potential in China

The Data of the Sewage and Sludge in 2004 in China

Area	Total Company Number	Volume of Industrial Sludge (10,000 tons)	Volume of Industrial Sludge without treatment (10,000 tons)	Population (10,000)	Volume of Household Sewage (10,000 tons)
Whole Country	70,630	2,211,425	140,668	129,988	2,612,669
Beijing	825	12,617	-	1,493	85,446
Tianjin	1,620	22,628	3,161	1,024	26,043
Hebei	2,888	127,386	4,449	6,809	79,350
Shanxi	3,196	31,939	-	3,335	62,345
Neimenggu	1,193	22,848	-	2,384	29,720
Liaoning	2,497	91,810	38,728	4,217	103,447
Jiling	846	33,568	-	2,709	53,355
Heilongjiang	1,501	45,190	-	3,817	69,150
Shanghai	1,602	56,359	17,702	1,742	136,966
Jiangsu	5,527	263,538	2,095	7,433	202,573
Zhejiang	5,733	165,274	4,415	4,720	116,052
Anhui	1,639	64,054	-	6,461	84,262
Fujian	3,086	115,228	53,720	3,511	77,740
Jiangxi	1,128	54,949	-	4,284	65,143
Shandong	5,000	128,706	10,729	9,180	135,308
Henan	4,089	117,328	-	9,717	133,324
Hubei	2,284	97,451	-	6,016	135,178
Hunan	3,139	123,126	-	6,698	126,881
Guangdong	6,733	164,728	2,757	8,304	376,989
Guangxi	1,731	122,731	448	4,889	96,045
Hainan	296	6,894	2,464	818	26,161
Chongqing	1,368	83,031	-	3,122	52,487
Sichuan	4,021	119,223	-	8,725	122,497
Guizhou	2,987	16,119	-	3,904	39,568
Yunnan	1,549	38,402	-	4,415	39,901
Xizang	30	993	-	274	3508
Shaanxi	1,834	36,833	-	3,705	38,977
Gansu	1,062	18,293	-	2,619	26,878

Qinghai	239	3,544	10,743	539	-
Ningxia	301	9,510	-	588	14,263
Xingjiang	686	17,671	-	1,963	42,369

Source: National Bureau of Statistics of China

According to Gray (2004)[11], the compositions in the sewage vary with the volume of the water used to flush the waste. The range of organic carbon in England from household sludge is around 13-20 mg/l. By using these data we can expect that the total organic waste from the sludge in China is 627132.22-964818.8 tons (339,646.97-522,533.8 tons from household sludge and 287,485.25-442,285 tons from industry sludge).[12] From the latest research, the separated organic sludge could reach the yield of 200-500 L CH_4/kg range. Considering the situation in China we suggest utilizing the latest yield ratio. Then the total potential from the sludge in China will exceed 1751.87 TWh (the highest will reach 2, 695 TWh). But there is another source referring to this , the Chinese scholars, Gu Shuhua et al., (2005) claimed that the national biogas output from organic waste could reach10.7 billion cumber meters per year[13]. There could be difference compared to our result due to the source selected.

Household Wastes in China (2004)

Area	Family Number (1,000)	Household Waste (10,000 tons)	The Volume of Treatment (10,000 tons)	Treatment Percentage (%)
Whole Country	370,785	15,509.7	8,088.7	52.1
Beijing	4,750	491	392.8	80
Tianjin	3,181	181.6	110.7	61
Hebei	18,933	741	310.6	41.9
Shanxi	8,926	592.4	87	14.7
Neimenggu	7,393	329.2	136	41.3
Liaoning	13,133	778.8	384.9	49.4
Jilin	8,076	571.8	300.4	52.5
Heilongjiang	11,850	1,059.7	275.2	26

[11] N.F.Gray (2004), *biology of Wastewater Treatment*, Imperial College Press, Second Edition
[12] The industry waste is more reliable than organic waste but need special pre-treatment before utilizing there organic solid for the digestion.
[13] Final General report of national action plan for industrial scale biogas development, 2004.

Shanghai	5,844	609.7	123.3	20.2
Jiangsu	22,941	817.7	743.7	91
Zhejiang	15,242	705.2	605.5	85.9
Anhui	18,612	466.8	119.2	25.2
Fujian	10,496	290.5	235.8	81.2
Jiangxi	11,807	258.7	126.1	48.7
Shandong	29,225	1,242.8	1,069.3	86
Henan	26,813	681.5	376.9	55.3
Hubei	17,232	891.3	512.8	57.5
Hunan	19,006	488.9	159	32.5
Guangdong	19,991	1,561.5	757.9	48.2
Guangxi	12,464	228.7	139.3	60.9
Hainan	1,900	82.2	55.8	67.8
Chongqing	10,477	237.2	116.4	49.1
Sichuan	25,380	579.9	259.8	44.8
Guizhou	10,350	202.5	80.5	39.8
Yunnan	11,486	200.1	150.9	75.4
Xizang	549	38	-	-
Shaanxi	9,956	350.2	127.8	36.5
Gansu	6,468	292.1	113.1	38.7
Qinghai	1,346	57.7	55.1	95.4
Ningxia	1,542	135.3	39.6	29.3
Xingjiang	5,414	345.3	123.8	35.9

Source: National Bureau of Statistics of China

Only the separated organic waste could be utilized in the production of the biogas, so it will takes long time for educating people how to separate them properly. Even in this condition, we think organic waste as one of the most promising sources for biogas industry. According to the experience in European countries, 30% of the total waste is composted by organic. However, in China, the consumption behavior decides the composition of the organic will be higher than in Europe. In order to compare with Sweden, we also assume 30% is the average organic content. If 5% of the organic waste could be recycled as the input for the biogas generation, the data show the potential might reach 3,350 TWh (considering the treatment percentage at the moment.). However, it will take long time to achieve this because of the waste separation. In Sweden, it took almost ten years to educate the citizens the importance to separate the household waste and how to do so. Due to the special situation in China, the government would have to take more time to make the people sort the different waste properly.

The Number of Animal Breeding in China (2004)

Area	Animal Breeding (10,000)						
	Cattle	Pigs	Sheep	Goats	Poultry[a]	Horses	Rabbits[b]
Whole Country	13,781.8	48,189.1	17,088.2	19,550.9	1,037,116	763.9	19,664.1
Beijing	29.3	243.2	120.9	37.6	-	0.3	-
Tianjing	43.4	252.4	74.6	19	-	0.4	-
Hebei	795.5	2,945.9	1,413.7	948	-	35.5	-
Shanxi	212.2	452.7	594.2	404.6	-	4.2	-
Neimenggu	514.7	711.2	3,599.4	1,719.1	-	68.7	-
Liaoning	329.1	1,364.8	634.9	569.6	-	31.3	-
Jilin	525	568	347.6	62.5	-	57.8	-
Heilongjiang	532.8	1,217.3	705.4	448.2	-	45.5	-
Shanghai	1.2	50.8	6.6	55.4	-	-	-
Jiangsu	65.8	1,910.8	20.2	1,176.7	-	1.1	-
Zhejiang	39.3	1,125.3	125.5	131.2	-	0.1	-
Anhui	461.8	1,969	2.2	951.6	-	0.6	-
Fujian	107.8	1,241.8	-	128.9	-	-	-
Jiangxi	366.4	1,441.5	13.1	94.3	-	-	-
Shandong	998.8	3,058.2	696	2,590.8	-	15.5	-
Henan	1,423.9	4,232	470	3,440	-	19.4	-
Hubei	406.7	2,190	0.9	342.8	-	1.6	-
Hunan	583.6	4,343.4	0.1	671	-	3.6	-
Guangdong	395	1,989.1	-	32.2	-	0.1	-
Guangxi	739.7	2,671	-	278.1	-	39.9	-
Hainan	147	370.2	-	90.1	-		-
Chongqing	163.7	1,720.2	0.2	285.5	-	2.4	-
Sichuan	1,105	5,627.3	344.7	1,134.3	-	84.8	-
Guizhou	758.9	2,033.1	22.1	398.9	-	78.5	-
Yunnan	788.6	2,605.5	93.6	759.6	-	79.8	-
Xizang	612.8	26.2	1,151.1	664.4	-	42.5	-
Shaanxi	300.9	756.6	208.7	733	-	1.3	-
Gansu	381.3	641	1,000.4	302	-	25.4	-
Qinghai	383.8	106.3	1,434.9	328.8	-	27.1	-
Ningxia	85.7	117.6	410.1	83.4	-	0.5	-
Xingjiang	482.3	206.7	3,597.3	669.5	-	95.8	-

[a]Data is from FAOSTAT DATABASE, poultry including chicken, duck, geese and poultry birds

[b]Data is from FAOSTAT DATABASE

Source: National Bureau of Statistics of China

According to the methods provided by Batzias et al., (2004), the selected values for various factors used as input data in calculation process of ABEPE forecasting model is:

Animal Grouping	By-product factors				
	Total manure (t/head year)	Dry solids (t/head year)	Availability factor	Biogas yield factor (m3/dry t)	Energy factor (MJ/m3)
Cattle	10.8	1.54	0.45	281	21.6
Pigs	1.89	0.216	0.80	649	
Sheep/Goats	0.64	0.222	0.35	120	
Poultry	0.034	0.01	0.70	359	
Horses	8.82	2.6	0.10	160	
Rabbits	0.056	0.029	0.05	359	

From the table above we can calculate the unit yield of different animals groupings.

Animal Grouping	Unit Yield (m^3 biogas)
Cattle	2103,1164
Pigs	211,958208
Sheep/Goats	5,96736
Poultry	0,085442
Horses	366,912
Rabbits	0,0291508

Thus we can calculate the theoretical potential from the manure in China will reach 240 TWH per year by using the data from FAOSTAT DATABASE and National Bureau of Statistics of China.

Appendix Ⅱ: The calculation of Specific case in China

The total capacity of 10 industrial scale biogas plants can reach 7.5 million m^3 per year and those produced biogas would be treated in three decentralized upgrading plants based on assumptions. According to the calculation in Sweden, 1 m^3 untreated biogas (containing 55%-60% methane) can be converted into 0.579 m^3 (containing 95% methane), and then the total number of upgraded biogas from production is 4.3 million. From the data in Volvo, the vehicle V70-Volvo would consume 1 m^3 biogas/natural gas (containing methane 95%) every 9.6 kilometers, and if the accumulated distance every vehicle amount to 200 thousands kilometers (this number is obtained from the interview in Chongqing, the average distance for each taxi is 150 thousands kilometers per year.). It means the N (number of vehicles) can be supplied by biogas generated from 10 industrial scale plants.

N=4.3 million * 9.6/ 200000= 2046

And if half the potential (300 million cubic meters biogas) in Chongqing City can be utilized, the number of supported vehicle would increase largely.

N=300/7.5 * 2046= 81840

Appendix Ⅲ: The optimal time-scale for the development in Chongqing City

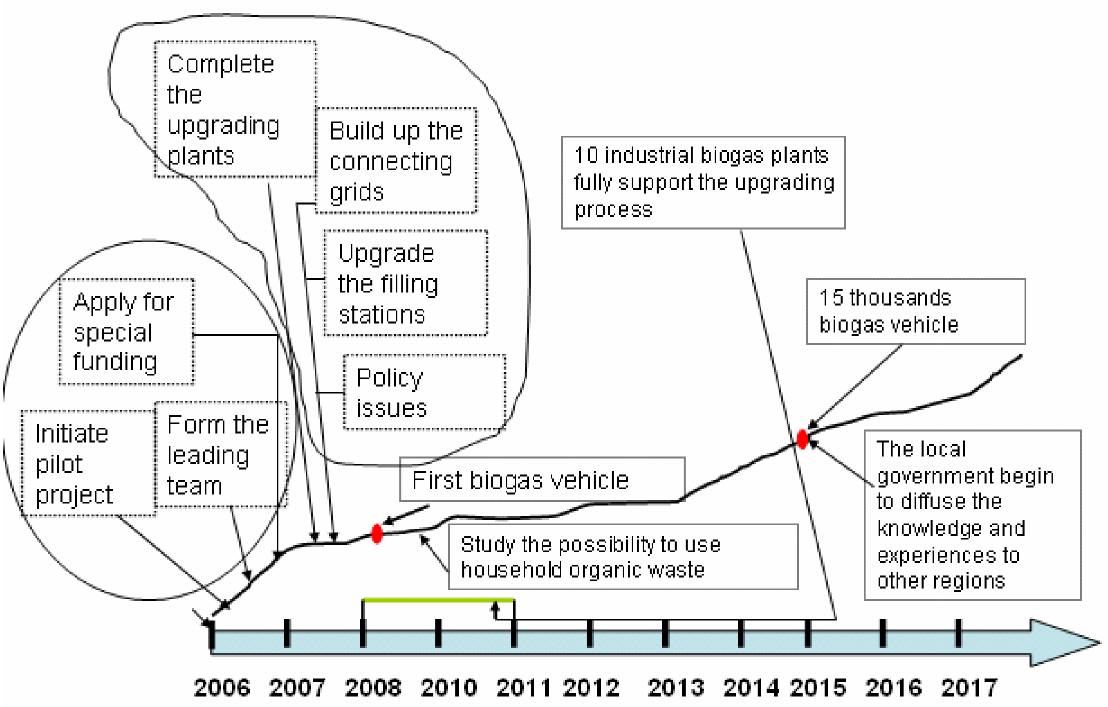

Figure 8,0-1 The time scale of the biogas development for transportation in Chongqing City

1. The year 2006-2007: The Chongqing government initiates the pilot project and starts to apply for special funding from central government. The government forms the special leading team to organize this project, studying the possibility and feasibility. If it is possible, increase the communication with foreign colleagues such as in Sweden, Germany, U.S and Japan.
2. The year 2007-2008: Complete the construction of biogas upgrading plants and build the connecting transferring grids from plants to municipal natural gas, finish the basic build-up of filling stations and increase its total number to satisfy the need from the market. Meanwhile, make up the relevant supporting policies for the development, for instance, the reduction of fuel tax on biogas, the free tolls for the highway road and bridges.
3. The beginning of 2008, first upgraded biogas would be injected into the natural gas grids. At the same time, the city would start to study the possibility of using organic waste as the main source, educate the citizens how to separate

the household organic waste.

4. The year 2008-2010, after the pilot project with 10 industrial scale plants and 3 decentralized upgrading plants, the city would increase the production capacity; more biogas plants would be involved in this area. At that point, the government would build some biogas plants whose main source is from household organic waste. Subsequently the output of production would increase a lot.
5. Until 2015, the objective of 15 thousands single-biogas driven vehicle would be achieved. The central government begins to diffuse the knowledge and lessons obtained in Chongqing city and apply them to other regions. The national development of biogas for transport use start.

Appendix Ⅳ: Interview list

Date	Company	Title	Name
21-April	Biogas Väst	Project Leader	Svensen, Bernt
09-jun	Fordonsgas	Marketing manager	Gunnar Ingelman
14-jun	Västerås	Secretary for the project	Per-Erik Persson,Sarah Nilsson
15-jun	SGA-gasforeningen	Secretary and coordinator	Michelle Ekman,Robbin F Grönstedt
20-jun	SGC	Researcher	Owe Jönsson
22-jun	Lund	Phd student	Maria Berglund, Joakim Nordqvist
28-jun	Gothenburg Energy	Researcher	David Knutsson
28-aug	Volvo Car Cooperation	Product strategy manager & Technical Specialist	Anders Wahlén Niklas Gustavsson
05-jun	China National Development and Reform Commission	Head of Renewable Energy and Rural Power Division	Conference in Jönköping, Sweden, Shi Li Shan
13-aug	Chongqing Public Transportation company	Manager Assistant	Wang zihan
13-aug	Construction for natural gas grids	Technical specialist	Ge Dudong
14-aug	The department of City planning	Officer assistant	Zhou Xiaoqing
03-aug	Municipal environmental department, Anshan City,	Secretary and coordinator	Telephone interview, Zhao Fangyu
25-Jul	Communication and transportation Department	Officer for Public Relation	Telephone interview, Hu Nan

Appendix Ⅴ: European Emission Standard

European emission regulations refer to standard approved by European Union to reduce the vehicle emission and protect the environment. The standards ranged from Ⅰ to ⅠⅤ.The details will be presented in the following tables.

Table1 European Standards for HD diesels, g/kwh(smoke m^{-1})

Tier	Date	Test	CO	HC	NOx	PM	Smoke
Euro I	1992, < 85 kW	ECE R-49	4.5	1.1	8.0	0.612	
	1992, > 85 kW		4.5	1.1	8.0	0.36	
Euro II	1996.10		4.0	1.1	7.0	0.25	
	1998.10		4.0	1.1	7.0	0.15	
Euro III	*1999.10, EEVs only*	*ESC & ELR*	*1.5*	*0.25*	*2.0*	*0.02*	*0.15*
	2000.10	ESC & ELR	2.1	0.66	5.0	0.10 0.13*	0.8
Euro IV	2005.10		1.5	0.46	3.5	0.02	0.5
Euro V	2008.10		1.5	0.46	2.0	0.02	0.5

* for engines of less than 0.75 dm^3 swept volume per cylinder and a rated power speed of more than 3000 min^{-1}

Table 2 European Standards for Diesel and gas engines, g/kwh (smoke m^{-1})

Tier	Date	Test	CO	NMHC	CH_4 [a]	NOx	PM [b]
Euro III	*1999.10, EEVs only*	*ETC*	*3.0*	*0.40*	*0.65*	*2.0*	*0.02*
	2000.10	ETC	5.45	0.78	1.6	5.0	0.16 0.21[c]
Euro IV	2005.10		4.0	0.55	1.1	3.5	0.03
Euro V	2008.10		4.0	0.55	1.1	2.0	0.03

a - for natural gas engines only
b - not applicable for gas fueled engines at the year 2000 and 2005 stages
c - for engines of less than 0.75 dm^3 swept volume per cylinder and a rated power speed of more than 3000 min^{-1}

Table 2 Emission Durability Periods

Period*	Vehicle Category†
100 000 km or 5 years	N1 and M2
200 000 km or 6 years	N2 N3 ≤ 16 ton M3 Class I, Class II, Class A, and Class B ≤ 7.5 ton
500 000 km or 7 years	N3 > 16 ton M3 Class III, and Class B > 7.5 ton

* km or year period, whichever is the sooner
† Mass designations (in tons) are "maximum technically permissible mass"

Appendix VI Examples of the standards for the compressor

(Source: Instructions for filling stations for methane gas powered vehicles, SGA)

7.5 Compressor

7.5.1

Compressors must fulfil the requirements contained in SS-EN 1012-1

7.5.2

The Swedish National Inspectorate of Explosives and Flammables must inspect the natural gas compressor with regard to material.

Material for pressurised mechanical components in compressors must be thoroughly tested and suitable for their purpose.

7.5.3

Systems must be present for collecting oil, water and condensation from the gas. Compressors with pressure relief systems should contain automatic drainage systems. In addition, a compressor's relief system should minimise gas emissions and return gas to the intake side.

7.5.4

Compressors should be equipped with a safety function that stops the compressor in the event of

-low inflow pressure,

-high outflow pressure,

-high temperature in the final stage,

-low oil pressure

-high hydraulic pressure (if appropriate) and

-high temperature in the hydraulic fluid (if appropriate)

The compressor must have pressure switches at each stage. As regards low-pressure switch in the intermediate stage, they must be equipped with some kind of time delay, to allow the compressor to start up.