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Exploring Opportunities for Biogas as a Vehicle Fuel in South Korea: Learning from Sweden

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Abstract

In this study, opportunities for utilizing biogas produced from anaerobic digestion of different organic wastes as a vehicle fuel in South Korea have been investigated, using experiences from Sweden as a basis for analysis. Strategic governmental policies and financial support have enabled many municipalities in Sweden to successfully develop biogas/biomethane as a locally produced renewable fuel. In South Korea, there is a strong need to reduce extreme dependence on imported oil for transportation, to prepare for the post-Kyoto climate framework, and to find new waste management methods which can serve as an alternative to the current ocean-dumping practices of organic wastes that are going to be banned from 2012. Due to these problematic conditions, there is emerging interest in the development of biogas as a road transport fuel. This study finds that the potential for organic waste to be utilized to produce biogas is significant in South Korea, yet that so far few investments have been made. Three biomethane development projects for transport have been recently launched in Seoul, Ulsan and Gangwon Province, with technological cooperation from Swedish companies. A recently announced new national vision, "Low Carbon, Green Growth", and various governmental plans for waste-to-energy are creating a favourable environment for the development of a biogas technological innovation system (TIS) for vehicle fuel. To be successfully expanded, the biogas TIS needs to prove its technical merits and establish a reputation in the early period of its Korean market implementation. Based on interviews with key stakeholders in the three projects, as well as in governmental organizations and research institutes, basic components of the biogas TIS in South Korea are identified, major blocking mechanisms are analyzed, and finally, strategies to achieve greater legitimacy of biogas as a vehicle fuel are suggested.

Executive Summary

Biogas is produced from the biological breakdown of organic matter through anaerobic digestion. Various types of organic waste can be used as substrates; livestock manure, sewage sludge, and food waste are generally main feedstocks. Also, landfill gas (LFG) is another common type of biogas. Biogas can be utilized for various energy services such as heating, electricity generation and vehicle fuel. To be utilized as a vehicle fuel, raw biogas needs to be upgraded, which mainly involves the removal of carbon dioxide to increase the methane content, up to more than 97% in some cases – similar to the composition of fossil-based natural gas. The use of upgraded biogas - biomethane - provides a number of different social and environmental benefits. It is considered the most environmentally-friendly commercial vehicle fuel on the market today, with well proven examples for instance in Sweden. Particularly when biomethane replaces diesel for public buses with long vehicle miles travelled, it improves local air quality, considerably reduces greenhouse gas emissions, and provides a sustainable solution to local organic waste management.

The Swedish experience is a leading example - the successful utilization of biogas as a vehicle fuel in Sweden today is the result of 20 years of efforts in the development of renewable fuels for transport. Renewable vehicle fuels, mainly bioethanol, fatty acid methyl esters (FAME), and biogas, account for about 4% of the energy use for road transport. The amount of biogas used for vehicles has been continuously increasing. The produced and upgraded biogas is distributed by independent pipelines or injected into the existing natural gas grid. There are approximately 16,900 natural gas vehicles (NGVs) in Sweden and 115 refuelling stations, and it is expected that the biogas fuel market will keep growing. The successful development of biogas fuel in Sweden is mainly a result of governmental financial support, research and development (R&D) investments, various legislative and economic policies, active initiation by local municipalities, and the conformity of biogas fuel to various international, regional and national goals.

There is emerging interest in biogas as a vehicle fuel in South Korea, and three biomethane projects are currently on-going. The potential for biogas production derived from highly concentrated organic waste, mainly from food waste, livestock manure, and sewage sludge, is about 96 thousand tonnes of oil equivalent[1] (TOE) in South Korea. There have also been investments for research and development of biogas technology; however, the level of biogas technology is still rather behind compared to leading countries in the field. Above all, upgrading technology, a core technology for the utilization of biogas as a vehicle fuel, is currently not well developed. Therefore, all three ongoing projects are based on technological cooperation with Swedish companies, especially for the maximization of biogas production and the upgrading process.

A new national vision, "Low Carbon, Green Growth", has created a very favourable environment for biogas development as a vehicle fuel. Follow-up plans from different ministries for the new vision have recognized biogas as a fuel for vehicles. In particular, the Waste Resource and Biomass to Energy Plan proposed the utilization of biogas for vehicle fuels as one of its major policies. The plan estimated the potential of utilizing the amount of different types of organic waste (food waste water, livestock manure and sewage sludge) currently dumped in the ocean. If the various ambitious targets of the plan are achieved, approximately 76 million m^3 of biomethane will be produced annually by 2012, which is equivalent to the annual amount of compressed natural gas (CNG) for 1,600 buses, one-tenth

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[1] The tonne of oil equivalent is a unit of energy corresponding to the amount of energy released by burning one tonne of crude oil, approximately 42 GJ.

of the total number of existing CNG bus fleets in South Korea. Contribution to reduced energy dependency, a solution to the coming ban on ocean dumping of organic waste, and the post-Kyoto framework are the main rationales suggested by the proponents of the biogas technological innovation system (TIS) for vehicle fuel. Furthermore, positive experiences of existing CNG buses and existing nation-wide natural gas pipelines are additional favourable conditions.

The basic elements of the biogas TIS for vehicle fuel in South Korea have started to appear. However, the number of actors, networks, and institutions is very small and there are not many activities among them. The lack of public knowledge on biogas as a vehicle fuel and the influence of incumbent dominant actors are discussed in this research as the major blocking mechanisms. Also, the relation between nuclear and renewable energy is discussed; the strong national focus on nuclear development may divert resources and thus might be detrimental to the development of biogas as a vehicle fuel.

Finally, to be successfully developed according to early timescales, the biogas TIS for vehicle fuel in South Korea needs to prove its technical merits and establish a reputation - a legitimation process. Four major strategies to increase this legitimacy are suggested. First of all, it is important to conform to established institutions. In this respect, the proponents of the biogas TIS have focused well on the major institutions in general. Secondly, the need for systematic well-to-wheel studies on biogas as a vehicle fuel is very much needed to activate discussion on the new TIS, which can eventually contribute to the legitimation process. Thirdly, the accumulation of actors with experience and trust is essential to legitimation. Finally, the formation of coalitions which include strong prime movers is greatly needed at this moment to strategically increase the legitimacy of the biogas TIS for vehicle fuel in South Korea.

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1 Introduction

1.1 Background

South Korea, a country located in North-East Asia, rapidly developed its economy in the last couple of decades and has become the world's 13th largest economy in 2007 from one of the poorest countries in the world in 1960s after the Korean War. Gross domestic product per capita in purchasing power parity has also skyrocketed from $1,513 in 1960 to $21,342 in 2005, a fourteen-fold increase (Gapminder, 2009). In line with its economic development, South Korea joined the Organisation for Economic Co-operation and Development (OECD) in 1996. Furthermore, South Korean industries have become global front-runners in many industrial sectors, such as shipbuilding, steel, automotive, semiconductors, electric home appliances and mobile phones.

However, the extremely rapid growth of the economy, driven by the manufacturing industry in the 1960s to 1980s has caused various environmental problems. Even though there has been so much improvement in environmental protection during the last decade, still the level of environmental performance in South Korea has not corresponded to the level of its economy. For example, South Korea was ranked at 51st out of 149 countries in the 2008 Environmental Performance Index (EPI), developed by Yale and Columbia Universities (Yale University & Columbia University, 2008). Additionally, the global climate crisis and high oil prices have put the country in a much more difficult situation than other countries in the world because it imports 97% of its energy from abroad and energy consumption is very high with still lower energy efficiency compared to other OECD countries. Therefore, at the 63rd anniversary of national liberation and the 60th anniversary of the founding of the Republic of Korea, on August 15 2008, President Myung-bak Lee ambitiously announced a new national vision, 'Low Carbon, Green Growth' for the next 60 years. Since then, all sectors in South Korea have been consistently trying to design follow-up plans to achieve the new vision.

In its recent report, World Energy Outlook 2008, the International Energy Agency (IEA) clearly stated that "current global trends in energy supply and consumption are *patently unsustainable*" (IEA, 2008c). To overcome the situation, it identifies two major energy challenges that the world has to overcome: 1) "securing the supply of reliable and affordable energy" and 2) "effecting a rapid transformation to a low-carbon, efficient and environmentally benign system of energy". To meet these challenges, reducing dependence on oil has become one of the priority issues for most countries around the world. Since the transport sector is the most dependent on oil (approximately 95%) compared to other sectors, such as industrial and residential areas, the development of renewable alternative fuels has been an area of high priority. So far, biofuels such as bioethanol, biodiesel and biogas are the most rapidly expanding and widely used types of renewable transport fuel, although they still accounted for only 1.5% of total global road transport fuel demand in 2006 (IEA, 2008c).

As the world's 4th largest importer of crude oil (IEA, 2008b), the extreme dependence on imported oil for transportation poses various challenges in South Korea. These include vulnerability in energy security, unstable oil prices, air pollution, and greenhouse gas emissions (GHGs). The transportation sector consumes about 21% of the total primary energy consumption in the country (PMO, 2008c). Therefore, it is a great concern for South Korea to develop locally produced renewable fuels to enhance its energy security, to improve air quality and to reduce GHGs emissions. Recently, there are emerging interests in utilizing biogas produced from different kinds of organic wastes through anaerobic digestion process for various end-uses among central government, local municipalities, and private sectors due to a range of domestic and international factors (Jaegeun Bae, 2008; Do & Phae, 2008; Heo, 2005, 2009; S. M. Hong, 2008; J. Y. Kim, Song, & Kim, 2005; K. M. Kim, 2008; Koh, 2007; ME, 2007, 2008a, 2008b, 2008d, 2009a; MKE, 2007b; ME, 2007; Oh, 2007; Paek, Kim, Kang, Ryou, & Cho, 2005). These different governmental documents, researches and presentations commonly argue that there is a great potential of different organic wastes to produce biogas in South Korea and the utilization will bring various environmental, social and economic benefits to the country. Among various ways of utilization, a few of the researches and governmental documents asserts that a vehicle fuel might be the most suitable way of utilization of biogas from organic waste in South Korea.

In line with this new emerging interest, three cooperative projects utilizing biogas as a vehicle fuel have been recently launched in different municipalities in South Korea with technology and knowledge transfer from Sweden, a leading country in the field of biogas utilization as a road transport fuel. However, while there are at least a number of academic researches on the utilization of biogas for electricity generation, there are very few academic researches on the use of biogas as a vehicle fuel in South Korea. In other words, there is a clear lack of understanding on biogas technology especially as a vehicle fuel and its potential and various possible benefits. In addition, there is a need to find how to develop a new renewable vehicle fuel among central government, local municipalities and other proponents of biogas fuel for vehicles. Thus, it is timely, appropriate and meaningful to introduce Swedish experience as a good example in the utilization of biogas for vehicle-fuel. Also, considering the fact that the development of renewable energy usually requires various governmental economic, legislative and institutional supports, it is important to examine how the new renewable technology, biogas as a vehicle fuel, can be diffused successfully.

1.2 Purpose and Research Questions

This research explores opportunities for biogas as a vehicle fuel in South Korea. Therefore this research addresses the following main focus question:

How can biogas as a vehicle fuel be successfully diffused in South Korea in such a manner that it contributes to reduce extreme dependence on imported oil for transportation, to improve air quality, to reduce greenhouse gas emissions, and to establish a sustainable organic waste management system?

As an exemplary case, the development of biogas as a vehicle fuel in Sweden is examined in order to briefly address the three following sub-questions:

1) How was biogas developed as a vehicle fuel in Sweden?

2) What is the present situation and future of biogas as a vehicle fuel in Sweden?

3) What factors have influenced the successful development of biogas as a vehicle fuel?

In order to understand the very formative period of biogas technology for vehicle fuels in South Korea, the questions below are investigated:

1) What is the potential of biogas as a vehicle fuel from different types of organic waste?

2) What governmental plans are related to the development of biogas as a vehicle fuel?

3) What are the major rationales for the utilization of biogas as a vehicle fuel?

Finally, this thesis presents analysis of the current situation in the development of biogas as a vehicle fuel and provide recommendations on what kind of development strategies are needed for the main actors in South Korea (such as the central government, local municipalities and private companies) to successfully diffuse biogas as a road transport fuel in the near future in response to the major barriers for its development.

1.3 Research Justification

As shortly discussed above, the end-use of biogas from different kinds of organic waste is various. However, in this research, the main focus is on the utilization of biogas as a vehicle fuel. At the moment, biogas is not utilized as a fuel for vehicles in South Korea at all. Even, it is not very actively utilized for other purposes. However, at least, a number of academic studies can be found on the utilization of biogas for heating, electricity generation or combined heat and power plants (CHP), whereas, to my knowledge, there has been no academic research on biogas as a vehicle fuel in South Korea. In addition, there are very little mention of biogas as a vehicle fuel in the First National Energy Master Plan 2008-2030 (PMO, 2008c) and biogas as a vehicle fuel is not included in the Renewable Energy RD&D Strategy 2030 - Bioenergy for Transport (MKE, 2007a) but mentioned briefly in another volume, the Renewable Energy RD&D Strategy 2030 – Organic Waste in Bioenergy Sector (MKE, 2007a). This is indicative that to date, biogas has not been generally considered as an important type of fuel for transportation.

Nevertheless, initiated not by the central government but by local municipalities, biogas utilization projects for vehicle fuel have been launched in three different municipalities in South Korea; Seoul city, Ulsan city and Gangwon Province. Thus, there is a need for greater research and it is timely to introduce and discuss opportunities for biogas as a vehicle fuel in South Korea to increase the social understanding of the technology and to bring the issue into the social, political and academic arena. Lastly, the major reasons why Sweden is chosen as an exemplary case are because Sweden is the leading country on the utilization of biogas as a vehicle fuel in the world as mentioned above and also the three ongoing biogas vehicle fuel projects in South Korea are joint projects with two Swedish companies with their technological expertises and know-how; Swedish Biogas International (SBI) for the Seoul and Gangwon projects and Scandinavian Biogas (SBF) for the Ulsan project. Therefore, the Swedish experience is a good and appropriate example use in this research.

1.4 Research Methodology

First of all, participation in the Biogas Highway exhibition at the ECO-TECH Scandinavia in Göteborg, Sweden from 21-22 November, served the purpose of understanding the biogas technology in general as well as biomethane development as a vehicle fuel in Sweden. In addition, attending a seminar, "Fuelling the future – biomethane as a vehicle fuel", during the exhibition enabled the author to meet key actors in the Swedish biomethane market and to establish contacts with them. Especially, Mattias Svensson, Research Manager at Swedish Gas Center (SGC), provided very relevant literature for the author to understand the topic.

In October 29-30, the author visited Göteborg again for further research; visiting a biogas plant at Gryabb, Biogas West project in the Business Region Göteborg, biogas fuelling stations and Göteborg Energi. Göteborg was chosen because not only it is one of the leading cities in the utilization of biomethane as a vehicle fuel, but also, unlike other leading cities, there is an existing natural gas pipeline in the city similar to the situation in South Korea. Another visit was done on November 6 to Linköping since it is also one of the leading cities and the Swedish Biogas International, a Swedish company doing business in South Korea, is based on Linköping. During the visit to the city, the author met Helena Kock Åström, Environmental-strategist at the Municipality of Linköping and Anders Ek, Process Manager at Swedish Biogas International and visited two biogas plants. These two short research trips provided valuable on-site experiences, a general picture of biomethane as a vehicle fuel, and the development of biogas as vehicle fuel in Sweden, mostly reflected in chapter 2 and 3.

After coming back to South Korea in January 2009, various literature, governmental reports, and conference presentations obtained from the library service of Lund University including electronic resources, the two research trips, home pages of related international, Swedish and Korean associations, and general web search engines have been reviewed to further understand the successful development of biomethane in Sweden and to explore biogas opportunities in South Korea. In addition, three interviews were done in January as follows.

▪ Soon-chul Park, Researcher, Bioenergy Research Center, Korea Institute of Energy Research, January 8, 2009, Daejeon.

This interview was done to understand the bioenergy potential and the utilization of biogas since he is a leading researcher in the fields.

▪ Keun-mo Kim, Vice director, UNISON Co., Ltd., January 12, 2009, Daejeon.

This interview was done to obtain general information on biogas technology in South Korea because Keun-mo Kim has written a few articles on Biogas and his company owns a biogas plant for electricity generation.

▪ Ki-dong Kim, Researcher, Korea Gas Corporation (KOGAS), January 15, 2009, Seoul.

This interview was done to understand the possibility of biogas as a vehicle fuel in South Korea in general because Ki-dong Kim was identified as the most active government researcher in the utilization of biogas as a vehicle fuel in South Korea. These three interviews mostly helped the author to organize chapter 4.

From the interviews done in January and news search, three on-going biogas projects for vehicle fuel were identified. Consequently, to understand the three projects and their perspectives in the development of biogas as a vehicle fuel in South Korea, additional three interviews were done in Seoul, Ulsan and Gangwon Province as shown below. They were reflected in chapter 4.6 and used as major sources for the analysis in chapter 5.

▪ Won-ok Lee, Biogas Team, Environment Policy Division, Gangwon Provincial Government, May 17, 2009, Chuncheon.

▪ Christer Svedin, Process Director, Scandinavian Biogas Korea (SBK), May 20, 2009, Ulsan.

▪ Hwan-mok Jeong, Manager, Ecoenergy Holdings Co., Ltd., May 25, 2009, Seoul.

Finally, to understand perspectives from Academia on the utilization of biogas as a vehicle fuel, additional three interviews were done as follows. Even though they are involved in the biogas research in general, none of them is doing a research in the utilization of biogas as a vehicle fuel in particular. Therefore, the interviews were generally reflected in chapter 4.

▪ Jae-keun Bae, Professor, Environmental Science, Seoul Industrial University, May 26, 2009, Seoul.

▪ Chang-hyun Kim, Professor, Biogas Center, Hankyung University, May 27, 2009, Anseong.

▪ Se-eun Oh, Professor, Environmental Engineering, Hanbat University, April 23, 2009, Daejeon.

1.5 Scope and Limitations

As mentioned above, there has been no official vehicle in South Korea running on biogas. In other words, the utilization of biogas as a vehicle fuel has not started yet. Thus, available information and data related to the utilization of biogas as a vehicle fuel in South Korea is very much limited. As a result of this, if South Korean specific data is not available, assumptions have been made from the Swedish case. The calculations and assumptions should be considered not as specific to South Korean situation but indicative.

Technological aspects of biogas as a vehicle fuel during production, upgrading, distribution, and use phases are not covered in depth in this research. Also, thermal gasification technology of organic materials is not considered as one of the possible ways to produce biogas, since it is still in the development phase, though the commercialization of the technology seems quite close, at least in Sweden (Göteborg Energi, 2008).

Furthermore, comparison with other types of major biofuels, biodiesel and bioethanol, is not included in this research. At this moment, only biodiesel is commercially available in South Korea and the introduction of bioethanol is under discussion. Three types of organic waste such as livestock manure, sewage sludge, and food waste are mainly discussed in this research, excluding other types of organic waste such as agriculture residue, energy crops, forestry residues, and etc. Lastly, interview with major vehicle manufacturers (Hyundai, KIA, GM Daewoo, SSangyong, etc), local CNG bus companies and local gas distributors are not included in this research. Due to time constraint, it was decided not to include them in the scope of the research. In addition, since the utilization of biogas as a vehicle fuel has just started to develop, they have not shown much interest in this field yet. However, it is almost no doubt that they are important stakeholders in the biomethane market as vehicle fuel. Especially, once biogas is produced and upgraded successfully in South Korea, their role will become more important. Thus, their views and roles need to be included in future researches.

1.6 Target Group

Biogas systems are very complex to understand compared to other renewable energy, such as wind, solar and other bioenergy technologies. This is because the main technology of producing biogas, anaerobic digestion technology, is considered as a technology for both waste management and renewable energy production. There are a great number of different actors involved in the system especially in the production phase related to the three main types of organic waste mentioned earlier. Thus, this research aims to provide information not only for current actors but also for various potential actors in the biogas process chain: production, upgrading, distribution and consumption. The central government including different related ministries can obtain a general understanding of how biogas utilized as a vehicle fuel, how Sweden has become successful with what governmental supports, and finally what opportunities South Korea has to develop biogas for transport. Local municipalities can find one solution for their problems including air quality improvement, GHGs emissions reduction, future ban of ocean dumping and local development. Especially, local municipalities can get an idea of how they can take advantage of already announced different national plans related to the utilization of organic waste. Environmental NGOs (non-governmental organizations) against air pollution, global warming, ocean dumping of organic waste and the excessive use of fossil fuels can find one possible solution from this study. Universities can initiate further researches on the utilization of biogas for transport. Also, foreign companies interested in biogas market in South Korea for vehicle fuel can understand the current situation in South Korea and different government plans for the utilization of biogas in the future to find business opportunities, especially considering the fact that most plans are only available in Korean. Lastly, those who are interested in the development of locally produced renewable energy can find a good example from the Swedish case and increase their understanding on the development of renewable energy in a formative period.

1.7 Theoretical Background and Analytical Framework

A new innovative renewable technology, either biogas, wind power or solar power, is not usually diffused successfully at first, even if it is strategically supported by the government or socially supported by major international trends, such as global warming or peak oil. One renewable technology can be introduced and diffused very successfully in one country, but it might fail in other countries. Various factors influence the development of a renewable technology. Biogas technology as a vehicle fuel is not an exception. For example, unlike Sweden, a neighboring country, Finland has not achieved a similar level of development of biogas as a fuel for transport. Savola argued that a more comprehensive and integrative approach to manage environmental issues and a regional empowerment policy with the provision of financial support to reduce GHGs emissions have enabled Sweden to develop biogas much faster than Finland as well as different national prioritization (Savola, 2006).

Many scholars have developed several theories to better understand "the process whereby a specific new technology emerges and is improved and diffused in society". In order to analyze the process of the development of biogas in South Korea more systematically and to propose development strategies, one of the analytical frameworks is applied in this research. It is a theory of emerging technological innovation systems (TIS), developed by several researchers: (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Bergek, Jacobsson, & Sandén, 2008; Carlsson & Stankiewicz, 1991; Jacobsson, 2008; Jacobsson & Bergek, 2004; Jacobsson & Johnson, 2000).

A TIS can be defined as "network(s) of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of generating, diffusing, and utilizing technology" (Carlsson & Stankiewicz, 1991). It is composed of three main elements: actors, networks and institutions.

Actors are firms and other organizations along the whole supply chain of a specific technology (Bergek, Jacobsson, & Sandén, 2008; Jacobsson & Bergek, 2004). For example, in the case of biogas technology as a vehicle fuel, actors could be different feedstock providers, biogas producers, upgrading companies, gas distributers, refuelling station companies, natural gas vehicles (NGVs) manufacturers, bus companies, NGV drivers, venture capitalists, central and local governments or other related organizations (Jacobsson & Bergek, 2004). Among the different actors, an actor "who is technically, financially and/or politically so powerful that it can strongly influence the development and diffusion process" is considered as a 'prime mover' (Jacobsson & Bergek, 2004). Other significant actors are non-commercial organizations which operate to support certain technologies.

Networks are composed of important channels for the transfer of knowledge (Bergek, Jacobsson, & Sandén, 2008; Jacobsson & Bergek, 2004). Learning networks between biogas producers and local universities or political networks among biogas producers, distributers and NGV manufactures can be good examples. Sometimes, they provide direction for the various actors mentioned above by forming the perception of what is technologically feasible and desirable (Jacobsson & Bergek, 2004). Moreover, they can be influencing on the institutional set-up (Jacobsson & Bergek, 2004).

Institutions mean "the norms and rules regulating between actors and the value base of various segments in society" (Jacobsson & Bergek, 2004). They can be hard regulations such as waste management laws and vehicle fuel standards or they can be norms and cognitive rules, that is, "what actors think is right and what they want to do by what they know and are able to do"(Bergek, Jacobsson, & Sandén, 2008).

When a new technology is introduced, these structural elements of TIS - actors, networks and institutions - are very weak in terms of their numbers and functions (Bergek, Jacobsson, & Sandén, 2008). Therefore, until the elements are put in place a TIS can undergo a formative period for a long time, and this could be for several decades in some cases. Once the TIS becomes mature and self-sustained after going through 'a cumulative process of many small changes', it steps into a growth phase (Bergek, Jacobsson, & Sandén, 2008).

An effective approach to investigate the dynamics of the formative phase is to focus on different sub-processes of the TIS (Bergek, Jacobsson, & Sandén, 2008; Jacobsson & Bergek, 2004). These different processes, also labelled as 'functions" (Bergek, Jacobsson, & Sandén, 2008; Jacobsson & Bergek, 2004), are described in the table 1-1 below. These functions are not mutually independent from one another but closely interconnected (Jacobsson & Bergek, 2004).

Table 1-1 Functions of Technological Innovation Systems

Development of formal knowledge	The breadth and depth of the formal, research-based knowledge base and how that knowledge is developed, diffused and combined in the system.
Entrepreneurial experimentation	Knowledge development of a more tacit, explorative, applied and varied nature – conducting technical experiments, delving into uncertain applications and markets and discovering/creating opportunities, etc.
Materialisation	The development of (and investment in) artefacts such as products, production plants and physical infrastructure.
Influence on the direction of search	The extent to which supply-side actors are induced to enter the TIS, or put more subtly, direct their search and investments towards the TIS.*
Market formation	Articulation of demand and more 'hard' market development in terms of demonstration projects, 'nursing markets' (or niche markets), bridging markets and, eventually, mass markets (large-scale diffusion).
Resource mobilisation	The extent to which the TIS is able to mobilize human capital, financial capital and complementary assets from other sources than suppliers and users and the character of this mobilisation.
Legitimation	The socio-political process of legitimacy formation through actions by various organisations and individuals. Central features are the formation of expectations and visions as well as regulative alignment, including issues such as market regulations, tax policies or the direction of science and technology policy.
Development of positive externalities ('free utilities')	It reflects the strength of the collective dimension of the innovation and diffusion process. It also indicates the dynamics of the system since externalities magnify the strength of the other functions.

Source: Bergek, Jacobsson, & Sandén, 2008

Most of these processes listed in the table above have not appeared for 'biogas TIS for vehicle fuel in South Korea since the technology/system is in the very beginning of the formative period. Therefore, the focus of this study will be limited on the 'legitimation' process. Legitimacy is "a matter of social acceptance and compliance with relevant institutions" (Bergek, Jacobsson, & Sandén, 2008)". The forerunners of a new technology generally lack familiarity and credibility, that is, legitimacy. It is very crucial to achieve a certain level of legitimacy in the very initial stage in order to "access to capital, markets and governmental protection" (Aldrich & Fiol, 1994). In other words, it is 'a prerequisite for the formation of new TIS (Aldrich & Fiol, 1994; Bergek, Jacobsson, & Sandén, 2008). However, legitimacy is not automatically given but should be achieved through conscious actions by various actors in "a socio-political process of legitimation" (Aldrich & Fiol, 1994; Bergek, Jacobsson, & Sandén, 2008).

Bergek, Jacobsson and Sandén (2008) argued that gaining legitimacy in the energy and transport sector might be notably problematic since incumbent technology system have had secured their positions very solidly for several decades, longer than a century in some cases. They are very powerful and organized to protect their interests, simultaneously enjoying their direct and indirect subsidies. Not to compromise their interests, it is very likely that not only are they reluctant to adopt new technologies, but also they are willing to hinder the development of new TIS (Bergek, Jacobsson, & Sandén, 2008).

Therefore, it will be analyzed how the TIS of biogas as a vehicle fuel in Sweden achieved a level of legitimation to successfully go through the formative phase. Then, when the Korean situation is discussed, the main focus will be on how current actors are trying to increase the legitimacy of the biogas TIS and what part of the theory is found to be applicable or not in South Korean case to better understand the diffusion of the biogas TIS for vehicle fuel in general and the legitimization process.

1.8 Outline

Chapter 1:

This chapter contains background of the research, research questions, research justifications, methodology, scope and limitations and target group to provide readers with the structure as well as the purpose of the research. It also introduces an analytical framework for the research.

Chapter 2:

This chapter presents a general introduction biogas and anaerobic digestion. In addition, chapter 2 explains the distribution and final uses of biogas, mainly focused on the utilization of biogas as vehicle fuel. Different features and expected benefits of biogas as vehicle fuel are presented as well.

Chapter 3:

This chapter introduces the Swedish experiences of biogas development as vehicle fuel. Starting with a brief introduction of Sweden with its energy system, the general situation of biogas as vehicle fuel in Europe is introduced. Then, the present, past and future of biomethane development and major factors to its success are analyzed.

Chapter 4:

This chapter aims to provide biogas opportunities as a vehicle fuel in South Korea. The current situation of organic waste in South Korea is presented including the potential of organic waste. Chapter 4 also analyzes the level of biogas technology, various governmental plans on biogas utilization and the three ongoing biogas projects in South Korea. Finally, the major rationales for the development of biomethane as a vehicle fuel are analyzed.

Chapter 5:

Based on the analysis in the previous chapter, Chapter 5 analyze the biogas TIS in South Korea for vehicle fuel in terms of its basic components and discusses major blocking mechanisms and the relations between renewable and nuclear energy. Finally chapter 5 suggests strategies to support the legitimation process of the TIS.

Chapter 6:

Chapter 6 presents conclusion containing reflections and recommendations for future research in the utilization of biogas as a vehicle fuel in South Korea.

2 Background

This chapter is mainly a literature review on biogas technology for vehicle fuels. Various books and journal articles collected from Lund University library service and research papers and informative publications on biogas from Swedish Gas Center, Swedish Biogas Association, and Swedish Energy Agency are main sources. This chapter aims to introduce the following key components of biogas systems so that the reader can have basic understanding on what biogas is and how it is produced, distributed and used, especially as a vehicle fuel.

2.1 Biogas and Anaerobic Digestion

Biogas, in this thesis, refers to a gas produced from the biological breakdown of organic matter in an anaerobic environment, shortly anaerobic digestion (Berglund, 2006). Anaerobic digestion naturally takes place in various environments, for instance, in marshes and the stomach of ruminants (Swedish Biogas Association, Swedish Gas Center, & Swedish Gas Association, 2008). It can be also produced in a controlled environment such as a biogas plant where organic matter is pumped into a fully airtight container. For more than 100 years, humankind has utilized biogas under controlled environment and the technology has been incessantly improving (Swedish Biogas Association et al., 2008). As shown in the biogas route map below, diverse substrates can be used in a biogas digester, for instance, livestock manure, household organic waste, industrial food waste, sewage sludge, agriculture residue, forest residue, dedicated energy crops and etc. Biogas can be extracted from landfills as well, which is generally named LFG (Landfill Gas).

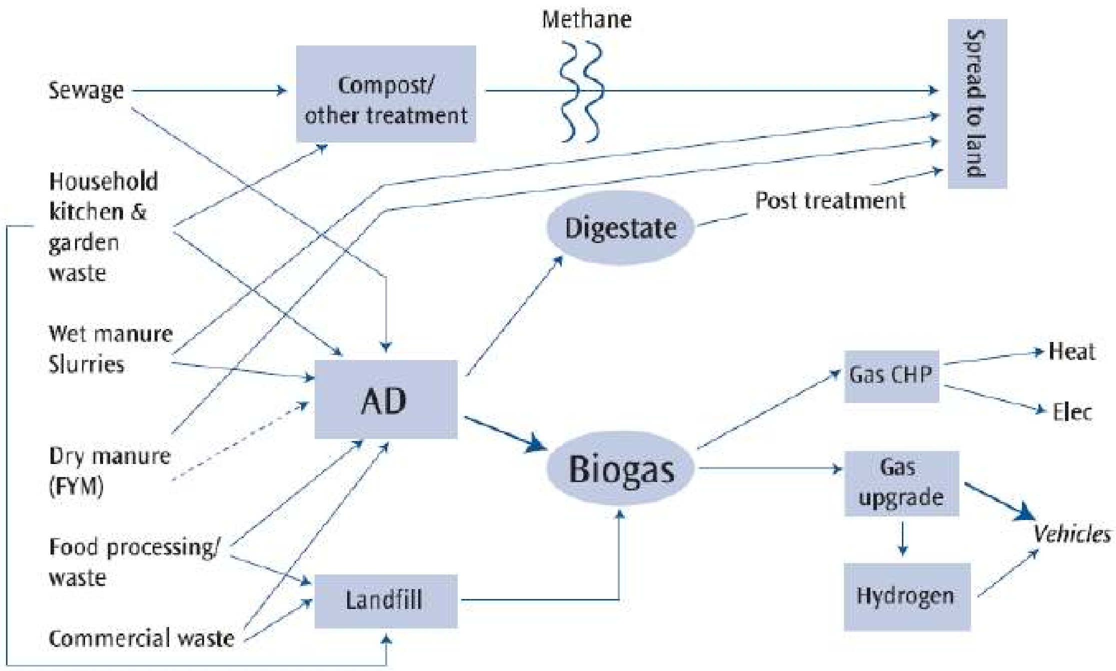

Figure 2-1 Biogas Route Map

Source: NSCA, 2006

Raw biogas produced from the controlled environment is typically composed of methane (50–80%), carbon dioxide (20–50%) and traces of other gases such as nitrogen and hydrogen sulphide (Lantz, Svensson, Björnsson, & Börjesson, 2007). The composition is largely influenced by the nature of different feedstocks as shown in the table 2-1 below (Swedish Gas Centre, 2007). Also, other factors including process design and level of production technology influence the composition. Usually LFG has the smallest methane content, because biogas generation from landfill sites is not optimized in the same way as in an anaerobic digester (Swedish Biogas Association et al., 2008). The composition can be different from country by country as well. Some countries also apply co-digestion, putting different substrates together into a digester in order to increase methane production. For example, in Sweden some co-digestion plants put slaughterhouse wastes together with sewage sludge and in South Korea some biogas production facilities put food waste water with livestock manure.

Table 2-1 Overview of content of the biogas produced at different types of plants

Component	**Entity**	**Centralised AD-plant**	**Sewage Waste Station**	**Landfill**
Methane, CH_4	Vol-%	60 - 70	55 – 65	45 – 55
Carbon dioxide, CO_2	Vol-%	30 – 40	35 – 45	30 – 40
Nitrogen, N_2	Vol-%	< 1	< 1	5 – 15
Dihydrogen sulphide, N_2S	ppm	10 - 2000	10 - 40	50 - 300

Source: Eriksson & Olsson, 2007

The volume of original substrate reduces after digestion because most of the carbon and energy content is given off as in methane and carbon dioxide. In fact, this was the main reason why anaerobic digestion technology was adopted in sewage water treatment plants. Yet, the organic matter is hardly fully decomposed during the digestion process. Thus, the end products are not only biogas but also bio manure, a nutrient-rich organic residue. This digestate can be utilized as bio-fertilizer since it provides humus and nutrients to the soil, especially favoured by organic agriculture. Furthermore, unlike fresh undigested manure, biomanure does not cause odor problems. However, the bio manure should be carefully checked whether it contains some contaminants before used as fertilizer. For example, dependent upon their sources, it is common that sewage sludge can contain higher amount of heavy metals than allowable limit values (Swedish Biogas Association et al., 2008). In Sweden, biomanure is generally spread over farmland. To ensure quality of biomanure – hygienic, high nutrient content, allowable contents of heavy metals and etc, Sweden established the Swedish certification system for biomanure (Swedish Biogas Association et al., 2008). In the beginning,

Various advantages and disadvantages of different substrates are described in the table 2-2 below based on Swedish context. Again, some of these characteristics might not be true in other countries, whereas some of them are quite universal.

Table 2-2 Advantages and disadvantages for each substrate

Sewage sludge		**Organic urban waste**	
Advantages	*Disadvantages*	*Advantages*	*Disadvantages*
Readily available	Difficulties in getting acceptance for the residue	from restaurants - easily available and high quality	Complicated and expensive pre-treatment
Existing plants	Limited to the sewage sludge production	Solution of waste problems	Household waste - difficult to quality ensure
Increased potential in process optimization		Low-cost substrate	Separation and collection – a barrier
Crops		**Manure**	
Advantages	*Disadvantages*	*Advantages*	*Disadvantages*
Large overall potential	Expensive substrate	Low-cost substrate	Low gas potential
No hygienization required	High water content in ley crops	Solution for odor problems	High water content
Low water content and high gas potential	Competition with food production	Income for the farmer	Wide spread – long transport distances
Cultivation of ley crops is favorable for the soil	Complicated input process for ley crops	Reduced methane leakage	

Source: Mårtensson, 2007

The amount of biogas is typically stated in Nm^3, a normal cubic meter, the metric expression of gas volume at standard conditions and it is generally defined as being measured at 0 °C and 1 atmosphere of pressure (273.15 K and 1.01325 bar) (Swedish Gas Centre, 2007) Methane is a primary constituent of fossil-fuel natural gas. If biogas is purified, it can be almost identical to natural gas. As a result, purified biogas can be mixed with natural gas and used in the same way (Swedish Biogas Association et al., 2008). In this research, a term 'biomethane' is used as a terminology to indicate the upgraded biogas, almost identical to natural gas. A typical energy content of methane is about 10 kWh (36 MJ) per normal cubic meter, whereas carbon dioxide has nothing. Therefore, the energy content of biogas is directly related to the methane content. Accordingly, if methane content is 60%, the energy content is about 6 kWh per normal cubic meter (Swedish Gas Centre, 2007)

2.2 Distribution and Usage of Biogas

Biogas can be distributed as in a gaseous form (CBG) or in a liquefied form (LBG) through pipelines, either separate or existing grid for natural gas, if it is upgraded (Lantz et al., 2007). Also, biogas can be transported by tank lorries. When biogas is upgraded and injected to the existing natural gas grid, the sale and marketing of biomethane is significantly supported, because the volumetric production of biogas can be unstable, if substrate supply is not constant. Thus, end-users do not bear the risk from the instability if they receive gas from the existing pipeline together with natural gas whose supply is generally stable. Furthermore, biomethane can be used in various ways once it is injected (Swedish Biogas Association et al., 2008). Lastly, without any further measures, the consumption of biomethane can be immediately increased when the production capacity is increased (Karlsson, 2008). Transferring in a liquid form usually decreases distribution cost significantly, because the energy per litre is concentrated 600 times by converting from a gaseous to liquid form compared with gas at atmospheric pressure, although it requires additional compression cost (Swedish Biogas Association et al., 2008).

The usage of biogas can vary. It can be used for diverse energy services such as heating, electricity generation, and vehicle fuel, although the last one essentially requires an upgrading process to make biogas almost identical to natural gas as mentioned earlier. LFG is typically collected and flared off before, but these days many landfills utilize generated biogas for heating or electricity generation (Swedish Biogas Association et al., 2008). Therefore, biogas technology provides environmentally-friendly and effective solutions to a society in various sectors such as organic waste management, transportation, renewable energy development, GHGs emissions reduction, biodiversity and etc. (Swedish Biogas Association et al., 2008).

Prior to combustion, only water vapour needs to be eliminated from the gas for heating purpose. In Sweden, if there is surplus heat after internal use, it is sometimes distributed farther to be utilized for district heating network (Swedish Biogas Association et al., 2008). If biogas cannot be used as fuel for vehicles, CHP (Combined Heat and Power plant) is probably most advanced end usage, producing both power and heat. In case of CHP utilization, approximately 30-40% of the energy content can be consumed as electricity and a portion of the remainder is potentially available as heat. It is very important to remove particulate matter and any corrosive substances in raw biogas before combustion (Swedish Biogas Association et al., 2008).

2.3 Biomethane as Vehicle Fuel

There are different types of biofuels from various feedstocks through a number of diverse processes. Generally, biodiesel and bioethanol are commonly used biofuels in the world. Biogas is the only type of biofuels produced from anaerobic digestion process. As discussed earlier, biogas should be upgraded in order to be utilized as a road transport fuel, that is, the removal of the carbon dioxide and other gases to increase the methane content, up to more than 97% in Swedish case. Then, the upgraded gas, biomethane, is almost identical to natural gas and thus it can be used as fuel for natural gas vehicles (NGVs). Although it is widely recognized that still gasoline and diesel are dominant fuels for vehicles in the world, there are 10 million vehicles running on natural gas in the world; 2 million in Pakistan, 1.8 million in Argentina, 1.6 in Brazil, 1.2 in Iran, 1.1 million in Europe (NGV Communications Group, 2009). Sweden and South Korea have a similar number of NGVs in use, 16,900 and 17,123 respectively. Therefore, using natural gas for vehicles is not uncommon and NGV industries are growing.

The upgrading process increases the heating value of the gas resulting in driving longer distance with a same volume. A consistent quality should be guaranteed from different types of biogas plants (Mårtensson, 2007), which means there is a need for the fuel standard. Currently a number of different upgrading technologies are adopted: mainly water scrubber technologies, chemical absorption, PSA (Pressure Swing Adsorption) and membrane separation (Mårtensson, 2007). Before distributed as CNG, biomethane has to be deodorized and pressurized up to 200 bars as well (Swedish Gas Centre, 2007). While the production technology of biogas has been used many countries, upgrading technology is a relatively recent technology area and has not been practiced widely in the world so far. However, the experience from Sweden and other countries has proven that it is feasible to do it "with high reliability and at reasonable cost" (NSCA, 2006).

There are a series of advantages of utilizing biomethane as a vehicle fuel compared to conventional fuels as shown in the Table 2-3 below. Many environmental and social benefits are listed. Also, Swedish Biogas Association, Swedish Gas Center and Swedish Gas Association (2008) clearly state that "biogas is the most environmentally-friendly vehicle fuel on the market today". Arguably, it might be true 'in Sweden'. However, it is very important, especially for South Korean readers, not to overlook the fact that these features can be wrong or significantly different, all depending on how biogas is produced, upgraded, distributed and used for what kind of vehicles in which countries from what kind of substrates. In addition, it is very critical to examine what fuel is substituted by biomethane in order to precisely calculate the overall environmental benefits of biomethane. Therefore, it is vital to take a life cycle analysis (LCA) approach in order to evaluate a comprehensive environmental performance of biomethane compared to other alternative fuels in order to make a decision for a specific case.

Table 2-3 Features of Biogas and Their Expected Benefits

Features of Biogas as a Vehicle Fuel	**Expected Benefits**
It is a locally produced fuel.	It contributes to securing energy supply of the country and promotes local development.
It is a renewable fuel.	There is no risk of future depletion.
The carbon content in biogas comes from nature's own photosynthesis.	It does not add net GHGs to the atmosphere.
The octane rating of methane is high.	Efficiency of engine is high.
Liquid digestate is produced as a byproduct.	It can be utilized as fertilizer.
The emissions of NOx, hydrocarbons and particles are much less than conventional fuels.	Less air pollution is generated.
It can be produced from various substrates. (sewage sludge, different organic wastes, energy crops, forest and agriculture residue, etc)	It reduces a country's dependency on imported energy. It contributes to more sustainable waste management and provides a chance to agriculture industry.
Biogas engine is less noisy compared to diesel and petrol engines.	It can be a significant advantage for inner city buses and trucks.
Gas fuel infrastructure is built.	It can serve for hydrogen gas in the future.
Biogas is released into the atmosphere in case of leakage because it is lighter than air.	It does not pollute land and groundwater.

Source: Eriksson & Olsson, 2007; Lantz et al., 2007; Mårtensson, 2007; Swedish Biogas Association et al., 2008

As NSCA (National Society for Clean Air and Environmental Protection) in the UK and other Swedish researchers pointed out in their analyses, these social and environmental benefits of biomethane as a vehicle fuel could be maximized when heavy duty vehicles running on diesel with long vehicle miles travelled are replaced by vehicles running on biomethane (Lantz et al., 2007; NSCA, 2006). Freight trucks and public buses are good examples of this application as they have been early targets for the development of biomethane for vehicle fuels in Sweden and a few other countries.

Detailed discussions on the benefits of biomethane as a vehicle fuel will be presented in the chapter 4 later. The figure below clearly shows the complexity of the biogas system has been discussed so far. As implied by the two separated pieces, how to utilize biogas all relies on where in the biogas process decision maker puts emphasis on.

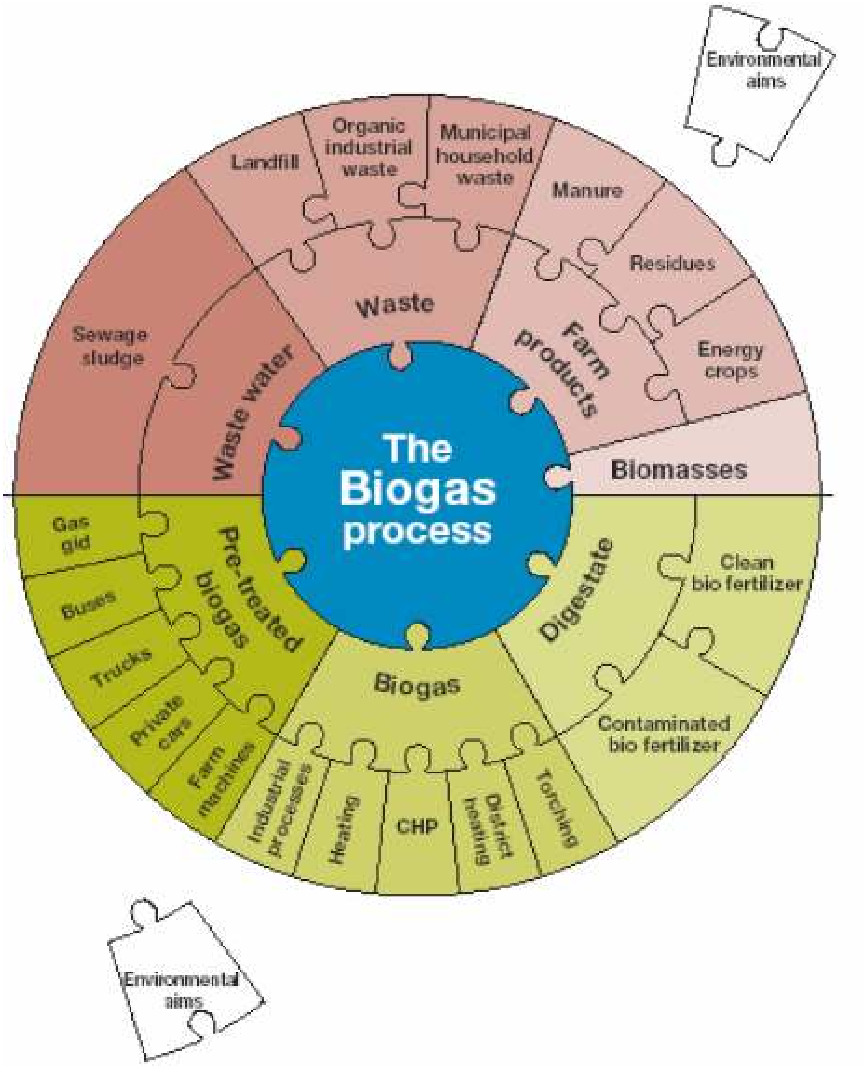

Figure 2-2 The Biogas Process

Source: Swedish Biogas Association et al., 2008

3 Biogas Experiences as a Vehicle Fuel from Sweden

Sweden is a country located on the Scandinavian Peninsula in Northern Europe with a population of 9.3 million inhabitants and with an area of 450,000 km^2. It is certainly one of the leading nations in the world in terms of its environmental performance as it was ranked at the second place in 2008 Environmental Performance Index among 149 nations (Yale University & Columbia University, 2008) and the first place in the Climate Change Performance Index 2008 among 56 countries in the world (Germanwatch, 2008) (cf. 51st for South Korea in both indexes). In correspondence with its superior environmental performance, Sweden has been excellent in gradually being independent from oil. Especially, the existence of the Commission on Oil Independence has attracted strong attention from other countries in the world.

Since the 1970's oil crisis, Sweden has invested greatly in the development of alternative energy sources. As a result of this, the share of oil in 2006 in total energy supply went down to 32% from 75% in 1970, largely thanks to the decreased demand for oil in residential heating sector (Swedish Institute, 2008). Now about 43% of the energy supply comes from renewable energies in Sweden, which is higher share than most EU member countries. Sweden is also very active in developing alternative renewable fuels such as mainly bioethanol and biogas. In case of the development of biogas for transport, Sweden has been not only developing it successfully, but also leading other countries over the last decade (Rutledge, 2004). Therefore, analyzing Swedish experience can provide valuable lessons for South Korea to explore opportunities of biogas as a vehicle fuel in order to reduce its dependency on oil, to protect environment and to achieve local development, even if the specific social, environmental, economic and political conditions of Sweden are not same as South Korea.

3.1 Biogas as a Vehicle Fuel in Europe

According to the extensive study from Eriksson and Olsson (2007) on the potential of biogas as a vehicle fuel in Europe, the biogas production in Europe was continuously growing between 2000 and 2005 and increased up to about 5 MTOE (million tonne of oil equivalent) in 2005. The UK and Germany are the two largest producers, respectively about 1.8 and 1.6 MTOE. Sweden was ranked at seventh with the production volume of 0.11 MTOE (Eriksson & Olsson, 2007). However, in respect of utilizing biogas as a vehicle fuel, Sweden is exclusively the leading country and Switzerland is catching up. The final usages of biogas in most other countries are heat and electricity production. Even though there are 1 million NGVs are running in Europe now, the situation, biogas is not widely utilized for vehicle fuels, has not significantly changed. The reason why Sweden chose such a different track compared to other European countries will be discussed later in this Chapter.

In the last couple of years, there were some positive changes for the future utilization of biogas in some of European countries. Initiating biogas as a vehicle fuel since 2003, Switzerland met 37% of the gas demand for vehicles in 2005 with biogas (Jönsson, 2006). At December 2008, it was reported that there were around 7,000 NGVs in Switzerland, mostly cars, and 112 refuelling stations were in operation (NGV Communications Group, 2009). Germany, as a country where the number of biogas plants notably increased from 120 in 1991 to 3,000 in 2005, has not been active in terms of utilizing biogas as a vehicle fuel. However, in 2006, German Gas Association set up a target to provide 20% of transport fuels from biogas by 2020 (Jönsson, 2006). Lastly, in 2006 the Austrian oil and gas company, OMV, came to an agreement to utilize biogas as a vehicle fuel and made their marketing concept for the new fuel composed of 20% biogas (Jönsson, 2006).

In accordance with these increasing interests on biogas as a road transport fuel, the European Union has been carrying out a project, Biogasmax, since 2006. The objective of the project is "to address urban challenges related to air and water pollution, as well as waste management" with the budget of 17 million € until 2009 (Biogasmax, n.d.; Svensén, 2007). To meet the objective, it focuses on the production and utilization of biogas as a vehicle fuel. As show in the figure 3-1 below, 28 public and private partners from 8 countries in Europe are participating in the project with different specific tasks, e.g. six sites from four countries: Stockholm and Göteborg (Sweden), Lille(France), Torun and Zielona Góra (Poland), and Rome and Bern (Italy). More information about the Biogasmax project can be found at www.biogasmax.eu. The Biogasmax Final Conference on Biomethane will be held from 7 to 9 September at Göteborg, Sweden.

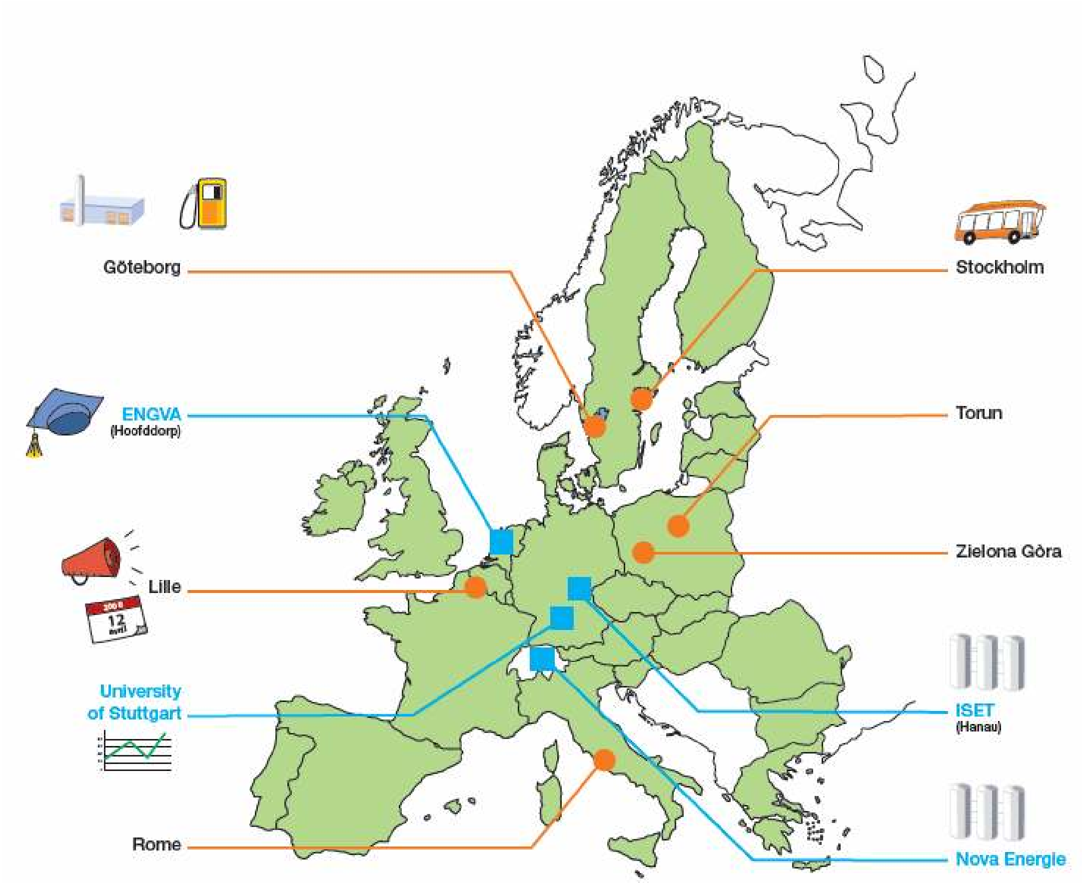

Figure 3-1 Biogasmax Main Partners in Europe

Source: Biogasmax, n.d.

There have been several studies on the potential of biogas as a vehicle fuel in Europe. Eriksson and Olsson (2007) concluded that based on three different scenarios the biogas production in 2015 would account for 9% to 60% of the total heavy duty vehicle diesel consumption in five European countries: Sweden, Denmark, Germany, the UK and France. Svensén (2008) also predicted that 25-35% of fossil fuels in transport sector in Europe could be replaced by biomethane by 2030 in the consideration of the facts that 1.4 million kilometres of natural gas grid, a wide range of biomass feedstock and high efficient production both from digestion and gasification, 600,000 NGVs and 2,000 existing stations; 1 million NGVs and 3,000 stations now (NGV Communications Group, 2009).

3.2 Present

In Sweden 2007, about 130 TWh of energy were used for transport: 96 TWh for domestic transport and 34 TWh for foreign transport. With no doubt, the demand was mainly covered petrol and diesel fuels, accounting for about 89% of the domestic transport energy requirement. Renewable vehicle fuels accounted for about 4% of the energy use for road transport (Swedish Energy Agency, 2008a). To any major extent, there are three renewable fuels for vehicles in Sweden such as bioethanol, FAME (Fatty Acid Methyl Esters) and biogas (Swedish Energy Agency, 2008b). As shown in the figure 3-2 below, biogas has been a part of renewable motor fuels in Sweden and the absolute amount has been increasing.

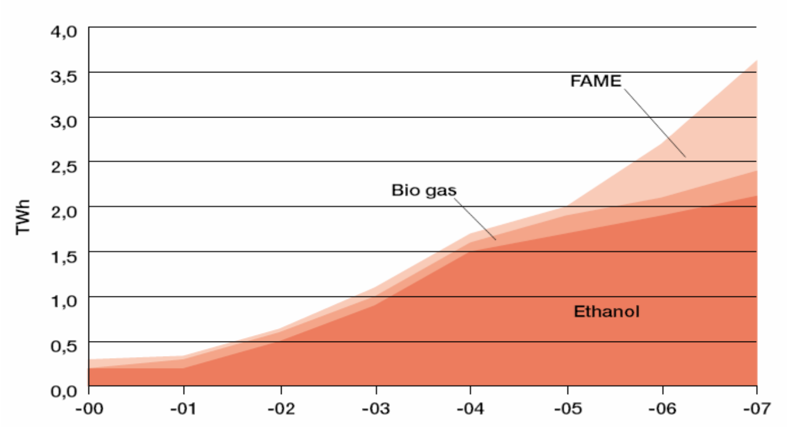

Figure 3-2 Final Energy Use of Renewable Motor Fuels

Source: Swedish Energy Agency, 2008a

As shown in the table 3-1, 1.3 TWh of biogas was produced at 233 different crude biogas production facilities in 2005, Sweden (Swedish Gas Centre, 2007). The largest share of the production comes from municipal sewage treatment plants, which makes Sweden very unique compared to most other European countries where the share of sewage purification plants in biogas production is not dominant (Eriksson & Olsson, 2007). Landfill sites also account for the second largest share of the total production, even though the amount of gas produced from landfills have notably decreased since 2002 and will be decreased due to the national ban on landfilling organic waste in 2005 (Eriksson & Olsson, 2007). Centralized co-digestion plants using manures, household and industry organic wastes, and ley[2] crops together have been growing recently (Eriksson & Olsson, 2007). Lastly, a small amount of raw biogas is produced from farm scale plants and industrial wastewater treatment plants.

[2] Annual or short-period perennial grass crops, typically for grazing.

Table 3-1 Production and Use of Biogas in 2005, Sweden

Biogas plants	Number	Energy in biogas (TWh/year)
Municipal sewage treatment plants	139	0.56
Landfills	70	0.46
Industrial wastewater	4	0.09
Co-digestion plants	13	0.16
Farm plants	7	0.01
Total	233	1.3 TWh

Source: Swedish Gas Centre, 2007

The biogas produced from these facilities is used not only for vehicles but also for heating and power generation. Some of them are flared off as well. The biogas used for vehicles is mostly produced at co-digestions plants as well as sewage treatments plants. Biogas produced at landfill sites is mainly utilized to produce heat (Eriksson & Olsson, 2007).

As discussed in the chapter 2, the biogas used for vehicles needs to be upgraded up to about 97% of methane according to the Swedish standard (see Appendix 1). There are about 31 upgrading plants running in Sweden (Held, 2006). Two major upgrading technologies used in Sweden are water scrubber and PSA technologies. After being upgraded, the biogas is injected to the existing natural gas pipeline grid in some of the cities in the western part of Sweden. In the other parts of Sweden where there is no existing natural gas pipeline, biogas is distributed by independent pipelines or trailers. The Swedish natural gas grid is currently installed from Malmö to Stenungsund (Swedish Biogas Association et al., 2008).

According to the statistics from Swedish Energy Agency, in 2007, Sweden imported 954 million Nm^3 of natural gas, equivalent to 10.5 TWh (Swedish Energy Agency, 2008a). User sectors including industry, residential sector and transportation fuel consume 7.4 TWh and the rest used for CHP and district heating plants (Swedish Energy Agency, 2008a). A share of the motor fuel sector was about 2.6% or 25 million Nm^3.

In Sweden, vehicles running on gas typically have two tank systems – one for petrol and the other for gas, known as bi-fuel cars. The gas is either imported natural gas, upgraded biogas, or any mixture of the two gases (Swedish Energy Agency, 2008b). As shown in the figure 3-3 below, including both natural gas and upgraded biogas, amount of gas used for NGVs has been constantly increasing since 1995 and reached about 54 million Nm^3 in 2007. Out of the total gas consumed for vehicles, approximately 28 million Nm^3 was biogas, 19% of the total biogas production (EurObserver, 2008). The year 2006 was a significant year for the development of biogas as a transport fuel in Sweden, because the amount of biogas used for vehicles surpassed that of natural gas in 2006 for the first time. Since then more than 50% of the total gas used for NGVs in Sweden has been compressed biogas (CBG).

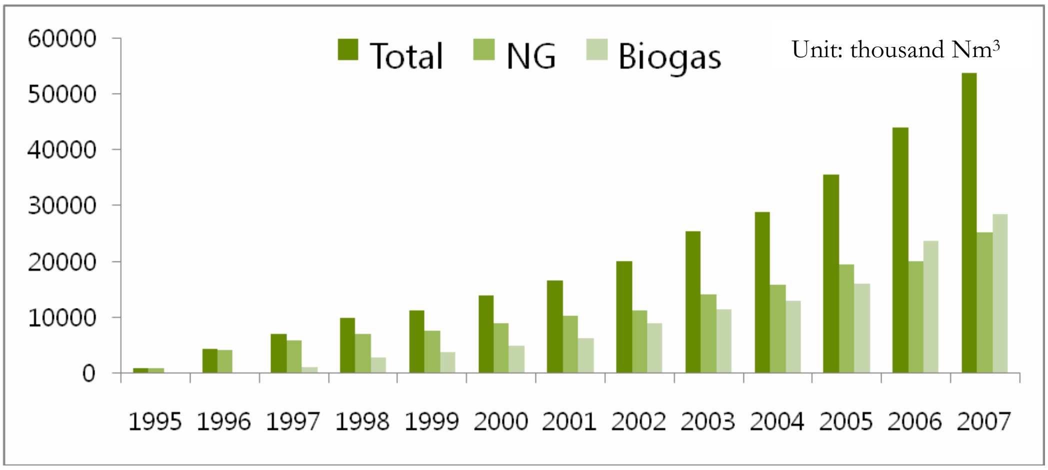

Figure 3-3 Delivered Volumes of CNG and CBG for Vehicles

Data Source: Swedish Gas Association

In line with the increasing volume of CNG/CBG, numbers of the NGVs and the refuelling infrastructure in Sweden also have been steadily increasing as shown in the figure 3-4 below. Biogas is being used both in light-duty and heavy-duty vehicles in Sweden. According to the latest GVR report in April 2009, there are 16,900 NGVs in Sweden: 15,650 cars, 850 buses and 400 trucks (NGV Communications Group, 2009). As of 2008, 15 models of light duties, 15 models of passenger cars, several modes of buses were available to consumers, manufactured by Iveco, FIAT, Ford, Mercedes, VW, Volvo, Citroën, Opel, Peugeot, Ekobus, Irisbus and MAN (Svensén, 2008).

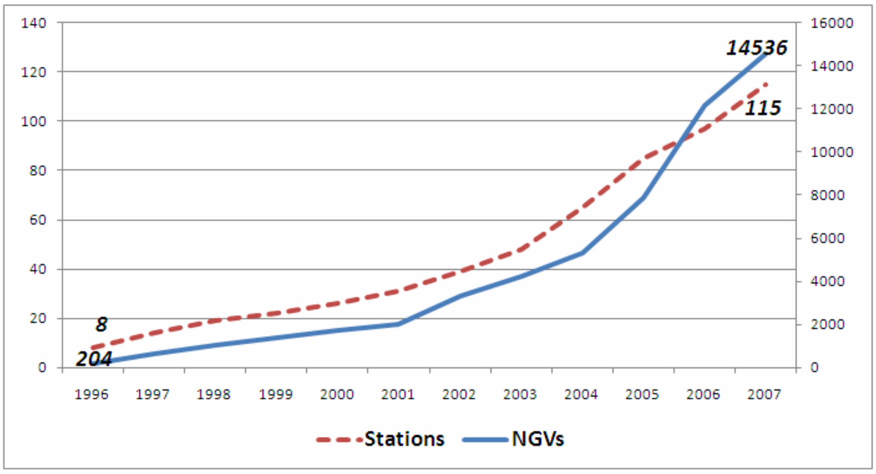

Figure 3-4 Numbers of NGVs and Refuelling Stations in Sweden

Source: NGV Communications Group, 2009

These vehicles can be refuelled at public or private stations: 92 and 30 respectively (GVR, 2008). The public stations are mainly for passenger cars. More than half of the public stations provides only biogas (Swedish Energy Agency, 2008b), because the natural gas grid is installed only in the southwestern part of Sweden as explained earlier. The private stations are mainly for bus fleets in major cities. In 2008, 19 cities had bus fleets running on gas and 15 of them solely depends on only biogas (Boisen, 2008). The successful expansion of the refuelling network was cooperatively led by four different distributor organizations in Sweden: E.ON Gas Sweden in southern part, Fordonsgas Sverige AB in western part, Svensk Biogas AB in eastern/central part and finally AGA Gas in the Stockholm area. They have two common targets, 400 stations in total and increase of the sales in gaseous fuel up to around 2-300 million Nm^3 by 2014 (Boisen, 2008). Boisen (2008) argued that the achievement of the targets will be mainly influenced by the rate of installation of new production capacity of biogas (Boisen, 2008).

3.3 Historical Development

This chapter will provide the reader with the necessary information to understand the historical development of biogas as a vehicle fuel in Sweden. Sandén and Jonasson (2005) explained the history of alternative fuels development in Sweden from 1974 to 2004 with main focus on "the effects of shifts in the relative strength of three external landscape forces": the oil crisis, air pollution, and climate change (Sandén & Jonasson, 2005). The each factor was a main driving force for the development of alternative fuels in Sweden in 1974-1985, 1986-1997 and 1998-2004 respectively as shown in the figure 3-5. To briefly introduce the historical development of biogas as a road transport fuel in Sweden, this chapter basically will follow the analysis of Sandén and Jonasson. Also, an MSc thesis from Savola (2006) on 'Biogas systems in Finland and Sweden - Impact of government policies on the diffusion of anaerobic digestion technology' will be used as a main reference. Those readers who wish to know more of this in detail are recommended to read the two original sources.

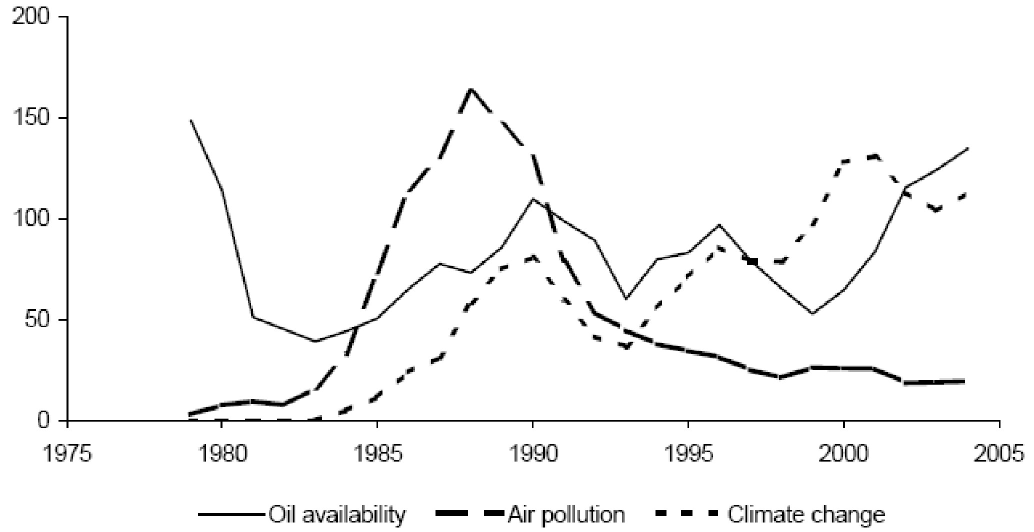

Figure 3-5 Articles in Swedish newspapers (weighted with total number of articles in the database each year, the weight for 2004=1)

Source: Sandén & Jonasson, 2005

First term: 1974-1985 – oil availability

In the first term, from 1974 to 1985, there was no significant progress in biogas development as a vehicle fuel. Though anaerobic digestion (AD) technology appeared first in 1960s, it was mainly used as a technology to reduce the volume of sewage sludge in municipal waste water treatment plants (WWTP). Then, the 1970's oil crisis resulted in the research and development of biogas technologies. Anaerobic technology was further implemented in waste water treatment in different industries and biogas plants using manure from farms appeared.

Second term: 1986-1997 – local air quality

During the 1980s the public concern on local air quality was increased and became the key motivation for alternative and clean fuels (Sandén & Jonasson, 2005). Municipal buses got earlier attention first. Since the bus companies were municipally owned, they provided a favourable environment for testing alternative fuels and technical managers tried experiments and discussed the results regularly with the Swedish Public Transport Association (Sandén & Jonasson, 2005).

The emergence of biogas as a fuel was closely linked to the provision of natural gas from the very beginning (Sandén & Jonasson, 2005). Natural gas was introduced to Sweden first in 1985 through a pipeline from Denmark to Malmö. Then, Malmö Energy company provided an idea to Malmö Transit Authority (Malmö Lokaltrafik, ML) to use natural as fuel for buses. Since the city wanted to improve the air quality, ML decided to modify two LPG buses into CNG buses and finally the fist CNG buses were in operation in 1988 in Malmö, Sweden (Sandén & Jonasson, 2005). In late 1980s, because it was generally believed that the pipeline would be extended from Göteborg to Stockholm, several cities such as Stockholm, Linköping and Trollhättan prepared to introduce CNG buses as a temporary measure until the expected pipeline extension (Sandén & Jonasson, 2005). The existing NGV technology made easier to introduce biogas running buses. However, due to the political decision of not extending natural gas pipelines in 1991, these cities decided to keep going for biogas. In 1996, Linköping decided to increase the utilization scale of biogas and Uppsala introduced biogas bus as well. In 1997, as a result, 49 buses running on biogas were in operation in Trollhättan, Linköping, and Uppsala when the total number of CNG buses in Sweden were 178 (Sandén & Jonasson, 2005). Thus, as Sandén & Jonasson (2005) argued, ironically, biogas got its first step from the expectation on future introduction of the natural gas pipeline and got more support from the withdrawal of the pipeline.

In 1990s, climate change gradually gained social and political attention and finally became a primary concern after the 1995, which stimulated discussion on renewable fuels at the national political level (Sandén & Jonasson, 2005). Finally, a report from a parliamentary commission set a target, an introduction of 10-15% alternative fuels in 2010, and recommended carbon dioxide and energy tax exemption for renewable fuels (Sandén & Jonasson, 2005).

Third term: 1998-2004 - climate change

Influenced by increasing concern on global warming, the new Swedish Prime Minister, Göran Persson, suggested a new national vision, Sweden as a leading 'green country' in 1996 in his inaugural speech. Furthermore, soaring oil prices in 1998 stimulated Swedish society to come up with "the idea of a grand transition to a sustainable transport system" (Sandén & Jonasson, 2005). As a result of this, several tax benefits and legislation supports provided for the development of biogas as vehicle fuel in this period. In line with the social interest, the three largest cities Stockholm, Göteborg and Malmö took the lead in developing a market for environmental cars. In late 1990s and early 2000s, many biogas projects on production, upgrading, distribution and vehicles got great financial supports from 'Local Investment Programme' (LIP) and 'Climate Investment Programme' (KLIMP). In addition, the EU directive on renewable vehicle fuels, 2% and 5.75% by 2005 and 2010, supported the promotion of biogas as a vehicle fuel in Sweden.

3.4 Future

Recently, there has been a number of positive news for the development of biogas as a road transport fuel. A new technology, gasification of cellulose waste from the forest industry, is being tested in Göteborg (Boisen, 2008; Göteborg Energi, 2008). In 2009, a new important scheme has been launched by the Swedish government to support a creation of a few co-operatives composed of around 20 farms for each. Once the farms produce raw biogas from livestock manure, the gas is gathered into a common upgrading plant through pipeline and then upgraded for vehicle fuels. The project will be completed by 2014 and financial support from the government is about 600 million SEK (about €64 million) (Boisen, 2008). There are also a number of projects going on for the introduction of heavy duty vehicles using dual-fuel engines with LNG and LNG distribution network for long-distance running heavy duty vehicles (Boisen, 2008). Finally, brand-new NGV models are attracting consumers. Although Volvo withdrew its Volvo S80/V70/S60 Bi-Fuel models in 2006, a huge blow to NGV and biogas industries in Sweden (Svensén & Larsson, 2008), new models such as MB B-class, new Volkswagen Passat Eco Fuel, and Opel Zafira were added to the market recently (Boisen, 2008).

The theoretical potential of biogas production in Sweden has been estimated in different studies. Linné and Jönsson estimated that annually 14 TWh can be produced mainly from cultivated crops, manure, food wastes, and sludge from sewage treatment plants (Linné & Jönsson, 2004). Also, Swedish Gas Centre reported that 92 TWh can be produced from the gasification of forest residues (Held, 2006). Most recently, the Associations for Gas, Waste Management and Water recalculated previous estimates of the potential for biogas: 10,6TWh from waste and 59TWh from forestry waste (Zinn, 2008). Assuming that total energy needed for road transport in Sweden is 100TWh, around 10 to 90% of the total energy for transport in Sweden could be covered by biogas theoretically. With these theoretical potentials, people in Biogas industry expect to increase the share of biogas in fuel consumption from current 1% to around 5 to 20% by 2020 (Rutledge, 2004; Undén, 2008). Lastly, Eriksson and Olsson (2007) forecasted the Swedish biogas production, as well as other European countries, based on three scenarios: 1) planned projects, 2) catching-up, and 3) feed-in tariff. In the first scenario, the prediction was based on biogas plants that were under construction in 2007 or for which decisions for construction had been made. The second one was based on the assumption that countries in Europe have about the same potentials for producing biogas per inhabitant according to the Biogas Barometer's statistics. The last scenario was based on the assumption that the countries would introduce a feed-in tariff system similar to the one in Germany to promote biogas as a renewable energy. The result of the forecast is shown in the table 3-2 below. The production level can be increased by 21 to 422% and be able to provide fuel for 10 to 41% of the heavy duty vehicles in Sweden based on the assumption that all biogas produced is used for heavy transportation in 2015. Therefore, as all these predictions showed, the biogas fuel market in Sweden still has a significant potential to continue its growth.

Table 3-2 Forecast of Swedish Biogas Production in 2015

Type of Measure	Production in 2005	Planned Projects	Catching Up	Feed-In Tariff
Production (ktoe)	116	140	173	605
Increase		21%	49%	422%
Share in heavy transport	8%	10%	12%	41%

Data Source: Eriksson & Olsson, 2007

3.5 Key Factors to Success

Josephine Bahr Ljungdell from International Secretariat in Swedish Energy Agency said that the successful utilization of biogas as a vehicle fuel in Sweden is the fruits from more than 30-year continuous national effort to find alternatives to oil right after the 1970's oil crisis (Ryu, 2009b). Therefore, it is difficult to generalize which factors have been key factors in the long development period and how it precisely influenced the development. However, since there are few examples of countries actively utilizing biogas as a fuel for transportation, it is meaningful for South Korea to recognize some of the major factors based on a number of literatures.

The National Society for Clean Air and Environmental Protection (NSCA) in the UK pointed out in its study that the development of biogas in Sweden as a road transport fuel was possible to be initiated in the beginning mainly due to surplus of biogas and a low electricity price which provided low economic incentives for electricity generation (NSCA, 2006). The surplus was the outcome from the motivation of stabilizing sludge and reducing its volume in municipal sewage treatment plants (Lantz et al., 2007) and the low electricity price was primarily owing to the large share of hydro and nuclear power in electricity production. Regarding the low electricity price, it is interesting to compare Sweden with Germany. In Germany, a country with the largest volume of raw biogas production in Europe, one of the major reasons why the development of biogas is exclusively focused on electricity generation is due to a well established feed-in tariff system for electricity production from renewable sources. Unlike from Germany, Sweden implemented a green certificate system which did not provide strong economic incentives for electricity generation with biogas (Jönsson and Persson, 2003).

3.5.1 International, regional and national goals

First of all, the development of the biogas system in Sweden was significantly supported by the various ambitious international, regional and national goals and initiatives regarding energy, environmental and sustainability issues (Lantz et al., 2007). On the international level, the Kyoto Protocol set a GHGs emissions reduction target for Sweden. On the EU level, 5.75% of biofuels in 2010, 10% of biofuels in 2020, and 20% of the total energy from renewable source in 2020 created a favourable environmental for the development of biogas fuel (Mårtensson, 2007). On the state level, the Swedish parliament has 15 national environmental quality objectives. The introduction of biogas system is positively affected by many of these objectives (Lantz et al., 2007). Guidelines proposed by the Commission on Oil Independence (Commission on Oil Independence, 2006) also encouraged biogas development (Persson, 2006). One of the non-binding targets is the reduction in the use of petrol and diesel by 40-50% by 2020. Lastly, there is a target to biologically treat 35% of the municipal organic waste by 2010.

3.5.2 Governmental financial supports

Different forms of governmental financial support were also critical to the biogas fuel development. The government has invested a lot of money into the biogas fuel industry. In the period of 1993 and 1997, 315 MSEK in total was invested to RD&D of the use of alternative fuels and vehicles in Sweden by the Communication Research Agency (Kommunikations Forsknings Beredningen, KFB) and other stakeholders. Out of the total, 150 MSEK, almost a half, was spent for biogas; 30 from KFB and 120 from the stakeholders respectively (Sandén & Jonasson, 2005). In addition, as discussed earlier, investment support for biogas facilities including both for production and upgrading has been provided in the form of either LIP or KLIMP. The local investment programme (LIP) provided 6.2 billion SEK to municipalities for their green projects. It usually covered about 30% of the investment costs. Out of the total, approximately 250 MSEK was spent for clean vehicles and renewable fuel production (Sandén & Jonasson, 2005). The climate investment programme (KLIMP) was launched in 2003. It received applications for grants from local authorities and other parties planning a project to reduce GHGs emissions or contribute to energy savings. The Swedish Environment Protection Agency was a main operator of the program. The program provided SEK 481 million in 2003 to 31 programmes (Swedish Energy Agency, 2008a). The main evaluation criterion is how effective a program contributes to GHGs emission reductions in terms of the amount of grant. In 2007, the new VINNOVA report concluded that biogas project were the most effective among different KLIMP recipients (Zinn, 2008). The last decisions on KLIMP investments were taken in May 2008. The government will not provide any more funds for this kind of program in the future. A new system for investment support will come up sooner or later (Swedish Biogas Association et al., 2008). These two programs covered around 30% of investment costs in biogas production and upgrading facilities and a number of municipalities received subsidies from the programs when they purchase biogas vehicles for municipal purpose (Ekman, 2007). The construction of necessary infrastructure including upgrading and distribution facilities is relatively very costly investment. Thus, it was clearly stated in the latest report jointly produced by the Swedish Biogas Association, Swedish Gas Center, and Swedish Gas Association that "without being ensured its financial viability by the central governmental grants in the form of LIP and KLIMP, it would have been impossible to develop biogas as a vehicle fuel in Sweden up to the current level" (Swedish Biogas Association et al., 2008).

3.5.3 Economic incentives

Different government and municipality policies provided economic incentives for biogas fuel consumers. Energy taxation including energy, sulphur and carbon dioxide taxes might be the most important one to be mentioned. It is one of the major economic incentives in Sweden to meet various political targets in the field of energy and climate policy. Though the initial rationale of energy taxation was mainly fiscal, it functions as a key economic policy to increase energy efficiency and to develop renewable energies in Sweden now (Swedish Biogas Association et al., 2008). Different rates are used for different fuels, depending on their emission level and how they are used. In case of fuels for vehicles, the prices of gasoline and diesel contain carbon dioxide and energy taxes, whereas biogas and other renewable vehicle fuels are generally exempted from energy taxes until 2013 and from the carbon tax as well. This governmental tax policy has kept the price of CNG/Biogas 20-30% less expensive than those of gasoline and diesel. Furthermore, biogas car owners receive several financial advantages (Petersson, 2008; Swedish Biogas Association et al., 2008). Firstly, private individuals receive subsidy of 10,000 SEK (around 1100 €) from the government when they buy biogas cars. If a company purchase biogas vehicles, the value of the car for taxation is set at 60% of that for petrol-driven cars. Secondly, drivers of eco cars including biogas cars are free from paying the congestion charge in Stockholm and parking fees in many cities in Sweden.

3.5.4 Legislative policies

Different forms of legislative policies also effectively promoted the development of biogas as a vehicle fuel. To provide accessibility for clean car drivers and to support the expansion of biofuel market, a new law so called the Pumps Act was introduced in April 2006. Initially, the act required all petrol stations annually supplying more than 3000 m^3 of petrol or diesel fuel must provide at least one renewable fuel as well. The first response from the stations was exclusive installation of E85 pumps. Then, the state provided grants to encourage petrol stations to sell non-ethanol renewable fuels. As a result, biogas industry got the most benefit from the grant; 61 additional biogas pumps were installed in Sweden, as of February 2008 (Swedish Energy Agency, 2008a). Also, the act tightened the sales volume criterion later by 1000 m^3, which is expected to cover around 60% of all filling stations by 2010 (Swedish Energy Agency, 2008b). Furthermore, government procurement policy ensures that 75% of governmental fleet is covered by clean cars. Also, many local municipalities adopted similar procurement policies up to 100% in order to support the initial market formation of biofuel industries (Ekman, 2007).

3.5.5 Other factors

Very high level of cooperation in agriculture, waste industries, biogas industries, gas distribution, transit authorities, regional energy providers and vehicle manufacturers has been very crucial to the success as well (Rutledge, 2004). The Biogas West program in Göteborg is an excellent exemplary case to show how all these different actors have been fruitfully coordinated The provision of bi-fuel vehicles in NGV market was very favourable to the development. Since, it is bi-fuel, running on gasoline or gas, drivers does not bear disadvantages of relatively insufficient refuelling stations of biogas and can choose gasoline or gas based on their relative prices. The bi-fuel vehicles do not significantly compromise their functionality and performance as well (Rutledge, 2004). It is definitely one of the reasons for the expansion of biogas fuel market in Sweden. An only-gas vehicles strategy would not have resulted in similar development of the market. Finally, a strategic focus on transit buses was very effective as well. Due to very long daily travel distance and fixed routes, the buses have been 'anchor customers' (Rutledge, 2004) for biomethane providers in Sweden.

3.6 Legitimation of Biogas Fuel in Sweden

From the continuous economic and legislative government supports founded on its commitment to reduce GHGs emission, air pollution and the use of fossil fuels has resulted in gradual enhancement of the legitimacy on biogas technology system as a vehicle fuel in Sweden. Also, the legitimation process of biogas fuel was supported from the development of other types of renewable fuels in Sweden. As discussed earlier, the attention and development of ethanol brought significant advantages for biogas in terms of R&D, economic and legislative supports. Initial electric vehicle projects in Stockholm and

Göteborg also left a gift for other renewable fuels including biogas. Even though the projects ended as total failures, at least they contributed to the establishment of new organizations supporting the development of new vehicles and fuels; the Environmental Vehicles in Stockholm and a similar organization in Göteborg (Sandén & Jonasson, 2005). These organization continued experiments on various types of fuels and vehicles, which benefited the emergence of NGV and biogas technology as well.

Furthermore, the increased number of actors and activities improved the legitimacy of biogas as a vehicle fuel. As discussed in the historical development, local municipalities, waste management companies and bus companies took very significant roles in the formative period of the development. They initiated the biogas projects and conducted demonstration projects together. Biogas was an attractive option for municipalities since they could simultaneously manage major municipality issues, waste management, local air quality and GHGs emission later. Sandén & Jonasson (2005) analyzed that it was possible to effectively create cooperation among different actors involved in local biogas projects, because in Sweden waste management and bus companies were just different parts of the same municipal administration. The successful demonstration projects not only improved the knowledge and technology but also, more importantly, created "dedicated actors and networks" (Sandén & Jonasson, 2005). Later, in early 1990s when bus companies became privatized and unfavourable for technical experiments due to cost minimization, these dedicated actors including project leaders and technical experts left municipalities and became knowledge distributors and strong advocates of renewable fuels they had developed (Sandén & Jonasson, 2005).

4 Biogas Opportunities as a Vehicle Fuel in South Korea

4.1 Background

Biogas was utilized in early 1970s for cooking in rural areas in S. Korea (K. M. Kim, 2008). Then, in 1990s, anaerobic digestion technology was imported and introduced to some of livestock and other industries with government initiatives. Due to the lack of human resource and know-how of operation, deficient technology system, and insufficient policy supports, this first trial to utilize biogas from anaerobic technology in a large commercial scale was considered as a total failure (K. M. Kim, 2009). However, since the banning the direct landfill of sewage sludge in 2003 and food waste in 2005, the interest in anaerobic digestion has been increasing due to its effectiveness of reducing, reusing and stabilizing the waste as well as producing methane which can be used as a renewable energy source (Heo, 2005).

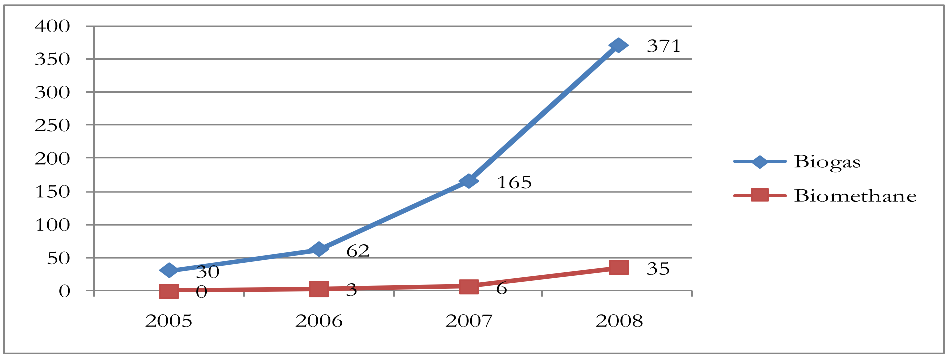

Figure 4-1 Search Result with Keywords, 'Biogas' and 'Biomethane'

Based on a news search using a media portal service provided by Korea Press Foundation, the number of newspaper articles with the key words 'biogas' and 'biomethane' are shown in the figure 4-1 above. The number of the articles mentioning biogas and biomethane significantly increased every year. Another search from January 1 to January 24 2009 shows that already 37 and 3 articles produced with the same keywords respectively. Therefore, even though these numbers are absolute figures, not compared with the total number of newspaper articles in each year, the result might be interpreted that social interest in biogas has been increasing during the last a few years in South Korea. From some of the articles, it is found that five provinces and 9 cities including Seoul are planning to utilize biogas for power generation, heating and vehicle fuel (see Appendix 2 for more details). There are three projects going on for vehicle fuel; one in Seoul, another one in Wonju city in Gangwon Province, and the last one in Ulsan city. All three projects have signed MoUs with Swedish companies. These three projects are the first attempts utilizing biogas as a commercial vehicle fuel.

There are several reasons why some municipalities are interested in biogas for transport rather than other end-uses. Firstly, economically it might be more profitable. In general, the retail prices of electricity for industry and households in South Korea are relatively lower compared to other OECD countries (IEA, 2007). Also, compared to PV and wind, the rate for biogas in feed-in-tariff system is much lower. A research estimated that the retail price of biomethane as a vehicle fuel produced from food waste water can be 60-80% more profitable than electricity generation with the current feed-in-tariff system (K. D. Kim & Son, 2007). Also, another research by Jin and Jo concluded from their cost benefit analysis of bio-energy projects for electricity generation in Korea that the economic feasibility of the projects is not high (Jin & Jo, 2008). However, they added that if the price of kerosene becomes doubled and the price of carbon credit increases, the projects become economically feasible. Furthermore, based on the research of Ki-Dong Kim from Korea Gas Corporation, they recommended that if biogas is used as a vehicle fuel, the operating profit will be much higher (100 won/m^3) than electricity generation (6.15 won/m^3). Secondly, environmentally it might be a better option. As discussed earlier, use of biogas as a vehicle fuel after upgrading can reduce not only GHGs, but also other air pollutants which cannot be achieved from other end-uses. In 2004, Daejeon Metropolitan City Development Authority conducted a pilot project of utilizing biogas produced from Geumgo landfill site as a vehicle fuel in Daejeon. Upgraded biogas (96% of methane) was produced 60 cubic meters per hour and three modified garbage trucks ran on the gas. As a result, the performance was equal to CNG and the trucks exhausted 9.4% less CO, 30% and less NMHC(non-methane hydrocarbons) compared to when they ran on diesel (J. Y. Kim et al., 2005). Finally, biogas as a vehicle fuel can bring other benefits. It provides less noise from heavy duty vehicles, more efficient use of energy, less dangerous in case of accident, and one step forward to hydrogen economy.

4.2 Situation of Organic Waste in South Korea

Due to the large population and small land, population density in South Korea is the 3rd highest in the world. Especially, the Seoul National Capital Area, the 4th largest urban area in the world, has 46% of the total South Korean population and vehicles; 24.5 million people with 7 million vehicles. Rapid urbanization and industrialization by economic growth caused environmental pollution and finally South Korea came to have the highest environmental load among OECD member countries (ME, 2008a). From the waste point of view, although municipal waste per person has become reduced to the similar level of developed countries, municipal waste per land is still very large. Thus, there is a need to manage a great amount of waste to protect environment. In other words, from a biogas technology point of view, there is a great potential of organic resource to be utilized as energy. Among different types of waste, three types of organic waste such as sewage sludge, livestock manure and food waste are highly potential feedstocks for the anaerobic digestion.

4.2.1 Sewage Sludge

The sewage distribution rate in 2007 in South Korea was about 87.1% (cf. Sweden 85%). According to the Sewage Sludge Management Plan, released in June 2008 by the Ministry of Environment (ME, 2008c), approximately 7,631 tonnes of sewage sludge (SS) is generated daily from 347 sewage water treatment facilities as of December 2007 and the amount is expected to increase up to about 10,259 tonnes by 2011 from 460 sites; a little more than 30% increase in both amount and number of facilities. The generated sludge is treated by four different methods as shown in the table 4-1 below. Ocean dumping is a dominant way followed by recycle and incineration. Since it was banned to directly landfill sewage sludge in July 2003, the cheapest way, ocean dumping, has been a main method of sewage sludge management. However, due to the strengthening international regulation on ocean discharge and increasing environmental concern of the ocean dumping on ocean ecosystem and human health, the need to establish inland management system of sewage sludge had been growing and finally the government established the new plan for the resourcization of sewage sludge (ME, 2008c).

Table 4-1 Sewage Sludge Management in South Korea

Year	Total (tonne)	Ocean Dumping	Recycling	Incineration	Landfill
2005	7,052	77.0%	11.0%	11.0%	1.0%
2006	7,446	71.2%	15.3%	12.5%	0.9%
2007	7,631	**68.5%**	**18.5%**	10.9%	2.1%
↓	↓	↓	↓	↓	↓
2011	10,259	**0.0%**	**69.5%**	29.0%	1.5%

Data Source: ME, 2008; MKE, 2007b

The new plan puts a priority on the reduction followed by recycling, incineration and landfill in order. Thus, with the improvement of the sludge digestion facilities and technology development, the first step will be increasing efficiency of the anaerobic digestion process to reduce the volume of sewage sludge. Simultaneously, it aims to increase the recycling rate of sludge. Main aim is on the utilization of sludge as energy. To achieve the aim, it sets a strong target to dramatically reduce the share of ocean dumping in sewage sludge management from current 68.5% to 0% by 2011 through building additional 52 recycling and 16 incineration facilities with the total budget of 588 billion won; about 50% each from the budget of central and local governments. With this plan, it is expected that about 70% of the generated sewage sludge will be recycled as landfill cover material, solid fuel, raw material for cement production and compost, depending on the location of treatment facilities.

Table 4-2 Biogas Production Facilities in Sewage Treatment Plant

Treatment Capacity (1,000 m^3 / day)	Total	<10	10-50	50-100	100-250	250-500	500<
Number of Sites	69	1	19	10	14	13	12

Source: MKE, 2007b

Table 4-2 above shows the number of installed anaerobic digestion facilities in sewage treatment plants in different scales. Anaerobic digestion technology is generally used in these plants. It is reported that about 340,000 m^3 of biogas is produced daily from these 69 facilities and approximately 60% of the gas is methane, thus, 204 thousand m^3 of methane gas is produced per day. Currently most produced methane gas is simply flared off or partially used as boiler fuel for heating. The main problem of the existing anaerobic digestion process is the low production efficiency resulting in high running cost. Therefore, it is required to improve the efficiency and utilize the gas in a more cost efficient way.

4.2.2 Food Waste and Food Waste Water

The amount of food waste in 2005 was about 13 thousand tonnes per day shown in the table 4-3 below. The volume was increased in 2005 due to the ban on direct landfill of food waste from January 2005. The share of landfill method in food waste treatment has been continuously falling down while recycling has been dramatically increasing. In 2005, about

93% of food waste was recycled, 4% was incinerated and 3% was landfilled. The lower table shows the share of different methods in recycling. As shown in percentage, the food waste is mainly recycled as compost for farming and feed for livestock; together 89%. However, there are many problems reported from these two treatment methods. The high salinity in the produced compost owing to a peculiarity of food culture in South Korea causes land acidification. Also, it is generally reported that it is very difficult to secure stable demand for compost, so even the produced compost was sent to landfill in some cases (MKE, 2007b). In case of the feed method, due to the upheaval of Mad Cow Disease, most facilities are constrained in their operation (MKE, 2007b). Accordingly, interest on anaerobic digestion as a solution to the reduction and resourcization of food waste has been increasing and its share has been growing as an alternative method to the recycling to compost and animal feed. In addition, the increasing trend is expected to continue (MKE, 2007b).

Table 4-3 Food Waste Management in South Korea

Year		1999	2001	2003	2005
Total Volume (tonne/day)		11,577	11,237	11,398	12,977
Treatment Method	Landfill	59%	34%	25%	3%
	Incineration	7%	9%	7%	4%
	Recycling	34%	57%	68%	93%
Recycling Method	Feed	61%	55%	50%	44%
	Compost	37%	41%	44%	45%
	AD	2%	4%	6%	**11%**

Data Source: ME, 2007; MKE, 2007b

Numbers of public and private food waste treatment facilities are shown in the table below including various treatment methods in the lower table. Even though local municipalities are responsible for treating food waste, only about 35% of the facilities are public-owned. The others are private facilities consigned from local municipalities to deal with food waste. However, the operation rate of private facilities (66%) is quite lower than that of public ones (91%). The reason for the low rate is that again the quality of feed and compost is not good enough to induce consumers to purchase (MKE, 2007b).

Table 4-4 Food Waste Treatment Facilities in South Korea

	Number of facilities	Installed Capacity (tonne/day)	Treatment Volume (tonne/day)	Operation Rate
Total	256	13,364	9,928	74%
Public	90 (35%)	4,198	3,839	91%
Private	166 (65%)	9,166	6,089	66%

	Feed	Compost	AD (combined with sewage)	AD (exclusive use of food)	Others
Total	111	103	7	8	23
Public	16	50	7	6	13
Private	95	53	-	2	10

Source: MKE, 2007b

AD plants account for a small part of the total facilities. The main reason for this is a lack of high efficient AD technology (MKE, 2007b). The produced biogas from the AD plants is utilized for internal boiler use in case of small-scale facilities and for CHP in some of large-scale plants. The central government has a plan to increase the share of public facilities up to 60% by closing old facilities and constructing new ones (MKE, 2007b). These new facilities will be mostly AD plants exclusive use of food waste. Therefore, it is urgently required to develop a technology to maximize the production of biogas in anaerobic digestion.

As mentioned briefly earlier, food waste in South Korea generally contains much salt. Consequently, the process of producing feed and compost from food waste requires a lot of water. Together with the water originally contained in the food, the treatment process generates a great amount of food waste water (FWW). It is another important type of organic waste which could be used as a substrate for the production of biogas with anaerobic digestion technology. The volume of food waste water in 2006 was a little more than 8,200 m^3 per day, about 5,400 m^3 of which is dumped into the sea. To protect the ocean, in 2006 the Ministry of Maritime Affairs and Fisheries (now merged into the Ministry of Land Transport and Maritime Affairs) set a target to reduce the dumping volume by 50% by 2011. Later in 2007, the Ministry of Environment set a higher target, dumping no food waste water into the sea by the end of 2012 in its new plan, the 'Master Plan of Inland Treatment and Resourcization of Food Waste Water 2008-2012' (ME, 2007). This plan basically aims 1) to switch over from ocean dumping to inland treatment of food waste water by utilizing it as energy and 2) to establish infrastructure for the utilization and to secure demand for produced energy (ME, 2007).

4.2.3 Livestock Manure

According to the Environment Statistics Portal from the Ministry of Environment (http://stat.me.go.kr/), there were about 145 million domestic animals in South Korea in 2007. From these livestock animals, approximately 130 000 tonne of livestock waste water (including excrement, urine and cleaning water) is generated daily (Jaegeun Bae, 2008; MKE, 2007b). As of the end of 2003, 89% of livestock waste water is recycled through composting and liquefied fertilizer facilities, 4% is dumped into the sea and 7% is treated in various ways (MKE, 2007b). About 92.4% of the farms have installed facilities in their sites and the rest 7.6% commission their duties into specialized facilities. There are 47 public treatment facilities in large scale. Only 3 of them adopt the AD technology. If the amount of livestock manure (LM) currently generated daily is treated with anaerobic digestion technology, the amount of biogas will be about 430 million m^3 per day and the amount of methane will be 300 million m^3 per day (MKE, 2007b). This is a great potential to be utilized.

4.2.4 Landfill Gas (LFG)

There are 1,170 closed-down landfills (MKE, 2007b) and 242 landfills in operation all over the country. Total landfill area is about 30 million m^2 and landfill capacity is about 416 million m^3. In terms of its capacity, Sudokwon Landfill Site is the largest landfill site in South Korea. Its size is about 19.8 million m^2 and landfill capacity 228 million tonnes in the country. It is estimated that only about 31 of the total landfill sites are large enough (landfill capacity is larger than 1 million tonne) to utilize the landfill gas (LFG) (EMC, 2009). Average methane content of the LFG from major landfills in South Korea is reported about 58% as shown in the table 4-5 below (EMC, 2009). So far, LFG has been utilized for mostly electricity generation and as a middle-quality fuel (55-65% methane). However, the Environment Management Corporation has started a LFG utilization project which contains the utilization of LFG as a high-quality fuel (97% methane) to substitute some of natural gas consumption.

Table 4-5 Result of Measurement of LFG Content in Twelve Major Landfills

	Major Content (%)				Trace Gas (ppm)		
Content	CH_4	CO	O_2	N_2	NH_3	H_2S	VOCs
	57.9	39.5	0.6	2.1	8.5	86.2	2.48

Data Source: EMC, 2009

4.3 Potential of Organic Waste

The Ministry of Knowledge Economy roughly estimated that about 2.3 million TOE of biomass is available as shown in the table below (MKE, 2007b). If South Korea transforms all the three types of highly concentrated organic waste such as sewage sludge, food waste and livestock manure into energy, 96,000 TOE might be available (MKE, 2007b). However, the assumptions under the estimation were that 30% for food waste, 50% for sewage sludge and only 3% of livestock manure are available out of the total amount. Thus, if livestock manure can be utilized more, the total amount utilizable amount will be greatly increased (MKE, 2007b). Another research by K. M. Kim estimated that about 2 million tonnes of biogas can be produced from livestock manure, food waste, agricultural residue, and industrial organic waste, which can substitute 10% of natural gas currently used in S. Korea (K. M. Kim, 2008). Therefore, the potential of biogas production in South Korea is significant enough to be utilized.

Table 4-6 Available Organic Waste in Biomass (Unit: 10,000 toe/yr)

Agricultural Residue	105		
Forestry Residue	85		
Waste Paper, Waste Wood	32		
Highly Concentrated Organic Waste	9.6	Food Waste	5.1
		Livestock Manure	3.0
		Sewage Sludge	1.5
Total	231.6		

Data Source: MKE, 2007b

4.4 Level of Biogas Technology in South Korea

The R&D of renewable energy in South Korea has been driven by National Renewable Energy Research and Development Program since 1988, led by the Ministry of Knowledge and Economy (MKE), restructured from Ministry of Commerce, Industry and Energy in Feb 2008. The program has supported 765 projects between 1988 and 2006 with 439 billion Won covering 62% of the total projects budget. About 8.4% of the grant has been given to the 110 projects in bio sector. Out of the 110 projects, biogas projects were 36 and the total budget was 25 billion Won, of which 63% was governmental grant. These projects (35 completed and 1 ongoing) were mostly on the production of biogas from organic waste resource (livestock manure, sewage sludge, food waste, etc.) and the collection and utilization of LFG. As a result of the projects, several anaerobic digestion plants in a pilot scale were tested and three demonstration plants have been put into operation in Changnyung, Suwon and Cheongyang (10tonne/day for the first two and 20tonne/day for the last). The foci of the projects were mainly on how to increase the efficiency of digestion, how to upgrade methane content and how to utilize digestate. Recently, the focus has been shifted to the co-digestion of different organic wastes and utilization of biogas for CHP (MKE, 2007b).

There are a very small number of organic waste-to-energy facilities in South Korea now and the existing facilities are mostly for sewage sludge digestion. The anaerobic digestion facilities for food waste and livestock manure are quite few. It's because of the difficulties in building a new waste treatment facility in large scale due to domestic conditions such as high land price and strong NIMBY syndrome, thus, it's hard to ensure the economy of scale (MKE, 2007b). In addition, from the utilization of the produced biogas point of view, the present utilization technologies are mainly for boiler for heating and gas turbine for electricity generation. These technologies are typically on-site use in a limited scale. Therefore, it is required to develop technologies to store and transfer of the produced biogas for active utilization (MKE, 2007b). In addition, there is a great need to develop waste-to-energy technologies.

The table below shows the result of a survey of 82 experts in organic waste field including governmental organizations, industries, research institutes and universities (MKE, 2007b). They were asked to estimate how far the domestic technologies have developed in terms of 3 core- and 11 sub-technologies. As shown in the table below, the level of transformation technology is relatively higher (70.4%) compared to other two core technology sectors. In case of sub-technologies, biological transformation technology has the highest level (74.4%).

However, the two very essential sub-technologies for the utilization of biomethane as vehicle fuel, 'Upgrading' and 'Highly concentrated Fuel' technology, are significantly lower. The level of 57.3 and 66% means a level to move on from pilot projects to the demonstration stage of developed technologies (MKE, 2007b). Due to a lack of better reference, even though the result of survey is based on the very subjective opinion of the experts, it can be roughly drawn that the level of core technologies for biomethane vehicle fuel projects is not in place yet, resulting in the inevitable import of such technologies from overseas in the short to medium term.

Table 4-7 Level of Domestic Technologies in Bioenergy Sector from Organic Waste

Sector	Core Technology	Weight	Level	Sub-technology	Weight	Level
Organic Waste	Resource Securing	25	66.5	Energy Potential Assessment	20	70.2
				Resource Collection and High Concentration	30	63.8
				Pre-treatment	30	67.4
				Post-treatment	20	65.2
	Energy Transformation	45	70.4	Biological Transformation	60	74.4
				Chemical Transformation	10	64.6
				Thermal Transformation	20	66.6
				others	10	59.8
	Energy Utilization	30	65.3	Direct utilization (Middle-quality Gas)	15	70.5
				Upgrading and elec. Generation	70	66.0
				Highly Concentrated Fuel	15	57.3
	Total		68			

Source: MKE, 2007a

4.5 Various Government Plans on Biogas Utilization

During the research for the utilization of biogas as vehicle fuels in South Korea, various recent governmental initiatives and plans were found. To understand various emerging interests in the central government related to the topic of this research, it is important to understand some of the initiatives and plans.

4.5.1 'Low Carbon, Green Growth'

Date of Announcement: August 15, 2008

As mentioned in the introduction briefly, in August 2008, President Myung-bak Lee suggested the new national vision, 'Low Carbon, Green Growth (저탄소, 녹색성장)' for the next 60 years at the 60th anniversary of the founding of the Republic of Korea in the later part of his address (M. Lee, 2008). Because the impact of the vision of President has always been very influential in Korean history, the new vision has dominated in many governmental ministries and agencies as well as industries and society in general. In addition, many new plans from different Ministries has been established since August 2008 and some of them are closely related to the topic of this research. Thus, it is important to check some parts of his original address as follows.

> He started the 'Low Carbon, Green Growth' section by saying that "the Korean economy is undergoing difficulties stemming from the energy crisis". In order to overcome the crisis we need "more creative ideas and dauntless resolution." The world is entering "the age of an environmental revolution" and "an age of new energy is now being opened". "For the Republic that does not produce even a single drop of oil, such changes are both a crisis and an opportunity as well". Since S. Korea "exhibited great capacities in turning crises into opportunities" in the past two oil crises, "now is the time for us to turn the recent surge in oil prices into an opportunity to transform economic fundamentals and create new growth engines".
>
> "**Green growth refers to sustainable growth which helps reduce greenhouse gas emission and environmental pollution**". "It is also a new national development paradigm that creates new growth engines and jobs with green technology and clean energy". "The **renewable energy industry** will create several times more jobs than existing industries".
>
> "I am committed to **ensuring energy security more than anything else** with a view to laying the groundwork for green growth overcoming the energy crisis."
>
> "**The Government will make all-out investments to boost the use of new and renewable energy from the current 2% to more than 11% by 2030** and, ultimately, to more than 20% by 2050. R&D investments in green technology will be increased more than two times", thereby making Korea a leading powerhouse in the green technology market, which is expected to amount to 3 quadrillion won by 2020."
>
> "In addition, great emphasis will be placed on **nurturing eco-friendly and highly efficient green cars** as one of the new growth engines. **During my term in office, I will help empower Korea to emerge as one of the top four nations producing green cars** in the world."
>
> "It is said that the Stone Age did not end for a lack of stone, and the oil age will end long before the world runs out of oil. Even if soaring oil prices drop in the years to come, **now is the time for us to bid farewell to the era of excessive oil dependence**".
>
> "If Korea makes an audacious and swift move just as it did to advance its information capabilities to make up for belated industrialization, the country will undoubtedly be **reborn as a green power"**.

Even considering the fact that such address is quite rhetorical, it shows strong commitment to move forward 'Low Carbon and Green Growth' society. Since the announcement of the new vision, various governmental ministries and agencies have announced follow-up plans related to their works. In addition, the government proposed Low Carbon, Green Growth Base Law into the National Assembly in February 2009 to effectively coordinate different policies in climate change, renewable energy development and sustainable development from various governmental organizations. Regarding the topic of this thesis, some of the points are very much related. Shortly summarized, it seems that the government is very committed to developing of renewable energy and nurturing green cars to overcome country's excessive oil dependence. If the commitment is true and resulted in substantial changes in the governmental support for renewable energy and eco-car, it might create a very favourable environment of developing biogas as a vehicle fuel since the development very much fits into the new vision. However, there has been very sharp criticisms on the new vision in terms of whether the new vision is really 'green' or only seems 'green' but 'grey' or 'yellow' (S. Hong, Yun, Oh, & Hong, 2009; Korea Environment Council, 2009).

4.5.2 National Energy Master Plan

Date of Announcement: August 27, 2008
Ministry in Charge: National Energy Committee composed of Prime Minister's Office (PMO), Ministry of Strategy and Finance (MOSF), Ministry of Education, Science and Technology (MEST), Ministry of Foreign Affairs and Trade (MOFAT), Ministry of Knowledge Economy (MKE), Ministry of Environment (ME), Ministry of Land, Transport and Maritime Affairs (MLTM)

As mentioned earlier, various new governmental plans followed up the new vision. Just 12 days after the announcement of 'Low Carbon, Green Growth', the National Energy Committee' announced the first 'National Energy Master Plan (국가에너지기본계획)' for 2008-2030, the highest national energy strategy. This Master Plan influences on the basic direction and principles of various sub-plans for different energy sources (oil, coal, natural gas, renewable and etc), but does not constrain the details of the sub plans with word by word from the National Energy Master Plan. It defines basic directions of national energy policy as "to achieve 'Low Carbon, Green Growth', to create a new growth engine and jobs by green technology and clean energy, to support sustainable economic growth and finally to promote energy security, energy efficiency and environmental protection for future generation".

To summarize the core contents of the plan:

1) The five major visions of the plan are shown below.

5 Visions	Indicator	2006	2030
Energy Self-Sufficient Society	Self Development Ratio of Energy Resource[(a)]	3.2%	40%
	Share of Renewables	2.2%	11%
Low Energy Consumption Society	Energy Intensity[(b)] (TOE/$1000)	0.347	0.185
Oil-free Society	Oil Dependency[(c)]	43.6%	33%
Energy for Everybody	%age of Energy Shortage Household[(d)]	7.8%	0%
Green Technology and Clean Energy	Level of Energy Technology	60%	World Top Level

(a) Self Development Ration of Energy Resource: A ratio for the share of energy developed by Korean companies outside of country out of the total energy import
(a) Energy Intensity: Amount of energy needed to produce one unit of GDP, TOE/$1,000
(c) Oil Dependency: A ratio of oil in total primary energy supply
(d)%age of Energy Shortage People: The household which spend more than 10% of their income for purchasing energy for lighting and heating.

2) And, the plan sets up 10 Tasks as follows

T1. Increase Energy Efficiency
T2. Create Effective Energy Market and Establish Rational Price System
T3. Develop and Increase the Share of Renewables and Make it a Growth Engine
T4. Increase the Energy Supply from Nuclear and People's Acceptability on it
T5. Increase the Ability of Overseas Energy Resource Development
T6. Secure Stable Energy Supply
T7. Increase Capacity to Respond Climate Change
T8. Nurture Next Generation Energy Industry by Energy Technology Innovation
T9. Advance Domestic Energy Industry into Foreign Markets
T10. Achieve Energy Welfare and Energy Security Society

Before discussing some of the important contents of the plan related to the topic of this research, it is important for readers to have basic understanding on Korean energy system.

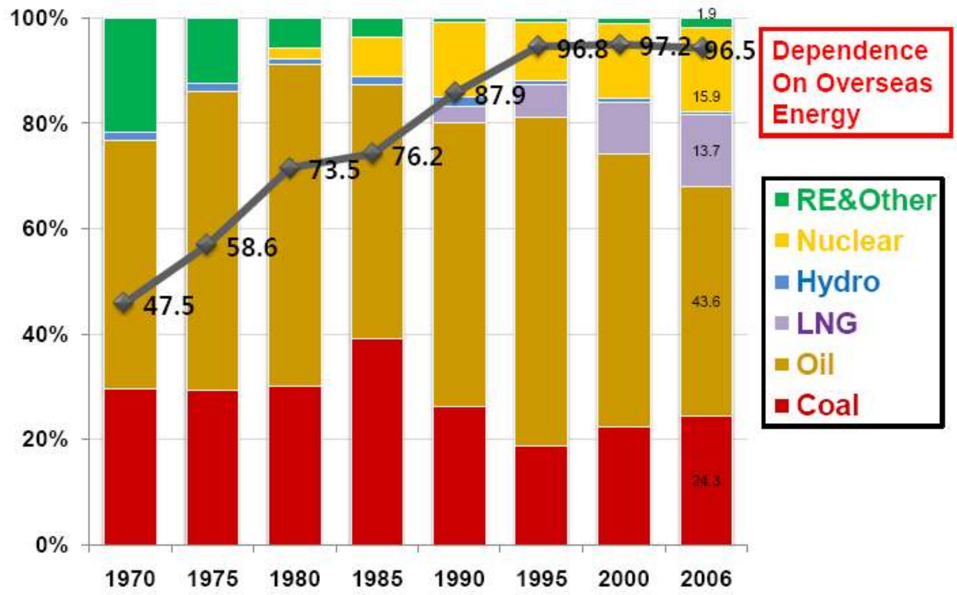

Figure 4-2 Composition of Primary Energy in South Korea from 1970 to 2006

Source: Korea Energy Economics Institute

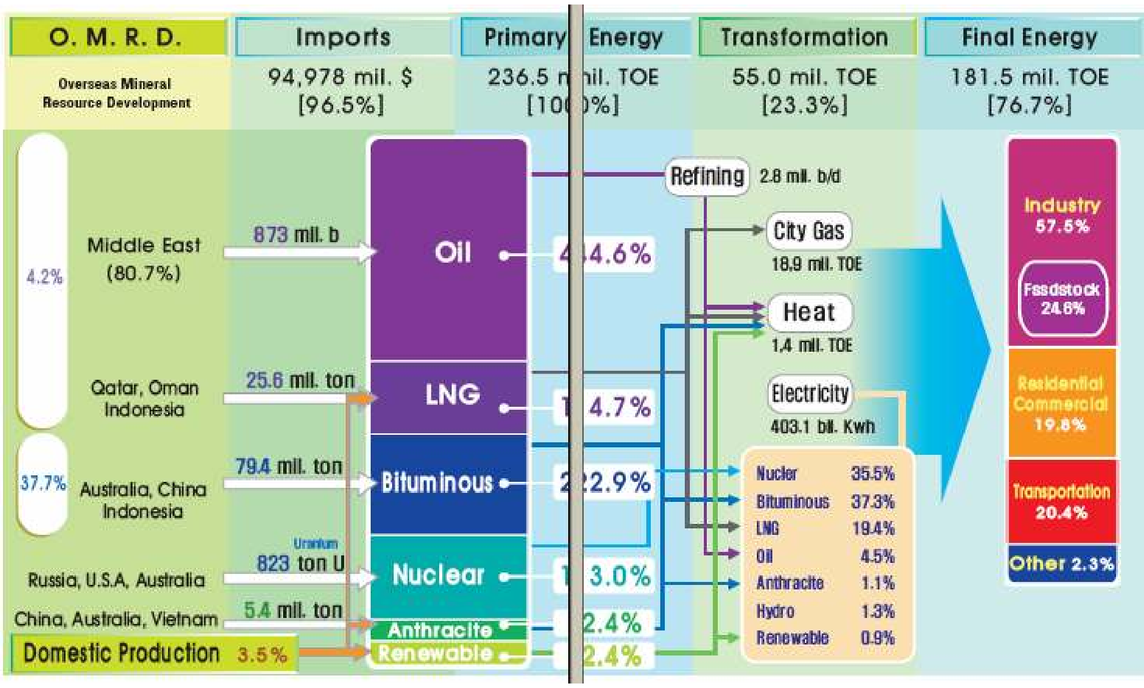

Figure 4-3 Energy Balance Flow 2007

Source: KEEI, 2008

The figure 4-2 above shows the composition of primary energy in South Korea from 1970 to 2006. As emphasized in the beginning, the dependence on overseas energy in Korea is very high, 96.5%. As shown in the second figure 4-3, the rest 3.5% are a little amount of LNG, anthracite and various renewable energies. The dependence on overseas energy was continuously increasing from 1970 to 1995 when the economy was rapidly developed and it has been stable since 1995 at about 97%. After the two oil crises in 1970's South Korea tried to reduce the share of oil in its primary energy, resulting in the decrease of the share from 61.1% in 1980 to 43.6% in 2006 while the shares of nuclear energy, LNG and coal were greatly increased as follows.

	1980		2006	
Nuclear	2.0%		15.9%	Nuclear power plant started in 1977
LNG	0.0%	▶	13.7%	LNG was introduced first in 1986
Coal	7.6%		22.1%	Coal power plant started in 1983

The share of coal (38.4%, bituminous and anthracite) is the largest in electricity generation followed by nuclear (35.5%) and LNG (19.4%). The share of renewables in electricity generation is very small, 0.9%, while fossil fuels account for about 62.3% of power generation, which will very likely create a big problem for South Korea from 2013 when it will receive a target to reduce GHGs emissions from the Post-Kyoto negotiation. About 80.7% of oil comes from Middle East. So if anything happens in Middle East, Korean Economy is heavily affected, in other words, energy security is very vulnerable. South Korea has the 6th largest crude distillation capacity and 6th largest exporter of petroleum products (35 Mt) in the world (IEA, 2007). Therefore, if oil for non-energy-use is excluded, the oil dependency in 2006 is not 43.6% but actually 29.3% which is lower than the average of OECD, 41% (PMO, 2008c). In other words, a substantial portion of imported oil is not consumed as a source of energy but as a raw material.

Natural gas is imported as LNG by Korea Gas Corporation. About 74% of imported LNG is transformed to CNG (called city gas) and distributed to regional city gas providers, then the providers, with exclusive rights, distribute city gas to consumers for various purposes including transportation (mainly public CNG buses). The rest of imported natural gas is used for heating and electricity generation. The share of LNG in electricity generation is 19.4%. The share of transportation in final energy consumption is about 20.4%, mostly oil.

Directly related to the topic of this research, as one of the 10 tasks of the Master Plan is 'to Develop and Increase the Share of Renewables and Make it a Growth Engine', the Master Plan sets a target for the renewable energy development. To understand the renewable policy in Korea, it is important to first understand the definition of renewable energy in Korea. In Korean, renewable energy means '신▪재생에너지 (New▪Renewable Energy)'. There are 8 types of energy in the 'renewable' category and 3 types of energy in the 'new' category as follows:

Renewable E: PV, Solar Thermal, Biomass, Wind, Hydro, Ocean, Waste, Geothermal

New E: Fuel Cell, IGCC & Liquefied Coal, Hydrogen

As shown in the figure below, in 2006, renewable energy mostly comes from 'Waste' which is in the category of 'New' energy in Korean term. The 'Waste' includes various wastes which can be used as energy; 46% from waste gas, 30% from heat recovery from incineration, 9% from refined waste oil which in general are not part of renewable energies in other countries (ME, 2008b). Thus, readers should be careful to comprehend the renewable statistics from South Korea. If the 'waste' is excluded, the share of renewable in primary energy supply becomes more minimal since the share of real renewable energies (PV, solar thermal, biomass, wind, small hydro, ocean, waste, geothermal, excluding large hydro) is only about 7.3% of the total renewable in 2006, that is, 0.16% of the total primary energy supply.

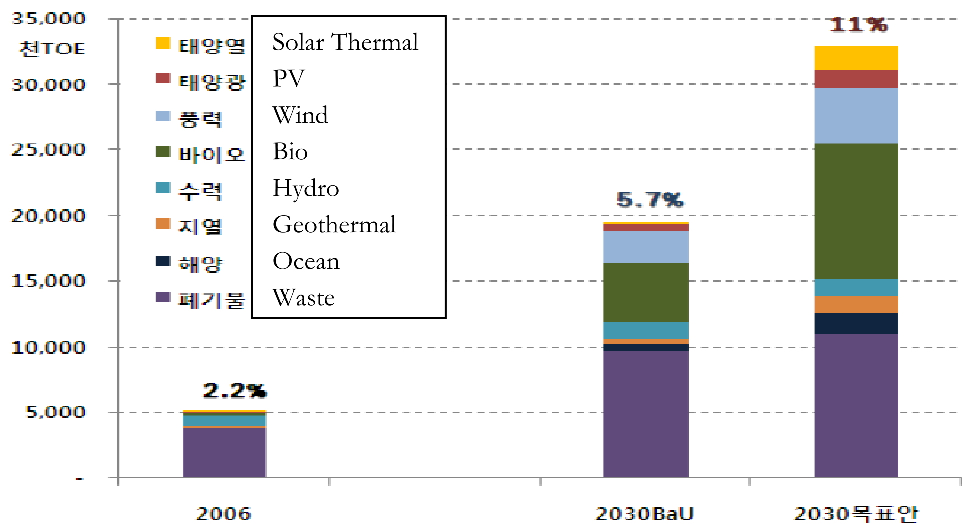

Figure 4-4 Composition of Renewable Energy in South Korea (2006, 2030BaU, 2030 Target) and its Share of Total Primary Energy Supply

Source: PMO, 2008c

As shown in the figure 4-4 above, the Master Plan estimates the BaU (business as usual) scenario for the share of renewables in 2030 will be 5.7%. Then, it sets a target to increase the share up to 11% by mainly increasing wind, solar and bioenergy, which means the share in 2030 will be increased to 4.3% with the Master Plan compared to BaU and the amount of renewable energy will be increase up to 32,062 KTOE compared to 18,593 KTOE in BaU scenarios. Whether this target, included in the speech by President Lee, corresponds to the strong commitment of 'Low Carbon, Green Growth' or not is difficult to analyze in this research. Nevertheless, considering the three facts that 1) it is a target for 2030, not for 2010, 2015 or 2020, 2) the consumption of renewables from 1990 to 2006 was increased by 11.2% in each year in average and 3) the annual increase will be 8.0% in average in this Master Plan, it is somewhat difficult not to accept the severe criticism from environmental NGOs that the Master Plan sets up 'too weak target for renewables'. The author participated in the seminar for the discussion on the draft of the Master Plan among governmental officials, researchers from public and private energy think-tanks, and NGO representatives. Participants from NGOs insisted that the target for 2030 (it was 9% in the draft) will be achieved by 2030 without the Master Plan considering the trend of renewable energy development in last couple of years.

For the task number 3, expansion of the renewable energy development and diffusion, the Master Plan sets up several strategies and two of them are closely related to biogas as vehicle fuel as follows

1) Support <u>bioenergy and waste fuels</u> first due to their relatively higher cost effectiveness

2) Support electricity generation from CHP and production of <u>biogas for transportation from municipal organic waste and livestock waste</u>

Even though that is the only part where the word 'biogas' is mentioned in 181-page Master Plan, it is important that the highest national plan for energy policy in South Korea does recognize the biogas technology for vehicle fuels and sets up it as one of the strategies to achieve one of the 10 major tasks for the new national vision.

4.5.3 Waste-to-Energy Master Plan

Date of Establishment: May 2008
Ministry in Charge: Ministry of Environment

In 2007, the South Korean government amended 'the 2nd National Waste Management Plan' based on the paradigm shift of waste management from 'Create a Pleasant Society' by reduction, recycling and safe treatment to 'Establish a Sustainable and Resource-circulating Society' by zero waste and CO_2 reduction (ME, 2008a). In the new paradigm, one of the primary focuses is on the expansion of waste-to-energy policy. In accordance with the focus, in the next year, the Ministry of Environment established Waste-to-Energy Master Plan (폐기물에너지화 종합대책) to boost economy and to cope with climate change (ME, 2008a).

The plan estimates that 20,491 tonnes of organic waste per day can be utilized as energy source as shown in the figure 4-5 below. The different organic waste volumes are derived from the amount of organic waste which will be prohibited to be dumped in the sea from 2012. However, not all this amount could be utilized soon as energy instead of ocean dumping due to various obstacles. Thus, the ME set up a short-term target that annually 1.6 million tonnes of the organic waste will be used as energy by 2012 (about 22% of the total organic waste dumped in the sea now) and by 2020 the whole amount (approximately 7 million tonnes/yr = 20,491*365) of organic waste will be reused as energy source. Once waste-to-energy technology becomes mature and economic efficiency is secured, the amount of industrial organic waste sent to landfill now will be utilized as well. The plan states that waste-to-energy is the most realistic alternative for the organic waste currently dumped in the ocean (ME, 2008a).

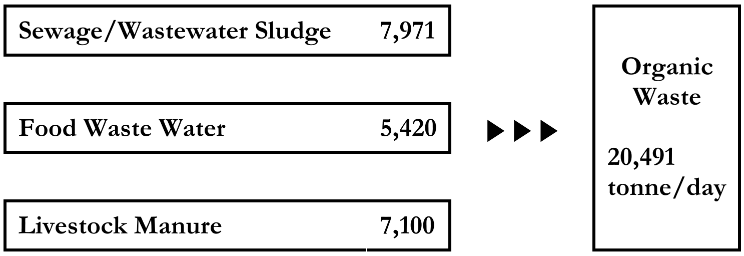

Figure 4-5 Amount of Organic Waste Currently Dumped in the Ocean

Data Source: Ministry of Environment, 2008a

To achieve the short-term and long-term targets mentioned above, the plan designed a very ambitious and massive-scale policy. With the cooperation from other ministries and local municipalities, they are going to build 16 innovative 'waste energy towns' and 41 individual facilities all over the country, dividing into 4 regions: Central, Eastern, Honam and Youngnam area. 1)Waste-to-Energy and Electricity Generation Project of Organic Waste is one of the main pillars in this 'waste energy town' project together with 2)RDF (Refuse Derived Fuel) and Electricity Generation Project of Combustible Waste, 3)Collection and Electricity Generation Project of LFG, and 4)Incinerator Remaining Heat Collection Project. Detailed plan is described in the table below.

Table 4-8 Waste Management Facility Expansion Plan

	Waste-to-energy Volume (thousand tonne/yr)	Capacity (tonne/day)		
		Drying & RDF	Biogasification	
			Food Waste Water (FWW)	Co-digestion of FWW and Livestock Manure
Total (sites)	1,632	1,280 (4)	2,690 (11)	1,580 (12)
Town	1,014	1,000 (1)	1,820 (4)	560 (3)
Individual	618	280 (3)	870 (7)	1,020 (9)

Data Source: Ministry of Environment, 2008a

There will be 7 'waste energy towns' (4+3) producing biogas from food waste water and/or livestock manure. Moreover, 16 (7+9) additional individual facilities will be built to produce biogas. Around 62% of organic waste currently dumped in the sea will be treated in energy towns and the rest 38% will be utilized as energy in new individual facilities. This policy is expected to cost 962 billion won (42% central government, 46% local municipalities, 12% private investment) by 2012. The expected benefits by 2012 from the plan are shown in the table below. Approximately 308 billion won of financial benefit is expected and 2,624 jobs will be created by 2012.

Table 4-9 Expected Benefits from Waste-to-Energy and Electricity Generation Project of Organic Waste

(Unit: billion Won)	Total	2008	2009	2010	2011	2012
Expected Financial Benefit	**308**			**27**	**44**	**238**
Waste Management Cost Reduction	219			22	32	165
Oil Substitution	74			4	10	60
CERs	16			0.4	3	13
Job Creation	**2624**	**151**	**241**	**964**	**908**	**360**
Construction	2386	151	241	912	852	230
Operation	238			52	56	130

Data Source: Ministry of Environment, 2008a

4.5.4 Waste Resource and Biomass to Energy Plan

Date of Announcement: October 2008
Ministry in Charge: Ministry of Environment

Just about 4 months after the announcement of the Waste-to-Energy Master Plan, the Ministry of Environment published a new plan titled 'Waste Resource and Biomass to Energy Plan (폐자원 및 바이오매스 에너지 대책), which makes the former one, Waste-to-Energy Master Plan, obsolete. One of major reasons why the Ministry set up a new plan just 4 months after the 'old new' plan is highly likely due to the new national vision, Low Carbon, Green Growth. The catch phrase in the title for the former one was Waste-to-Energy Master Plan 'for the Revival of Economy and Climate Change' (경제살리기와 기후변화대응을 위한)' whereas the latter one is Waste Resource and Biomass to Energy Plan 'for Green Growth and Climate Change' (녹색성장과 기후변화 대응을 위한). Thus, the new plan was might be highly influenced by the new national vision. Not only the title but also the content was changed.

It is explicitly written in the plan that the plan itself is a 'representative example' of Low Carbon, Green Growth, because the utilization of waste resource and biomass energy brings about 1) reduction of environmental pollutant by treating wastes → Environmental-Friendly, 2) reduction of GHGs emission from the production and use of renewable energies → Low Carbon, 3) job creation in livestock industry who are suffering from the increase of grain price and treatment cost → Green Growth, and finally 4) increase of national wealth by decreasing energy import.

Further, it says the reason for the share of renewable in primary energy supply is mainly due to the lack of cooperation among different ministries for waste-to-energy and the lack of governmental policy and financial support for biomass-to-energy. Thus, it is strongly required to establish a close 'cooperation system' among the Ministry of Environment (ME), Ministry of Food, Agriculture, Forestry and Fisheries (MIFAFF), Ministry of Knowledge Economy (MKE) and Korea Forest Service (KFS).

In addition, it points out that financial support for biomass-to-energy is relatively smaller than other renewable as shown in the table 4-10 below. The budget for waste resource and biomass is only about 5% of the budget for PV, geothermal and solar thermal.

Table 4-10 Budget for Different Types of Renewables in the Renewable Energy Local Distribution Program by MKE in 2008

Total (mil Won)	PV	Geothermal	Solar Thermal	Waste Resource & Biomass	Others
41,340	7,213	7,350	7,000	340	19,437

Source: ME, 2008b

The plan emphasizes that biomass from wastes can be utilized to produce energy in a massive scale relatively earlier with low cost compared to other renewable as the comparison shown in the table 4-11 below. In addition, it is a very effective solution for the reduction of GHGs emissions.

Table 4-11 Unit Cost of Production of Different Types of Renewables

	PV	Wind	Small Hydro	Waste
Unit Cost of Production	716	107	70	71

Source: ME, 2008b

Therefore, it suggests that the national target for the share of renewables in 2030 (11%) and 2050 (20%) can be greatly achieved from the utilization of wastes and biomass as shown in the figure below, a contribution of half of the total in 2050.

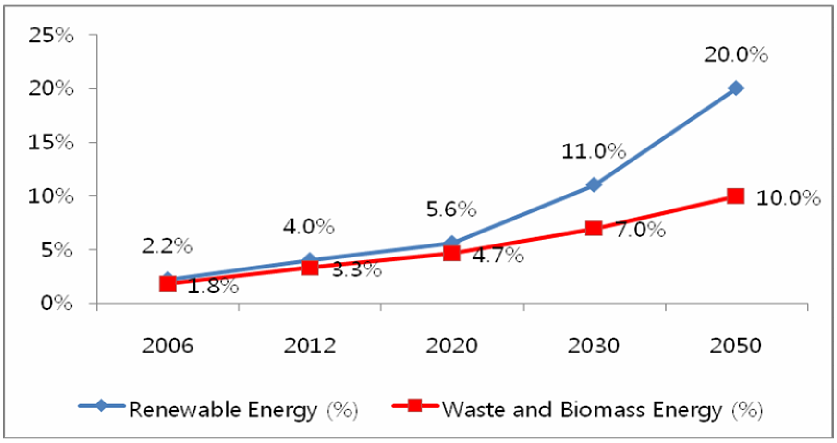

Figure 4-6 National Targets for Renewables

Source: ME, 2008b

Seven major tasks were proposed. Task 1, 4, 6, and 7 are very closely related to the utilization of biogas as a vehicle fuel.

Task 1 – Waste-to-Energy of the Waste Incinerated and Landfilled.

Under the Task1, the second section is about 'Biogas and Solid Fuel from Organic Waste' as follows.

1) Food Waste to Energy

The 54% (1.78 million tonnes/yr) of the food waste water (3.31 million tonnes/yr) generated from the recycling process of food waste (4.88 million tonnes/yr) is dumped in the sea. The ministry plans to expand 11 additional biogas production facilities (0.89 million tonnes/yr) of food waste water by 2012 which will treat the half of the food waste water (FWW) currently dumped in the sea. Further, by 2020, 100% of the food waste water currently dumped in the sea will be treated to produce biogas and the gas will be utilized for electricity generation or vehicles fuels.

To understand the magnitude of the biogas production according to the plan above, some calculations are shown below based on the assumptions provided in the Waste Resource and Biomass to Energy Plan.

Calculations

Amount of food waste water treated in the new 11 facilities by 2012 ≒ 2,438 tonnes/day

Amount of produced Biogas: 2,438 tonnes/day * 84㎥/tonne ≒ 204,822㎥/day

Assuming the methane content of biogas is 50% ≒ 204,822㎥/day * 0.5 ≒ 102,411㎥/day

Assuming the amount of methane used for a CNG bus = 47,500㎥/yr,

Assuming that the facility runs 300 days per year, the number of CNG buses possibly running on the biomethane produced from the food waste water is:

= (102,411㎥/day * 300) / 47,500㎥/yr = 647 buses

To sum up, a half of the food waste water currently dumped in the ocean will be treated in 11 new facilities in 2012 and the amount of produced biomethane from the 11 facilities will be enough to run 647 CNG buses for a year.

2) Livestock Manure to Energy

Out of the total amount of livestock manure (LM) generated (45 million tonnes/yr), 83% is treated to be compost and liquid fertilizer, 12% is treated in public treatment facilities, and the rest 5% (2 million tonnes) is dumped in the sea. Currently, there are two demonstration projects of biogas plant using livestock manure at Cheongyang and Icheon. Once these projects become successful and demonstrate the effectiveness of the facilities, the Ministry will distribute similar facilities in other places. However, there is not a concrete plan for further expansion at this moment.

3) Sewage Sludge to Energy

Out of the total amount of sewage sludge (SS) generated (2.78 million tonnes/yr) from 347 sewage treatment plants all over South Korea, 69% (1.9 million tonnes/yr) is dumped in the sea. The Ministry plans to treat 20% of the dumped sewage sludge to produce solid fuel by 2012 and by 2020 it plans to treat 88% of the currently dumped sewage sludge either to produce solid fuel or to produce biogas. The plan does not specify how much of them will be used to produce biogas. However, it seems that the focus of the utilization of sewage sludge currently dumped in the ocean is to utilize to produce solid fuel.

4) Co-digestion of Organic Waste to Energy

In order to increase the efficiency of biogas production, it is needed to co-digest food waste, livestock manure and sewage sludge (ME, 2008b). Currently, there are 6 co-digestion facilities using sewage sludge and food waste (300 tonnes/day) and 1 facility in Paju in Gyeonggi Province using livestock manure and food waste together (80 tonnes/day). The Ministry plans to build 12 more co-digestion facilities using food waste and livestock manure by 2012 (1,580 tonnes/day).

4) Expansion of LFG and Waste to Energy

The Ministry plans to collect about 95% of LFG by 2012 and use for electricity generation, city gas, and vehicle fuels. Out of the total 250 landfill sites, 15 of them in a large scale are running LFG-to-energy facility by private investment but smaller landfill sites are not utilizing LFG due to the lack of economical efficiency. Currently, Sudokwon Landfill Site is utilizing LFG for electricity generation (steam turbine, 50MW, 550 Nm^3/min) which is the largest scale electricity generation from LFG in South Korea. The private company in charge of this project is Ecoenergy Holdings which is a Korean partner to Swedish Biogas International from Sweden and they jointly launched one of the three existing biomethane projects for vehicle fuel in Seoul (will be explained later in detail).

In addition, local municipalities are running 14 smaller scale electricity generation facilities from LFG (total capacity 21 MW). The ME plans to build more facilities to utilize LFG: 27 more by 2012 and 41 more by 2020. By 2012, the six large ones (10N㎥/min) will be for electricity generation and 21 middle ones (2N㎥/min) are for vehicle fuels and city gas.

The Table 4-12 below summarizes government plans on the utilization of biogas from different types of organic waste which have been discussed so far and also shows how many CNG buses could run on the amount of biogas produced from the planned projects to provide the scale of the planned biogas projects. If there is no specified plan, assumptions are made by the author. As a result, the amount of biogas produced from the planned projects (food waste water, landfill gas, co-digestion) together with 10% utilization of the livestock manure and sewage sludge currently dumped in the ocean could run about 1,619 CNG buses annually by 2012. If total amount of FWW, LM and SS is fully utilized to produce biogas for vehicle fuel, theoretically around 22,000 CNG buses could be running on the amount of the produced biogas.

Table 4-12 Government Plans on the Utilization of Biogas from Organic Waste

		FWW	LM	SS	Co-digestion	LFG
Total amount (tonnes/year)		4,880,000	45,000,000	2,780,000		
Amount dumped in the ocean (tonnes/year) [% to the total amount]		1,780,000 [54%]	2,000,000 [4%]	1,900,000 [68%]		
Future Plan		890,000	not specified	not specified	6+1+12 sites	21 middle ones
Assumptions	Implementation rate	100%	10%	10%	100%	100%
	Daily amount of biogas produced (m^3/tonne)	84	20	50	50	2 Nm^3/min
	Methane content	50%	50%	50%	50%	60%
	Operation days	300	300	300	300	300
Available amount (tonnes/day)		2,438	548	521	1,960	2,880 (Nm3/day)
Produced biomethane (Nm3/year)		30,723,288	1,643,836	3,904,110	14,700,000	25,920,000
How many CNG buses could run annually on the amount of biogas produced		647	35	82	309	546

Data Source: ME, 2008b

Task 4 – Create a Sudokwon 'Environment and Energy Town' Demonstration Site

Sudokwon in Korean means 'the Seoul National Capital Area (SNCA)', a region located in the north-west of South Korea including Seoul, Incheon Metropolitan City and Gyeonggi Province. It covers only about 12% of the land size of South Korea, but almost half of the entire South Korean population (24.5 million) lives in the area, resulting in the world's 4th largest urban area. Sudokwon Landfill Site, as mentioned above, is the largest landfill in the nation and it will be available until 2044 (ME, 2008b). The ME plans to utilize some parts of the future landfill area (4.5 million m^2) in the site for the construction of 'Environment and Energy Town' as a demonstration project and it will be spread out if it becomes successful. The detail project plan is creating the town with four themes (waste-to-energy, bioenergy, renewable energy, and environmental and cultural place) and promoting it as a world famous tourist place.

Task 5 – Create 'Environment and Energy Town' in 10 Regions

As discussed earlier, the former plan, sets up to build 16 innovative 'waste energy towns' and 41 individual facilities all over the country, dividing into 4 regions: Central, Eastern, Honam and Youngnam area. This 'Environment and Energy Town' is an upgraded version of 'waste energy town'. Basically it divides the country into 10 big regions and establishes 1 or 2 such towns in each region with waste-to-energy facilities, LFG collection facility, remaining heat collection from incineration, PV, wind power and biomass-to-energy facilities.

Task 6 – Create 600 Low Carbon, Green Growth Villages

Try to increase energy self-sufficiency rate of rural area up to 40-50% by 2020, the ME will create four demonstration villages first from 2010 and increase by 2020. The villages will effectively utilize food waste, livestock manure, and agricultural residues to produce biogas.

Task 7 – R&D, Human Resource Training and Nurture Industry

1) R&D

Currently, to develop technology in the field of waste resource, a project certified as one of Eco-STAR Projects from the ME and Korea Environmental Industry & Technology Institute (KEITI) is going on with the budget of 79.6 billion won from 2007 to 2014. One of the R&D fields suggested in the plan is 'upgrading biogas and developing biofuels for vehicles'.

2) Human Resource Training

About 10 000 experts and researchers will be nurtured to lead green industry. Also, there will be cooperation projects among industry, universities and research institutes. The establishment of graduate schools specialized in environment and energy was proposed.

Finally, the overall expected benefits of the Waste Resource and Biomass to Energy Plan are as follows:

1) Economic benefits: 3.4 trillion won by 2012 and 8.6 trillion by 2020

2) Job creation: 43 thousand jobs by 2012 and 126 thousand by 2020

3) Oil substitution effect: 25.8 million barrels by 2012 and 57.7 million by 2020

4) GHGs emissions reduction: 13 million tonnes by 2012 and 28 million by 2020

Therefore, it can be concluded that, with its various targets, the 10 planned towns, the 600 planned villages, the R&D and human resource training plans, this latest comprehensive governmental plan, closely following the new national vision, might create a very favorable environment for different actors to be interested in the market of biogas fuel.

4.5.5 The State of the Organic Waste-to-Energy Facility

Date of Announcement: April 2009
Ministry in Charge: Waste to Energy Team, Ministry of Environment

Finally, there was a recent survey by the Ministry of Environment on the state of the organic waste-to-energy facility. It is not a governmental plan but a long report to present the result of the survey (ME, 2009a). It is important to emphasize some of the results in this research. The questionnaires were answered by public and private facilities which use renewable energy produced from food waste, food waste water, livestock manure and sewage sludge in order to understand the current situation of organic waste to energy.

Table 4-13 Number and Capacity of Organic Waste-to-Energy Facility

	Total	Food Waste	Food Waste Water	Livestock Manure	Sewage Sludge	Co-digestion
Facility	38	1	4	6	17	10
Capacity (tonne/day)	19,851	200	1,745	500	12,803	4,603
Unit Capacity		200	436	83	753	460

Data Source: ME, 2009a

The facilities using sewage sludge as substrate is the largest share followed by co-digestion and livestock manure. Also, capacity per unit is the largest in sewage sludge. The capacity of biogas plants using livestock manure is relatively small.

Table 4-14 Development of Organic Waste-to-Energy Facility

	Total	Food Waste	Food Waste W	Livestock Manure	Sewage Sludge	Co-digestion
2006	30	1	2	3	16	8
2007	3		1	1	1	
2008	5		1	2		2
Total	38	1	4	6	17	10

Data Source: ME, 2009a

About 80% of the facilities were built before 2007 and it is observed that traditionally sewage sludge and co-digestion types of biogas plants were favored but recently the number of facilities from livestock manure, sewage sludge and co-digestion are increasing.

Table 4-15 Produced Biogas and Different Usages

	Produced Biogas (000 Nm3/yr)	Different Usages				Simple Treatment (flared off, etc)
		Total	Elec. Gen.	Selling Gas	Internal Use	
2007 (A)	43,998 (100)	30,383 (69.1)	4,105	2,868	23,410	13,615
2008 (B)	44,383 (100)	37,362 (84.2)	8,749	1,561	27,052	7,021 (15.8)
B-A (%)	385 (0.9)	6,979 (23.0)	4644 (113.1)	△1,307 (△45.6)	3642 (15.6)	△6,594 (△48.4)

Source: ME, 2009

In 2007, about 69.1% of the produced biogas was utilized for electricity generation, sold to other gas consumers, or internally used, mainly for heating. The rest 30% was mainly flared off. The percentage of not being flared off in 2008 was increased up to 84.2%, which was guessed to be driven by high oil prices and governmental waste-to-energy policy (ME, 2009a). The amount of utilized biogas in 2008 (37,362 Nm^3/yr) is equivalent to 129,320 barrel of oil and its value is about 23.2 billion won (ME, 2009a).

According to the press release in April 2009 related to the survey (Choi, 2009), the ME has a plan to revise Enforcement Ordinance of the Waste Management Act in the first half of this year and, with the close cooperation from other related Ministries, the ME is preparing amendment of different laws in order to utilize biogas and LFG from organic waste for city gas, vehicle fuels and other high value-added energy resources. In fact the City Gas Business Act was amended in March 25 2009, which included 'biogas' in the definition of city gas. This amendment enables to provide biogas from organic wastes as city gas. In addition, the ME is preparing to conduct a demonstration project of utilizing LFG as a vehicle fuel at the Sudokwon Landfill Site in order to get necessary data for setting up the CBG (Compressed Biogas) fuel standard from organic wastes and landfills, according to the Ministry, it will start in this year. Finally, the press release estimates if we utilize different types of the organic waste (food waste, food waste water, livestock manure, sewage sludge) currently dumped in the sea to produce biogas through the anaerobic digestion, it could provide 19.8 million GJ of energy equivalent to 3.21 million barrels of oil (about 700 billion won), resulting in the significant contribution to tackling climate change and promoting green growth (Choi, 2009).

4.6 Three Ongoing Projects

As mentioned above, there are three ongoing biogas fuel projects in South Korea as of June 2009. They are pioneers in the field of biogas technology for vehicle fuel in the country and the various governmental plans discussed above were partially influenced by the projects as well.

4.6.1 Biogas Vehicle Fuel Project at Seonam Sewage Treatment Facility in Seoul City

"A major breakthrough for us in the Korean market" - Peter Undén, CEO from SBI (SBI, 2009)

"This marks the beginning of what is expected to be the world's largest facility for producing biogas for vehicle fuel" - Steve Broadbent, Managing Director, Flotech Group (Flotech, 2007)

"It will contribute to creating clean Seoul and it is a right project in this era of high oil price and environmental protection" – Seung-guk Moon (Shin, 2008)

In December 2007, the Metropolitan Government of Seoul, a capital of South Korea with a population of 10 million, signed an MoU with Biomethane Seoul Co., Ltd., a joint venture established by four partners listed below, to upgrade biogas from Seonam Sewage Treatment Facility (SSTF) and utilize the upgraded biogas, biomethane, as a vehicle fuel.

- Seonam Environmental Technology Co., Ltd: A Korean company consigned to manage Seonam Sewage Treatment Facility from Seoul city.

- Swedish Biogas International AB (SBI): A Swedish company in biogas production and upgrading from Linköping, Sweden

- Greenlane Biogas Limited (GBL): A Swedish company in biogas upgrading solutions

- Ecoenergy Holdings Co., Ltd: A Korean company in renewable energy development, especially in electricity generation from LFG renewable energy development. A Korean partner to GBL and SBI

The SSTF generates about 86,000㎥ of biogas per day during the treatment process. Some of the produced biogas (60% methane) is now partially utilized for internal energy use side, but the rest is simply flared off. The new project will install new equipments in order to upgrade the produced biogas into biomethane (> 97% methane) to use for vehicles. The total project budget is about 5.1 billion Won (25% foreign investment). It is expected that about 4,200N㎥ of biomethane will be produced daily from June 2009 and will be sold as vehicle fuel for the community shuttle buses currently running on imported CNG. According to their calculation, the expected amount might be enough to run around 30 buses annually. The price of biomethane will be set up at approximately 85% of the CNG price for vehicles. With this project the Seoul city expects to improve air quality and also reduce annually about 2,100 tonnes of carbon dioxide by substituting around 774 thousand N㎥ of natural gas (equivalent to about 900 thousand liter of diesel). In addition, it is expected to create another income of half billion Won by registering the project as a Clean Development Mechanism (CDM) project and selling CERs (Certified Emission Reduction) for 10 years. If the project becomes successful in June 2009 as planned, it will be the first case in South Korea to use biomethane, a renewable fuel, for vehicles. The SMG and Ecoenergy Holdings have a plan to apply similar projects in other sewage water treatment facilities after setting up related legislations including a fuel standard in cooperation with the Ministry of Knowledge and Economy and Ministry of Environment based on the data from the project.

4.6.2 Yongyeon Wastewater Treatment Plant Biogas Production Facility Project in Ulsan City

"This project will contribute to the cost reduction for food waste management, to the new technology transfer, and to the utilization of organic waste to renewable energy. Eventually, it will improve the eco-city image of Ulsan and it will be a breakthrough for the development of environmentally-friendly industry" – Mangwoo Park, Mayor of Ulsan (Oh, 2007)

"We will make this Ulsan project as a demonstration project and will diffuse this project to the whole country" – Eungryeol Park, Municipal Waste Team, Ministry of Environment (Mok, 2008)

In 2006, a Swedish biogas company, Scandinavian Biogas Fuels AB (SBF), conducted a pilot project to sub-optimize the digestion process at Jaglim waste water treatment plant in Busan in 2006. From this experience in South Korea, on November 28 2007, SBF signed a new contract with Ulsan Metropolitan city, one of the 6 metropolitan cities (gwangyeoksi) in South Korea, with a population of 1.1 million, to improve the biogas production at Yongyeon sewage treatment plant. SBF basically takes over the operation of the two existing digesters at the plant and invests 18 million dollars, re-designing the process to increase the efficiency and increasing the volume of food waste as additional substrate together with sewage sludge. It is expected that around 180 tonnes of food waste, a half of the total food waste generated in Ulsan every day, will be treated in the new process. As a result of the project, approximately 13,800 Nm^3 of biomethane is expected to be produced after being upgraded. SBF obtained a right to operate the new facility and sell the biomethane for the next 15 years. Then the facility will be given to Ulsan city. It is beneficial to the city government since it can save the amount of money for the new facility investment and also it is expected to be cheaper to treat food waste at Yongyeon than other food waste treatment facilities in the city; approximately saving 10 dollars per tonne of food waste. In addition, the maximization of the digestion process will reduce about 30% of the current volume of sewage sludge.

According to the plan of SBF, in September 2009 biomethane will be produced from the new process. It will be sold to nearby industries as an energy source. However, if distribution infrastructure is established and related legislations are set up in the future, it will be sold as vehicle fuel. The amount of biomethane produced from Yongyeon will be enough to run around 100 CNG buses. There are around 500 buses and 6 garbage trucks currently running on CNG in Ulsan. Like the project in Seoul, Ulsan city also will register its project as a CDM project and create additional income from the project. Ulsan city expects to reduce around 4,700 tonnes of carbon dioxide with the new project.

4.6.3 Biomethane Fuel Project in Gangwon Province

"Ocean dumping of organic waste will be banned from 2012. There are numerous expected benefits in this project. Our province will position itself as a leading province in bio and environment industry" – Gyuseok Cho, Environment Policy Department, Gangwon Provincial Office (Kwak, 2009)

"We are contacting some of Korean municipalities about biogas projects and the success in South Korea will be our step toward other Asian markets including China" - Jean Bernard Collin from SBF (Ryu, 2009a).

"Every week, 5,000 truckfuls of sludge, food waste, and other organic material from Seoul alone are dumped into the sea outside the city. This equals approximately 15 million cubic meters of raw gas sludge a week. Now, with this contract, we will be able to help the Koreans make biogas out of the sludge, replacing gasoline and diesel and providing them with large volumes of renewable and climate-smart fuel." - Per Ewers, CEO at Scandinavian Biogas (SBF, 2007).

In 2006, the Gangwon Provincial Government and Swedish Biogas International mutually agreed to initiate a joint project for the technology transfer to upgrade biogas as a vehicle fuel. After conducting a feasibility study, on April 16, 2008, both parties singed an MoU to start Biomethane Vehicle Fuel Project. They decided to install a facility at Wonju city to upgrade biogas produced from sewage sludge, livestock manure, slaughter house residue, and food waste water. The planned biomethane production facility will be located near Wonju sewage treatment plant and Gangwon slaughter house (2nd largest in the nation) in order to conveniently use the biogas from sewage sludge and slaughter house residue as substrate. The facility will annually produce about 5 million Nm^3 of biomethane from approximately 79 thousand different organic wastes: 16 thousand tonnes of slaughter house residue, 5 thousand tonnes of sewage sludge, 13 thousand tonnes of livestock manure and 45 thousand tonnes of food waste water. Nearby organic waste providers expect to treat their waste in a cheaper way with this new facility. About 73 thousand tonnes of biosludge generated from the production of biomethane will be utilized as organic compost and be sold to farmers.

With this project, the provincial office expects to prepare the future ban on ocean dumping of organic wastes in 2012, to improve air quality, to reduce GHGs emissions in the province and to create additional income from registering the project as a CDM project. The amount of biomethane will be enough to run about 40,000 buses. Thus, Gangwon province set up a long term plan to expand biomethane production facility for vehicle fuels in other cities in the province, to build distribution infrastructure and to replace around 40,000 diesel and gasoline running vehicles with NGVs by 2015. Now, there are 133 buses, 2 garbage trucks, and a few hundred of passenger cars running on CNG in the province with 2 refuelling stations. The provincial office has shown a relatively strong interest in the utilization of biomethane as vehicle fuel and definitely shown their strong will to continue. For example, Gangwon Provincial Office is the only local municipality in South Korea which has a separate team titled 'Biogas Team' under the Environment Policy Department and 4 officials are working now. In addition, the 3rd Asia Pacific Natural Gas Vehicles Association International Conference & Exhibition (ANGVA 2009) will be held in October 2009 at Donghae city and also the 13th International Association for Natural Gas Vehicles (IANGV) Biennial Conference and Exhibition will be held in Chuncheon city in 2012. Both cities are located in the province.

Swedish Biogas International involved in Gangwon and Seoul projects also actively look for various business opportunities in South Korea. The company even provides information in Korean in its homepage (http://www.swedishbiogas.eu/1/1.0.1.0/2/3/index.php), which shows their strong interest in Korean market. There have been interesting political activities between South Korea and Sweden related to biogas development. In February 2009, South Korean Ambassador, Hee-yong Cho, visited Scandinavian Biogas and expressed great interest in biogas as a locally produced sustainable fuel. Just recently in May 2009, Göran Persson, former Prime Minister of Sweden who was mentioned earlier as a person initiating the new national vision, Sweden as a leading 'green country', visited Ulsan city as an advisor from SBF with Erik Danielsson, Chairman of the Board in SBF and had a talk with the mayor of Ulsan about the progress of the biogas project and environmental policies of Ulsan.

4.7 Rationale for the Development of Biomethane as Vehicle Fuel

So far, the background, the situation of potential organic wastes, the level of technology, governmental R&D for biogas technology development, various types of related governmental plans and finally the three ongoing projects have been discussed. In order to promote organic waste-to-energy technologies, the Ministries, researchers, project developers, local municipalities have suggested a number of expected benefits from the utilization of biogas produced from different types of organic wastes especially in the close relation to what the governments, society and international community are concerned about, in other words, rationales for their plans, researches and projects. Admittedly, what rationales to choose and how to emphasize them will greatly influence the level of legitimacy they will achieve for their new technology. Thus, it is important to examine what kind of rationales they have made to promote the development. Even though there have been a various rationales suggested, there are some major ones in common. In this chapter 4.7, those core ones will be emphasized again in depth.

4.7.1 Extreme Energy Dependency

The total primary energy consumption in 2007 in S. Korea was 242.9 million TOE, a 46.4% increase during the last decade while the GDP increase was 63.8% (KEEI, 2008). Since S.

Korea hardly produces energy, it imports 96.5% of its primary energy from overseas. As a result, S. Korea is the 2nd largest importer of coal, the 4th of crude oil, and the 9th of natural gas in the world (IEA, 2007). The self-sufficiency index (energy production/total primary energy supply) of South Korea in 2007 was 0.1873, which is the sixth[3] lowest among OECD member countries and thus much lower than the average (0.6855) (IEA, 2008a).

Therefore, securing energy supply has been always one of the utmost national priorities of the country agenda. After the oil crises in 1970s, the energy mix of S. Korea became more diverse in order to reduce its extreme dependence on oil as we discussed earlier (PMO, 2008c); the share of oil in primary energy consumption became reduced from 61.1% in 1980 to 43.6% in 2006 (PMO, 2008c). The figure 4-7 below shows the latest energy mix in S. Korea. Though reduced, the share of oil still is the largest and non-renewable fossil fuels account for 82.8%. Nuclear energy is also a very significant source of energy and renewable energies is included in the 'others' category taking a very small part of the total.

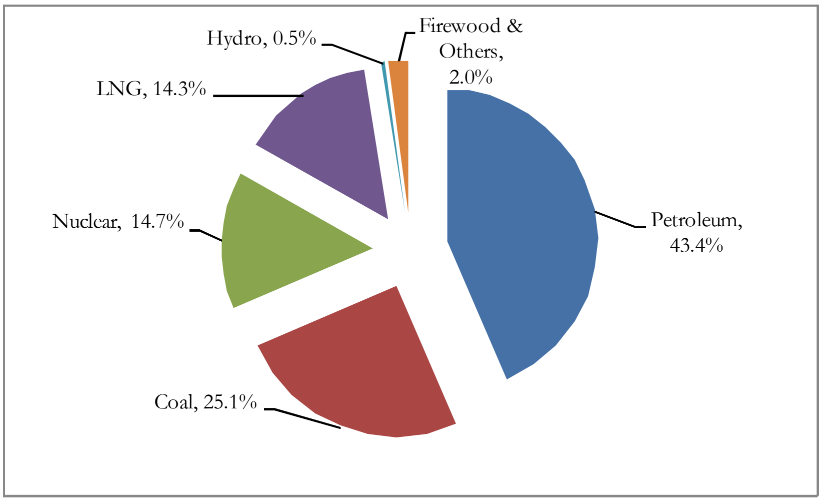

Figure 4-7 Primary Energy Consumption by Source in 2007

Source: KEEI, 2008; NEC, 2008

Extreme dependence on imported oil makes South Korea very vulnerable to the change of international oil price, especially in this era of high oil price. Eshita Gupta estimated the oil vulnerability index of 26 net oil-importing countries in the world. South Korea (0.98) was ranked at the second place after the Philippines (1.11) and categorized in the most vulnerable group (cf. Japan 0.49, Sweden 0.37) (Gupta, 2008). In addition to the high vulnerability, the prices of petroleum are notably very high in South Korea compared to other countries in the world. According to the International Fuel Prices 2007 provided by GTZ (German Technical Cooperation), the retail prices of diesel and gasoline in South Korea were 133 and 165 US cents/litre, respectively the 16th and 7th highest among 171 countries (cf. Sweden: 144-7th and 146-19th respectively (GTZ, 2007). Thus, development of domestically produced renewable fuels in South Korea is a very urgent key issue. The price system of consumer gasoline price in South Korea from March 2009 in average is shown in the figure 4-8 below for reference (Park, 2009).

[3] After Luxembourg, Ireland, Italy, Japan and Portugal. Sweden (0.6578) is similar to the average.

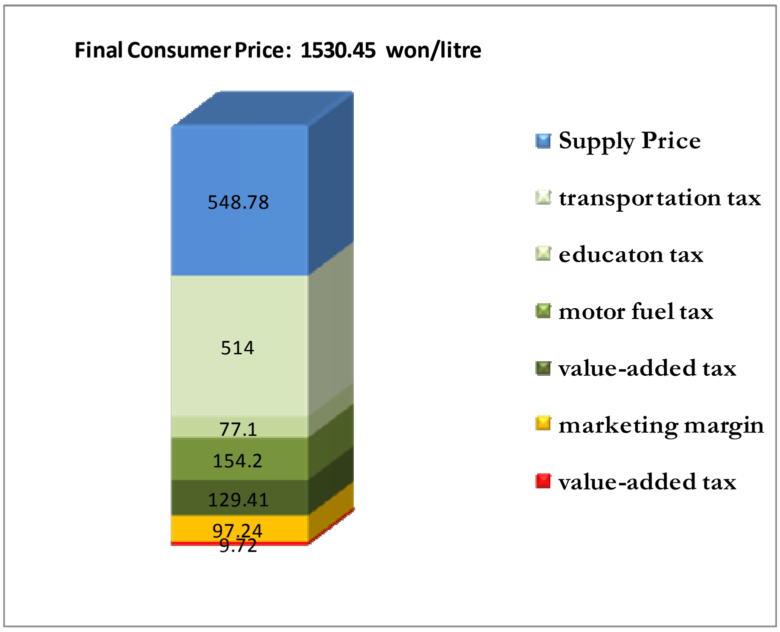

Figure 4-8 Price System of Gasoline in South Korea

Source: Park, 2009

As shown in the figure 4-7 above, natural gas accounts 14.7% of the total primary energy consumption, a rapid increase from 3.2% in 1990. In 2007, S. Korea imported about 33.2 million TOE of LNG mainly from Qatar, Oman and Indonesia and domestically produced 0.35 million TOE. This means that S. Korea depends about 98.5% of its natural gas consumption on import (KOGAS, 2007). About 55% of the total LNG was transformed into city gas and used in different sectors as you see in the table 4-16 below. The share of CNG used for transportation was about 3% of the total CNG consumption; the amount was 615 KTOE (KEEI, 2008). It is expected that the demand for natural gas in South Korea will increase by 54 million TOE in 2030, 2.2% increase every year (PMO, 2008c). However, not only world primary demand for natural gas is expected to grow by about 50% by 2030, but also the price is expected to increase (IEA, 2008). Therefore, the international competition for securing natural gas supply will be much more intense.

Table 4-16 Consumption of Natural Gas in Different Sector in 2007

<table>
<tr><td rowspan="8">Primary Consumption

34.7 MTOE</td><td rowspan="5">City Gas</td><td rowspan="5">55%</td><td>Residential</td><td>51%</td></tr>
<tr><td>Industry</td><td>28%</td></tr>
<tr><td>Commercial</td><td>16%</td></tr>
<tr><td>Transportation</td><td>3%</td></tr>
<tr><td>Public & others</td><td>2%</td></tr>
<tr><td>Electricity Generation</td><td>42%</td><td rowspan="3" colspan="2"></td></tr>
<tr><td>District Heating</td><td>2%</td></tr>
<tr><td>Own Use & Loss</td><td>1%</td></tr>
</table>

Data Source: KEEI, 2008

The First National Energy Master Plan 2008-2030 expressed its major concerns about the continuation of the new era of high oil prices, the increasing alarm on peak oil and the emergence of resource nationalism (PMO, 2008c). Thus, the development of domestically produced biomethane as a vehicle fuel could be one of the strategies to reduce Korea's dependency on imported energy in order to be well prepared to the future risks by substituting imported non-renewable fuels (gasoline, diesel and natural gas) with domestically produced renewable fuels, biomethane. Especially, as the President Lee started the new national vision by saying "the Korean economy is undergoing difficulties stemming from the energy crisis," the contribution of biogas as a vehicle fuel to the less energy dependency could be a very strong rationale to support the idea of introducing biogas fuel, especially considering the fact that biomethane fuel not only reduces energy dependency, but also decreases air pollutants compared to fossil fuels.

4.7.2 A Solution to the Coming Ban on Ocean Dumping

The development of biomethane especially from food waste, food waste water, livestock manure, and sewage sludge can be one of the effective and efficient solutions to prepare for the coming ban on ocean dumping of organic waste. This rationale was mentioned by all interviewees, all governmental plans and most of the newspaper articles concerning the utilization of biogas by organic waste-to-energy. According to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter established in 1972, shortly called the London Convention, the definition of 'dumping' means "any deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures at sea" (IMO, 1972).

Figure 4-9 Ocean Dumping Sites

Ocean dumping has been a long-time practice in South Korea. It has become 'official' since 1978 to protect rivers and the shore and to reduce the load of land waste management and now there are three designated areas, one in the Yellow sea and the other two in the East Sea (B. G. Lee & C. G. Hyun, 2007) as shown in the figure 4-9 above. The amount of dumped wastes had been continuously increasing until 2005 and became almost ten-fold, 9.9 million m^3, compared to 1 million m^3 in 1990 as shown in the figure 4-10 below. With such an enormous amount of waste being dumped in the ocean, serious environmental and health problems have emerged, including marine ecosystem destruction and the detection of the high concentration of heavy metals in seafood from the dumping zone (MOMAF, 2006). As a result, the level of social concerns on ocean dumping has significantly risen in early 2000's and several demonstrations and campaigns against the government by environmental NGOs and fishery industries.

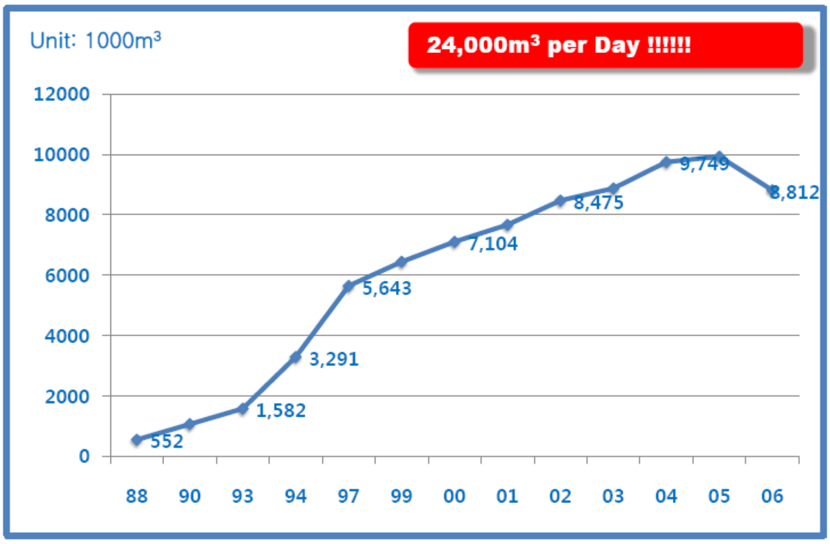

Figure 4-10 Amount of Dumped Waste to the Ocean

Source: www.oceandumping.re.kr

To solve those problems and also to join the 1996 London Protocol, a strengthened international law from the London Convention, the MOMAF (now merged into the MLTM) announced the Comprehensive Improvement Measures against the Ocean Dumping of Land Waste in March 2006 (MOMAF, 2006). The plan aims to establish the land-treatment-first policy and half the amount of wastes currently dumped until 2011 compared to the level of 2005. To reach the goal, it announced the complete ban on sewage sludge and livestock manure from January 2012 and of food waste water from January 2013 (MOMAF, 2006). This means 3,218 livestock industry enterprises and 283 local governments and municipalities should find alternative ways to deal with 5.9 million cubic meters of wastes they used to dump by the planned time. As promised, the government finally ratified the 1996 London Protocol in January 2009 and it was put into force in February 2009. Therefore, the planned ban on ocean dumping of organic waste could be a very strong driver for the utilization of biogas and the rationale of using the amount of organic wastes which will be prohibited to be dumped soon first is adopted in most governmental plans. Of course, it is important to notice that not the total amount of waste will be only treated in an aerobic digestion to produce biogas and also it is more uncertain to predict that the produced biogas from the waste will be upgraded and used as a vehicle fuel considering the lack of technology, infrastructure, legislation and most importantly successful demonstration projects at this moment. However, once the waste is treated in an anaerobic digestion, the chance to be utilized for vehicle fuels later will be there. In addition, an aerobic digestion of the waste to produce energy is a much more sustainable way compared to landfill, compost, and feed as well as meeting the new national vision in many perspectives.

4.7.3 Preparation for the Post-Kyoto Framework

Another frequently mentioned rationale for the utilization of biomethane as a vehicle fuel is that utilizing biogas from organic waste as a vehicle fuel can be one of the effective and efficient strategies for South Korea to tackle the seemingly most important contemporary global environmental issue, climate change. South Korea has a very unique position in the Kyoto Protocol (KP) as shown in the figure 4-11 below. Even though, it is a member of OECD since 1996, it was recognized as a Non Annex I party, a developing nation, to the KP when it was signed in 1997, because it was a developing nation when it joined the UNFCCC in 1992 and it developed rapidly from 1992 to 1997. Being put into a category of Non-Annex I, South Korea was not given an obligatory target for GHGs emissions reduction.

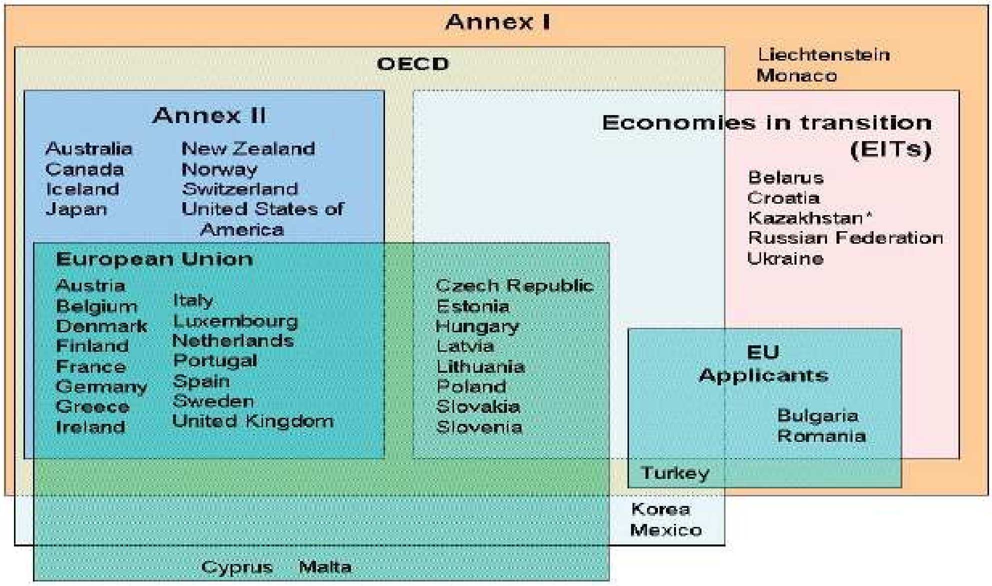

Figure 4-11 Position of South Korea in the Kyoto Protocol

Source: Zsuzsanna Ivanyi, Regional Environmental Center

	1990			2005								
Country	Total CO_2	PC CO_2	GDP PC	WR	% of world	Total CO_2	T Δ 90-05	PC CO_2	PC Δ 90-05	GDP PC	GDPΔ 90-05
US	5002	20.0	28263	1	21.1%	5957	19%	20.1	1%	37267	32%
CHINA	2241	2.0	1625	2	18.9%	5323	137%	4.1	105%	6012	270%
RUSSIA	2044	13.8	10270	3	6.0%	1696	-17%	11.9	-14%	9648	-6%
JAPAN	1009	8.2	23691	4	4.4%	1230	22%	9.6	17%	27817	17%
INDIA	575	0.7	1655	5	4.1%	1166	103%	1.1	57%	3072	86%
GERMANY	924	11.6	21303	6	3.0%	844	-9%	10.2	-12%	26210	23%
CANADA	469	16.9	22833	7	2.2%	631	35%	19.2	14%	29693	30%
UK	599	10.4	21605	8	2.0%	577	-4%	9.5	-9%	29571	37%
S.KOREA	241	5.6	9814	9	1.8%	500	107%	10.3	84%	19598	100%
ITALY	413	7.3	21701	10	1.7%	467	13%	8.0	10%	25381	17%

Figure 4-12 Top Countries with High CO2 Emissions (From the Consumption and flaring of fossil fuels)

Data Source: Energy Information Administration (EIA) in the US and World Bank

1) Total -million metric tons, Per Capita (PC) -metric tons (Data Source: EIA in the US)

2) GDP PPP per capita, Constant 2000 International US$ (Data Source: World Bank)

3) Highlighted countries: Annex I Parties, Non-highlighted countries: Non-Annex I Parties

4) Russian and German figures of CO2emission in 1990 are from 1992(RU) and 1991(GE) figures respectively.

However, unlike Mexico and Turkey who are exempted from the KP and the members of OECD as well, Korea's contribution to the climate change is very significant in terms of both total and per capita GHGs emission as shown in the figure 4-12 above. In 2005, the total amount of GHGs emissions in South Korea was 9th largest in the world and even per capita emission was as high as other developed countries, even slightly higher than that of the UK and Japan, which significantly differentiates the position of South Korea among Non-Annex I parties, especially compared to China and India. According to the statistics of the Energy Information Administration in the US, the increase of the total emission in S. Korea between 1990 and 2005 was the highest among OECD countries, more than doubled (107%). Now, carbon intensity of S. Korea is one of the highest among in OECD. Therefore, there is almost no doubt to expect to be given an obligatory target for its GHGs emissions reduction in whatever forms in the post-Kyoto framework. It is not the matter of whether South Korea receives a target, but the matter of how strict target will be given compared to other Non-Annex I parties and whether the target is set up based on certain year or on business as usual scenario as South Korea is actively promoting now.

The exemption from the KP does not mean that South Korea did nothing about 'tackling' climate change or 'preparing Post-Kyoto' framework, more precisely speaking. The South Korean government has made four National Action Plans for Climate Change since 1999.

Yet, it is believed that the impact has not been very significant (PMO, 2008b). About one month after the president address for 'Low Carbon, Green Growth', the Prime Minister's Office established the Comprehensive Basic Plan for Climate Change (기후변화대응 종합기본계획) (PMO, 2008b). According to the plan, there will be strong governmental drives to be actively involved in the global efforts to mitigate climate change such as improving carbon intensity, introducing a carbon tax and emission trading scheme, and doubling R&D investment for climate change (PMO, 2008b). As follow-up plans, 9 Ministries, 2 Administration, 1 Service and 1 Agency jointly established the National Mater Plan for Climate Change (국가 기후변화 적응 종합계획) for 2009-2030 (PMO, 2008a). According to the plan, 88.6% of general public does recognize climate change a serious problem but the level of understanding on climate change adaptation. In addition, the depth of understanding on the risk of climate change among policy makers is turned out to be low. Thus, it defines the current situation of South Korea on the strategies for climate change adaptation is in a stage of problem recognition.

Now, the transportation sector accounts about 20% of the total emission in South Korea. However, it seems that there are not many effective strategies to reduce GHGs in this sector at this moment. First of all, the government is planning to increase the number of CNG buses. When inner city diesel bus fleets are replaced with CNG buses, greenhouse gas emissions is significantly reduced. However, natural gas is not a renewable fuel but a fossil fuel, still causing global warming. Secondly, it is generally known that the governmental plan to develop and commercialize electric and fuel-cell vehicles will not happen in near future. Finally, in terms of other types of biofuels such as biodiesel and bioethanol, the supply of biodiesel (BD5 & BD20) started in 2006 driven by international trend to regulate GHGs emissions and the supply of bioethanol is under consideration now. The government set up a distribution target of biodiesel as shown in the table 4-17 below. It is expected to meet the target this year since (KEMCO, 2008). Since the distribution of biodiesel can revive rural area, the MKE, the MAF and the ME all are very much interested in the expansion (KEMCO, 2008). Furthermore, the government is planning to introduce RFS (Renewable Fuel Standards) to promote further distribution of biodiesel.

Table 4-17 Biodiesel Distribution Targets

year	2006	2007	2008	2009	2010	2011	2012
Target kL/yr	100,000	100,000	200,000	300,000	400,000	500,000	600,000
BD ratio,%	0.5	0.5	1	1.5	2	2.5	3

Source: KEMCO, 2008

In conclusion, the expansion of biodiesel seems the only renewable-fuel policy in the transportation sector to reduce GHGs emissions in near future. Utilizing biogas as a vehicle fuel can significantly reduce GHGs emission as demonstrated in Sweden. Even though, the exact reduction should be carefully estimated for specific cases in South Korea considering what substrate is used, how biogas is produced, upgraded, and distributed with which technology as well as what is replaced by biomethane, it is clear that the amount of reduction will be much bigger compared to the use of CNG, BD5 and BD20. The discussion on GHGs emissions reduction in South Korea will be much stronger year by year and this rationale can be an interest for many different governmental ministries, local municipalities and private companies. Thus, it is quite important for the proponents of biogas for vehicle fuels to strategically take most advantage out of this rationale if they desire higher levels of support.

4.7.4 Positive Experience of CNG Bus

Besides the three major rationales discussed above, there are other aspects of the South Korean situation favourable to the development of biogas as a vehicle fuel. Firstly, the existing CNG buses in the country and the positive past experience with the buses are frequently mentioned by interviewees. After testing the environmental characteristics, safety, and engine performance of the CNG bus from 1998 to 2000, the Korean government introduced CNG buses mainly for the 2002 World Cup hosting cities in order to reduce city air pollution caused by diesel buses (Lee, n. d.). With strong governmental financial and legislative support, there are now 16,538 buses are running on CNG in S. Korea and 121 public refuelling stations are spread out all over the country, mainly in Seoul, six Metropolitan Cities and Gyeonggi Province (GVR, 2008).

Now, the introduction of CNG buses is considered as one of the successful environmental policies due to its excellent environmental performance and safety (Lee, n. d.). In January 2009, the Research Institute of Public Health & Environment reported that the introduction of CNG buses in Seoul significantly contributed to the improvement in air quality; especially the level of PM10 was marked the lowest since the monitoring started in 1995 (RIPHE, 2009). From this positive experience of CNG buses, many local governments and municipalities are planning to increase the number of CNG buses. For example, Seoul Metropolitan Government has a plan to increase the share of CNG buses in total urban bus fleet from the current 70% to 100% by 2010 (RIPHE, 2009). In addition, the Ministry of Environment reported its goal to replace all urban diesel buses in Korea with CNG buses by 2012 in its recently announced Environmental Action Plan for Green Growth (ME, 2009b). This positive experience can be a strong driver for the development of biogas as a vehicle fuel, because it secures stable end-use demand for upgraded biogas, installs necessary infrastructure and finally promotes better understanding of CNG buses among public.

4.7.5 Existing Natural Gas Pipeline

The Korea Gas Corporation (KOGAS), a public corporation, was established in 1983. Because it is exclusively in charge of import and distribution of natural gas in South Korea, the KOGAS imports the largest amount of natural gas in the world as a single organization with 19 LNG carriers. It distributes LNG to 17 power stations and 30 city gas companies all over S. Korea through a nationwide 2,715 km long pipeline network and by tank lorries (KOGAS, 2006). Then city gas companies directly provide the natural gas to consumers. The LNG is first transformed into city gas and used for industry, transportation, residential, commercial and public and others sector. The transportation sector used 615 thousand TOE of city gas. This existing pipeline grid is very favourable for the development of biogas. Regardless of which end-use service the biogas is utilized for, injection to the existing pipeline network is a good system to maximize the use of produced biogas (Lantz et al., 2007). Also, the mixture use of upgraded biogas and natural gas can secure a stable supply for final services since the production of biogas is not as stable as the provision of natural gas (Eriksson & Olsson, 2007). Lastly, government has a plan to increase the length of the grid from 2,715 to 3,585 km by 2030 (PMO, 2008c). Thus, the countrywide existing pipeline network is a clear advantage for S. Korea to develop biogas compared to those countries which do not have such infrastructure and thus it is a strong rationale for the promotion of biomethane as a fuel for transport.

5 Analysis and Discussion

5.1 Components of Biogas TIS for Vehicle Fuel in South Korea

5.1.1 Actors

The table below summarizes the three ongoing biogas projects for vehicle fuels in South Korea at the moment in terms of resource supply, production, upgrading, distribution and final consumption based on the information obtained from interviews and supplemented with newspaper articles. It is expected that the Seoul and Ulsan projects will produce biomethane very soon while the Wonju project has not started the construction for production and upgrading facilities yet. Thus, if we exclude the Wonju project, the current actors in the biogas TIS for vehicle fuel in South Korea are two municipalities (Seoul and Ulsan), two sewage water treatment plants (Seonam and Yongyeon), and two Swedish companies (SBI, SBF). Additionally, several Ministries, such as the Ministry of Knowledge and Economy (MKE), the Ministry of Environment (ME) and the Ministry for Food, Agriculture, Forestry and Fisheries (MIFAFF), are engaged in the biogas TIS through their related plans and regulations.

Table 5-1 Biogas Projects for Vehicle Fuel in South Korea

<table>
<tr><th></th><th>Resource Supply</th><th>Production</th><th>Upgrading</th><th>Distribution</th><th>Consumption (Nm^3/day)</th></tr>
<tr><td>Seoul</td><td>SS from Seonam STP</td><td>Existing biogas production at Seonam STP</td><td>Korean-Swedish joint venture (Seonam, EH, GBL, and SBI)</td><td>Existing Grid</td><td>4,200 (Existing CNG Buses)</td></tr>
<tr><td rowspan="2">Ulsan</td><td>SS from Yongyeon STP</td><td rowspan="2" colspan="2">Co-digestion (SBF)</td><td rowspan="2">Under consideration</td><td rowspan="2">13,800 (Nearby industries)</td></tr>
<tr><td>FW from Ulsan City</td></tr>
<tr><td rowspan="4">Wonju</td><td>SS from Wonju STP</td><td rowspan="4">Co-digestion (Wonju city & SBI)</td><td rowspan="4">Wonju city & SBI</td><td rowspan="4">Under consideration</td><td rowspan="4">13,700 (CNG Buses)</td></tr>
<tr><td>Slaughter house Residue from Gangwon SH</td></tr>
<tr><td>LM from nearby livestock industry</td></tr>
<tr><td>FWW from FWTP</td></tr>
</table>

The potential of new actors entering the market is very big. For resource supply, livestock industries, farmers, sewage treatment plants, landfill sites, food industries, food waste treatment plants, big restaurant chains and slaughter houses throughout the nation are potential actors. For the production sector, as surveyed by the ME recently, there are already 38 organic waste-to-energy facilities using food waste, food waste water, livestock manure, and sewage sludge with anaerobic digestion technology. They are very strong candidates since those facilities treating food waste water and livestock manure already have been mentioned in the latest organic waste-to-energy plan from the ME as discussed earlier. Thus, assuming that there will be construction of new anaerobic digestion facilities for the amount of organic wastes which are not currently treated with AD technology, the number of actors in production is likely to be increased significantly. For the upgrading process, as emphasized many times before, there is no Korean company offering upgrading technology of biogas at this moment. Sole reliance on the foreign technology for upgrading will last for quite some time. However, since the upgrading technology is not particularly complicated and considering the fact that there are governmental plans to support R&D of biogas upgrading technology and there will be a technology transfer in the future between the Korean partner and the Swedish company in the three ongoing projects, the dominance of foreign technology in upgrading field will be challenged by the domestic industry.

In terms of the distribution of biomethane, it might be inevitable for biogas producers to closely cooperate with 33 local city gas distributors who own the exclusive right to supply natural gas in their regions by law. In fact, the distributors do not have a right to control in case of biogas. However, since the cost for installing new pipelines is considered very expensive, it is reasonably expected that there will be a close cooperation between biomethane producers and local city gas distributors in any forms of contract. Therefore, local city gas distributors are expected to be main actors in distribution. Regarding this aspect, Göteborg in Sweden might be a good model since it mixes biomethane with natural gas in the existing pipeline. For the end-users of biomethane, the existing 17,000 CNG buses are very strong potential candidates. There are also passenger cars running on CNG. However, the number is too small (approximately 800 vehicles) to be main consumers yet. Like Sweden, public buses are expected to be anchor customers in a formative period.

Although no universities are specifically researching the utilization of biogas as a vehicle fuel, there are universities researching the production and utilization of biogas in general such as Department of Environmental Engineering at Seoul Nation University, Hankyung National University Biogas Research Center, and Department of Environmental Engineering at Hanbat National University. In addition, the Bioenergy Research Center in the New and Renewable Energy Research Division at Korea Institute of Energy Research, Korea Gas Corporation, Korean Association for Natural Gas Vehicles, Korea Environment and Resources Corporation and Environmental Management Corporation are potentially important actors related to their research and activities.

5.1.2 Networks

Again, since it is the very beginning of a formative period, it was difficult to find any significant networks specifically formed for the biogas TIS for vehicle fuel in South Korea. However, there was a "Waste-to-Energy Forum" from July to December 2007, initiated by the Ministry of Environment, where various experts from governments, universities and private companies meet together twice per month to discuss various waste-to-energy issues including the utilization of biogas from organic wastes. As a follow-up forum, the "Waste and Biomass to Energy Forum" started in November 2008 (ME, 2008b). Also, Korea Gas Corporation, Environmental Management Corporation, Korea Environment and Resources Corporation, and Korean Association for natural Gas Vehicles organize a joint seminar to study LNG and biogas as a fuel for transportation. Additionally, there was a seminar in April 2009 on Strategies for Growth in the Biomass Industry organized by Korea Institute of Energy Research at the 2009 Green Energy Expo Conference in Daegu where around 200 participants discussed biogas for vehicle fuel as one of the agenda for the seminar. Finally, as mentioned earlier, the ANGVA 2009 will be held this year in Gangwon province and again one of the themes of the conference is biomethane as vehicle fuel. It will be an important venue for various actors to share information and form various networks.

5.1.3 Institutions

In case of hard institutions, Waste Management Act (폐기물관리법), Management and Utilization of Livestock Manure Act (가축분뇨의 관리 및 이용에 관한 법률), Petroleum and Petroleum Substitute Fuel Business Act (석유 및 석유 대체연료 사업법), Clean Air Conservation Act (대기환경보전법) and City Gas Business Act (도시가스사업법) are directly related laws for the utilization of biogas as a vehicle fuel produced from different types of organic waste. To support the development of biogas as a vehicle fuel, these legislation need to be amended. The definition of biogas has been added into Petroleum and Petroleum Substitute Fuel Business Act. However, once the three ongoing projects prove the utilization of biogas as a vehicle fuel is technologically stable, environmentally desirable and economically viable, there will be a strong push to further amendments of the legislation. In addition, a vehicle fuel standard for biogas currently being prepared by the MKE will be a significant regulation. In case of soft institutions, there are many norms and cognitive rules prevalent in the biogas TIS for vehicle fuel. To name a few, the new national vision, 'Low Carbon, Green Growth', is very influential as an umbrella rule. In terms of waste management, the principle of waste-to-energy is getting more and more attention as one way to achieve sustainable waste management. In addition, general public agree that dumping of organic waste in the ocean cannot be continued. Also, being locally produced and being renewable are becoming important for the development of new energy source.

5.2 Blocking Mechanisms

Jacobsson and Bergek (2004) identified some of the general blocking mechanisms for some of renewable energy technologies to be diffused. The mechanisms are high uncertainty, lack of legitimacy, weak connectivity, ambiguous behaviour of established firms and government policy (Jacobsson & Bergek, 2004). In addition, lack of some core technologies, governmental support, necessary legislation and human resource are typically observed barriers in a formative period for a new TIS to be diffused. These blocking mechanisms are generally found in the biogas TIS for vehicle fuel in South Korea as well. In this chapter, two blocking mechanisms in particular to the current biogas TIS system for vehicle fuel in South Korea are discussed.

5.2.1 Lack of Knowledge

Almost all interviewees mentioned the lack of understanding of biogas as a main barrier for the development of biogas as a vehicle fuel in South Korea. It is understandable that the general public is not accustomed to biomethane as a vehicle fuel since there has been no example of such application in the country yet. The level of understanding in the government on the utilization of biogas as vehicle fuel has been improving little by little as shown in the table 5-2 below in a chronological order. It usually had not been mentioned at all or a little bit in the documents in 2007 and 2008 and finally became recognized clearly in the latest document.

Table 5-2 Mentioning on Biogas as Vehicle Fuel in Various Governmental Plans

Publisher	Title	Biomethane as Vehicle Fuel
MKE (Nov 2007)	Renewable Energy RD&D Strategy 2030 - Bioenergy for Transport (180 pages)	It recognizes that methane gas produced from organic waste is one of the bioenergy types, but It considers only biodiesel and bioethanol under the category of 'bioenergy for transport'.
MKE (Nov 2007)	Renewable Energy RD&D Strategy 2030 - Bioenergy for Transport (235 pages)	The development of biogas system for vehicle fuel is clearly mentioned as one of the R&D sectors to focus on in the utilization of organic waste.
ME (Dec. 2007)	Master Plan of Inland Treatment and Resourcization of Food Waste Water 2008-2012 (25 pages)	It not only clearly awares the utilization of biogas as a vehicle fuel is one of the options, but also promotes it as a strategy of dealing with FWW. In addition, it suggests necessary legislative changes and development strategies of such application.
ME (May. 2008)	Waste-to-Energy Master Plan (111 pages)	The utilization of biogas from organic waste is one of the major contents of the plan. However, the utilization as vehicle fuel is hardly discussed. It mentions just once that there is a LFG to vehicle fuel project.
ME (May. 2008)	Sewage Sludge Master Plan (63 pages)	Not mentioned. It only mentions sludge-to-solid fuel method and electricity generation from biogas
PMO (Aug. 2008)	National Energy Master Plan 2008-2030 (179 pages)	Mentioned once. GTL (Gas-to-Liquid), CTL (Coal-to -Liquid) and BTL(Biomass-to-Liquid) are mentioned under the 'Oil Free in Transportation' sector and hybrid, electric and fuel-cell vehicles are mentioned as next generational vehicles.
ME (Sep. 2008)	Waste Resource and Biomass to Energy Master Plan (115 pages)	Mentioned many times. The utilization of biogas produced from food waste water, landfills, and livestock manure as vehicle fuel is clearly stated. Moreover, necessary legislative changes and detail plan for the construction of biogas facilities are stated.

In addition, research on biofuels from think tanks, such as the Korea Energy Economics Institute (Jeonghwan Bae, 2006) and Samsung Economic Research Institute (Kang, 2007), did recognize biogas produced from organic waste as a part of the bioenergy system, but when it comes to biofuels they only considered biodiesel and bioethanol. Finally, industries lack technologies and experiences to develop biogas technology for vehicle fuels. As mentioned earlier, the level of technology in energy transformation and utilization of organic waste is about 65-70% of the level of leading countries and the failure of anaerobic digestion in 1990s were mainly due to the lack of accumulated domestic knowledge and effective timely feedback from foreign technology and equipment providers. Therefore, it will take time for Korean society to become aware of and accumulate the necessary information and knowledge on biogas from organic waste as one type of biofuels. Success of any of the three ongoing projects will most likely accelerate the understanding on the technology.

5.2.2 Hindrance from Dominant Actors

Bergek, Jacobsson and Sandén (2008) argue that it is difficult in particular in energy and transport sectors for a new TIS to acquire legitimacy since incumbent technologies, actors and institutions have secured their positions for a long time and they usually block the development of new TIS. The development of biogas TIS for vehicle fuel in South Korea is not an exceptional case in this respect.

In order to be officially recognized as a vehicle fuel in South Korea, biogas needs to be clearly defined as a vehicle fuel in Petroleum and Petroleum Substitute Fuel Business Act. The Petroleum and Petroleum Substitute Fuel Business Act had not recognized biogas as a vehicle fuel but finally added the definition in the Article 5(8) of the Enforcement Decree of the act on April 30. However, still the Act needs to be further amended in terms of the production, distribution and sale of the biogas fuel. Among different biofuels, only biodiesel is supplied in South Korea and five major oil refinery companies (Korean National Oil Corporation, SK Energy, Hyundai Oilbank, S-Oil, and GS Caltex) have an exclusive right to distribute biodiesel. Thus, it is firmly blocked for other actors to enter their business. For example, in 2007, in close cooperation with local farmers, Buan county in North Jeolla Province tried to provide biodiesel from rapeseed for school buses, but it was tackled by the incumbent actors as a violation of the Act and finally halted (Y. Lee, 2008). It is generally believed that it might be quite difficult for any biofuel developers including biogas to do their business without the cooperation/consent from the five powerful dominant actors.

In addition, stimulated by the increased number of modified CNG passenger cars from 48 in 2006 to 719 in 2007, on February 26 2009, the Korea LPG (liquefied petroleum gas) Association had its regular annual meeting and decided to visit the ME and MKE many times in 2009 to strongly protest against the engine modification of diesel vehicles into CNG vehicles and to visit the Congressman's office who proposed a law to financially support the cost for the CNGV engine modification. Also, they are planning to propose policies to limit the type of vehicles running on CNG and increase the tax on CNG similar to other types of vehicle fuels (Song, 2009). Lastly, even though it is not clear whether the 33 local city gas distributors, with their exclusive right to supply natural gas in their regions through existing pipelines, will be favorable to receive upgraded biogas into their grid or not, they might be reluctant to cooperate if biomethane does not guarantee the same quality of imported natural gas or does not provide additional economic benefit to them.

In conclusion, LPG industry has clearly shown their position against the diffusion of CNG passenger cars and there are some possibilities for major oil distributors and local city gas providers not to support the development of biogas as vehicle fuel. Especially, considering the fact that each group has formed a coalition acted together for their common interests, it will be very problematic for the biogas TIS for vehicle fuels to be against their dominance.

5.3 Nuclear versus Renewable

Sandén and Jonasson (2005) explicitly stated that "nothing related to energy in Sweden escapes the issue of nuclear power". In case of renewable energies in Sweden, the relationship with nuclear has been generally negative, even described as 'nuclear power trauma'. Due to the incompletely solved dispute between pro and anti nuclear groups regardless of the referendum, whatever discussion on renewable energy was understood only "as a substitute for nuclear power" and any plan to encourage further promotion of renewable energies had to be "justified in that context" (Jacobsson & Bergek, 2004). This trauma tackled the development of renewable energy in Sweden in two major ways. Firstly, the value of each renewable technology was always underestimated by "how many nuclear power reactors it might replace", which not only significantly weakened its legitimacy but also misguided people to recognize its growth potential. Secondly, renewable energy had a hard time to get support from the capital goods industry. Firms were reluctant to enter the renewable energy industry, because the interest in renewables was perceived as a betrayal of Swedish industry which had significantly benefited from the nuclear power in the past (Jacobsson & Bergek, 2004).

However, for the development of biogas as a vehicle fuel in Sweden, a different story took place (Sandén & Jonasson, 2005). After the 1980 referendum on nuclear power caused by the 1979 Three Mile Island Accident in the US, the Swedish government changed its position on the introduction of natural gas, from 'no' in 1979 to 'yes' in 1980. This decision led to the introduction of CNG buses in Malmö which in turn enabled the emergence of biogas running buses a few years later. Then in 1988, two years after the Chernobyl accident, given from previous political changes, the Swedish government had four incompatible goals; 1) low electricity prices for the basic industry, 2) preservation of unexploited rivers, 3) a cap on carbon dioxide emissions and 4) nuclear phase-out. To solve the puzzle, the ruling party, the Social Democrats made an agreement with the Liberal Party and the Centre Party to get rid of the cap on carbon dioxide and the initial date for the nuclear phase-out. Instead of compromising its strongest anti-stance on nuclear, the Centre party succeeded in achieving subsidies for CHP running on biomass and for the development and demonstration projects of ethanol. Also, the cancellation of the extension plan of the existing natural gas pipeline was decided in order to keep away from competition with biomass. As a result from this so-called 'three party agreement', a development and demonstration program of biofuels was launched in 1992. As explained earlier in Chapter 3, this program and the decision of not expanding the pipeline positively influenced on the development of biogas as a vehicle fuel.

Although this special relation between nuclear and renewable energy in Sweden cannot be applied to other countries in general, biogas TIS for vehicle fuel in South Korea has also an interesting relation to nuclear energy and it is worthwhile to be discussed. Korea is the world 6th largest producers (149 TWh) of nuclear energy after the US, France, Japan, Germany and Russia. There are 20 nuclear power plants in operation and additional 6 units are under construction. The share of nuclear in total domestic electricity generation is about 37% (installed capacity 26%). As shown in the table 5-3 below, the First National Energy Master Plan 2008-2030 announced that the share of nuclear in primary energy supply will be increased from 15.9% to 27.8% by 2020 while the share of renewable energy will be increased from 1.9% to 10.7%. With this target, the share of nuclear in total electricity generation will be almost 60% by 2030. To achieve the goal, there will be about 6-10 additional nuclear power plant construction.

Table 5-3 Share of Different Types of Energy in Primary Energy Consumption

	2006	2020	2030
Oil	43.6%	26.2%	33.0%
Coal	24.7%	23.2%	15.7%
LNG	13.7%	11.9%	12.0%
Nuclear	15.9%	22.1%	27.8%
RE	1.9%	5.8%	10.7%
Fossil Fuel	82.0%	61.3%	60.7%

Source: PMO, 2008c

The Master Plan states that nuclear energy is "the most realistic alternative to actively prepare the new era of high oil price and climate change". Also, as mentioned earlier, the expansion of nuclear energy supply and of the people's acceptability on nuclear' is one of the main tasks in the Master Plan, thus, one of the key strategies in Low Carbon, Green Growth.

Table 5-4 Share of Annual Budget for Green Tech Development

	2008	Share	2009	Share	Change 2008-2009
Green Tech Development	**10,812**	**100%**	**13,071**	**100%**	**20.9%**
Renewable Energy	2,079	19.2%	2,424	18.5%	16.6%
Nuclear, Nuclear Fusion	3,775	34.9%	4,683	35.8%	24.1%
Env-Friendly Industry	1,324	12.2%	1,375	10.5%	3.9%
Green Car, LED, etc	372	3.4%	662	5.1%	78.0%
Climate Change Related	3,262	30.2%	3,927	30.0%	20.4%

Data Source: Korea Environment Council, 2009

The table 5-4 above shows that how much budget is allocated in 2008 and 2009 to the 'Green Tech Development' sector, one of the 4 sectors in Low Carbon, Green Growth. There are 5 sub-groups in the sector including nuclear technology. It is arguable that whether nuclear is a green technology or GHGs-free technology. However, it is strongly advertised as a green and carbon-free technology in South Korea. In fact, South Korea, together with Japan, is actively lobbying to include new nuclear facilities to be eligible for CDM in the Post-Kyoto mechanism. In line with the distinct pro-nuclear stance, the largest amount of money was spent for the development of nuclear technology in 2008 and will be a top recipient in 2009 as well. While the volume of budget for nuclear increased by 24.1% and its share increased from 34.9% to 35.8%, the volume of budget for renewable increased by 16.6% and the share decreased from 19.2% to 18.5%. Therefore, several scholars and environmental NGOs have argued that the nuclear-focused new national vision is not 'low carbon, green growth' and the target and support for renewable energies should get more attention (S. Hong et al., 2009; Korea Environment Council, 2009). It is too complicated to conclude whether nuclear energy should be strongly focused in South Korea to achieve Low Carbon, Green Growth or not in this research. However, it might be concluded that the renewable energy development will be more supported if the government moves away its strong focus on nuclear.

There is no direct relation between nuclear energy and biogas as a vehicle fuel since nuclear does not provide fuel for vehicles. However, the strong focus on nuclear development in South Korea might influence on the development of biogas in two opposite directions, positive and negative. If biogas developers choose to utilize biogas for vehicle fuels since there are less incentives and supports for electricity generation due to the strong focus on nuclear, then the impact would be positive. However, if it is assumed that biogas technology system would have got much more support to grow, if there had not been strong focus on nuclear, then the impact might be negative. In addition, considering the facts that strong focus on nuclear took away more chances for general public to be exposed renewable energies in general, the impact might be negative. In conclusion, the impact of the dynamics between nuclear and renewable energies in South Korea on the development of biogas as a vehicle fuel is not very clear at this moment, but since the government and environmental NGOs see the relation as incompatible, the strong focus on nuclear might be a barrier for the development of biogas as a vehicle fuel.

5.4 Legitimation Strategies

As discussed in the beginning, legitimacy is not given but can only be achieved through conscious actions by various actors in a socio-political process of legitimation (Aldrich & Fiol, 1994; Bergek, Jacobsson, & Sandén, 2008). The most common strategy is to conform to established institutions (Bergek, Jacobsson, & Sandén, 2008). As discussed earlier, there are several established institutions favourable for biogas fuel to conform to, for example, the target for oil dependency and renewable energy set by the National Energy Master Plan, the various targets and plans set by the Waste Resource and Biomass to Energy Plan for each type of different organic waste, the future ban on ocean dumping, expansion plan of CNG buses, and Low Carbon, Green Growth. Also, the coming national target for GHGs emission which will be given from the Post-Kyoto discussion in 2009 will be a very favourable institution for biogas fuel proponents. However, some of these institutions do not recognize the role of biogas as a fuel in their plans or recognize a little on biogas utilization as a vehicle fuel. To promote biogas as a vehicle fuel, the retail prices of different fuels in South Korea need to be further emphasized. Compared to the economy level of South Korea expressed in GDP per Capita, the prices of natural gas for industry, unleaded premium and automotive diesel oil are mostly similar or higher to the prices of other further developed countries. Furthermore, the price of electricity for both industry and households are by and large lower than the others. Therefore, this current price system provides a favourable opportunity for biogas as a vehicle fuel. Assuming that the price of oil and natural gas will continue to increase in a long term, the argument for biogas for transport will be stronger.

Table 5-5 Retail Prices [(a)] of different Fuels in Selected Countries in US Dollars/Unit

	Korea	Sweden	Japan	UK	France	US
Heavy Fuel Oil For Industry (tonne)	**514**	915	516	465	318	308
Light Fuel Oil for Households (1,000 litres)	**922**	1328	598	680	764	645
Automotive Diesel Oil (litre)		1.21	0.75	1.52	1.12	0.67
Unleaded Premium litre	**1.52**	1.56	1.15	1.71	1.56	0.62

Nat Gas for Industry (107 kcal GCV)	**504**		402	379	394	305
Nat Gas for Households (107 kcal GCV)	**659**		1246	801	752	464
Electricity for Industry (kWh)	**0.07**		0.12	0.13	0.05	0.06
Electricity for Households (kWh)	**0.10**		0.19	0.22	0.15	0.10
		OECD				
Automotive Diesel Oil (2006)(b)	**1554**	1541	1179	2219	1621	
GDP PPP per Capita, (2005)(c)	**19598**	28937	27816	29571	27033	37267
GDP per Capita, (2005)(d)	**13210**	29954	39075	26891	23494	37267

(a) Prices are for 1st quarter 2007 or latest available

(b) This data from (PMO, 2008c), US$/toe

(c) This data from UNEP GEO Data Portal, Constant 2000 International US$ per person

(d) This data from UNEP GEO Data Portal, Constant 2000 Constant 2000 US$ per person

Source: IEA, 2007

Secondly, legitimation can be achieved from technology assessments (TA) by experts. In a formative period, general public lack of knowledge and experience of a new technology. Thus, technology assessments can provide necessary information on the performance of the new technology and its potential to be developed. However, as emphasized by Bergek, Jacobsson and Sandén (2008), the role of TA is 'not unproblematic'. The technology assessments usually cannot provide "universally relevant, acceptable as well as stable system boundaries and performance criteria" and be dependent from its political nature (Bergek, Jacobsson, & Sandén, 2008). Thus, a result of a TA might be significantly challenged by another TA. There have been no researches which can be considered as a technology assessment in the field of biogas as a vehicle fuel in South Korea yet. The latest Waste Resource and Biomass to Energy Plan from the Ministry of Environment provides information on how much GHGs emission might be reduced from the production of biogas by simply multiplying the amount of methane production by 21 (global warming potential of methane). Even considering the limitation that there is no biogas vehicle in South Korea, the estimation looks too simple. To be further legitimized, well-to-wheel analysis of a specific case need to be done, precisely estimating how much GHGs emission could be reduced during the resource exploitation, production, distribution and consumption of a functional unit of a biogas, biodiesel, bioethanol, diesel, gasoline, natural gas and other possible fuel options.

Thirdly, the legitimation can be established "on the accumulation of actors in a TIS, the experience of and familiarity with a new technology as well as trust in various actors supporting it" (ME, 2008b). As discussed, the potential of new entry of actors in biogas TIS for vehicle fuel in South Korea is very high. Many municipalities and stakeholders are waiting for the result of the 3 ongoing projects. As mentioned in the beginning, the role of a 'prime mover' is very important in a formative period. In case of Sweden, Volvo and Göteborg and Linköping municipalities were prime movers in the early phase of the development. Especially in terms of Volvo participation, it was a main strategy of the biogas fuel coalition to enrol the Swedish car companies to make the use of their vehicle technology as well as their political power (Bergek, Jacobsson, & Sandén, 2008). Similarly, Hyundai Motor Company, Korea Gas Corporation, and Seoul city might be prime movers in South Korean biogas fuel development. Since Hyundai has about 50% of domestic automobile market share and produces CNG buses, it will be very influential if they become more active in the development of biogas TIS for vehicle fuel. The active participation of Seoul city will bring a significant impact to the development as well considering its huge population (10 million) and the amount of organic waste it produces. In addition, about 6,000 CNG buses out of the total 16,000 in South Korea are running in Seoul and the city has a plan to increase the share of CNG bus from the current 70% to 100% by 2010 as mentioned before. Thus, the success of the project at Seonam will be a key factor to the establishment of legitimation on the biogas TIS for vehicle fuel in South Korea in a formative period. Especially, once a few CNG city buses start running on biogas labelled as 'biogas bus, it will be very symbolic for the development of biogas as a vehicle fuel and influential for Seoul citizen to recognize domestically produced biogas from organic waste as a type of clean and renewable fuel.

Lastly, once there will be more actors in the system, the formation of coalition will help legitimation process. In Swedish case, the Swedish Gas Association (since 1915), the Swedish Biogas Association (since 1988), and the Swedish Gas Center (since 1990) have taken important roles to publish informative materials and to promote increased use of biogas fuel. Thus, the formation of similar associations might contribute to the increase of the legitimation in South Korea. Additionally, possible future bilateral cooperation between the Swedish and Korean biogas associations might provide familiarity and trust on the biogas technology as a vehicle fuel for South Korea. Now various actors in the central government, local municipalities and industries are preparing educational tours of the Swedish biogas industry. These visits will be likely to become critical moments of the legitimation process in the formative period of biogas fuel TIS in South Korea. In addition, the formation of such coalitions, described as 'running in packs' (Bergek, Jacobsson, & Sandén, 2008), will be helpful to change some regulative framework. Therefore, the three ongoing project participants need to bring more powerful actors to form a coalition with them such as major car manufacturers, local gas distributors and CNG bus industries.

6 Conclusions

6.1 Reflections

Through the utilization of biogas as a vehicle fuel, Sweden has shown a very valuable example of how to sustainably manage different types of organic waste and simultaneously improve air quality, tackle the global climate crisis, and step towards an oil-free society. The successful development was the result of favorable conditions, the conformity of biogas fuel to various goals, governmental financial support and R&D investments, various legislative and economic policies, and the active role of local municipalities. With increasing concerns on the unsustainable waste management of organic waste, the extreme dependency on imported oil for transport and the coming obligation to reduce GHG emissions, South Korea is trying to learn lessons from the Swedish exemplary experience.

It is reasonable to state that this research cannot draw a clear decision whether vehicle fuel is the most optimal end-use of biogas in South Korea, in other words, whether it is valuable for South Korea to strategically support the development of biogas fuel as one of the major alternative fuels to the current domination of fossil vehicle fuels. However, it has been discussed in this thesis that biogas as a vehicle fuel is definitely one of the possible utilizations of organic waste, that much potential of organic waste does exist, that interest on biogas fuel is gradually emerging from top-down and bottom-up processes, that various rationales have been suggested for the development, and finally, that different governmental plans are recognizing significant positive implications of biogas fuel toward the new national vision "Low Carbon, Green Growth".

The diffusion of a new TIS is led by dynamics of different actors, networks and institutions. These basic components have started to appear in the biogas TIS for vehicle fuel in South Korea. To be diffused successfully the biogas TIS for vehicle fuel needs to build up its legitimacy especially in this formative period. This legitimacy might take a long time to be established. For example, the development of the biogas TIS for vehicle fuel in Sweden started in 1989. Although different governmental plans show a promising future of biogas fuel development, they do not guarantee the actual implementation of the various ambitious plans. Especially, the level of legitimacy for renewable energy in general in Sweden cannot be easily achieved in South Korea considering its different social, political and economic conditions.

The lack of public knowledge on biogas as a vehicle fuel, the possible impediment from incumbent dominant actors and institutions are the main blocking mechanisms for the development of biogas fuel identified in this thesis. Thus, the proponents of biogas TIS for vehicle fuel need to strategically conform to established institutions, to produce technological assessments, to accumulate actors with experience and trust, and finally, form a coalition to effectively support biogas as one of optimal alternative fuels. Especially, the ongoing project in Seoul will take a very important role in the legitimation process considering it will be the first project in South Korea producing biomethane from organic waste as a fuel for public CNG buses and the significant implications of its host city; the capital of the country with a huge potential for the production, distribution and consumption of biogas fuel as well as its political power.

As shown in the Swedish experience, a close cooperation among various local actors initiated and coordinated by a local municipal government might be a good strategy for the development of biogas fuel in South Korea as well. Since the impending ocean dumping issues, the improvement of air quality, and establishment of follow-up plans for the "Low Carbon, Green Growth" initiative are urgent issues for local municipalities, they can take many advantages of developing biogas as a locally produced renewable fuel from local organic waste. The current direction of focusing on existing public CNG buses as prime end-users is an effective strategy that can be continuously supported. Utilizing the amount of currently dumped organic waste in the ocean first is also able to maximize benefits of the biogas development as a vehicle fuel in this formative period.

6.2 Recommendations

There has been very little research on this topic in South Korea, and there are still many limitations in this research, which can be explored in much greater depth. The major ones include:

- The perspectives and positions of major car manufacturers, major oil refinery companies, and regional city gas distributors were not reviewed in this research. Due to their significant positions and political powers, their perspectives on the development of biogas as a vehicle fuel need to be analyzed in-depth.

- Also, as mentioned in the beginning of this thesis, relations between biogas and other types of alternative renewable fuels needs to be researched to better understand the dynamics in their competition.

- Since the amount of available organic waste for biogas fuel production is generally not large enough to meet the significant proportion of the total transport fuel demand, the potential of dedicated energy crops for biogas production also needs to be investigated.

- A systemic cost-benefit analysis of a specific utilization case of biogas as a vehicle fuel compared to other types of fuels needs to be done.

- The development of CDM projects on biogas as a vehicle fuel in South Korea needs to be carefully examined. It is generally observed that there is a high level of belief on the possibility of CDM projects on biogas as a vehicle fuel. However, it might not be easy to establish a baseline and prove additionality of biogas fuel CDM project, since there has not been such case.

- Finally, establishment of Public-Private Partnerships for the development of biogas as a vehicle fuel in South Korea compared to the successful case in Göteborg in Sweden as a specific case study will be meaningful to further analyze.

Appendix 1: Swedish Standard for Biogas as Vehicle Fuel

Property	Unit	Biogas, type A	Biogas, type B
Wobbe index	MJ/Nm^3	44.7 – 46.4	43.9 – 47.3
Methane content	vol-% *	97±1	97±2
Water dew point at the highest storage pressure (t = lowest average daily temperature on a monthly basis)	°C	t - 5	t - 5
Water content, maximum	mg/Nm^3	32	32
Maximum carbon dioxide + oxygen + nitrogen gas content, of which oxygen, maximum	vol-% vol-%	4.0 1.0	5.0 1.0
Total sulphur content, maximum	mg/Nm^3	23	23
Total content of nitrogen compounds (excluding N_2) counted as NH_3, max.	mg/Nm^3	20	20
Maximum size of particles	µm	1	1

* at 273.15 K and 101.325 kPa

Source: Swedish Gas Centre, 2007

Appendix 2: Biogas Projects Appeared in News Media

Entity	Field	Content	Source	Date
Gangwon Province	Vehicles	- established a plan to have 1,000 vehicles running on biogas by 2020 - 4 new refuelling stations will be built in 2009 - host IANGV EXPO and ANGVA EXPO	Gangwon -ilbo	06-Jan-09
Seoul Special City	Vehicle Fuel	- Sewage sludge as substrate - MOU with SBI and GBL from Sweden - 7,000 N ㎥ --> 3,000 N ㎥ biomethane - 30 buses can run with the gas everyday - CDM opportunity	New Wire	11-Aug-08
Gangwon Province	Vehicle fuel	- 20 billion Won investment - expected production - 500 million m^3/yr from 80 thousand tonnes of organic wastes - can run 110 buses everyday - MOU with Swedish Biogas International	Hankook -ilbo	16-Jan-09
Ulsan City	Vehicle fuel	- (Scandinavian Biogas Fuels AB) - 180 tonnes of food waste and sewage sludge - 13,800 Nm3/day - can run 100 buses/day - CDM opportunity	Hankyung	05-Jan-09
Goyang City	Heating	- food waste as substrate - daily waste treatment: 260 tonnes	Naeil	29-Dec-08
Northern Gyeongsang Province	Electricity Generation	- 13.9 billion Won investment in 2009	Yonhap News	16-Jan-09
Jeju Province	Electricity Generation	- 2 billion Won investment - 50 tonnes of pig manure/day - 1,335 kWh/day	The Hankyoreh	05-Jan-09
Gongju City	Electricity Generation	- livestock manure as a substrate	Newsis	26-Dec-08
Paju City	Electricity Generation	- food waste and livestock manure	Korea.kr	23-Dec-08
Gyeonggi Province	Electricity Generation	- 9.8 billion Won investment - organic wastes as substrates	Asia Economy	22-Dec-08
Incheon Metropolitan City	Electricity Generation	- Sewage sludge and food waste water - 70 billion Won investment by 2013	Maeil Economy	17-Dec-08
Pocheon City	Electricity Generation	- 50-60 tonnes of food waste per day - 23-24 tonnes of food waste water per day	Medical Today	04-Dec-08
Southern Jeolla Province	CHP	- Daewoo E&C Co., Ltd made a contract with the province - DBS(Daewoo Two Phase Anaerobic Bio-Gas System) technology - 100 billion Won scale - exports its technology to Italy as well	The Herald Business	14-Jan-09

Changnyeong County	CHP	- 100 tonnes/day of livestock manure and food waste - 9,600 kWh/day - 1,000 households for a year - CDM opportunity	Yonhap News	13-Jan-09
Rural Development Administration	CHP	- research project - 3 billion Won investment for 3 years from 2009	Korea.kr	31-Dec-08
Asan City	CHP	- Livestock, food waste water, and sewage sludge as substrates - 2,867 kW/day --> 318 households	Kukinews	16-Dec-08

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