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The Prospects for Biogas Systems in Rural China - Incentives, Barriers and Potentials

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Abstract

Due to the multiple benefits of biogas systems, the Chinese Government has made great efforts to promote the development of biogas systems in rural China, especially household biogas plants and medium and large scale biogas plants to treat manure and waste water from intensive livestock and poultry farms. This thesis conducts a comprehensive literature review to understand the current situation of biogas systems in rural China in the light of feedstock, technologies and utilization of biogas and digested residue. A number of incentives and barriers affecting the production and utilization of biogas and digested residues are analyzed, in terms of policy, economy, technology and society.

Based on the analysis of future social economic development in rural China, the examination of a variety of policies and the comprehensive literature review on the promotion of biogas plants, a number of measures are proposed. The policy advice for the development of household biogas plants in rural China is to slow down development, strengthen the education and training of farmers on the proper utilization of biogas plants, improve the rural biogas service network and ensure the quality of biogas plants as well as the associated facilities, and provide more funding for research and development of household biogas plants.

As for medium and large scale biogas plants, in order to promote the further expansion, it is important to strengthen the enforcement of environmental protection law, develop multi-channels to raise the investments, set up the market for the products of medium and large scale biogas plants, and provide more funding for the capacity building of qualified technicians and improve the technology of biogas plants and auxiliary equipment for industrialization. A number of policy instruments are also suggested in this thesis to encourage the use of biogas and digested residue.

Key Words: Rural China, Household Biogas Plants, Medium and Large Scale Biogas Plant, Incentives, Barriers, Policy Instruments, Implementation Factors

Executive Summary

Biogas systems can contribute to rural development, utilization of renewable energy, climate change mitigation, as well as environmental protection. Due to its multiple benefits, the Chinese Government has made great efforts to promote the development of biogas systems in rural China, especially household biogas plants and medium and large scale biogas plants for intensive livestock and poultry farms. China has the largest number of household biogas plants in the world. By the end 2008, there were 30.5 million household biogas plants in rural China. However, it was that only 60% of these digesters were operating normally in 2007. Meanwhile, only 6% of the total medium and large scale intensive livestock and poultry farms built medium and large scale biogas plants to treat manure and waste water in 2005.

In order to better promote and improve biogas systems in rural China, a comprehensive literature review of the various sources in both Chinese and English was undertaken for this thesis. It analyzes the current development of household biogas plants and medium and large scale biogas plants for intensive livestock and poultry farms. Furthermore, the incentives and barriers affecting the production and utilization of biogas and digested residue are identified in terms of policy, economy, technology and society, and measures for the future development are proposed.

Based on the analysis of future social economic development in rural China, the examination of a variety of policies and the comprehensive literature review on the promotion of biogas plants, a series of measures are put forward. The thesis suggests that the development of household biogas plants should slow down and the development objectives should be reset because of rapid urbanization and large numbers of migrant workers, the building of new socialist countryside, the separation of crop planting from animal farming, and the transition from scatter breeding to intensive livestock and poultry farming. All these changes will reduce the users of household biogas plants in rural China and result in the shortage of fermentation materials for household users.

Moreover, considering current practices of developing household biogas plants, it is found that the fast development has led to a great shortage of qualified biogas technicians resulting in the poor quality of household biogas plants. The lack of education and training for farmers and the poor follow-up services have further made more household biogas plants break down in a short time. Therefore, the most important action is to strengthen the capability of biogas technicians and farmers, ensure the quality of biogas plants as well as the related follow-up services and management. Considering the trend of social change, centralised biogas systems at the village level should be explored and promoted, though further research is needed.

The investment from the Chinese Government for medium and large scale biogas plants built for intensive livestock and poultry farms has been greatly increased in recent years. However, based on the extensive and thorough policy analysis, it is found in this thesis that there are few policy instruments in favour of the construction and operation of medium and large scale biogas plants. Apart from the current subsidy for building of biogas plants, multiple channels should be set up to raise the high initial investment, such as low interest loans and preferential taxes on the construction. Moreover, the enforcement of environmental law must be strengthened.

Besides, a number of policy instruments need to be initiated to encourage the utilization of biogas and digested residue, so that the owners have strong incentives to operate and maintain biogas plants to make profits. For example, a price subsidy for the use of biogas should be provided; the current subsidy for power price of biomass power projects needs to be increase

and biogas power must be guaranteed to be fully purchased by power grid companies; new policy instruments should be established to support biogas as vehicle fuel; the current subsidy for manufacturing chemical fertilizer must be removed and a price subsidy for purchasing organic fertilizer should be designed and implemented.

It can be seen that the current rapid expansion of biogas systems in rural China is mainly pushed forward by the Chinese Government with large amount of subsidies. However, few policy instruments have been designed to encourage the utilization of biogas and the digested residues. Thus farmers only have the incentives to construct biogas plants, but fewer incentives to operate and manage them, which can not sustain the development of biogas systems in rural China. Market-based policy instruments can provide a way to promote the further development of biogas systems in rural China. Although further research is required on how such market-based policy instruments can be designed and effectively implemented in rural China.

Table of Contents

LIST OF FIGURES	III
LIST OF TABLES	IV
1 INTRODUCTION.....	5
1.1 BACKGROUND.....	5
1.2 RESEARCH QUESTIONS	7
1.3 TARGET AUDIENCES	8
1.4 METHODOLOGY	9
1.5 SCOPING AND LIMITATIONS	10
2 THE OVERVIEW AND BACKGROUND	12
2.1 OVERVIEW OF A BIOGAS SYSTEM.....	12
2.2 FEEDSTOCK	13
2.3 ANAEROBIC PROCESS.....	14
2.4 BIOGAS PLANTS (DIGESTERS).....	14
2.5 UTILIZATION OF BIOGAS AND DIGESTED RESIDUE.....	15
2.6 BENEFITS AND PROBLEMS OF BIOGAS AND DIGESTED RESIDUE	16
3 BIOGAS SYSTEMS IN RURAL CHINA.....	18
3.1 BACKGROUND AND DEVELOPMENT	18
3.2 FEEDSTOCK	20
3.2.1 <i>Manure</i>	20
3.2.2 <i>Crop residue</i>	22
3.2.3 <i>Energy crops</i>	23
3.3 TECHNOLOGIES	23
3.3.1 <i>Household biogas plants</i>	23
3.3.2 <i>Medium and large scale biogas plants</i>	25
3.4 UTILIZATION	26
3.4.1 <i>Household biogas plants</i>	26
3.4.2 <i>Medium and large scale biogas plants</i>	28
4 INCENTIVES AND BARRIERS FOR BIOGAS SYSTEMS IN RURAL CHINA	31
4.1 BIOGAS PRODUCTION.....	31
4.1.1 <i>Incentives for household biogas plants</i>	31
4.1.2 <i>Barriers for household biogas plants</i>	36
4.1.3 <i>Incentives for medium and large scale biogas plants</i>	41
4.1.4 <i>Barriers for medium and large scale biogas plants</i>	46
4.2 BIOGAS AND DIGESTED RESIDUE UTILIZATION.....	52
4.2.1 <i>Cooking and heating</i>	52
4.2.2 <i>Electricity and CHP</i>	52
4.2.3 <i>Vehicle Fuel</i>	53
4.2.4 <i>Digested residue</i>	54
5 DISCUSSIONS AND CONCLUSIONS	57
5.1 ADVICES FOR HOUSEHOLD BIOGAS PLANTS.....	57
5.2 ADVICES FOR MEDIUM AND LARGE SCALE BIOGAS PLANTS.....	58
5.3 ADVICES FOR THE USE OF BIOGAS AND DIGESTED RESIDUE	59
5.3.1 <i>Subsidy for biogas</i>	59
5.3.2 <i>Electricity and CHP, and vehicle fuels</i>	60
5.3.3 <i>Digested residue</i>	63

5.4 CONCLUSION..... 63

5.5 FURTHER STUDY 66

BIBLIOGRAPHY 67

APPENDIX..... 76

APPENDIX 1 POLICIES, LAWS AND REGULATIONS WITH REGARD TO BIOGAS DEVELOPMENT IN CHINA
76

APPENDIX 2 DIFFERENT CLASSIFICATION OF THE SCALE OF INTENSIVE LIVESTOCK AND POULTRY
FARMS 78

List of Figures

Figure 1-1 Primary Energy Demand in China in the Reference Scenario.....	5
Figure 1-2 Components of energy consumption for daily life in rural China in 2007	6
Figure 1-3 The analytical framework	9
Figure 2-1 Overview of a biogas system.....	12
Figure 3-1 Number of household biogas plants installed in rural China (1973-2008)	19
Figure 3-2 the number of biogas projects for agricultural waste (1996-2005).....	20
Figure 3-3 Current utilization situations of crop residues in rural China	22
Figure 3-4 Household biogas plant in rural China.....	24
Figure 3-5 Pig-Biogas-Fruit Model in Southern China.....	27
Figure 3-6 Four in One Model.....	27
Figure 3-7 Five in One Model.....	28
Figure 3-8 Comprehensive utilization model.....	29
Figure 3-9 Ecological model	30
Figure 3-10 Anaerobic-aerobic model	30
Figure 4-1 Investment from Central Government for Household Biogas Plants	33
Figure 4-2 Administration of New Energy Promotion.....	35
Figure 4-3 Population and urbanization ratio (1990-2007)	38
Figure 4-4 Investment from Central Government for Medium and Large Scale Plants 2001-2005.....	43

List of Tables

Table 1-1 the classification of the scale of biogas plants.....	10
Table 2-1 Composition of biogas	13
Table 2-2 Methane yields of different feedstock material.....	13
Table 3-1 the classification of the scale of biogas plants.....	18
Table 3-2 Poultry and livestock manure resources in China in 2007	21
Table 4-1 the classification of the scale of livestock and poultry breeding	39
Table 4-2 the number of intensive livestock and poultry farms in 2005	39
Table 4-3 the number of medium and large scale intensive livestock and poultry farms (2005) 39	
Table 4-4 Summary of various kinds of incentives and barriers for expanding biogas production in rural China	49
Table 4-5 Summary of various kinds of incentives and barriers for expanded biogas utilization in rural China.....	55
Table 5-1 Comparison of purchase price of electricity produced by biogas between Germany and China in 2006.....	60
Table 5-2 Policy instruments in favour of utilization of biogas as vehicle fuel in Sweden	62

1 Introduction

1.1 Background

China is in the process of rapid industrialization and urbanization and its annual GDP growth rate has been around 10% during the last two decades. Along with the rapid economic development, the energy consumption is growing fast in China. In the last decade, China's primary energy consumption has risen almost 100% while it has only increased 8.1% in OECD countries during the same period and China has become the second largest energy user, behind only USA (H. Y. Ma, Oxley, Gibson, & Li, 2010). It is predicted that the energy consumption of China will continue increasing during the next half decade (Crompton & Wu, 2005; IEA, 2007). As is shown in Figure 1-1, it is forecast China's primary energy demand will increase from 1742 million tons of oil equivalent (Mtoe) in 2005 to 3819 Mtoe in 2030 under Reference Scenario, with annual increase rate of 3.2%(IEA, 2007).

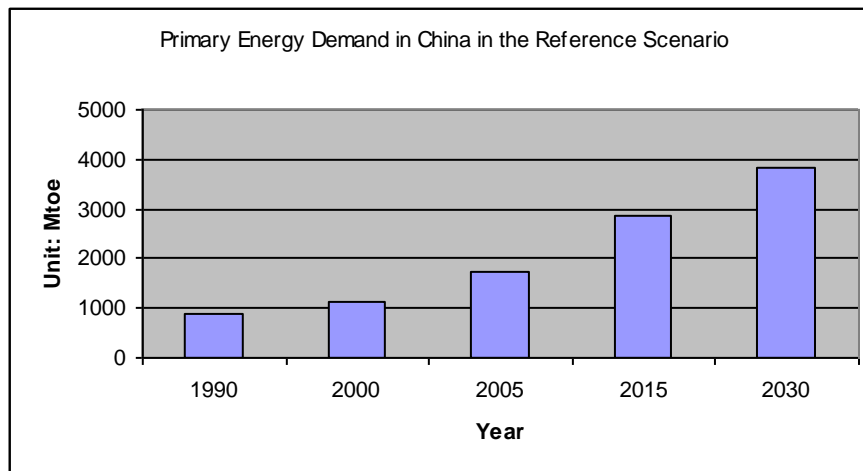


Figure 1-1 Primary Energy Demand in China in the Reference Scenario

Source:(IEA, 2007)

China has switched from a net energy exporter to a net energy importer. The energy consumption was 11.6% less than production in the mid 1980s, while since 2005 consumptions was approximately 10% more than production (H. Y. Ma, Oxley, & Gibson, 2009). In 2005, almost 50% of total oil consumption had to be imported and net imports of petroleum and products have more than doubled from 2000 to 2006 (NBSC, 1996-2007). Meanwhile, it was estimated that the proved economic recoverable reserves of coal, oil and natural gas can only be exploited by 48 years, 11 years and 41 years respectively, which are far below the world average (P. D. Zhang, Y. L. Yang, Y. S. Tian, et al., 2009). According to OECD projection, China will rely more and more on the global market to import fossil fuels such as petroleum, gas etc(OECD, 2007). It is also forecast that China will surpass the United States and become the biggest oil and gas importer in the world after 2025(IEA, 2009). Therefore energy security is a main concern of the Chinese Government.

Due to the large consumption of fossil fuels for the high-speed economic development, China has become the largest emitter of greenhouse gases in the world (Richerzhagen & Scholz, 2008). Although China has no obligation for any greenhouse gas (GHG) emission reduction, it has attracted broad attention from countries all over the world. With entering the post-Kyoto Protocol era, China has been facing more and more pressure to reduce GHG emission (P. D. Zhang, Y. L. Yang, Y. S. Tian, et al., 2009).

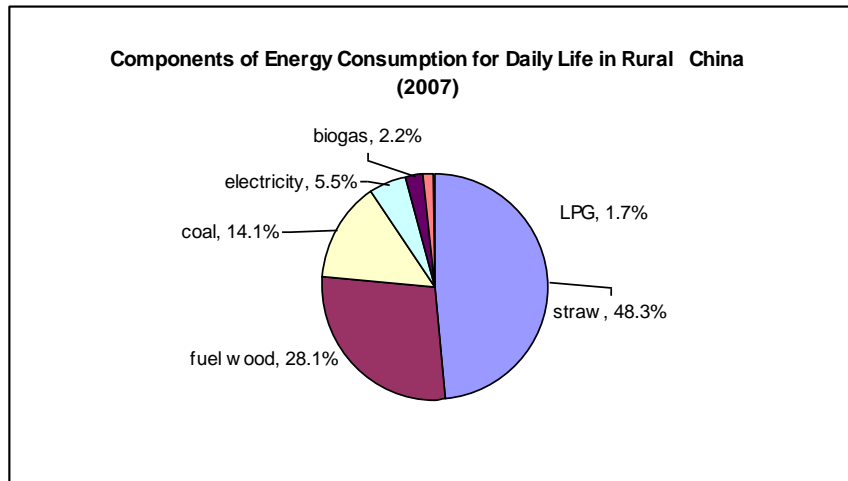


Figure 1-2 Components of energy consumption for daily life in rural China in 2007

Source:(Kou, Zhao, Hao, & Tian, 2008)

Meanwhile, China has a rural population of 750 million and most of them still use traditional biomass energy because of economic and technical limitations (SCIO, 2007). As is shown in Figure 1-1, straw and firewood account for 48.3% and 28.1% respectively in energy consumption for daily life in rural China in 2007 (Kou, et al., 2008). The use of the firewood and straw can cause serious environmental problems such as indoor and outdoor pollution and deforestation etc. Moreover, the amount of coal consumption for livelihood in rural China is increasing due to the economic development, which results in not only a great amount of CO₂ emission, but also SO₂ and other noxious gases that lead to environmental and health problems (P. D. Zhang, Jia, & Wang, 2007) .

As a country with a long history of agriculture, China has made great achievements in feeding 22% of the world population (1.3 billion) on only 7% of the global arable land (130 million ha) without net food import. However, such accomplishments are based on more intensive production methods and more specialised farming systems (M. Chen, Chen, & Sun, 2008). The traditional self-sufficient farming has been gradually replaced by market-oriented farming, which has resulted in the separation between livestock production and crop planting (M. Chen, et al., 2008). Farmers prefer more convenient mineral fertilizer rather than collecting and recycling organic wastes, which broke the closed nutrient cycle between plant and animal production (M. Chen, et al., 2008).

It was found that at least 12% of the crop residues and 25% of the livestock manure were discarded without proper utilization in China (X. Gao, Ma, Ma, Zhang, & Wang, 2002). Correspondingly, the use of mineral fertilizer has increased fourfold from 1979 to 2004 and

the total consumption of mineral fertilizer in China in 2004 accounted for more than 1/3 of the world's total (M. Chen, et al., 2008). A large part of the mineral fertilizer is believed to be lost to the water and air, since the efficiency of using the mineral fertilizer by crops is quite low in China (Z. L. Zhu, Norse, & Sun, 2006).

On the other hand, due to the rapid development of livestock production, the disposal of animal waste has become a serious problem. It was found that the numbers of cattle, pigs, and sheep and goats have increased by 8.5%, 18.9% and 31.2% respectively in the past five years (M. Chen, et al., 2008). What's more, livestock farming has turned out to be more centralized too. For example, the percentage of pig farms with more than 500 heads almost doubled in China from 1999 to 2004 (M. Chen, et al., 2008). In the areas with highly intensive livestock farming, the local crops can only take up a small amount of nutrients in livestock manure, and therefore the surplus of manure can cause serious environmental problems such as eutrophication.

In order to deal with energy security, climate change, energy shortages and environmental pollution in rural areas, China has been making great efforts to promote the use of modern and clean renewable energy carriers in rural areas (P. D. Zhang, Jia, et al., 2007). Biogas is a kind of clean and renewable energy. Moreover, biogas system can treat organic wastes and turn them into organic fertilizer. Therefore, the Chinese Government has regarded biogas as an important way to improve farmer's incomes, promote the adjustment of agricultural structures, protect rural environments and improve farmer's living conditions (Willem & Wang, 2009). Great efforts have been made to promote the development of biogas plants in rural China in recent years, particularly household biogas plants and medium and large scale biogas plants for intensive livestock and poultry farms. The former is mainly used to providing clean and renewable energy for rural farmers, while the latter is mainly utilized for treating manure and solving environmental problems.

China has the largest number of household biogas plants in the world. By the end 2008, there have been 30.5 million household biogas plants built in rural China, producing 12 billion m³ of biogas annually (NDRC, 2009). 3.45 billion Yuan was invested from the Central Government to construct household biogas plants between 2001 and 2005(MOA, 2007). However, it is found that only 60% of household biogas digesters were operating normally in 2007 (Wu Di Zhang et al., 2006) and the comprehensive utilization of household biogas system in rural China only accounted for 37.3% of total rural household users in 2005 (G. Q. Hu, 2008). Meanwhile, 90% of the intensive livestock and poultry farms didn't have facilities to treat waste water, which was discharged directly into the rivers and lakes, causing eutrophication and environmental pollution (Y. Li, 2002). There were only 700 medium and large scale biogas plants built for intensive livestock and poultry farms in 2005, accounting for only 6% of total medium and large scale intensive livestock and poultry farms (MOA, 2007). In order to better promote and improve the biogas systems in rural China, the thesis aims to analyze the current situation of development of household biogas plants and medium and large scale biogas plants for intensive livestock and poultry farms, identify the incentives and barriers, thus proposes the countermeasures for future development.

1.2 Research questions

The thesis aims to analyze the prospects of an expansion of biogas systems in rural China.

Research questions: How to improve the development of biogas systems in rural China?

The sub-questions are as follow:

- What is the current situation of biogas systems in rural China?
- What are the key incentives and barriers for the development of biogas systems in rural China?
- How can policy makers and decision makers strengthen the incentives and overcome the barriers?

The author will first introduce the component and functions of a biogas system in general in Chapter Two. After that, the historical development and the current situation of household biogas plants and medium and large scale biogas plants in rural China are depicted in Chapter Three. In Chapter Four, based on comprehensive document and policy analysis, a number of incentives and barriers will be identified and evaluated, in terms of production and utilization of biogas and digested residues. In Chapter Five, possibilities to strengthen existing incentives and to overcome barriers are suggested and discussed and successful lessons for biogas development from Sweden and Germany will be also referred in the last chapter.

1.3 Target audiences

It's critical to make appropriate policies to promote the development of biogas systems in rural China considering the huge amount of public and private investment and the great environmental and social benefits. The main potential audience of this research are policy makers and decision makers, however, other audiences can also benefit from the study. The target audiences include:

- Policy makers and decision makers: This study can assist policy makers and decision makers to establish effective policies so as to provide incentives and overcome the barriers for the development of biogas system in rural China. Considering this year is the time for China's government to set up another 5 year plan for rural biogas development. The result of the study may contribute to the design of the essential strategy.
- Officers from rural energy departments: The analysis of potential incentives and barriers for the development of biogas system in rural China will help officers from rural energy departments to take more practical measures.
- Entrepreneurs of SMEs and investors: The analysis will provide better knowledge with regard to the risk and opportunity in the Chinese rural biogas market.
- NGOs: The study will make them better understand the future development of biogas in rural China so that they can find more opportunities to involve in the development of biogas systems in rural communities.
- Researchers: This research can provide a comprehensive analysis on the development of biogas systems in rural China and lead to further research interests.

1.4 Methodology

A comprehensive literature review of various sources in both Chinese and English was undertaken, including academic, government, NGOs and International organizations, so as to understand the research question in a comprehensive way. In order to find the practical problems of biogas systems in rural China, documents written by working staff from Rural Energy Departments and Rural Energy Offices in different provinces are analyzed, as well as in a number of cities and counties. The majority of documents are collected from CNKI Database and Wanfang Database (in Chinese), ScienceDirect and Springer (in English) and Google scholar search etc.

A number of research methods have been applied in the study, including:

Policy analysis: a multiple of policies with regard to sustainable agriculture and rural development, renewable energy, climate change, environmental protection and biogas development in China have been fully analyzed;

Case analysis: a number of articles with regard to the current development of household biogas plants and medium and large scale biogas plants in different provinces and cities have been analyzed, which were mainly written by officers of rural energy departments and can reflect the real situation of biogas development in rural China;

Comparative study: the biogas development in Germany and Sweden are studied in order to learn the successful experiences for promoting biogas development;

Interviews: personal and telephone interviews as well as emails consultation have been done with experts on biogas both in Sweden and China in order to better understand the policies, economic measures, technologies and social factors for promoting biogas development.

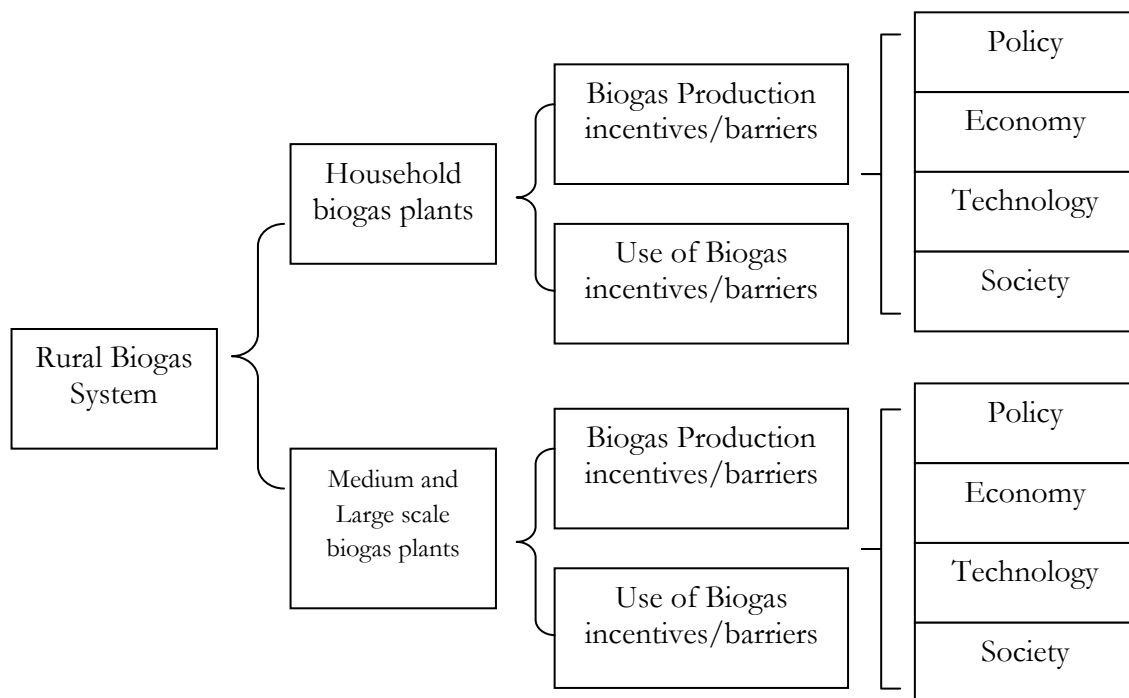


Figure 1-3 The analytical framework

The paper’s analytical framework is shown in Figure1-3. The rural biogas systems are divided into two categories: household biogas plants and medium-large scale biogas plants which are built for livestock and poultry farms to treat the manure. For each category, incentives and barriers in terms of biogas production and utilization are analyzed respectively. In order to study the incentives and barriers in a structured way, PEST model has been applied, which is mainly used to analyze the macro environment of the development, in the perspective of policy, economy, society and Technology (Su, 2007).

1.5 Scoping and Limitations

In rural China, the biogas plants can be mainly classified into household biogas plants and small, medium and large scale biogas plants, which are also referred to as biogas projects. The size of a household biogas digester is usually of 8 m³, while the volume of single biogas digester of a small scale biogas plant is between 20 m³ and 50 m³ (MOA, 2007), which is shown in table 1-1.

The medium and large scale biogas plants have the size of single biogas digester larger than 50 m³ and 300 m³ , and the total volume larger than 100 m³ and 1000 m³ respectively (MOA, 2007). The medium and large scale biogas plants should also own the pre-treatment facilities for raw materials such as feed-in, stirring equipments, and facilities for the integrated utilization of biogas as well as the digested residues(MOA, 2007).

Table 1-1 the classification of the scale of biogas plants

Scale	Volume of single digester(m ³)	Total volume(m ³)	Biogas production per day(m ³ /day)
Large	≥300	≥1000	≥300
Medium	300>V≥50	1000>V≥100	≥50
Small	50>V≥20	100>V≥50	≥20
Household	8	8	1.2

Source: (GEI, 2008; MOA, 2007)

The thesis focuses on the study of household biogas plants and medium and large scale biogas plants for intensive livestock and poultry farms in rural China, which the Chinese Government has made great efforts to promote in recent years. A large amount of investment has been provided for the construction of them. In 2007, *China’s rural biogas project planning (2006–2010)* was set up only for two kinds of biogas plants, which proposes to construct 40 million household biogas plants and 4000 medium and large scale biogas plants for intensive livestock and poultry farms by the end of 2010 (MOA, 2007). Although, there are a number of small scale biogas plants in rural China, the priority of biogas system development in rural China is set for household biogas plants and medium and large scale biogas plants for intensive livestock and poultry farms. Therefore, the study of small scale biogas plants in rural china is not included in this thesis.

The thesis won’t study biogas plants built for municipal sectors or industrial sectors either. Although there are some medium and large scale biogas plants for industrial waste water in rural China, the majority are built for intensive livestock and poultry farms. There are also a

number of biogas systems built for treating domestic waste water in rural China; however, it's not the focus of biogas system development in rural China, which is also excluded in this study.

One of the limitations of the thesis is that most of the data are secondary and there are no filed studies. Nevertheless, a great number of documents have been reviewed as well as all kinds of policy documents with regard to the development of biogas system in rural China. Moreover, cases and surveys from different provinces and cities have been analyzed so as to get a real picture of biogas system in rural China. In addition, personal interviews and telephone interviews as well as consultation via emails with experts on biogas in China, Sweden, Germany and Australia have been made.

One of the big challenges of the study is that the development of biogas system in rural China has multiple objectives, thus policies with regard to rural development and sustainable agriculture, renewable energy, climate change mitigation and environmental protection have to be analyzed. Besides, the policies with regard to the development of biogas system in rural China are changing quickly in recent years; therefore all the documents up to 2010 need to be examined and utilized.

2 The Overview and background

2.1 Overview of a biogas system

Biogas is mainly composed of methane and carbon dioxide, which is produced when organic material is decomposed by specialized micro-organisms in the absence of oxygen, which is also called anaerobic digestion (Berglund, 2006). It can be formed in natural environment with limited access to oxygen, such as marshes, the stomach of ruminants and rice paddies. However, biogas can also be produced in a biogas plant, where organic material is put into a completely airtight container (SBGF, SGC, & SGA, 2008). The feedstock can be sewage sludge, household organic waste, manure, agricultural crops etc, while the final products are biogas and the digested residues which are nutrient rich. Biogas can be used for cooking, heating, generating electricity, making vehicle fuel etc(Lantza, Svensson, Bjornsson, & Borjesson, 2007), while digested residue can be utilized as organic fertilizer, pesticide or feedstock for pigs and fish etc(G. Wang et al., 2007).

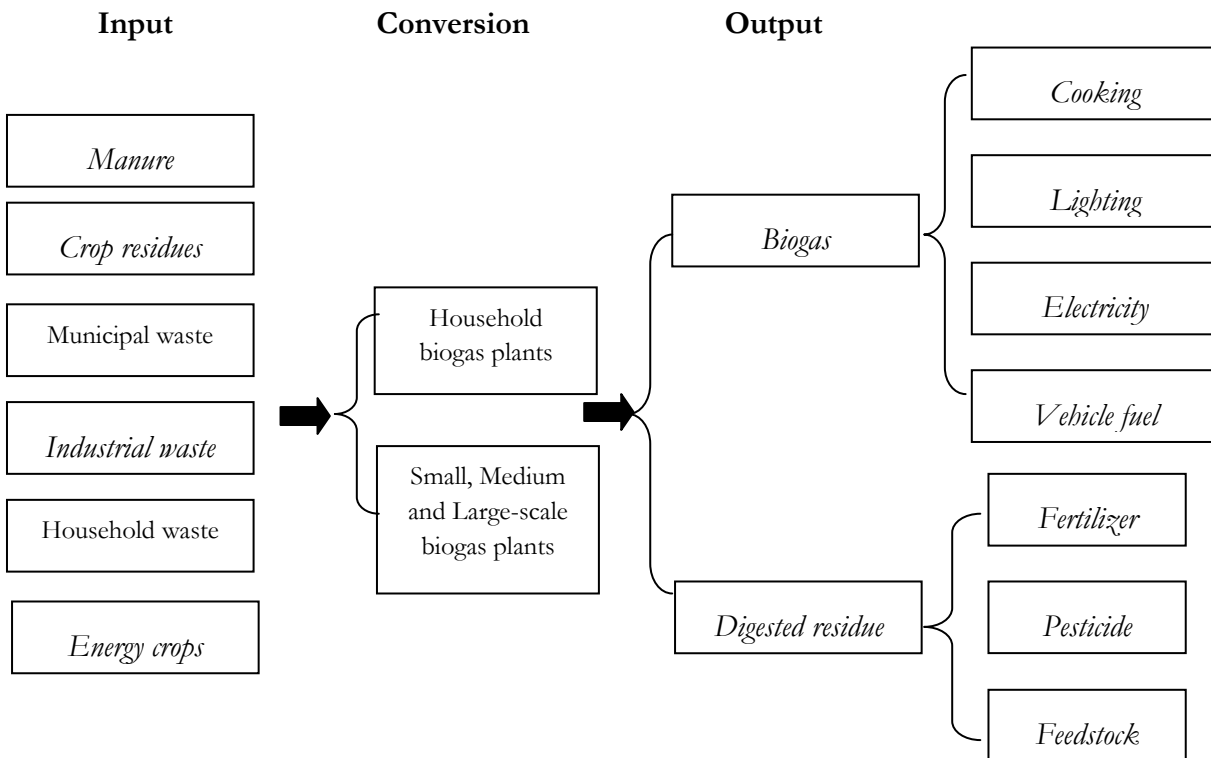


Figure 2-1 Overview of a biogas system

Source: adapted from (Lantza, et al., 2007) and (G. Wang, et al., 2007)

Methane is the main part of biogas, which usually consists of 45-85% methane, 15-45% carbon dioxide, traces of hydrogen sulphide, ammonia and nitrogen, and often saturated with water vapour (SBGF, et al., 2008). Table 2-1 provides some average biogas composition values found in most of the literature. The heating value of biogas with the average methane content of 50% is of 21 MJ/m³(Seadi et al., 2008).

Table 2-1 Composition of biogas

Compound	Chemical Symbol	Content (Vol.-%)
Methane	CH ₄	50-75
Carbon dioxide	CO ₂	25-45
Water vapour	H ₂ O	2(20°C)-7(40°C)
Oxygen	O ₂	<2
Nitrogen	N ₂	<2
Ammonia	NH ₃	<1
Hydrogen	H ₂	<1
Hydrogen sulphide	H ₂ S	<1

Source:(Seadi, et al., 2008)

2.2 Feedstock

Feedstock for the production of biogas is very diverse, ranging from animal manure, slurry, to agricultural residues and by-products. Also, sewage sludge, municipal solid wastes, organic wastes from food and agricultural industries and organic wastes from households can be used as feedstock. Besides, biogas can be produced by dedicated energy crops such as maize and can also be collected from landfill sites(Seadi, et al., 2008).

The amount and quality of biogas also depends on the type of feedstock, which is shown in Table 2-2(Seadi, et al., 2008). It can be observed the content of methane varies for different feedstock and corn silage per ton has the highest biogas production. If different feedstock are mixed and digested simultaneously in a biogas fermentation process, which is generally referred to as co-digestion, it usually results in a biogas with larger methane content(SBGF, et al., 2008).

Table 2-2 Methane yields of different feedstock material

Feedstock	Methane yield [%]	Biogas yield [m ³ /ton Fresh feedstock]
Liquid cattle manure	60	25
Liquid pig manure	65	28
Distillers grains with soluble	61	40
Cattle manure	60	45
Pig manure	60	60
Poultry manure	60	80
Beet	53	88
Organic waste	61	100

Sweet sorghum	54	108
Forage beet	51	111
Grass silage	54	172
Corn silage	52	202

Source: (Seadi, et al., 2008)

2.3 Anaerobic process

In the biogas process, complex organic compounds such as fats, proteins and carbohydrates are decomposed into methane, carbon dioxide and other final products by a number of different micro-organisms. There are three main steps in such process. In the first step called hydrolysis, the complex organic compounds are decomposed to simpler compounds such as amino acids and sugar by micro-organisms. The second step called fermentation will result in many intermediate products, for example fatty acids, alcohols and hydrogen gas. In the last step, a special group of micro-organisms called methanogens will produce the methane under specific environmental requirements(SBGF, et al., 2008). Methanogens need certain trace elements and vitamins and will die or grow slowly in the environment with oxygen. Besides they are also sensitive to temperature, acidity and other environmental factors(SBGF, et al., 2008).

Temperature plays a critical role in the anaerobic digestion process. It can be divided into three ranges: psychrophilic (below 25°C), mesophilic (25°C-45°C) , and thermophilic (45°C-70°C), under which bacteria can have active activity (Seadi, et al., 2008). Mesophilic and thermophilic range are important in biogas reaction, since bacteria are most productive in such conditions(Balat & Balat, 2009). In general, high temperature can shorten processing time and reduce the required volume of the digester. In fact, anaerobic digestion essentially stops below 10°C(Nijaguna, 2002). Therefore, digesters have to be heated or insulated in cold climate areas.

The pH value indicates the digester health since it influences the growth of methanogenic micro-organisms. The range of acceptable pH for methane formation is from 5.5 to 8.5, while most methanogens function optimally between 7.0 and 8.0(Seadi, et al., 2008). The relative amount of organic carbon and nitrogen in the feedstock, which is measured as Carbon/Nitrogen (C/N) ratio, can also influence the formation of biogas. A low C/N ratio can lead to pH values above 8.5, while a high C/N ratio may result in lower methane production rates(Ostrem, 2004).

2.4 Biogas Plants (Digesters)

A specially designed digester, an air proof reactor tank, is the core of a biogas system. Feedstock is decomposed in absence of oxygen in the digester, where biogas is produced. Besides, all digesters have a system to feed in feedstock and a system to output biogas and digested residue(Seadi, et al., 2008).

Nowadays, there are many types of digesters available in the world. The size of biogas plant can vary from a small household system of few cubic meters to a large commercial plant of several thousand cubic meters, often with several digesters(Seadi, et al., 2008).

The design and type of digester is determined by the dry matter content of the substrate, which is usually classified into wet digestion and dry digestion. The former is fed with dry matter content lower than 15%, while the latter between 20 and 40%(Seadi, et al., 2008). Wet digestion often involves manure and sewage sludge, while dry digestion is usually applied to solid animal manure, energy crops etc.

Digester can also be classified into two types: batch and continuous, according to the feedstock input and output. Batch-type digester is the simplest to build and usually applied for dry digestion. The digester is filled at once, and then is completely removed after the feedstock digests. In a continuous-type digester, the feedstock is continuously added and the digested material is continuously removed. Compared with batch-type digesters, continuous digesters produce biogas without interruption(Seadi, et al., 2008).

According to the source of the feedstock, the biogas plants can be categorized into agricultural biogas plants, waste water treatment plants, municipal solid waste treatment plants, industrial biogas plants and landfill gas recovery plants etc(Seadi, et al., 2008). The agricultural biogas plants are processing feedstock of agricultural origin, which can be further divided into family scale biogas plants, farm scale biogas plants and centralised or joint co-digestion plants, based on the relative size, function and location(Seadi, et al., 2008).

The methane content of the biogas varies and depends on the type of feedstock and the type of biogas plants, which is shown in table 2-3 (Eriksson & Olsson, 2007).

Table 2-3 Overview of content of the biogas produced at different types of plants

Component	Entity	Centralized Biogas 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 ₂ S)	ppm	10-2000	10-40	50-300

Source:(Eriksson & Olsson, 2007)

It can be seen that the methane content is the highest in the gas extracted from centralized biogas plant, while lowest from landfill which has the highest concentration of nitrogen.

2.5 Utilization of biogas and digested residue

The biogas can be utilized for a variety of energy services, such as heat, electricity and vehicle fuel(Lantz, et al., 2007; SBGF, et al., 2008; Seadi, et al., 2008).It can also be burned directly for cooking, lighting etc.

The direct burning of biogas in boilers or burners is the simplest way to utilize biogas, which does not need any upgrading. Biogas can produce heat either on site, or distributed through pipeline to the end users(Seadi, et al., 2008). Biogas is also utilized to generate combined heat and power (CHP) in many countries, which is very efficient utilization of biogas to produce energy. The biogas CHP power plant has an efficiency of up to 90% and generates 35% electricity and 65% heat(Seadi, et al., 2008). Before combustion, biogas need to be dried and

certain corrosive substances such as hydrogen sulphide should also be removed(SBGF, et al., 2008).

After upgrading, biogas can be utilized as vehicle fuel or injected into the natural gas network used as natural gas. The upgrading will remove all contaminants such as carbon dioxide and hydrogen sulphide, through which the content of methane will be increased from the average 50-75% to more than 95%(Seadi, et al., 2008). In addition, methane and carbon dioxide produced from biogas can be utilized to produce chemical products as an alternative to fossil sources. For example, carbon dioxide can be used to produce dry ice etc(Seadi, et al., 2008).

Apart from the biogas, anaerobic digestion can also convert the added feedstock into digested residue, which can be utilized as fertiliser in agriculture. The digested residue contains water, organic material, micro-organisms and various nutrients(SBGF, et al., 2008). It is found digested residue is better than raw slurry as fertiliser, since it is more homogenous, with an improved Nitrogen-Phosphorus balance and more inorganic nitrogen, and is easier accessible to the plants, thus improving the fertilisation efficiency of the treated feedstock (Seadi, et al., 2008).

The liquid residue can also be used as pesticide for fruit trees and vegetables(G. Wang, et al., 2007). In addition, the clean liquid and solid residue can also be added to the feedstock to raise pigs, which can accelerate the pig's growth (Qia, Zhang, Wang, & Wang, 2004; G. Wang, et al., 2007).

2.6 Benefits and problems of biogas and digested residue

The production and utilisation of biogas through anaerobic digestion have a number of environmental and social and economic benefits for the society.

Biogas is a kind of renewable energy as it is produced on biomass. The utilization of biogas can replace fossil fuels, thus contribute to the preservation of the natural resources and environmental protection as well as reduced carbon dioxide emission. In addition, the use of biogas can lead to reduced emissions of methane (CH₄) from untreated animal manure, the GHG potential of which is 23 times higher than that of carbon dioxide, thus contribute more to mitigate climate change(Seadi, et al., 2008). Since biogas from anaerobic digestion use national and regional biomass as feedstock, it also increases the security of national energy supply.

Anaerobic digestion is an excellent way to treat organic waste, which will be turned into biogas and the digested feedstock that can be used as fertiliser. Besides, anaerobic digestion can not only reduce the volume of waste, but also the cost for waste disposal(Seadi, et al., 2008).After anaerobic digestion, the unpleasant odours of organic wastes like manure can be reduced up to 80% and the digested residue is nearly odourless.(Seadi, et al., 2008)

The digested residue produced by a biogas plant is a valuable fertiliser, which is rich in nitrogen, phosphorus etc. The digested residue has a higher fertiliser efficiency than the raw animal manure, because of better nutrient availability and carbon/nitrogen ratio etc(Seadi, et al., 2008). The use of digested crop residue from anaerobic digestion can also reduce nitrogen leaching from agricultural land and improve efficiency in the utilization of plant nutrients(Lantza, et al., 2007) .Moreover, the use of the digested residue as fertiliser provides a closed nutrient cycle, thus resulting in the reduction of the use of mineral-based fertilisers(Lantza, et al., 2007).

Since the liquid residue can be used as a pesticide, it will reduce the cost for commercial pesticides(G. Wang, et al., 2007). Besides, the use of liquid and solid residue as feedstock can increase farmers' income on animal husbandry, since pigs fed with the residue can grow faster and need less feedstuff(Qia, et al., 2004). It is also believed that biogas production can make contribution to the rural economic development, create new jobs and improve farmer's income(Seadi, et al., 2008).

Despite the environmental and social and economic benefits of biogas production from anaerobic digestion, there are still some problems and challenges need to be addressed. For example, during the transportation and treatment of feedstock, methane leakage may occur. Thus feedstock and digested residue should be stored and transported in closed containers(SBGF, et al., 2008). If the feedstock is energy crops, there may have competition with food production for agricultural land. Moreover, it should be noticed that the digested residue may contain non-biodegradable contamination in the feedstock(Lantza, et al., 2007). It is found that the digested residues from the sewage treatment plants may have toxic substances, such as high content of heavy metals, residues of pesticides etc, which should not be used as fertilizers(SBGF, et al., 2008). Therefore measures should be taken to control the quality and safety of the digested residue used as fertilizers(Seadi, et al., 2008). In addition, the lack of knowledge and practice of farmers can be a problem for utilizing digested residue as organic fertilizer(Lantza, et al., 2007).

3 Biogas systems in rural China

This chapter begins with a brief description of history of biogas system in rural China, then depicts the current and potential biogas production in rural China and investigates the use of various feedstock as well as digestion technologies applied in household biogas plants and medium and large scale biogas plants for intensive livestock and poultry farms. The section also analyzes the current and potential final utilization of biogas for various energy services, as well as the utilization of the digested residue as fertiliser in agriculture.

3.1 Background and development

In rural China, the biogas plants can be mainly classified into household biogas plants and small, medium and large scale biogas plants, which are also referred to as biogas projects. The size of a household biogas digester is usually of 8 m³, while the volume of single biogas digester of small scale biogas plant is between 20 m³ and 50 m³(MOA, 2007), which is shown in table 3-1.

The medium and large scale biogas plants have the size of single biogas digester larger than 50 m³ and 300 m³, and the total volume larger than 100 m³ and 1000 m³ respectively(MOA, 2007). The medium and large scale biogas plants should also own the pre-treatment facilities for raw materials such as feed-in, stirring equipments, and facilities for the integrated utilization of biogas as well as the digested residues(MOA, 2007).

Table 3-1 the classification of the scale of biogas plants

Scale	Volume of single digester(m ³)	Total volume(m ³)	Biogas production per day(m ³ /day)
Large	≥300	≥1000	≥300
Medium	300>V≥50	1000>V≥100	≥50
Small	50>V≥20	100>V≥50	≥20
household	8	8	1.2

Source: (GEI, 2008; MOA, 2007)

China has a long history for the use of household biogas plants and Luo Guorui invented the first rectangular hydraulic digester in 1920 in Taiwan, China (G. Q. Zhang, 2005). However, the large-scale development of household biogas plants took place in rural China since 1970 in order to solve the problem of energy shortage and around 7 million biogas digesters were installed within 10 years (Y. C. Gao et al., 2006). But most of the household biogas plants have stopped running after 1-3 years due to the poor quality of the design and construction, the shortage of qualified technicians, the lack of funding and poor follow-up service and management etc (Y. C. Gao, et al., 2006; Y. L. Zhang, 2004). As is shown in Figure 3-1, the number of biogas plants dropped quickly from 1978 to 1983. After that, lessons have been summarized and the number of biogas plants increased slowly. Since 1990, different projects have been implemented to build household biogas plants such as Comprehensive Energy Construction in Rural Areas, Ecological Homeland and Enrichment Plan etc. and the number of biogas plants increased stably(Y. C. Gao, et al., 2006).

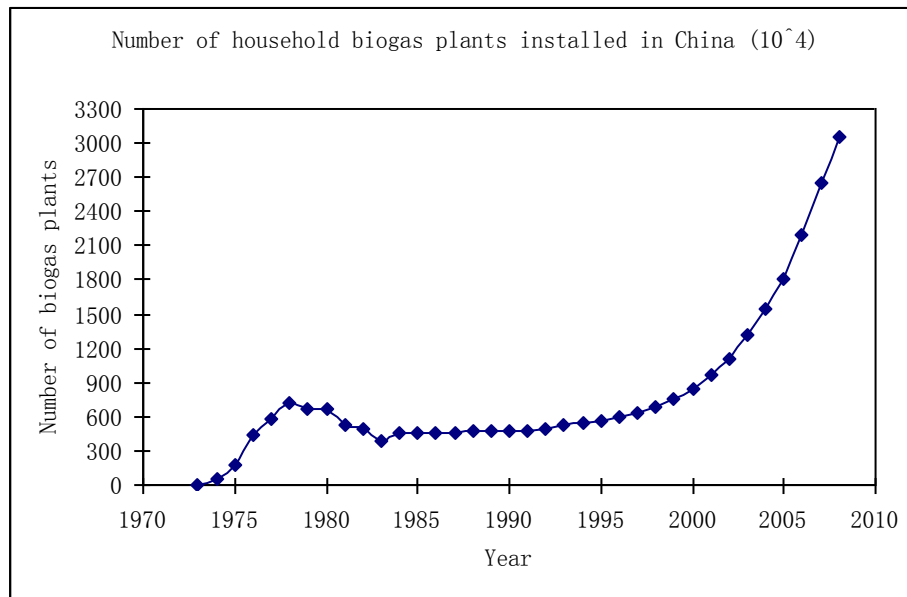


Figure 3-1 Number of household biogas plants installed in rural China (1973-2008)

Source:(Y. Chen, Yang, Sweeney, & Feng, 2010; Y. C. Gao, et al., 2006; NDRC, 2009)

It is believed that the development of rural household biogas is a critical way to build new socialist countryside and sustainable agriculture in the 21st century, which can help adjust agricultural structure, protect the rural environment, increase farmer's income and improve the quality of rural life(Y. Chen, et al., 2010). Therefore, the number of household biogas plants has been increasing sharply since 2000 due to the strong support from the government. China already has the largest number of household biogas digesters in the world (G. L. Deng, Li, Li, & Zhang, 2006). There were 26.5 million biogas plants by 2007 producing 10.5 billion m^3 gas and household biogas digesters are found all over the country, most in the Yangtze River Basin(G. Q. Hu, 2008). By the end of 2008, 30.5 million household biogas plants were built and produced up to 12 billion m^3 of biogas per year(NDRC, 2009). However, it is found that only 60% of household biogas digesters were operating normally in 2007(Wu Di Zhang, et al., 2006) and the comprehensive utilization of household biogas system in rural China only accounted for 37.3% of total rural household users in 2005(G. Q. Hu, 2008).

The development of biogas projects for agricultural wastes, including the medium and large scale biogas plants, has been utilized for treating organic waste and environmental pollution, rather than producing clean energy in rural China(Tian, Zhang, Lu, Ma, & Liu, 2007). It can be seen from the Figure 3-2, before 2000, the annually increased number of biogas projects was less 200. However, after year 2000, especially after year 2003, the number of biogas projects for agricultural waste has increased rapidly and it amounted to approximately 3500 in 2005, because a number of projects have been implemented to promote the construction of biogas projects since 2000, such as *Plan for construction of energy environmental engineering for medium and large scale livestock farms* etc (L. W. Deng, Chen, & Gong, 2008).

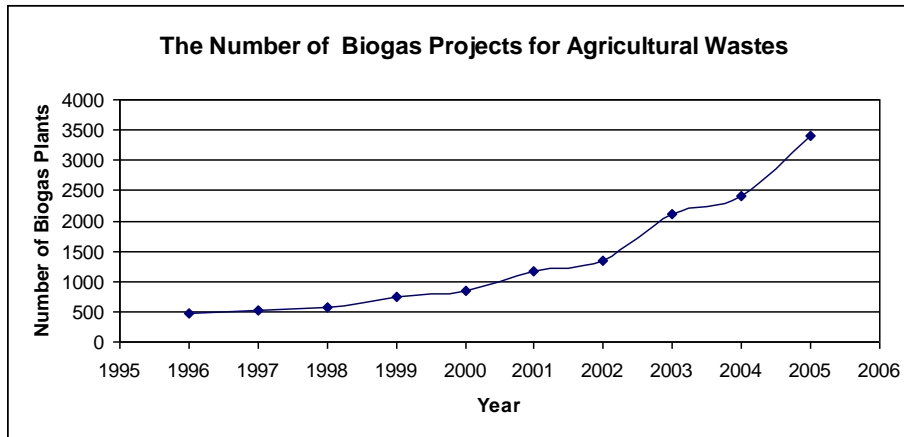


Figure 3-2 the number of biogas projects for agricultural waste (1996-2005)

Source:(MOA, 1996-2005)

However, most of the biogas projects for agricultural wastes are small scale in 2005, accounting for approximately 66% of the total biogas projects(L. W. Deng, et al., 2008). According to *China's rural biogas project planning (2006–2010)*, there were around 700 medium and large scale biogas plants built for intensive livestock and poultry farms, accounting for only 7% of total medium and large scale intensive livestock and poultry farms, and it is planned to build 4000 more during 2006-2010(MOA, 2007). In 2008, 2700 medium and large scale intensive livestock and poultry farms constructed medium and large scale biogas plants, accounting for 22.6% of total number of medium and large scale intensive livestock and poultry farms(MOA, 2009a), which means most of the medium and large scale intensive livestock and poultry farms haven't built biogas plants to treat the manure and waste water.

3.2 Feedstock

The main fermentation material for household biogas plants in rural China is livestock and poultry manure, most of which is from cattle, pigs and chicken and crop straw(Y. Chen, et al., 2010). For medium and large biogas plants for intensive livestock and poultry farms, the major raw material is livestock and poultry manure(L. W. Deng, et al., 2008). At present, energy crops are not used as feedstock for biogas plants to produce biogas in rural China.

3.2.1 Manure

The total quantity of manure can be calculated based on the poultry and livestock species, manure quantity and breeding cycle. As is shown in table 3-2, the total amount of poultry and livestock manure added up to approximately 3.97×10^9 ton in 2007 in China (P. D. Zhang, Y. L. Yang, Y. S. Tian, et al., 2009).

The total quantity of manure can also be estimated based on the number of livestock and poultry as well as the annual dry excrement of livestock and poultry(Yuan, Wu, & Ma, 2005).It is calculated that the current total quantity of dry manure of livestock and poultry in China is around 1.47×10^9 tons, among which about 1.02×10^9 tons can be collected, which is equivalent to 1.07×10^8 tons of standard coal(Z. Y. Wang & Li, 2007). Moreover, according to *Livestock industry development planning (2010–2020)*, it is estimated that manure of livestock and

poultry will amount to 2.5×10^9 tons and 4×10^9 tons in 2010 and 2020 respectively and of which the collected amount is equal to 1.2×10^8 and 1.6×10^8 tons of standard coal respectively (Y. Chen, et al., 2010). Therefore, the total amount of livestock and poultry manure for biogas production is rich in China.

Table 3-2 Poultry and livestock manure resources in China in 2007

Animal species	Breeding quantity (10 ⁴)	Manure discharge rates	Breeding cycle (day)	Excrement amount (10 ⁴ t)
Cattle	13944.2	8.2t/year	365	114342.5
Horse	719.5	5.9t/year	365	4244.8
Donkey/mule	730.6/345.1	5.0t/year	365	5378.1
Pig sale	68050.4	5.3kg/day	300	105200.1
Pig stock	49440.7	5.3kg/day	365	95643.1
Chicken	731852.17	0.10kg/day	55	40251.87
Sheep	36896.6	0.87t/year	365	32100.1
Total				397160.6

Source: (P. D. Zhang, Y. L. Yang, Y. S. Tian, et al., 2009)

However, it is found livestock and poultry farming has become more centralized and intensive. For example, the intensive livestock farms with more than 500 pigs each year almost doubled their contribution of pig production to the total pig production from 1999 to 2004 (M. Chen, et al., 2008). In 2005, the production of livestock and poultry from medium and large scale intensive livestock and poultry farms amounts to 12.5% of total production, though the number of the farms only accounts for around 2% of the total number of intensive livestock and poultry farms (MOA, 2007)¹. In addition, at the end of 2008, the production of intensive livestock and poultry farms accounted to more than 50% of the total livestock and poultry production (Mo & Liu, 2009), and it is estimated that the production of intensive pig farms will account for 65% of the total production by 2015 (MOA, 2009b). Furthermore, large amount of intensive livestock and poultry farms are gathering around in certain areas, resulting in the excessive amount of manure in the areas (Peng, 2007).

Therefore, although the total amount of manure from livestock and poultry in rural China is abundant, more and more are collected in intensive livestock and poultry farms, especially the medium and large scale farms. Meanwhile, farmers of household biogas plants are getting short of manure since more and more farmers give up scatter breeding of livestock and poultry.

¹ As for the classification of intensive livestock and poultry farms, please see Appendix 2

3.2.2 Crop residue

The availability of the crop straw mainly depends on the production of crops, the collection rate and the purpose of the crop utilization(Gu, Zhang, & Wang, 2001). It is estimated that there are of 6.81×10^8 tons of agricultural residue produced every year and 5.46×10^8 tons of them can be collected, of which 2.9×10^8 tons can be utilized to generate energy, equal to 1.45×10^8 tons of standard coal(Z. Y. Wang & Li, 2007). Along with population growth, the total quantity of crop will continue to increase over the long term. It is predicted that $4\text{-}5 \times 10^8$ tons of crop residue can be utilized as modern high efficient energy resource after 2030, which is equal to $2\text{-}3 \times 10^8$ million tons of standard coal(Y. Chen, et al., 2010). Thus, rural China is abundant in crop straw.

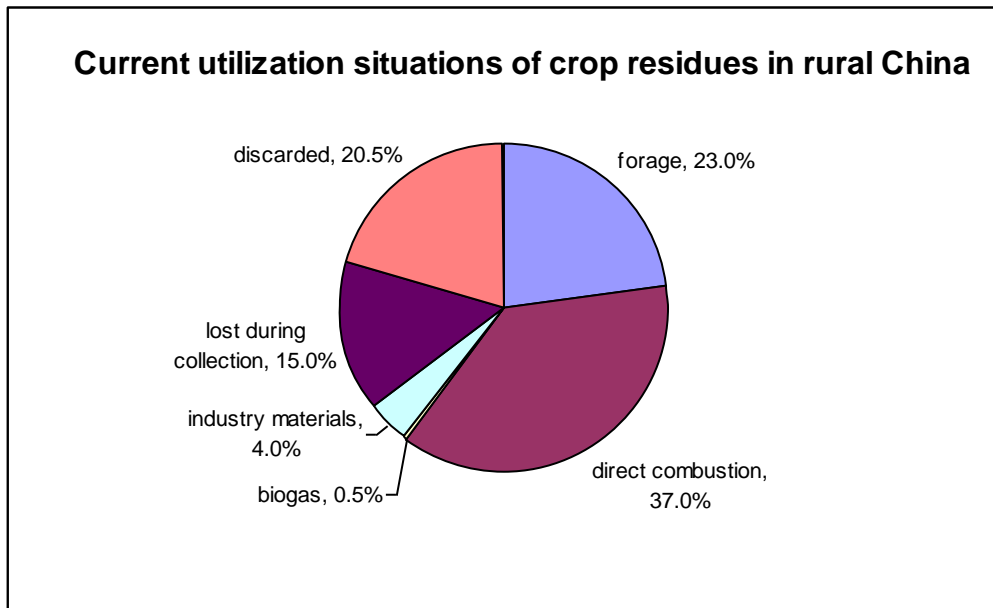


Figure 3-3 Current utilization situations of crop residues in rural China

Source:(H. Liu, Jiang, Zhuang, & Wang, 2008)

However, the main utilization of crop straw is still direct combustion as fuels for cooking or heating in rural China, which is low efficient. As is shown in figure 3-3, it is found that 37.5% of the total crop residues had been used for bio-energy (37% direct burning while 0.5% as biogas), 23% used for fodder, 20.5% discarded directly in the field, which was burned and led to serious environmental pollution, 15% had been returned to the fields which was lost during collection, and the rest 4% used for industrial materials such as for papermaking(H. Liu, et al., 2008).

In fact, it is inefficient and time-demanding when the crop residues are used as feedstock for anaerobic digestion, which generates less biogas(S. J. Wu, Liu, Wang, Liu, & Wang, 2008). The main organic components of crop residue are cellulose, hemi-cellulose, lignin, pectin and wax, which is short of effective nitrogen and phosphorus components, thus hinder microbial fermentation(G. Q. Zhang, 2005). In the process of anaerobic digestion, the micro-organism has a weak digestion capability to degrade lignocelluloses, resulting in a slow hydrolytic process and a low degree of hydrolysis, thus affects the subsequent process of acidification and gasification and leads to poor efficiency of input-output(S. J. Wu, et al., 2008).

Some success have been achieved on the pre-treatment of crop straw using physical, chemical and biological methods to increase the production of biogas(X. H. Chen & Zhu, 2007). Due to the lack of manure as fermentation material for household biogas plants, Ministry of Agriculture has encouraged and developed new methods to use crop straw to produce biogas. Biological method has been utilized to pre-treat straw and it is said the technology is mature(Kou, et al., 2008). By the end of 2007, there were 55000 household biogas plants and around 2650 centralised biogas plants using crop straw(Kou, et al., 2008).

However, there are still many problems. For example, the pre-treatment increases the cost and the secondary contamination may be induced by the chemical pre-treatment. In addition, it is still in the experimental stage to use biological method to pre-treat straw, thus it is difficult to apply at the large scale(Y. Chen, et al., 2010). Lantza et al (2007) find that straw has not been taken into account in the biogas potential in Sweden, because it is difficult to digest and better to be combusted for energy recovery(Lantza, et al., 2007). Moreover, in practice, it is found that it's difficult to feed in the crop straw and output the residue. Besides it forms the crust easily thus reducing the biogas production(G. Q. Hu, 2008). Therefore, crop residues may not be expected to produce biogas at large scale in the near future.

As a matter of fact, it is suggested that the most potential, practical and valuable way to utilize crop residues could be to develop crop residue as forage in China. As for bio-energy utilization, the development of crop residues gasification, crop residues liquid fuel and crop residues electricity should be emphasized(H. Liu, et al., 2008).

3.2.3 Energy crops

Dedicated energy crops such as leys have been used as feedstock to produce biogas in Europe and the number of biogas plants using dedicated energy crops was increasing during last years(Seadi, et al., 2008).In Sweden, it was estimated that 1.7×10^5 ha could be used to grow leys for biogas production in the future, equivalent to 12PJ/year(Lantza, et al., 2007). However, there are no reports on the utilization of energy crops to produce biogas in rural China.

3.3 Technologies

3.3.1 Household biogas plants

The rural household biogas digester is an anaerobic fermentation facility. As mentioned before, there are millions of family scale biogas plants in rural China, using very simple technologies. The main feedstock for the household biogas plants are household organic waste, livestock and poultry manure and human excrement etc. and the generated biogas is mainly used for the household cooking and lighting.

The household biogas plant is simple and cheap to be constructed using local produced materials and it is easy to operate and maintain. There are generally no specific control facilities and heating process such as mesophilic or thermophilic operation(Seadi, et al., 2008). The fermentation temperature of the household biogas plant is usually at normal temperatures, ranging from 10 to 25°C(G. Q. Hu, 2008).

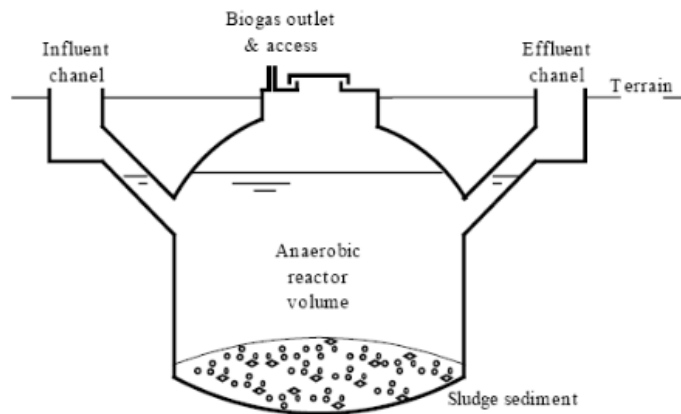


Figure 3-4 Household biogas plant in rural China

Source:(Seadi, et al., 2008)

The main type of rural household digester in China is the hydraulic biogas digester, which is built of clay, brick and concrete (G. Q. Hu, 2008), and accounting for 90% of household biogas plants(L. X. Zhang, Yang, Chen, & Chen, 2009). The digester is usually an underground reactor and is operated in a semi-continuous mode, where new feedstock is added once a day through influent channel and a similar amount of digested mixed liquid is removed through effluent channel each day, as is shown in figure 3-4(Seadi, et al., 2008). Since the digester is not stirred, the sedimentation of suspended solids must be taken away 2 to 3 times every year(Seadi, et al., 2008). The biogas digester is usually constructed in 8 m³, which is generally in combination with the renovation of the kitchen, the toilet and the pigpen and called *one plant with three remodelling*(MOA, 2007).

Although hydraulic digester is easy and cheap to construct and accounting for around 90% of household biogas digesters in rural China, there are a number of problems. The hydraulic digester is greatly influenced by the temperature, thus more biogas is produced in summer which less in winter. The second problem is the variation of the biogas pressure since there is no biogas storage, which is harmful to the biogas stove and other facilities. The third one is it's very difficult to clear up the residue each year, and even dangerous, because farmers usually don't have the equipment to clean and it's dangerous for them to get into the digester to get rid of the residue. In addition, the current hydraulic digester is mainly made of clay, brick and concrete, which is easily eroded by the H₂S, thus leading to the biogas leakage(S. B. Wu, Zhai, & Dong, 2008).

A series of standardized household biogas digesters have been built so as to adapt to different climate and fermentation feedstock and there are four main types of household biogas digesters including Hydraulic Digester, Separated Floating Bell-Type Digester, Partially Submerged Plastic Digester and Spherical Digester (Y. C. Gao, et al., 2006). There are new type of household biogas digesters made of glass fibre reinforced plastics (GRP) which entered the market in 2000(Wu Di Zhang, et al., 2006). The GRP digester has less maintenance cost, shorter construction time and longer operational life than the concrete one(D. S. Li, 2008). However, such kind of digester is much more expensive (S. B. Wu, et al., 2008).

In order to guarantee the quality of the household biogas plant and the associated facilities, 15 national standards with regard to rural biogas plants have been issued such as *Household Biogas Digester Standard Collection of Drawings* GB/T4750-2002, *Quality Assessment of Household Biogas Digester* GB/T 4751-2002, *The Operation Rules for Construction of Household Biogas Digesters* GB/T 4752-2002, *Household Biogas Stove* GB/T 3606-2001 etc(MOA, 2007). Except biogas digester, the biogas facilities mainly include biogas stoves, biogas lamps, biogas multi-function meter and biogas pipes and valves, which are provided to farmers through the way of open competitive bidding(Q. C. Hu, 2006b)

Currently the cold fermentation technology is one of the barriers to the development of household biogas digester(Y. Chen, et al., 2010). The rate of biogas production will speed up when the temperature increases, with the minimum temperature for biogas production at 10°C(H. R. Ma, 2003). In northern China, the average temperature is lower than 10°C during the winter so that there are only 8-9 months for efficient biogas production (H. Y. Hu, 2007). The use of *Four in One* eco-agricultural model(See 3.4.1.2) is one of ways to solve the problem, which uses the greenhouse to improve the temperature of the digester, however, the initial investment is high (Y. Chen, Yang, Feng, & Ren, 2008; Zhou, Wu, Chen, & Chen, 2008).

3.3.2 Medium and large scale biogas plants

The technology of medium and large scale biogas plants has been increasingly getting mature and the associated facilities are getting close to the international standard(Zhao, Dong, & Tian, 2008). The whole process of the biogas projects can be designed to treat different feedstock such as manure of pigs, chickens and castles, including the pre-treatment, anaerobic digestion, biogas distribution, making fertilizer, post-treatment of digested liquid etc(Zhao, et al., 2008). Most of medium and large scale biogas plants use vertical tanks for fermentation and a few of them use underground installations. Almost all the fermentation technologies have been applied in China, including Continuous Stirred-tank Reactor(CSTR), Anaerobic Sequencing Batch Reactor (ASBR), etc (L. W. Deng, et al., 2008). Generally fermentation process is at normal temperature without mechanical stirring and biogas production is approximately 0.5-0.6 m³/m³.day(L. W. Deng, et al., 2008). As for the associated facilities, biogas power generator sets have been successfully developed and a series of products for automatic control, desulphurization and dryer, solid-liquid separation etc have been manufactured(Zhao, et al., 2008).

However, the overall development of medium and large scale biogas plants are still far behind the international advanced level (Zhao, et al., 2008). It is found that the medium and large scale biogas plants are generally inefficient, although there are a number of fermentation processes, the biogas production is low due to low fermentation temperature and short of stirring (S. B. Wang, Zhang, & Cao, 2009). Moreover, the economic performance of the biogas plants is poor due to the inefficient utilization of the various products. The main purpose for developing medium and large scale biogas plants is to treat the waste and produce energy, while lack of the consideration of organic fertilizer manufacturing, the biogas power generation and use of the remnant heat etc (S. B. Wang, et al., 2009). In addition, there is lack of auxiliary equipments and standardized process for developing the medium and large scale biogas projects. Due to the limited technology and cost control, the traditional way of installing on-site is usually adopted, which takes long time, difficult to maintain and repair, and can't guarantee the quality. More manpower also need to be employed because of the outdated feeding and discharging facilities (S. B. Wang, et al., 2009).

3.4 Utilization

After the anaerobic fermentation, biogas and the digested residue will be produced by biogas plants. For the users of household biogas plants, biogas is usually used for cooking, heating and lighting, while the digested residue is mainly used as fertilizers, pesticide and even feedstock of livestock (G. Wang, et al., 2007). For the owners of medium large scale biogas plants, apart from cooking, heating, biogas is also utilized to generate electricity and can be upgraded to produce vehicle fuels too. The digested residue is either used as organic fertilizer or discharge to the natural environment after post-treatment of the waste water.

3.4.1 Household biogas plants

The rural household biogas plant is not only used to provide the clean energy, but also to increase the farmer's income and improve the environment. It is estimated that a 8 m³ household biogas plant can produce around 385m³ biogas each year, equivalent to 605kg standard coal, and generate 10-15 tons of digested residue which can be utilized as fertilizer for 0.13-0.2 hectare of vegetables (MOA, 2007).

In rural area, biogas is mainly used for cooking, heating and lighting. According to the survey in western areas (Sichuan, Shannxi and Inner Mongolia), 94% of the farmers use biogas for cooking and 28% of them for lighting. Around 25% of the farmers use the digested residue for fertilizing fruit trees and crops (J. Q. Zhang, 2008). Another survey in Jiangxi, Hubei, Henan and Shanxi provinces has revealed that 85.6% and 75.4% farmers use biogas for cooking and boiling water respectively, and around 28.3% for lighting, which is mainly utilized in the kitchen and greenhouse. It is found that 87.6% farmers apply the digested residue as fertilizers (L. B. Wang & Liu, 2008).

Over the years, several agricultural ecological models for household biogas applications have been developed, including *Three in One*, *Four in One* and *Five in One* eco-agricultural models in different parts of China (Y. Chen, et al., 2010), which emphasize the integrated use of the household biogas.

3.4.1.1 Three in One (Southern Model)

The *Three in One* eco-agricultural model, which is also called Southern Model, is made of the biogas digester, the pigpen and toilet, which is popular in southern China (Y. M. Wang, Liu, & Bian, 2005). The *Three in one* eco-agricultural model is also called pig-biogas-fruit system. The digester is simple to maintain, relatively cheap to build and has a long operational life. It's usually 8 m³ and built under the toilet and pigpen with a pipe linking them. The human waste, pig dung is washed down to the digester. After fermentation, biogas produced from the digester can be used for lighting and cooking, while the slurry can be used as fertilizer and pesticide for vegetables and fruit trees (IIIIEE, 2009).

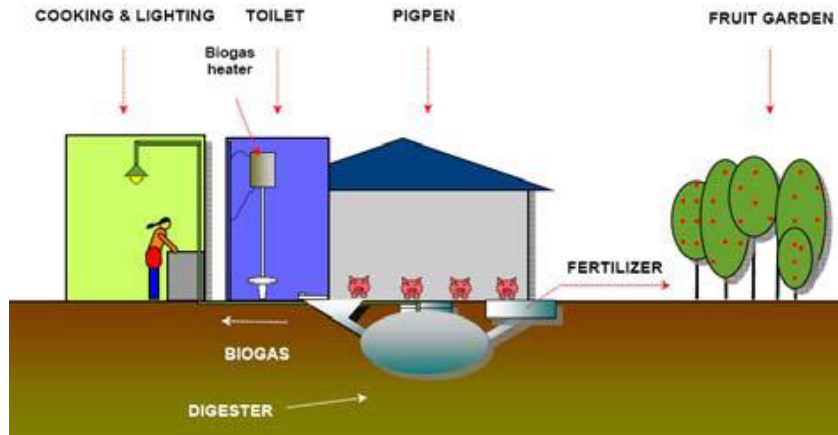


Figure 3-5 Pig-Biogas-Fruit Model in Southern China

Source: (IIIEE, 2009)

3.4.1.2 Four in One (Northern Model)

The *Four in One* eco-agricultural model, which is also called Northern Model, is mainly used in northern China, which consists of biogas digester, pigpen, toilet and solar greenhouse (C. X. Wang, Li, Gao, & Gao, 1998). The solar greenhouse is used to increase the temperature of the biogas digester during the cold season, thus improve the efficiency of biogas production. The warm temperature of greenhouse is in favour of the growth of vegetables and pigs (W. D. Zhang, Su, Liu, & Wu, 2001).

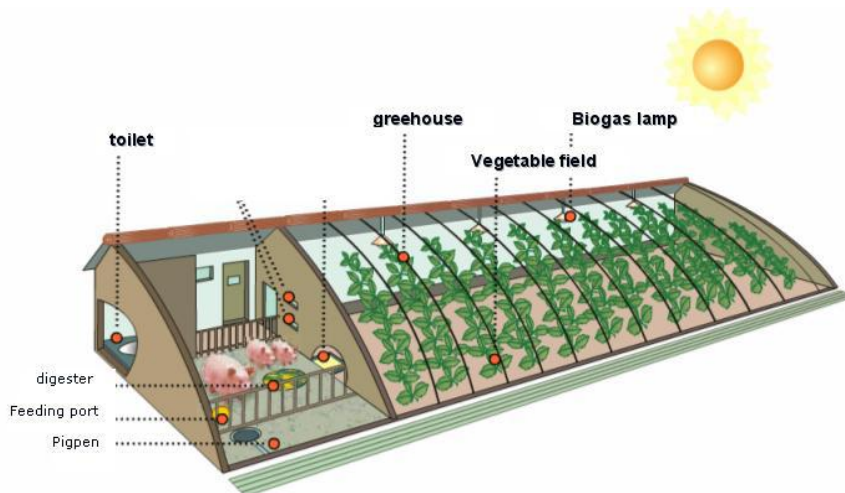


Figure 3-6 Four in One Model

Source:(H. H. Wang, 2005)

3.4.1.3 Five in One

The *Five in One* eco-agricultural model is used in the northwest China, where is short of water. The model is made of the biogas digester, barns, toilet, water cellar and water-saving

irrigation system (Qiu, Yang, & Yang, 2001). The use of water cellar and water-saving facilities can ease the burden on water resources caused by the irrigation of orchard (J. J. Liu, Qiu, & Yuan, 2007).

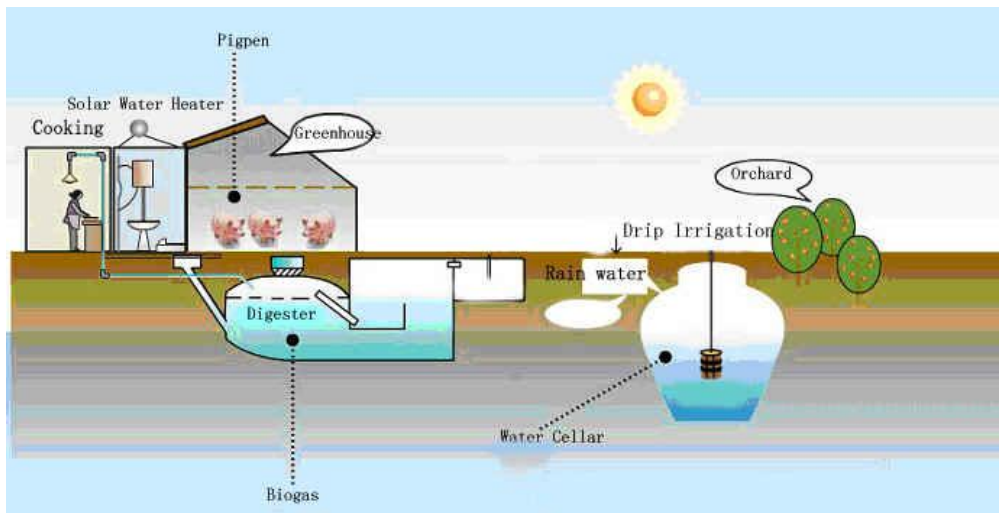


Figure 3-7 Five in One Model

Source: adapted from(H. H. Wang, 2005)

Besides the three basic eco-agricultural models, there are all kinds of local biogas eco-agricultural models, for example, *cattle-biogas-vegetable* in Wenzhou, Zhejiang Province, *Pomelo-biogas-livestock* in Meizhou, Guangdong Province, *cattle-biogas-fungus* in Fuyang, Anhui Province etc (F. L. Huang et al., 2007; S. B. Wu, et al., 2008).

3.4.2 Medium and large scale biogas plants

The biogas produced in the medium and large scale biogas plants is currently utilized for the production of heat and electricity. There are few reports of upgrading the biogas and using it as vehicle fuel or injecting it into the natural gas grid in rural China. In some cases, for example, when there is excess biogas in summer, the biogas is simply released or flared(J. M. Li & Sun, 2003).

The main use of biogas is still for cooking and heating. It can be connected to biogas stove, heater and lamp in the livestock farm and used for cooking in the dining room, lighting or keeping the livestock and poultry warm. Moreover, the biogas can be transferred through pipeline and provided to the local people for cooking and heating(J. M. Li & Sun, 2003). The price of the biogas for the local people is usually very low or for free (Lu & Song, 2008; Y. Z. Pang & Li, 2006). In addition, in some cases cooking and heating can not use all the biogas and the excess production is simply released(J. M. Li & Sun, 2003).

At the end of 2007, there are around 1700 large scale biogas plants to deal with agricultural wastes, however, only 5% of the biogas produced was utilized to generate electricity(Q. C. Hu, Zhu, Pan, He, & Li, 2009) . There are less 3% of biogas produced by medium and large scale biogas plants used to generate electricity in China, while in Germany, almost all the plants of around 3000 biogas plants produce electricity and 98% of them applies CHP and uses the remnant heat to heat the biogas digester(G. Wang, et al., 2007). At present, the

power generation equipments using biogas can be produced in China, from 10kW to 100kW. However, the technology for using the remnant heat and heat exchange is far behind Europe(G. Wang, et al., 2007). Almost all the electricity generated by biogas is utilized in the livestock farms and few are connected to the power grid(L. W. Deng, et al., 2008).

Some researches suggest that the biogas can be upgraded and used as vehicle fuel to replace the natural gas, or use the biogas as the raw material for chemical industry, such as the generation of CH₄ and CO₂, CO+H₂ etc(Y. Z. Pang & Li, 2006). Nevertheless, there are few researches and practices in rural China at present.

It is essential to dispose the comparatively large amounts of digested solid and liquid residue produced by medium and large scale biogas plants in a suitable way. At present, the digested residue is mainly used as fertiliser in agriculture land close to the biogas plants. If there are not enough agriculture farms to absorb the liquid residue, it will be discharged into the natural environment after the treatment to meet the standard for waste water discharge(Hua & Zhu, 2004). Although the liquid residue is regarded as quality fertilizer, it is usually provided to the local farmers for free. Some biogas plants utilize the solid residue to manufacture organic fertilizers and sell it to the market (Yao, Hao, & Guo, 2002).

Up to now, there are three types of medium and large scale biogas plants for intensive livestock and poultry farms to deal with the digested residue so as to produce energy, protect environment, manufacture fertilizer and save water(Hua & Zhu, 2004; MOEP, 2009). According to the scale of livestock and poultry farm, the surrounding environmental capacity etc., the types of biogas plants include comprehensive utilization model, ecological model and anaerobic-aerobic model(Hua & Zhu, 2004).

3.4.2.1 Comprehensive utilization model

Comprehensive utilization model is usually applied when there are fishing pools, agricultural farms, fruit trees orchard, or vegetable farm around the livestock farms, so that digested solid and liquid residue can be utilized as fertilizer and there is no need for waste water treatment. Biogas can be used for cooking and heating by local people who live close to the livestock and poultry farm(Hua & Zhu, 2004).

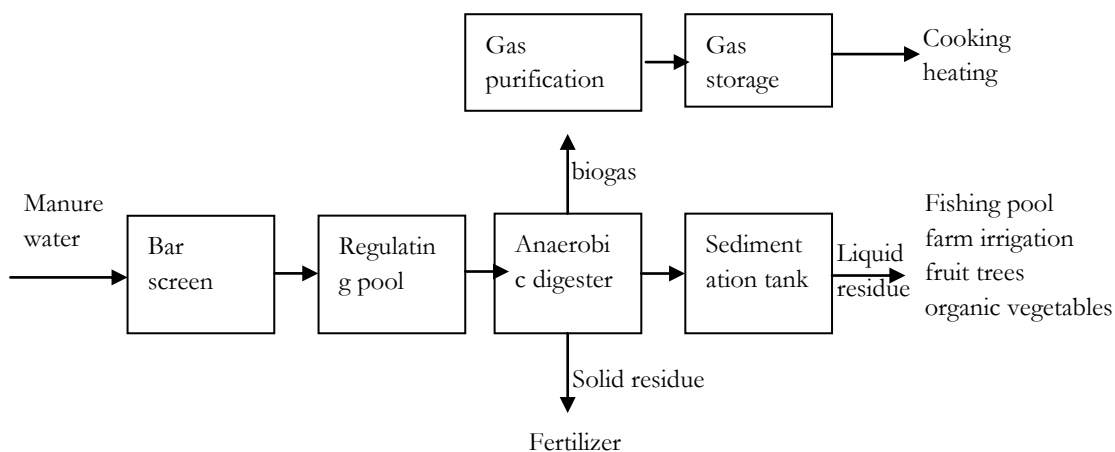


Figure 3-8 Comprehensive utilization model Source: adapted from (Hua & Zhu, 2004)

3.4.2.2 Ecological model

Ecological model is generally utilized when there are no fishing pools or agricultural farms around the livestock farm to use the digested residue. However, there are stabilization ponds that can treat the waste water and surrounding natural environment is not sensitive and has the capacity to absorb the waste water. The manure, separated solid residue and digested residue are usually composted to produce the organic fertilizer. Biogas can be used for cooking and heating or generating electricity(Hua & Zhu, 2004).

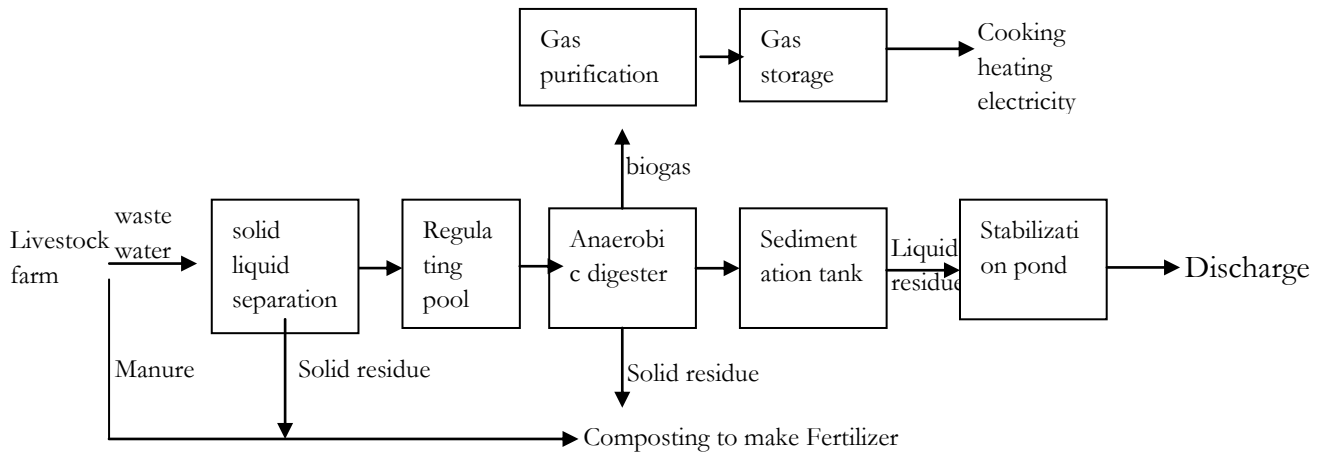


Figure 3-9 Ecological model

Source: adapted from (Hua & Zhu, 2004)

3.4.2.3 Anaerobic-aerobic model

When there are no fishing pools or agricultural farms around the livestock farm, and there is no enough space to build stabilization ponds, anaerobic-aerobic model is usually utilized, which is often applied in the intensive livestock farms built in suburban areas. The waste water must be treated using aerobic process before it meets the standard of waste water to discharge. The manure, separated solid residue, anaerobic and aerobic digested residue are usually used to produce the organic fertilizer by aerobic composting(Hua & Zhu, 2004). Biogas can be utilized for cooking and heating or generating electricity.

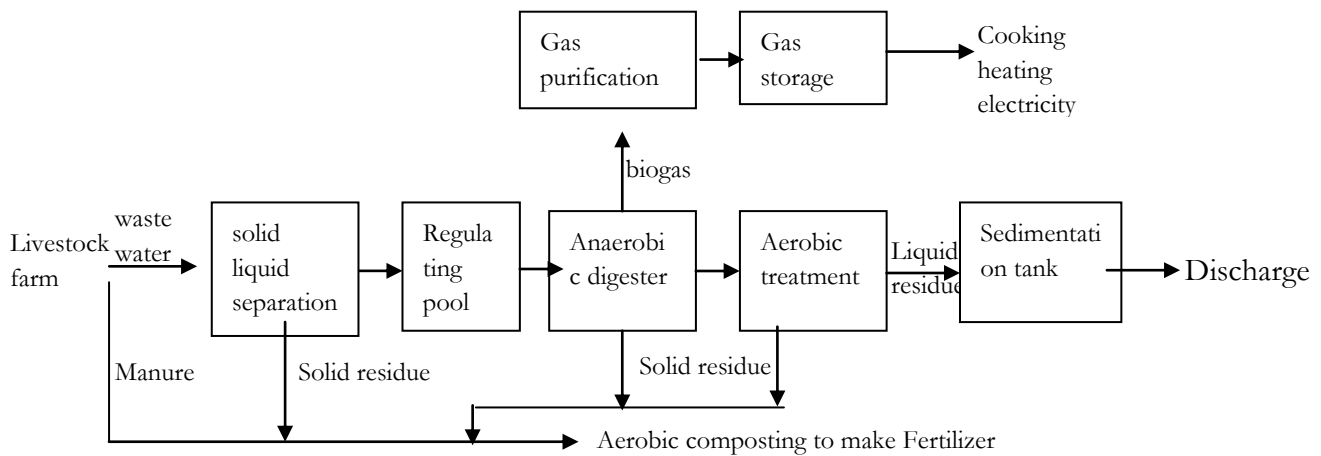


Figure 3-10 Anaerobic-aerobic model

Source: adapted from (Hua & Zhu, 2004)

4 Incentives and barriers for biogas systems in rural China

For the potential expansion of biogas systems in rural China, there are a number of incentives and barriers affecting biogas production and utilization of biogas and the digested residue. In his chapter the author analyzes the various incentives and barriers for the expansion of household biogas plants and medium large scale biogas plants respectively.

4.1 Biogas production

The biogas production in rural China is affected by a number of factors with regard to renewable energy, climate change, environmental protection, waste management and sustainable agriculture. There are different incentives and barriers for the construction of household biogas plants and medium large scale biogas plants. For the former, the main reason is to provide clean and renewable energy to farmers, while the latter is intended to solve the serious environmental problems caused by manure of intensive livestock and poultry farming. However, both of them aim to make a comprehensive use of the biogas system.

4.1.1 Incentives for household biogas plants

There are a number of incentives which affect the construction of household biogas plants in rural China, in terms of policy, economy, technology and society.

4.1.1.1 Policies

A number of policies, laws and regulations have been issued to promote the construction of household biogas plants in rural China, which can be classified into rural development, renewable energy, climate change etc.

Household biogas plants have been identified as an important way to increase farmers' income, promote the adjustment of agricultural structure, protect the rural environment and improve their living conditions(MOA, 2007). Thus a number of critical policies with regard to farmer, agriculture and rural area have called on to promote the household biogas plants, which have been regarded as one of the basic infrastructures in rural area. The most important ones are:

- *Circular of CPC Central Committee and State Council on Agriculture and Rural Work* (No.3 [2003])
- *Circular of CPC Central Committee and State Council on Increasing Farmers' Income* (No. 1 [2004])
- *Circular of CPC Central Committee and State Council on Further Strengthening the Work in Rural Areas to Raise the Overall Agricultural Production Capacity* (No. 1 [2005])
- *Circular of CPC Central Committee and State Council on Promoting the Building of New Socialist Countryside*(No.1 [2006])

Several national laws, regulations and policies related to renewable energy and energy saving also emphasizes to promote the use of biogas as one kind of renewable energy in rural area, for example

- *Energy Conservation Law of the People's Republic of China (2007)*
- *Renewable Energy Law of the People's Republic of China (2005)*
- *Agriculture Law of the People's Republic of China (2002)*
- *Regulation on Returning Farmland to Forest of the People's Republic of China (2002)*

People's Republic of China Renewable Energy Law states the government encourages and supports the utilization of renewable energy in rural areas including biogas. It is proposed that around 40 million rural households(equal to 0.16 billion people) and 80 million rural households (equal to 0.3 billion people)will use biogas for cooking and heating by 2010 and 2020 respectively, equivalent to 15 billion cubic meter and 30 billion cubic meter each year respectively in *Mid-Long Term Development Plan for Renewable Energy*(NDRC, 2007).

In addition, the construction of household biogas plants has been regarded as an important way to mitigate climate change, thus it has been included in China's policy on climate change. For instance, in *China's Policies and Actions for Addressing Climate Change*, it indicates that over 26.5 million rural household biogas plants were built by the end of 2007, reducing 44 million tons of carbon dioxide emission annually(IOUSC, 2008). In *China's Policies and Actions for Addressing Climate Change—The Progress Report 2009*, it underlines that there are 30.5 million household biogas plants in rural China by the end of 2008, which generated around 12 billion cubic meters of methane per year, equivalent to reducing carbon dioxide emission by over 49 million tons(NDRC, 2009).

Moreover, Ministry of Agriculture, the leading organization for the expansion of rural household biogas plants, have issued a number of regulations to plan, stimulate and manage the construction of household biogas plants in rural China, such as *Development Scheme for Service System of Rural Biogas in China (Tentative)*, *China's rural biogas project planning (2006–2010)* and *Regulations on Rural Biogas Projects Supported by National Bond (Tentative)* etc. For example, *China's rural biogas project planning (2006 - 2010)* sets up the detailed plan to guide the dissemination of household biogas digesters from 2006 to 2010 in rural China(MOA, 2007).

4.1.1.2 Economy

There are a number of economic incentives to promote the development of rural household biogas plants, including the large amount of subsidies from the central government and local governments, the reduced cost of energy on cooking and heating, the less expenditure on chemical fertilizer and pesticides etc. In addition, the introduction of CDM for household biogas plants can become one of the important ways to increase the investment.

Large amount of investment from the central government has been provided to promote the development of household biogas plants in rural China. The financial support from the central government has been increased quickly since 2001. The investment for rural

household biogas digester amounted to 3.45 billion Yuan²(equals to 0.345 billion Euro) from 2001 to 2005(MOA, 2007). In 2003, about 1 billion Yuan was invested in rural China by the Rural Biogas Project Supported by National Bond, which was launched by the Ministry of Agriculture and National Development and Reform Commission. Around 1 billion Yuan national bonds were invested by Chinese central government in 2004 and 2005 respectively for the construction of rural household biogas plants(MOA, 2007).

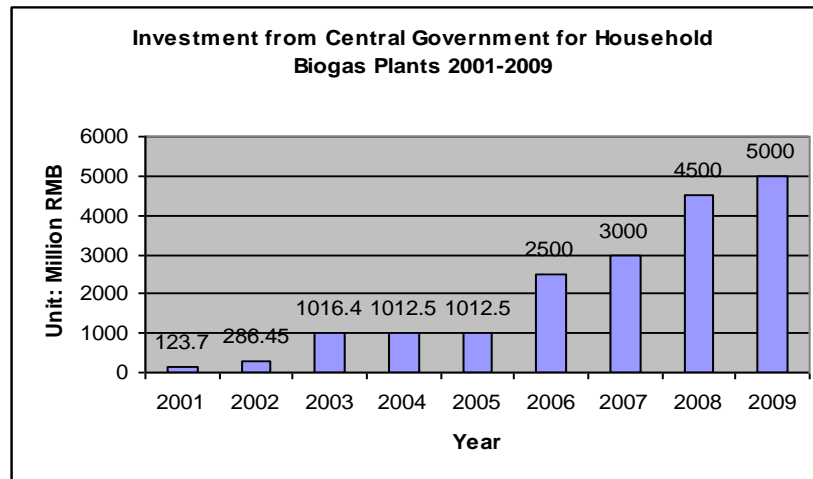


Figure 4-1 Investment from Central Government for Household Biogas Plants 2001-2009

Source:(B. Q. Li et al., 2010; MOA, 2007)

The investment was further increased after 2005, which amounted to 2.5 billion Yuan and 3 billion Yuan in 2006 and 2007 respectively(B. Q. Li, et al., 2010). In 2008, Ministry of Agriculture planned to invest additional 3 billion Yuan to build rural household biogas plants, set up rural biogas service system, and construct joint-household biogas projects as well as biogas projects for intensive livestock and poultry farming area, which has been regarded as one of the measures to stimulate economic recovery after financial crisis(P. D. Zhang, Y. L. Yang, Y. S. Tian, et al., 2009).

The investment of household biogas in rural China is usually shared by the central government, local governments and the users. The common household biogas plant is constructed in 8 m³, which is usually in combination with the renovation of the kitchen, the toilet and the pigpen and called *one plant with three remodelling*. The average investment ranges from 3000 to 3500 Yuan for *one plant with three remodelling*, while the subsidy from the central government is around 800-1200 Yuan, which is mainly used to purchase the construction materials such as concrete, biogas stoves and accessories as well as remuneration for biogas workers(MOA, 2007). According to *Regulations on Rural Biogas Projects Supported by National Bond*(MOA, 2003), the financial subsidy from central government is 1200 Yuan per household in the north-western and north-eastern areas, 1000 Yuan in the south-western area and 800 Yuan in other areas.

In 2007, *Development Scheme for Service System of Rural Biogas in China (Tentative)* was issued and it proposes to build rural biogas service network and each branch can serve 300-500

² Exchange rate of Chinese Yuan to Euro is 10:1

households and consists of one place, one pool to store fermentation materials, a set of feed-in and discharge equipments, a set of monitoring facilities, a set of maintenance tools and a set of biogas accessories. The investment for such service branch is around 31000 Yuan. The financial subsidy from central government is 19000 Yuan per service branch in western areas, 15000 Yuan in the middle areas and 8000 Yuan in eastern areas, which is mainly used for the purchase of feed-in and discharge facilities, monitoring and maintenance tools (MOA & NDRC, 2007).

In 2009, in order to help the low income farmers to install the household biogas plants, the subsidy from the central government for the development of rural household biogas plants has been further increased, which is 1500 Yuan per household in the western and north-eastern areas, 1200 Yuan in the middle areas and 1000 Yuan in eastern areas (GONDRC & GOMOA, 2009).

It is reported that an 8 m³ biogas digester can produce 385 m³ of biogas annually, equivalent to 605 kg of standard coal. In addition, it can provide 10-15 ton of digested residue each year, which can be used as fertilizer for 0.13-0.2 Ha land and reduce the use of pesticide by 20% (MOA, 2003). Thus the use of household biogas plant can reduce the cost for cooking and heating, as well as commercial fertilizers and pesticides. Moreover, the residue can improve soil quality and fertility, because it contains high proportions of nitrogen, phosphate, potassium etc (GEI, 2008), thus increase the production of fruits and vegetables without additional cost. Besides, pigs fed with the liquid residue not only need less feedstuff, but also grow faster (Qi, Zhang, Wang, & Wang, 2005). Therefore, farmers' income on fruit farming and animal husbandry can be increased by the use of the biogas digester.

The clean development mechanism (CDM) was proposed in Kyoto Protocol in order to deal with the problem of climate change. Under Kyoto Protocol, CDM allows the industrialised countries which have the commitment to reduce greenhouse gas (Annex B countries) to invest in projects and purchase the carbon emission reduction (CER) in developing countries, which is less expensive compared with emission reductions in their own countries (Y. Chen, et al., 2010). Since household biogas plants can reduce the emission of methane and the sale of verified carbon emission reduction (CER) will lead to extra economic return, therefore, CDM has provided new channel of finance for household biogas plants in China (Y. Chen, et al., 2010).

4.1.1.3 Technology

In General, the technology for building household biogas plants in China is mature (P. D. Zhang, Y. L. Yang, Y. S. Tian, et al., 2009). The hydraulic biogas digester is the main type of rural household biogas digesters in China, which is usually built of clay, brick and concrete (G. Q. Hu, 2008). The biogas plant is usually built in 8 m³ and is combined with the renovation of the kitchen, the toilet and pigpen, which is called *one plant with three remodelling* (MOA, 2003). National standards with regard to the construction of household biogas plants have been issued to guarantee the quality and safety, such as *Household Biogas Digester Standard Collection of Drawings* GB/T4750-2002, *Quality Assessment of Household Biogas Digester* GB/T 4751-2002, *The Operation Rules for Construction of Household Biogas Digesters* GB/T 4752-2002 etc (MOA, 2007). In addition, new type of household biogas digesters made of glass fibre reinforced plastics (GRP) was invented, which need short time to construct, less cost to maintain and has longer operational life than the concrete one (D. S. Li, 2008).

Besides biogas digesters, there are a number of companies that produce all kinds of biogas plant accessories such as biogas stoves, biogas lamps, biogas multi-function meter and biogas pipes and valves etc. National standards with regard to the biogas plant accessories have also been issued to guarantee the quality and safety, including *Household Biogas Stove GB/T 3606-2001*, *Household Biogas Lamp NY/T 344-1998*, *Biogas Pressure Meter NY/T 858-2004*, *Household Biogas Desulfurizer NY/T 859-2004*, etc(MOA, 2007).

4.1.1.4 Society

The Chinese government has been promoting the construction of household biogas plants in rural China for decades and the administrative network for the rural biogas development has been established from the central government to the local governments, which also involves research institutes, companies etc (Y. C. Gao, et al., 2006).

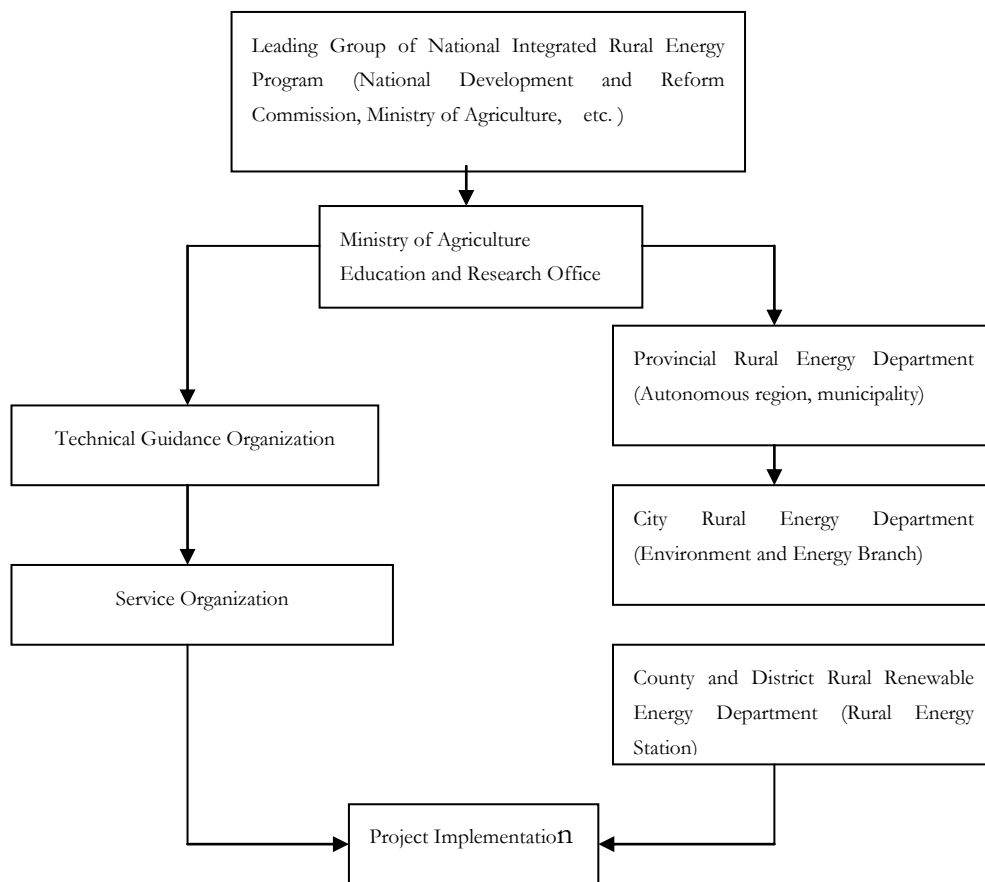


Figure 4-2 Administration of New Energy Promotion

Source: (Yu, 2007)

As is shown from the Figure 4-2, the administrative network is made of 4 levels: national, provincial (Autonomous region, municipality), city and county and district, with the support of technical guidance organizations and service organizations. In 2004, there were around 3600 administrative departments and agencies in total with 12000 working staffs, while the staffs and managers dealing with the biogas technical dissemination were around 26000, and

qualified masons and technicians with the licenses for digester construction were of 110000(Y. C. Gao, et al., 2006).

4.1.2 Barriers for household biogas plants

Though the household biogas plant has a number of advantages in terms of economic, environmental and social aspects, and the number of rural household biogas digesters is increasing very quickly since 2001, it has been found the dissemination of rural household biogas digesters encounters several main barriers. The major barrier comes from the change of social structure, such as the rapid urbanization and large amount of migrant workers, the construction of socialist countryside and the change from scatter breeding to intensive livestock and poultry farming in rural China. All the change of social structure will lead to the reduction of the users of household biogas plants and the shortage of fermentation materials.

Moreover, the current transnormal development of household biogas plants is mainly push forward by national projects, which have encountered a series of problems including lack of the funding, shortage of biogas masons and low quality of biogas digesters, poor follow-up services and management and low application of integrated biogas.

4.1.2.1 Policy: Building of Socialist Countryside

As the overarching document for the development of the farmer, agriculture and rural areas, *Circular of CPC Central Committee and State Council on Promoting the Building of New Socialist Countryside*(No.1 [2006]) has put forward the building of socialist countryside in rural China in 2006. The construction of a new socialist countryside requires developing production, improving living standards, fostering more civil behaviour, improving the cleanliness of villages and exercising democratic management. In order to improve the sanitation and the living environment, it emphasizes the separation of residential areas from the livestock and poultry farms, which used to be typical in rural areas, where farmers raised several pigs or chickens in their farmyards(CPC Central Committee & State Council, 2006).

In addition, the new socialist countryside requires saving construction lands through combining small villages and building centralized residential areas, thus resulting in the lack of the space for building household biogas plants and the decrease of scatter breeding in rural China(B. Q. Li, et al., 2010). The policy also calls for the adjustment of agricultural structure and advocates the development of intensive livestock and poultry farming in rural China, which will further reduce the number of farmers who adopt scatter breeding(CPC Central Committee & State Council, 2006). Without the manure from pigs and chickens, the household biogas plants will face the shortage of materials for fermentation.

For example, in Ji'an County, Jiangxi Province, it was found there is not enough space around the residential area to build pigpens and household biogas plants, since the building of new socialist countryside requires the separation of residential areas from the livestock and poultry farms(Z. X. Huang, Zhu, Liu, & Yang, 2008). Meanwhile, due to the adjustment of agricultural structure and the impact of market economy, a lot of farmers gave up the scatter breeding of pigs, resulting in the lack of fermentation materials for household biogas plants(Z. X. Huang, et al., 2008).

4.1.2.2 Economy: Lack of funding

The average investment for the household biogas digester with the renovation of the kitchen, the toilet and the pigpen is around 3000-3500 Yuan. Although the central government subsidizes 800-1200 Yuan for each household, there are around 2000 Yuan to be collected by the local government and the farmer. However, in rural areas the local government is usually short of fund and it's difficult for the farmer to get enough investment, which seriously affects the construction and quality of the biogas digester(Y. L. Zhang, 2004). It is found that in some remote areas in North China, the average annual income of farmers is less than 1000 Yuan and some even only 300-500 Yuan and the subsidy is not enough for them to build household biogas plants(Yang et al., 2008). In fact, the lack of funding is the biggest problem for the promotion of rural household biogas digester in Jilin Province (F. X. Pang, Na, Zhang, Zhang, & An, 2009). It was demonstrated in Anhui Province that it's very demanding to get enough investment, even with the subsidy from the local government (W. W. Liu et al., 2008).

4.1.2.3 Technology: Shortage of technicians

The shortage of biogas masons and technicians is a common problem due to the very rapid development of household biogas digesters in recent years (He, Zhu, Wu, & Jiang, 2006). Meanwhile, many biogas masons and technicians go to cities to look for other jobs because of the low salary of building household biogas plants (Sheng & Zhang, 2007). For instance, it is reported that there were severe shortage of qualified biogas masons in Wuxi County, Chongqing Municipality and many of them changed to other jobs(Z. Q. Chen, 2008). In Yuncheng City, Shanxi Province, many biogas masons who got certificate after training went out to look for other jobs because of the low income and biogas masons only got payment for the construction of biogas digesters and couldn't get payment for maintenance (K. J. Wang, 2007).The lack of qualified biogas masons and technicians also result in the low quality of biogas digesters. For example, 34 household biogas digesters were built in Shi Jialing village, Shanxi Province in 2006, half of them had leakage of water and gas due to the poor quality of the digesters(H. J. Liu & Liang, 2008)

In addition, there are a number of problems with the current main type of household biogas digesters. The rate of biogas production will speed up when the temperature increases, with the minimum temperature for biogas production at 10°C(Ma 2003). However, in northern China, the average temperature is lower than 10 °C during the winter so that there are only 8-9 months for efficient biogas production (H. Y. Hu, 2007). For instance, in Jilin Province and Hei Longjiang Province, the household biogas digesters can't work and even crack during the winter seasons(Bao, 2007; F. X. Pang, et al., 2009). The use of *Four in one* eco-agricultural model is one of ways to solve the problem, however, the initial investment is high (Y. Chen, et al., 2008). Moreover, for the hydraulic digester, it's difficult to take out of the residue which instead easily forms the crust, which caused a lot of troubles for farmers(H. J. Liu & Liang, 2008).

4.1.2.4 Society

The change of social structure including the rapid urbanization, large number of the migrant workers to the cities, the building of socialist countryside and the change from scattering-breeding to intensive livestock and poultry farming has negative impacts on the development of rural household biogas plants.

Rapid Urbanization

It is known that increasing urbanization will be experienced by each industrializing economy and society and China is at present undergoing rapid urbanization(UNDP, 2010). As is shown in Figure 4-3, though China's urbanization ration was only less than 30 percent in 1991, it rose up over 45 percent in 2007 and it will continue to increase. However, compared with other countries, particularly developed countries, urbanization in China is still low. The average urbanization ratio was 50 percent worldwide in 2007, while the ratio of the urban population was more than 70 percent in developed countries such as Germany, United States, the United Kingdom etc(UNDP, 2010).

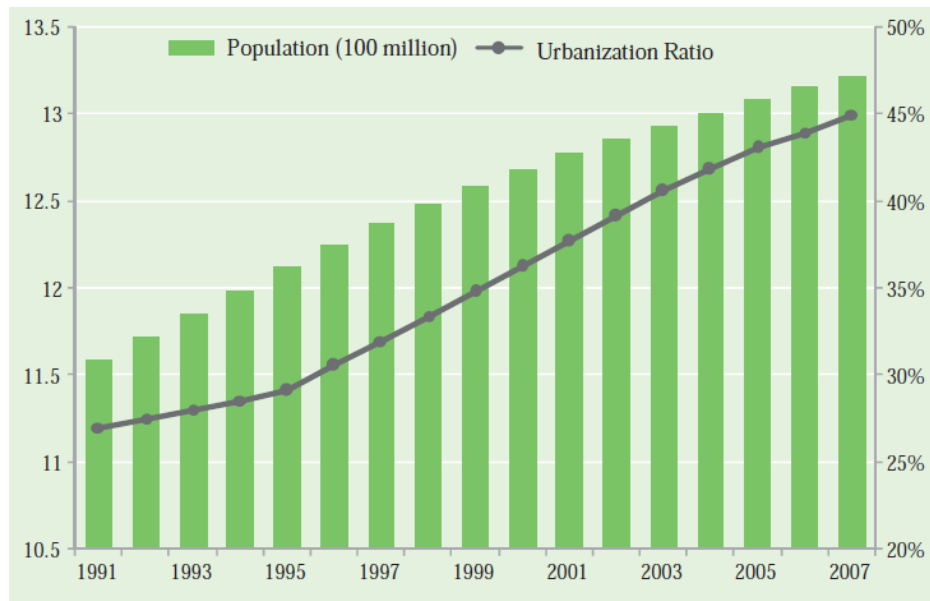


Figure 4-3 Population and urbanization ratio (1990-2007)

Source:(NBSC, 2008). Adapted from (UNDP, 2010)

It has been predicated by a number of research studies that the ratio of the urban population in China is probably to reach 65 percent by 2030, when its urban population will overpass 1 billion (UNDP, 2010). In the next 20 years, it is forecast that almost 350 million Chinese people are going to migrate from rural areas to urban areas, a number more than the current total population of the United States(UNDP, 2010). As more and more farmers move to the urban areas, they will have no enough space to raise pigs or chickens, or to build the household biogas plants. Therefore, the needs to build household biogas plants will decrease gradually as the urbanization ratio rises.

Change of Livestock and Poultry Breeding Style

In rural China, traditionally farmers tended to raise several pigs fed on the home-grown crops, which are then fertilized by the livestock's manure. However, such self-sufficient farming has been gradually replaced by modern market-oriented farming. Farmers would like to plant more crops or vegetables with better economic value in the markets and become much more specialised, resulting in the separation between livestock farming and crop planting (M. Chen, et al., 2008).

Meanwhile, due to the economic development and increasing demand of the people, livestock farming is developing very quickly. It is shown that from 1999 to 2004, the numbers of pigs, cow and beef cattle, sheep and goats have increased by 18.9%, 8.5% and 31.2% respectively (M. Chen, et al., 2008). Besides the increase of scale, livestock farming has also become more centralized and intensive livestock farming has gradually replaced the scatter livestock breeding. It is reported that intensive livestock farms with over 500 pigs per year almost doubled their contribution of pig production to the total pig production from 1999 to 2004. And the cattle, poultry and sheep had the similar trend too (M. Chen, et al., 2008).

China's rural biogas project planning (2006–2010) has defined the classification of the scale of livestock and poultry breeding in China, as is shown in Table 4-1. In 2005, there were 5.78 million intensive livestock and poultry farms in China and there were 11952 medium and large scale intensive livestock and poultry farms, which is shown in Table 4-2 and Table 4-3 respectively (MOA, 2007). Although the number of medium and large scale intensive livestock and poultry farms only accounts for 2.07% of the total number of intensive livestock and poultry farms, the number of livestock and poultry production reaches 12.5% (MOA, 2007).

Table 4-1 the classification of the scale of livestock and poultry breeding

Scale	Pigs (Sale)	Beef cattle(Sale)	Dairy Cow(Stock)	Sheep (Sale)	Chicken (Sale)	Hen (Stock)
Intensive number/year	>50	>10	>5	>30	>2000	>500
Medium large scale	>3000	>500	>200		>100,000	>50,000

Source: (MOA, 2007)

Table 4-2 the number of intensive livestock and poultry farms in 2005

Item	pigs	beef cattle	dairy cow	sheep	chicken	hen
Number per year Unit: 10,000 farms	183	48	35	187	47	78

Source: (MOA, 2007)

Table 4-3 the number of medium and large scale intensive livestock and poultry farms (2005)

Item	pigs	beef cattle	dairy cow	chicken	hen
Number per year Unit: one farm	6354	1273	1889	1778	658

Source: (MOA, 2007)

In addition, due to the concern of animal epidemic prevention, it is suggested that scatter breeding of livestock and poultry should be phased out, since it's difficult to prevent and control animal epidemic for scatter breeding. The outbreak of avian influenza in recent years have led some local governments to prohibit the scatter breeding and require the separation

of residential area from livestock and poultry farms(Lian, Bai, Dong, & Sun, 2007). (Ren & Qiao, 2006) propose that intensive livestock and poultry production should be encouraged in terms of the prevention of animal epidemic, which is also advocated and supported by *Animal Husbandry Act*.

In 2007, there were 2.244 million intensive pig farms with over 50 heads of annual sale, accounting for 48% of the total production of pigs and it is estimated that the production of intensive pig farms will account for 65% of the total production by 2015 (MOA, 2009b). At the end of 2008, the production of intensive livestock and poultry farms accounted to more than 50% of the total livestock and poultry production(Mo & Liu, 2009). It can be predicted that change to intensive livestock and poultry farming will continue and even accelerate due to the rapid economic development, the improving living standard, the concern of animal epidemic prevention and the encouragement and support of Chinese government.

Therefore, more and more individual farmers are getting short of feedstock for household biogas digesters, though the biogas fermentation material is rich in rural areas, which mainly consists of livestock and poultry manure including cattle, pigs and chicken etc(Y. Chen, et al., 2010). For example, it is reported that 34% household biogas digesters couldn't operate normally in Ji'an City, Jiangxi Province in 2008, due to the lack of fermentation material since more farmers gave up scatter breeding of livestock and poultry and livestock and poultry farming was getting more intensive(J. P. Zhu, Huang, Zou, Jiang, & Wu, 2008).

Poor follow-up services and management

A number of articles have pointed out that a lack of follow-up services and management of household biogas digesters is the critical problem for the rural energy development (Y. Chen, et al., 2010; S. B. Wu, et al., 2008; Y. L. Zhang, 2004). A lot of biogas digesters have broken down due to the poor follow-up services and management because the development of household biogas digester in rural area emphasizes mainly on construction rather than the management (Y. Chen, et al., 2010). (Wu Di Zhang, et al., 2006) find only 60% of 18 million household biogas digesters were operating normally in 2005. Although the national administrative network has been established, the county-level rural energy offices in most provinces are small with only 3-7 working staffs, which seriously affects the efficiency of biogas digester construction and management (Sheng & Zhang, 2007).For example, there were only 4 working staffs in energy office of Wu Yishan City, Fujian Province, who are responsible for the construction of household biogas digesters in the whole city and have no time and energy for the follow-up services(F. Y. Zheng, 2008). In addition, the rural energy offices are short of the funding for maintenance which also restrains its ability for follow-up service (S. B. Wu, et al., 2008). For instance, only 50 Yuan per household biogas digesters is provided for the training of the technician, the public education and other logistics in Wu Yishan City, Fujian Province and no other funding for the management and follow-up service(F. Y. Zheng, 2008).

Low level of education and training

Farmers are usually lack of the education and training on how to use the biogas digesters properly and how to make full use of the digested residue. The majority of biogas users have been found to only use the biogas for lighting and cooking, while the utilization of the residues from digesters have a low level of use (P. D. Zhang, Yang, & Li, 2007). In fact only 37.3% of the total rural household biogas users explored the comprehensive use of biogas in 2005 (G. Q. Hu, 2008). Most household biogas users are not able to integrate biogas

technology with eco-agriculture technology, because they have not received technically training (Y. Chen, et al., 2010). (Willem & Wang, 2009) found the benefits of residue as the replacement of fertilizer and pesticide are not realized. In fact, the biogas users apply more chemical fertilizer and pesticide than non-biogas users. They think the biogas digester is mainly regarded as a renewable energy technology and farmers only get general information about how to use the residue which is not enough.

In addition to the low application of integrated biogas use, due to the lack of education and training, farmers don't know how to operate the biogas digesters properly and have no knowledge about pH and the impact of temperature on the production of biogas, thus resulting in the less yield of gas and even the break down of the digester (F. Y. Zheng, 2008). Farmers also lack of the knowledge on safety and some may get into the digester to repair, leading to injury or loss of life (Sun, 2007).

4.1.3 Incentives for medium and large scale biogas plants

There are a number of incentives for the development of medium and large scale biogas plants, such as the serious environmental pollution caused by intensive livestock and poultry farms, renewable energy, climate change etc.

4.1.3.1 Policies

Similar to the construction of household biogas plants, the development of medium and large scale biogas plants has been influenced by a number of policies, laws and regulations with regard to rural development, renewable energy, and climate change. Moreover, the regulations related to environmental protection are in favour of the construction of medium and large scale biogas plants too.

In recent years, besides the promotion of household biogas plants, the important policies related to farmer, agriculture and rural area have called on to develop medium and large scale biogas plants. For example, *Circular of CPC Central Committee and State Council on Promoting the Building of New Socialist Countryside* (No.1 [2006]) put forward to support the building of medium and large scale biogas plants in rural China (CPC Central Committee & State Council, 2006).

National laws, regulations and policies related to renewable energy and energy saving, which emphasizes the use of biogas as one kind of renewable energy in rural area, also favours the development of medium and large scale biogas plants, such as, *Energy Conservation Law of the People's Republic of China* (2007), *Renewable Energy Law of the People's Republic of China* (2005), etc. It is planned to build 4700 medium and large scale biogas plants for intensive livestock and poultry farms as well as 1600 for industrial organic waste water, producing 4 billion m³ of biogas and generating 1 million kWh of electricity by 2010. The number reaches 10000 for intensive livestock and poultry farms and 6000 for industrial organic waste water by 2020, producing 14 billion m³ of biogas and generating 3 million kWh of electricity (NDRC, 2007).

Moreover, the construction of medium and large scale biogas plants has been included in China's policies on climate change, since it is an important way to mitigate climate change. For example, in *China's Policies and Actions for Addressing Climate Change*, it reveals that 26600 biogas plants has been built in livestock and poultry farms by the end of 2007, which is one

of the ways to control greenhouse gas emissions in rural area (IOSC, 2008). In *China's Policies and Actions for Addressing Climate Change—The Progress Report 2009*, it emphasizes that 2500 medium and large scale biogas plants have been constructed to treat industrial organic wastewater and the manure of large livestock and poultry farms, producing annually 2 billion m³ of biogas (NDRC, 2009).

In addition, due to serious environmental problems caused by intensive livestock and poultry farms, a series of regulations and standards are issued by Ministry of Environmental Protection to protect the environment, such as:

- *Administrative measures of pollution prevention for livestock and poultry farms (2001)*
- *Discharge standard of pollutants for livestock and poultry breeding (2001)*
- *Technical standard of preventing pollution for livestock and poultry breeding (HJ/T 81-2001)*
- *Technical Specifications for Pollution Treatment Projects of Livestock and Poultry Farms (HJ 497—2009)*

The construction of medium and large scale of biogas plants has been identified as efficient way to treat the waste from intensive livestock and poultry farms by the regulations. For example, the use of biogas digesters is the fundamental technology to treat the manure and waste water in *Technical Specifications for Pollution Treatment Projects of Livestock and Poultry Farms (HJ 497—2009)* (MOEP, 2009).

Besides, Ministry of Agriculture, the leading organization for the expansion of medium and large scale biogas plants, have issued a number of regulations to plan, stimulate and manage the construction of medium and large scale biogas plants in rural China as well. For example, *China's rural biogas project planning (2006 - 2010)* (MOA 2007) provides the detailed plan to guide the construction of medium and large scale biogas plants from 2006 to 2010 in rural China. In order to promote the development of medium and large scale biogas plants, *Plan for construction of energy environmental engineering for medium and large scale livestock farms* was issued in 1999 by Ministry of Agriculture. Moreover, a series of technical regulations of biogas engineering and regulations on the design of biogas engineering for intensive livestock farms were set up in 2006 (MOA, 2007).

4.1.3.2 Economy

The incentives from economic perspective include the subsidies from the central government and local governments, the exemption of the fines for environmental pollution, the potential cost saving for energy utilization, the potential income for selling the biogas or electricity generated by biogas, and the digested solid and liquid residue as organic fertilizers. Besides, the application of CDM for medium and large scale biogas plants has been regarded as a promising way to increase the investment.

The central government has also provided subsidy to promote the development of medium and large scale biogas plants in rural China. From 2001-2005, 81.15 million Yuan (equal to 8.115 million Euro) were invested to build 120 medium and large scale biogas plants for intensive livestock and poultry farms by central government in China, as is shown in Figure 4-4. At the end of 2005, there were 3500 medium and large scale biogas plants, treating 87

million tons of manure from intensive livestock and poultry farms (MOA, 2007).It can be seen that focus was household biogas plants, since 97.73% of the total investment 3.53 billion Yuan from central government was invested to the development of household biogas plants in rural China (MOA, 2007).

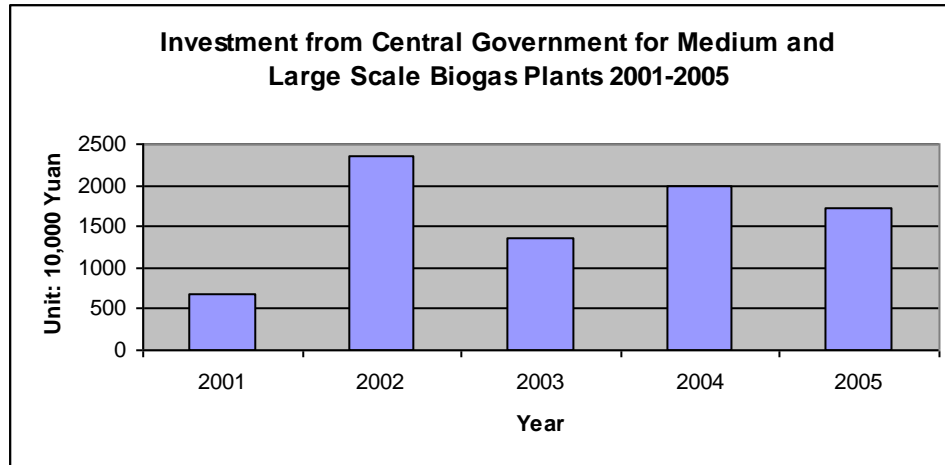


Figure 4-4 Investment from Central Government for Medium and Large Scale Plants 2001-2005

Source:(MOA, 2007)

The investment of medium and large scale biogas plants is generally shared by the central government, local governments and the owners of livestock and poultry farms. The medium and large scale biogas plants refer to the digesters with single volume more than 50 m³ and equipped with the pre-treatment facilities for raw materials such as feed-in, stirring equipments, and facilities for the integrated utilization of biogas as well as the digested solid and liquid residue(GONDRC & GOMOA, 2008).

The subsidy from the central government is usually less than 0.7-1.3 million Yuan per plant, which depends on the volume of the digesters and the number of farmers who are provided biogas from the plant. The subsidy from central government mainly support the construction of anaerobic digesters, the biogas distribution system to the farmers and the facilities to make use of digested solid and liquid residue(GONDRC & GOMOA, 2008). The financial subsidy from central government also varies in different areas, with less than 0.7 million Yuan for medium and large scale biogas plants in eastern area, and less than 1 million Yuan in middle area and less than 1.3 million Yuan in western areas. It is also required that the local governments should provide corresponding subsidy, which is at least 25% of total investment for local governments in eastern area, 15% in middle area and 10% in western area. The investment from the owner of the medium and large scale biogas plants should be more than 50% of the total investment(GONDRC & GOMOA, 2008).

In 2008, in order to stimulate economic recovery from financial crisis, additional 3 billion Yuan was planned by Ministry of Agriculture to promote the development of rural biogas and part of the investment was put to the medium and large scale of biogas plants for intensive livestock farming area (P. D. Zhang, Y. L. Yang, Y. S. Tian, et al., 2009).

In 2009, the investment from the central government was further increased to promote the development of medium and large scale biogas plants in rural China, and the number

depends on the volume of the anaerobic digesters etc. From 2009, the financial subsidy from central government will be increased to 45% of the total investment, within the limit of 2 million Yuan per medium and large scale biogas project, in western areas, 35% of the total investment and within the limit of 1.5 million Yuan in middle areas, and 25% of the total investment and within the limit of 1 million Yuan in eastern areas. The investment from the local governments is also requested to increase, with at least 5%, 15% and 25% of total investment for local governments in western, middle and eastern areas respectively (GONDRC & GOMOA, 2009).

According to *administrative measures of pollution prevention for livestock and poultry farms* (MOEP, 2001a), the intensive livestock and poultry farms will be charged 1000-30000Yuan fines if the manure and waste water are discharged into water body or other environment without proper treatment, or if stored manure and waste contaminate the environment through leaking, scattering, overflowing or emitting fowling odour. Therefore the intensive livestock and poultry farms will exempt from paying fine for environmental pollution since the medium and large scale biogas plants can treat the manure and waste water.

In addition, the produced biogas can be utilized for cooking and heating in intensive livestock and poultry farms, thus reduce the cost of energy use. Moreover, the large amount of biogas can also be sold to local farmers through pipeline, or generate electricity and sold to the grid, which will generate extra income for livestock and poultry farmers. The digested solid and liquid residue can also be used to manufacture organic fertilizer and provide more economic return.

CDM can also provide extra economic return to medium and large scale biogas plants. It has been found that the sale of verified carbon emission reduction (CER) can make medium and large scale biogas plants more economically viable, thus promote the development of medium and large scale biogas plants for intensive livestock and poultry farms (Duan & Wang, 2003).

4.1.3.3 Technology

The technology of medium and large scale biogas plants in rural China is getting mature and the associated facilities such as automatic control, desulphurization and dryer and biogas power generator etc can be manufactured. The whole process of building the medium and large scale biogas plants can be designed to treat various feedstock and all kinds of fermentation technologies such as Continuous Stirred-tank Reactor (CSTR), Anaerobic Sequencing Batch Reactor (ASBR), etc have been utilized (Zhao, et al., 2008). In order to guarantee the quality and safety of medium and large scale biogas plants, national standards have been issued, including *Regulations on the Design of Biogas Engineering for Intensive Livestock and Poultry Farms* (NY/T 1222-2006), *Technical Regulations on Operations, Maintenance and Safety of Biogas Engineering for Intensive Livestock and Livestock Farms* (NY/T 1221-2006), *Biogas Generating Set* (NY/T 1223-2006) and a series of regulations of biogas engineering (MOA, 2007).

4.1.3.4 Society

Along with the rapid urbanization and social and economic development, the global livestock and poultry industry is developing quickly, especially in developing countries. The production of meat, eggs and milk has been increasing 10% per year since the foundation of the people's republic of China and China has become one of big countries in the field of livestock and poultry farming (X. M. Zhang, 2009). In general, the livestock and poultry

farming has changed from scatter breeding to intensive production. At present, the average scale of pig farms is 650 heads and 22000 for poultry farms in China, and the production of small and medium scale livestock and poultry farms accounts for 70% of the total production of intensive livestock and poultry farms(X. M. Zhang, 2009). Around 80% of medium and large scale intensive livestock and poultry farms locate in populous areas in eastern and southern China or suburban areas of big cities like Beijing and Shanghai (X. M. Zhang, 2009).

Along with the fast development of intensive livestock and poultry farming, the corresponding environmental pollution is getting severe too. According to the survey done by Ministry of Environmental Protection in 23 provinces and cities where the intensive livestock and poultry farms are centralized, the annual production of manure was 2.4 billion ton in 1999, equal to 2.6 times of total industrial solid waste. The content of organic pollutants in manure, such as COD was 8118 ton, much more than the sum of the COD of industrial wastewater and domestic sewage (Gan, Ma, & Li, 2006; Y. Li, 2002). Moreover, 90% of the intensive livestock and poultry farms didn't have facilities to treat waste water, which was discharged directly into the rivers and lakes, causing eutrophication and environmental pollution(Y. Li, 2002). The loss of nitrogen and phosphorus from manure was even more than that from fertilizer and manure from intensive livestock and poultry farms has become one of the main sources of environmental pollution in rural China(Gan, et al., 2006).

The manure from livestock and poultry can have serious environmental impact, resulting in air pollution, water pollution, and soil pollution and increase the disease risks and health issues(Martinez, Dabert, Barrington, & Burton, 2009). The waste water from livestock and poultry farms contains a great amount of organic pollutants such as nitrogen and phosphorus and can lead to eutrophication in rivers and lakes. It can also contaminate the underground water through leaching(Xie, Chen, & Yu, 2007). The foul gas emitted from livestock and poultry farms consists of ammonia, sulphide etc which are harmful to the health of humans and animals. In addition, the emission of large amount of methane will contribute to climate change(Xie, et al., 2007). The concentrated waste water is also detrimental to the crops and can lead to the decreased production. Since it can block the soil pore space, thus severely reduce the soil quality (MOA, 2007). Besides, the waste water contains a mass of disease-causing microbes, bacteria, parasitic ovum, which are not only harmful to the animals and increase the death rate, but also threaten the health of human beings (MOA, 2007). Therefore, medium and large scale biogas plants need to be constructed in intensive livestock and poultry farms to treat the waste.

Besides, the building of new socialist countryside requires constructing centralized residential areas in order to save lands, and separating the living areas from livestock and poultry farms so as to protect human health, further resulting in the change to the intensive livestock and poultry farming (CPC Central Committee & State Council, 2006). Thus the construction of new socialist countryside will promote the building of medium and large scale biogas plants. In addition, the existing administrative network for the rural biogas development will also benefit the expansion of medium and large scale biogas plants in rural area through disseminating relevant information and providing associated services.

4.1.4 Barriers for medium and large scale biogas plants

Although medium and large scale biogas plants for intensive livestock and poultry farms are greatly promoted by the central government in recent years, there are still some major barriers for the expansion of the medium and large scale biogas plants.

4.1.4.1 Policy

Lack of the coordination between different departments

It's one of Ministry of Agriculture's goals to advance the development of livestock and poultry breeding, in order to adjust the agricultural structure and increase farmer's income. However, the prevention of environmental pollution caused by intensive livestock and poultry farming is not its key function. Meanwhile, Ministry of Environmental Protection focuses on the prevention of environmental pollution in industry and urban areas due to its limited financial, material and human resources, thus the environmental problems caused by intensive livestock and poultry farms were not seriously taken care of (Y. Li, 2002; Peng, 2007).

The lack of coordination between Ministry of Agriculture and Ministry of Environmental Protection can be seen from the different classification of the scale of intensive livestock and poultry farms in *Technical Specifications for Pollution Treatment Projects of Livestock and Poultry Farms* (MOEP, 2009) and *China's rural biogas project planning (2006–2010)* (MOA, 2007). At the level of local governments, the lack of coordination between different departments is even more serious (Peng, 2007).

Poor enforcement of environmental protection law

Although agricultural departments have clear function for promoting the development of livestock and poultry farming, the environmental departments are short of the measures to deal with the corresponding environmental pollution. Since livestock and poultry farms provide subsidiary foodstuff to urban citizens, it can not be just simply closed down (Y. Li, 2002). In addition, environmental departments are short of human resources, which also results in the poor enforcement of environmental protection law (Lin, 2009), thus the owners of intensive livestock and poultry farms don't have the incentives to build medium and large scale biogas plants to treat manure and waste water.

4.1.4.2 Economy

High initial investment

The initial investment for medium and large scale biogas plants is generally high. The total investment for large biogas plants producing 1000-2000 m³ of biogas daily will be 3-10 million Yuan, producing 500-1000 m³ of biogas daily will be 0.8-3 million Yuan. Compared with some simple medium scale livestock and poultry farms, the investment for the biogas plant may even be higher than the investment for the farms (J. M. Li & Sun, 2003; Yao, et al., 2002). Meanwhile, the livestock and poultry farming has been regarded as small profit industry, it is very difficult for the owners to build medium and large scale biogas plants with high initial investment (J. M. Li & Sun, 2003).

Difficult to get investment

Although the central government has provided a large amount subsidy for the construction of some medium and large scale biogas plants, the investment for most of medium and large scale biogas plants comes from the owners of the intensive livestock and poultry farms and local governments (Xu, 2008). At present, there are few economic policies to encourage the investment from other social agencies. China has set up a special loan to support rural energy development since 1987 with a discounted interest rate, which includes the construction of medium and large scale biogas plants (P. D. Zhang, Y. L. Yang, J. Shi, et al., 2009). However, the procedure is very complicated and the project has to be evaluated by the bank using evaluation methods for normal industrial projects. Since the economic benefits of biogas plants are usually less than its social and environmental benefits, thus generally resulting in the failure of the loan from the bank (J. M. Li & Sun, 2003).

Low economic return

Although the medium and large scale biogas plants have prominent environmental and social benefits, its economic return is poor (Yao, et al., 2002). At present, the main product of biogas plants is mainly used for cooking and heating in the intensive livestock and poultry farms, which can not generate extra income. Biogas is also provided to the local villagers through pipeline. However, the price of biogas is very low compared with commercial fuels (J. M. Li & Sun, 2003). Only very small fraction of biogas, 2.53% of the total biogas production of medium and large scale biogas plants, is used to produce electricity and utilized for its own farms (L. W. Deng, et al., 2008). The demand for the organic fertilizer made from digested solid and liquid residue is still small and it is usually provided for the local farmers for free (Yao, et al., 2002).

There are also very few taxation policies for the development of medium and large scale biogas plants. At present, there are two kinds of value added taxes: normal rate is 17%, while the preferential rate is 13%. Although the construction of medium and large scale biogas plants is given the preferential rate, it is not enough to stimulate the development of biogas projects, since the initial investment is too high (MOA, 1999; Yao, et al., 2002). In fact, the high tax has prevented the intensive livestock and poultry farmers to build biogas plants in Jiangmen city, Guangdong Province (Xu, 2008).

According to *Administrative measures of pollution prevention for livestock and poultry farms* (MOEP, 2001a), *The Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution* (NPC Standing Committee, 2000), *Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste* (NPC Standing Committee, 2004), and *Law of the People's Republic of China on the Prevention and Control of Water Pollution* (NPC Standing Committee, 2008) etc, the environmental pollution caused by the intensive livestock and poultry farms will be fined. However, due to the poor enforcement, it's difficult to collect the fines (Yao, et al., 2002).

4.1.4.3 Technology

The technology for the industrialization of medium and large scale biogas plants need to be improved. The design and construction for medium and large scale biogas plants are still not standardized and evaluation of the quality of biogas plant building is not sufficient (J. M. Li & Sun, 2003). The traditional way of installing on-site is generally practised resulting in poor quality (S. B. Wang, et al., 2009). Although all kinds of fermentation technologies have been utilized in China's medium and large scale biogas plants, the production of biogas is generally low since the fermentation process is usually at normal temperature and no mechanical

stirring is adopted (L. W. Deng, et al., 2008). The auxiliary facilities such as mechanical stirrer, separator of solid and liquid, de-sulphur facilities and control system etc need to be industrialized and commercialized (J. M. Li & Sun, 2003). There are short of qualified technicians, thus resulting in the poor quality of medium and large scale biogas plants. For example, in Jiangmen city, Guangdong Province there are no specialist for designing and constructing the medium and large scale biogas plants and most biogas projects were designed by amateurs such as engineers for house building (Xu, 2008).

4.1.4.4 Society

At present, the owners of intensive livestock and poultry farms don't have the incentives to build medium and large scale biogas plants (Yao, et al., 2002). It is found that owners of pig farms in Fujian Province generally ignore the environmental protection and is indifferent to social responsibility (Lin, 2009). (Peng, 2007) also found that the owners of intensive livestock and poultry farms generally don't have strong environmental awareness and will not protect the environment on a voluntary basis.

It is found the information and service with regard to medium and large scale biogas plants are difficult to acquire. The service network for medium and large scale biogas plants has not been established yet (J. M. Li & Sun, 2003).

Table 4-4 Summary of various kinds of incentives and barriers for expanding **biogas production** in rural China

Incentives /Barriers	Household biogas plant	Medium and Large scale biogas plant
Incentives		
Policy, laws and regulations	Farmer, agriculture and rural area: increase farmers' income, promote the adjustment of agricultural structure, protect the rural environment and improve their living conditions; basic infrastructure	Environmental Protection: an efficient way to treat the waste <i>Administrative measures of pollution prevention for livestock and poultry farms (2001), Discharge standard of pollutants for livestock and poultry breeding (2001) etc</i>
	renewable energy and energy saving: <i>Renewable Energy Law of the People's Republic of China (2005)</i> <i>Mid-Long Term Development Plan for Renewable Energy(2007): 40 million in 2010; 80 million in 2020</i>	renewable energy and energy saving: <i>Renewable Energy Law of the People's Republic of China (2005)</i> <i>Mid-Long Term Development Plan for Renewable Energy(2007): 4700 in 2010; 10000 in 2020</i>
	Climate change mitigation: <i>China's Policies and Actions for Addressing Climate Change(2008); China's Policies and Actions for Addressing Climate Change—The Progress Report 2009: reducing 49 million tons of CO₂</i>	Climate change mitigation: <i>China's Policies and Actions for Addressing Climate Change(2008); China's Policies and Actions for Addressing Climate Change—The Progress Report 2009: producing 2 billion m³ of biogas</i>
	Rural biogas development: <i>Regulations on Rural Biogas Projects Supported by National Bond (Tentative)</i> <i>China's rural biogas project planning (2006–2010)</i>	Rural biogas development: <i>China's rural biogas project planning (2006 - 2010)</i> a series of technical regulations of biogas engineering
Economy	Subsidy from central government: 800-1200 Yuan per household 1000-1500 Yuan per household since 2009	Subsidy from central government 0.7-1.3 million Yuan per plant; 1 -2 million Yuan per plant since 2009/25%-45% of total investment since 2009 From local governments:

		10%-25% of total investment; 5%-25% of total investment since 2009
	Reduced cost of energy on cooking and heating	Cost saving for energy utilization like cooking and heating
	Less expenditure on chemical fertilizer and pesticides	Income for selling the biogas or electricity generated by biogas
	CDM for household biogas plants	Income for selling the digested solid and liquid residue as organic fertilizer
		Exemption of the fin es for environmental pollution: e.g. 1000-30000 Yuan
		CDM for medium and large scale biogas plants
Technology	Mature technology for building household biogas plants; many companies producing the accessories such as biogas stove etc; National standards for household biogas plants and accessories	Design the whole process of medium and large scale biogas plants Utilize all kinds of fermentation technologies ; Can build associated facilities such as desulphurization and dryer etc. National standards with regard to the construction of medium and large scale biogas
Society	The administrative network for promoting household biogas development	Change to intensive livestock and poultry farming and the corresponding serious environmental problems
		The new socialist countryside: building centralized residential areas; separation of living areas from livestock and poultry farms
		The administrative network for

		promoting rural biogas development
Barriers		
Policy	The new socialist countryside: building centralized residential areas; separation of living areas from livestock and poultry farms	Lack of the coordination between different departments; poor enforcement of environmental protection law
Economy	Lack of funding for building household biogas plants: around 2000 Yuan, heavy burden for low-income farmers	High initial investment; Lack of the channel to get the investment; Low economic return
Technology	Short of qualified biogas technicians; low quality of household biogas digesters; can't work and crack during the freezing seasons; difficult to take out of the residue	The design and construction of biogas plants not standardized; Generally low biogas production; Auxiliary facilities need to be industrialized and commercialized; lack of qualified technicians
Society	Rapid urbanization and large amount of migrant workers: reduce the user of household biogas plants	Owners of intensive livestock and poultry farms lack of the awareness
	Change to intensive livestock and poultry farming; separation between livestock farming and crop planting: shortage of fermentation material	The service network hasn't been established;
	Poor follow-up services and management: emphasizing construction rather than the management; 60% operating normally in 2005; short of funding for maintenance	
	Low level of education and training: only 37.3% comprehensive use of biogas; lack of know-how to operate properly; safety issues	

4.2 Biogas and digested residue utilization

For the household biogas plants, the main use of biogas is for cooking, heating and lighting and the digested solid and liquid residue is generally used as organic fertilizer and pesticide. Due to the small amount of biogas production, there is no practice of generating electricity from the household biogas plants (D. Li, Yuan, Sun, & Ma, 2009).

At present, the biogas produced at medium and large scale biogas plants is mainly utilized for cooking, heating and lighting at the intensive livestock and poultry farms. In all, only around 1% of total biogas production of all medium and large scale biogas plants is used for providing biogas to local villagers and 2.53% of total biogas production is utilized to generate electricity (L. W. Deng, et al., 2008). Up to now, there is lack of research and no practice of using biogas to produce vehicle fuels in rural China (L. W. Deng, et al., 2008). Although the digested solid and liquid residue can be used to manufacture organic fertilizer, the market demand is relative low (Yao, et al., 2002). Therefore, it is necessary to analyze the incentives and barriers of utilizing biogas and digested residue so as to improve the economic return of biogas plants.

4.2.1 Cooking and heating

The utilization of biogas for cooking and heating is the easiest and most convenient way, with low investment, which has been widely adopted in household and medium and large scale biogas plants. The technology is mature and there are many companies producing the associated facilities such as biogas stove, biogas heater, biogas lamp etc, which are provided by the Chinese government as part of the subsidy for the building of household biogas plants. For medium and large scale biogas plants, the biogas can be sold to local villager through pipeline, which will generate extra income for the owners of the biogas plants. Compared with coal, straw, firewood, biogas is clean energy and can reduce the indoor and outdoor pollution, which is beneficial to the health of human being.

However, the production of biogas is not stable, which is excess in summer and short in winter (S. B. Wu, et al., 2008). Meanwhile, the LPG is getting popular in developed rural areas since it's easy and convenient to use and the supply can be guaranteed resulting in the less use of biogas (Yao, et al., 2002). In addition, nowadays, the price of biogas is very low and there is no standard or measures to guide the price of biogas, thus restraining the development of medium and large scale biogas plants. Besides, the distribution of pipeline will add extra cost. Since large scale residential areas usually don't locate nearby the intensive livestock and poultry farms, the biogas is generally provided to local villagers, who can not use all the biogas. Therefore, it is found the extra biogas is flared off in some livestock and poultry farms (J. M. Li & Sun, 2003).

4.2.2 Electricity and CHP

Although only a few medium and large biogas plants use biogas to produce electricity, it has been regarded as a promising sunrise industry (Yan, 2004). The development of electricity produced by biogas has been promoted by a series of laws, regulations and economic policies in recent years. *People's Republic of China Law of Renewable Energy* was passed on February 28th 2005 and was implemented on January 1st 2006, which has brought the utilization of renewable energy to the strategic height (P. D. Zhang, Y. L. Yang, j. Shi, et al., 2009).

A set of supporting laws and regulations have been issued soon after, such as *Temporary management for the price and cost sharing in renewable energy power generation*, *Administrative regulations on renewable energy power generation*, *Temporary method for managing the special capital of renewable energy development* etc, which provide 0.25 Yuan/kWh as additional subsidy to power generated from biomass power projects and to some extent have stimulated the development of electricity generated by biogas (L. W. Deng, et al., 2008). For example, biogas power project of Inner Mongolia Meng Niu AustAsia Model Dairy Farm Company which treated cattle manure and produced 10000 m³ of biogas per day, and biogas power project of Beijing DQY Agricultural Technology Company which dealt with chicken manure and produced 20000 m³ of biogas each day were constructed in 2006 (L. W. Deng, et al., 2008).

Besides, a series of biogas generating set from 10-700 kW have been invented including 40, 80, 200 and 500kW biogas generating sets and the technology is relatively mature. At present, the performance and quality of biogas generating sets in China is getting close to that in Germany, especially the large power generator (L. W. Deng, et al., 2008; J. M. Li & Yan, 2006; Yan, 2004).

However, there are still a number of barriers for the development of biogas power projects in China. Although 0.25 Yuan/kWh as additional subsidy to the power price of biomass power projects, it is very difficult for biogas projects to make profits due to the high cost. In addition, there is no additional subsidy for the biogas plants using animal manure and agricultural waste or utilizing CHP (L. W. Deng, et al., 2008). Most of biogas plants didn't build the waste-heat recovery system. The existing waste-heat recovery system has the maximum recovery efficiency of 35%, at least 5% lower than that in Germany or America (J. M. Li & Yan, 2006).

Since Chinese government hasn't proposed the law to require that the power grid company must purchase renewable energy power, power grid companies usually refuse to purchase biogas power with price above the cost. At present very few power projects of medium and large scale biogas plants have connected to the power grid in China (L. W. Deng, et al., 2008; J. M. Li & Yan, 2006), thus the owner of intensive livestock and poultry farms have no enough incentives to invest in biogas plants.

The electricity efficiency of biogas generating sets made in China is still relatively low, for example, biogas generating set of 0.2-0.6MW, the electricity efficiency is only 27%-30%, less than 5-6% of that in industrialized countries. Moreover, there is short of technical standards and regulations on the design, construction, operation and management of biogas power projects (J. M. Li & Yan, 2006).

4.2.3 Vehicle Fuel

It is believed the use of biogas as vehicle fuels is very promising in China (Y. Z. Pang & Li, 2006). In 2004, there were 23.82 million civil motor vehicles and it is forecast that the number will reach 140 million by 2020. Meanwhile, China is in lack of petroleum, thus biogas can be used to replace petroleum and natural gas as vehicle fuel (Y. Z. Pang & Li, 2006). It is reported that in 2004, the landfill gas was purified and compressed and used as vehicle fuel in Anshan City in China, which was mainly used for transporting garbage (D. Li, et al., 2009). However, there is few research and application of utilizing biogas as vehicle fuels in China at present (L. W. Deng, et al., 2008) Generally there is no policy to promote biogas as vehicle fuel in China up to now.

4.2.4 Digested residue

The solid and liquid residue of biogas plants can be used for manufacturing high quality organic fertilizer, which is rich in organic matter and humic acid and can improve soil fertility and increase the crop yield (G. Z. Zhang et al., 2009). However, few policy interventions favour making organic fertilizer from the digested residue in China. The high quality as organic fertilizer can be one of the positive incentives for farmers to use the digested solid and liquid residue. Besides, the reduced foul odour from digested manure compared with raw manure can encourage farmers to build biogas plants (Lantza, et al., 2007).

Nevertheless, there are many barriers for manufacturing organic fertilizer from the digested residue at present. First, the demand for the organic fertilizer is relatively small, which is mainly used for flowers, turf or greenhouse (Yao, et al., 2002). Second, the chemical fertilizer still dominates the whole market, which is cheap, easy and convenient to utilize with strong commercial network (Yao, et al., 2002). In fact, there is subsidy for manufacturing chemical fertilizer with preferential power price (Y. Li, 2002). Third, farmers lack the knowledge to use solid and liquid residue as fertilizer, for instance, they don't know whether it's safe or not to use solid and liquid residue, or how much should be applied etc (G. Z. Zhang, et al., 2009). Fourth, it is found that the solid and liquid residue is not convenient to transport and use, which is the main reason that farmers don't want to use them as fertilizer (G. Z. Zhang, et al., 2009). Last but not least, according to a survey, farmers would like to use the solid and liquid residue as fertilizer since it's usually free. Those who are willing to pay the residue, the price they can accept is also very low (G. Z. Zhang, et al., 2009).

Table 4-5 Summary of various kinds of incentives and barriers for expanded **biogas utilization** in rural China

Incentives/Barriers	Cooking and heating	Electricity or CHP	Vehicle fuel	Digested residue
Incentives				
Policy	-	A series of laws with regard to renewable energy and its power generation	It is believed very promising	-
Economy	Low investment	0.25 Yuan/kWh as subsidy		High quality organic fertilizer
Technology	Mature; many companies producing associated facilities	Biogas generating sets with relatively mature technology		-
Society	Clean, reduce indoor and outdoor pollution	-		Reduced foul odour
Barriers				
Policy	No policy supports the use of biogas	No guarantee to connect to the power grid	few researches and practices in China	Subsidy for manufacturing chemical fertilizer
Economy	Competition from LPG; price is very low; cost of distribution of pipelines	Subsidy isn't sufficient; no encouragement for using animal manure and agricultural waste or CHP;		The demand for organic fertilizer is low. The competition from chemical fertilizer, low price and easy and convenient to use

Technology	Not stable, excess in summer, short in winter	Electricity efficiency is low; lack of technical standards and regulations		difficult to transport the liquid residue , and not so convenient to use as chemical fertilizer
Society	-			Farmers lack of the knowledge on using solid and liquid residue as fertilizer

5 Discussions and Conclusions

The development of biogas plants in rural China has a multiple of policy objectives and undertakings with regard to rural development, renewable energy, climate change and environmental protection. Due to its multiple benefits of biogas systems, the development of household biogas plants as well as medium and large scale biogas plants has been actively promoted in rural China by Chinese government with large amount of investment each year.

At present, China owns the largest number of household biogas plants in the world with annual increased number of 2-3 million in recent years. However, only 60% of household biogas plants were operating normally in 2007 (Wu Di Zhang, et al., 2006), only 37.3% of total rural household biogas plant users made comprehensive utilization of biogas plants in 2005 (G. Q. Hu, 2008). Moreover, it is found that more and more farmers are getting short of feedstock for household biogas plants (Sheng & Zhang, 2007).

Meanwhile, there were 11952 medium and large scale intensive livestock and poultry farms in China in 2005, while only 700 medium and large scale biogas plants were built to treat the manure and waste water at that time, accounting for 6% of total medium and large scale intensive livestock and poultry farms, which caused serious environmental problems in rural China (MOA, 2007).

Therefore, in order to improve the biogas system in rural China, it is necessary to strengthen the incentives and weaken the barriers. It is of great importance to recognize that the incentives and barriers for the development of household biogas plants and medium and large scale biogas plants are different though connected. Furthermore, the incentives and barriers can be divided into two categories, those affecting the production of biogas and digested residue and those affecting the utilization of biogas and digested residue (Lantza, et al., 2007). Based on the previous analysis of incentives and barriers affecting the development of household biogas plants and medium and large scale biogas plants, the following sections aim to analyze how to strengthen the incentives and weaken the barriers.

5.1 Advices for household biogas plants

The policy advice for the development of household biogas plants in rural China is to slow down the development step, strengthen the education and training of farmers on the proper utilization of existing biogas plants, improve the rural biogas service network and ensure the quality of biogas plants as well as the associated facilities, and provide more funding for the research and development of household biogas plants.

There are at least a number of reasons to slow down the current transnormal development of rural household biogas plants. First of all, the current quick expansion of household biogas plants has led to the shortage of qualified biogas mason and technicians, and lack of quality assurance, resulting in the low quality of household biogas plants. Second, most of the farmers lack the knowledge on how to operate the biogas plant properly and make the integrated use of biogas and the digested residue, thus leading to the breakdown of biogas plants too. Third, there are also short of follow up services for the users of household biogas plants, who are even difficult to get a desulfurizer or take out the residue.

However, the most important reason for the slow down of household biogas plant implementation in rural China is due to the rapid social change. The fast urbanization and

large numbers of migrant workers as well as the building of new socialist countryside will reduce the users of household biogas plants greatly. In addition, the separation of livestock farming and crop planting, and change from scatter breeding to intensive livestock and poultry farming is unchangeable and accelerating, resulting in the shortage of fermentation materials for many users of household biogas plants. It is proposed to build 80million household biogas plants by 2020 (MOA, 2007), but it is necessary to reset the objective in the future.

It is extremely important to strengthen the education and training of farmers. It is said the success of household biogas plants only 30% depends on the construction, while 70% on the follow up maintenance and management (Sun, 2007), such as stir frequently, add feedstock and take away the residue regularly etc(Zhai, 2009). However, most of the farmers lack the knowledge to manage the biogas plant properly and make the comprehensive use of biogas and the digested residue. A great amount of household biogas digesters can't operate normally because farmers don't know how to manage the plant properly. Besides the public communication through television, radio and newspaper etc, consultation should be provided to make sure farmers fully understand the advantages and disadvantages of household biogas plants before they apply for the construction of biogas plants.

It is necessary to improve the rural biogas service network and ensure the quality of biogas plants as well as the associated facilities. In 2007, *Development Scheme for Service System of Rural Biogas in China (Tentative)* was issued, which put forward to constructing rural biogas service network and each branch can provide service for 300-500 households. Financial subsidy from central government is also provided with 8000-19000 Yuan per branch(MOA & NDRC, 2007). How to make such biogas service cost effective need however to be furthered studied. Moreover, capacity building for biogas mason and technicians must be carried out in order to strengthen their capability on the construction and management of household biogas plants. Measures should be taken to ensure the quality of biogas plants and the associated facilities such as biogas stove, desulfurizer etc. In 2009, it is reported that in Hei Longjiang Province, 90% of the household biogas plants built for three years was broken down, 70% of the household biogas plants built for two years stopped working, and half of the household biogas plants couldn't run for the first year, thus more than 100 million Yuan was wasted (Cui & Ma, 2009).

In addition, more funding should be provided for the research and development of household biogas plants, for example, how to increase biogas production during the cold season, how to design the household biogas plants so that it's easy to maintain. The research on using crop straw as fermentation material should be further studied, since there are still a number of problems for pre-treatment of straw and it is still at the experimental stage (Y. Chen, et al., 2010).

5.2 Advices for medium and large scale biogas plants

As for medium and large scale biogas plants, in order to promote the further expansion, it is important to strengthen the enforcement of environmental protection law, develop multi-channels to raise the investment, set up the market for the products of medium and large scale biogas plants, and provide more funding for the capacity building of qualified technicians and improve the technology of biogas plants and auxiliary equipments for industrialization.

The strict enforcement of environmental protection law such as *Administrative measures of pollution prevention for livestock and poultry farms* (MOEP, 2001a) will provide strong incentives for intensive livestock and poultry farmers to build medium and large scale biogas plants. However, it will depend on the cooperation between different departments, especially the Ministry of Agriculture and Ministry of Environmental Protection and the coordination of departments at local level. The collected fine can be used as funding to support the building of medium and large scale biogas plants.

Multi-channels should be developed to raise the investment, considering the high initial investment of medium and large scale biogas plants and the small profits of intensive livestock and poultry farms. Economic policies should be designed to boost the investment from other social agencies, such as the long low-interest loan which should consider the economic and social return as well. The taxation for the construction of medium and large scale biogas plants can reduce the investment and should be further improved with better preferential rate so that it's enough to stimulate the building of biogas plants.

The market of the products of medium and large scale biogas plants must be set up if a better economic return is expected to be achieved. A number of policies should be designed to increase the price of biogas, improve the profits of biogas power projects and economic viability of using biogas as vehicle fuels, and attract farmers to utilize the digested solid and liquid residue instead of chemical fertilizer. This will be further analyzed in the section 5.3.

It is essential to invest more funding to build the capacity of biogas technicians which are in great shortage at present. More research should be done to improve the technology of medium and large scale biogas plants as well as the auxiliary equipments so as to meet the demand of standardization and industrialization. The study for making biogas power generator, the biogas vehicle fuels etc. should also be supported to increase the economic value of biogas.

5.3 Advices for the use of biogas and digested residue

At present, there few economic policies to encourage the utilization of biogas and digested residue. For example, there are no taxes on the use of fossil fuels and the chemical fertilizer and no subsidies for the use of biogas either. Due to the cheap price of biogas and the low demand of digested residue, the farmers of intensive livestock and poultry don't have the incentives to build and operate the biogas plants. However, such low prices can't reflect the environmental and social benefits of biogas and digested residue. Therefore a series of policies should be set up so as to promote the utilization of biogas and digested residue.

5.3.1 Subsidy for biogas

Chinese central government has provided large amount of user subsidy for the building of household biogas plants and medium and large scale biogas plants. However, such subsidy only encourages the farmers to build the biogas plants, rather than maintain and manage the biogas plants. For medium and large scale biogas plants, besides the user subsidy, product subsidy, which is the subsidy for the use of biogas, should be provided, thus promoting the owners to maintain the biogas plants well and produce as much biogas as possible. The price of biogas should refer to that of LPG or natural gas, and the subsidy should be able to let the owners of the biogas plants make profits for using or selling biogas. Apart from the subsidy for biogas, taxes on fossil fuels such as LPG, coal etc. can also make biogas more economically attractive.

5.3.2 Electricity and CHP, and vehicle fuels

To use biogas to generate electricity and make vehicle fuel has been regarded as an effective way to realize the high added value of biogas (D. Li, et al., 2009). In fact, biogas power projects and biogas as vehicle fuels are popular in Europe and Germany and Sweden have been regarded as the leading countries in this field (L. W. Deng & Chen, 2007). Therefore, the successful lessons from Germany and Sweden can help promote the application of biogas power projects and biogas as vehicle fuels in China.

Electricity and CHP

In 2000, Renewable Energy Act (EEG) was issued in Germany, which encouraged the farmers to build biogas plants and use biogas to generate electricity. Renewable Energy Act (EEG) was revised in 2004 and particularly supported the small scale biogas plants to generate electricity. Besides the preferential feed-in grid power price, biogas power projects with less than 70kW installed capacity can get 15000 Euro subsidy and low-interest loan (L. W. Deng, et al., 2008).

Since farmers can make profits from biogas power projects, a great number of biogas power projects were constructed. In 1996, there were only 379 biogas plants, while in 2005 the number was more than 3800, of which over 2700 biogas plants treated manure and agricultural waste (Yan, Deng, & Ren, 2007). Due to the effect of economic incentive and law, most of the biogas plants in Germany use biogas to produce electricity, amounting to 98.5% of the total biogas production. In addition, 98% biogas plants apply co-generation of heat and power (L. W. Deng, et al., 2008).

It can be seen from the table 5-1, there are detailed regulations to encourage renewable energy power in Germany, with focus on small and medium scale biogas plants. The use of animal manure and agricultural waste as fermentation material, the utilization of co-generation of heat and power(CHP) and the application of new technology such as dry fermentation are particularly encouraged with additional bonus (L. W. Deng, et al., 2008).

Table 5-1 Comparison of purchase price of electricity produced by biogas between Germany and China in 2006

Germany		China
Basic feed-in price for the electricity	Bonus	Subsidy
Up to 150 kW Euro cent/ kWh	11.16	Article7 The grid-connected power price of biomass power projects will be determined by government fixed pricing, which is set by the responsible pricing department of the State Council according to the region as the benchmark power price. The grid-connected power price of biomass power projects will be calculated as the
150-500 kW Euro cent/kWh	9.6	
500kW-5MW Euro cent/kWh	8.64	
	Energy crop, animal manure etc:4-6 Euro cent/kWh	
	CHP: 2 Euro cent/kWh	
	New technology (dry fermentation, fuel cell)	

5-20MW Euro cent/kWh	8.15	etc.): 2 Euro cent/kWh	
The purchase price of electricity will be decreased 1.5% annually since January 1 st 2005			<p>desulfurized coal power price in 2005 of the province, autonomous region or municipality, plus the power subsidy price.</p> <p>The standard for the renewable energy power subsidy price is 0.25 Yuan/kWh, which is enjoyed for the first 15 years of operation. After 15 years of operation, the power subsidy price will be canceled.</p> <p>Starting in 2010, the renewable energy power subsidy price for new power projects approved each year will be 2% less than those approved in the previous year.(NDRC, 2006)</p>

Source: adapted from (L. W. Deng, et al., 2008);(NDRC, 2006)

However, there is no detailed regulation for renewable energy power in China. No bonus is provided for the biogas plants using animal manure and agricultural waste, or applying CHP. Only 0.25 Yuan/kWh is provided as subsidy for power price of biomass power projects, but it is very difficult for biogas projects to make profits due to the high cost (L. W. Deng, et al., 2008). Furthermore, it is not guaranteed that biogas power will be purchased by power grid companies, thus the owners of intensive livestock and poultry farms have no enough incentives to invest in biogas plants (L. W. Deng, et al., 2008).

Therefore, new policies should be introduced to increase the subsidy for power price of biomass power projects so that owners of biogas plants can make profits. Biogas power must be guaranteed to be purchased by power grid companies. Besides, there should be bonus to encourage CHP, since most of biogas plants in China didn't build the waste-heat recovery system (J. M. Li & Yan, 2006). In addition, the electricity efficiency of biogas generating set needs to be improved, and technical standards and regulations with regard to biogas power project should be issued as soon as possible.

Vehicle fuels

Sweden has been regarded as the leading country with regard to biogas upgrading to bio-methane as vehicle fuel (Eriksson & Olsson, 2007). Due to the policy instruments, to utilize biogas as a vehicle fuel is believed to be the most favourable use alternative. In 2005, the market price of upgraded biogas is about 20-30% lower than petrol on energy basis (Lantza, et al., 2007).

It is calculated that the total annual production of upgraded biogas in Sweden can meet the average annual fuel consumption of 8000 cars (Eriksson & Olsson, 2007). Municipal transportations have made great efforts to use biogas as vehicle fuel and there were

approximately 600-800 busses for municipal transportation that can use upgraded biogas in 2005 (Eriksson & Olsson, 2007).

As is shown in table 5-2, there are a number of policy instruments that encourage the utilization of biogas as vehicle fuel in Sweden including policy objectives, legislation, taxes and financial subsidies etc. For example, apart from Kyoto protocol on reduction of greenhouse gas emission, it is required that 12% of EU's utilization of energy should come from renewable sources by 2010 (European Commission, 1997). Besides, biogas fuel should account for at least 5.75% of all vehicle fuel sold in EU by 2010 (European Commission, 2001). Tax reduction and subsidies are also provided for the use of biogas as vehicle fuel (Lantza, et al., 2007).

Table 5-2 Policy instruments in favour of utilization of biogas as vehicle fuel in Sweden

Policy instruments	Biogas as Vehicle fuel
Policy objectives	Kyoto protocol; EU's renewable sources of energy; EU alternative fuels for road transportation; EU energy supply security
Legislation	Renewable vehicle fuel must be supplied at large petrol filling stations
Taxes	Biogas is exempted from energy and CO ₂ -tax on fossil fuels
Financial subsidies	Tax is reduced for the utilization of bi-fuel passenger cars provided by the employer; Exempted from the congestion charge trails in Stockholm for bi-fuel passenger cars; Subsidies are provided for investments in bi-fuel cars in some municipalities; Parking is free in some cities

Source: adapted from (Lantza, et al., 2007)

However, there are also some barriers for the use of biogas as vehicle fuel, such as bi-fuel vehicles are more expensive, biogas distribution infrastructure and biogas filling stations are limited and the competition from other fuels like ethanol etc(Lantza, et al., 2007).

Considering the rising numbers of motor vehicles and the shortage of petroleum in China, it is promising to develop biogas as vehicle fuels (Y. Z. Pang & Li, 2006). In fact, the Action Plan for Clean Cars was implemented since 1999 and 12 cities including Beijing, Shanghai have been selected to develop buses using LPG and compressed natural gas (CNG) (Y. Z. Pang & Li, 2006). In 2004, there were 30 CNG filling stations in Beijing and 1800 CNG buses which were expected to increase to 8000 by 2008 (Y. Z. Pang & Li, 2006). Therefore, using biogas as vehicle fuel can be explored in these cities. However, more policy instruments need to be introduced to support the development of biogas as vehicle fuel and

more research needs to be done to analyze the feasibility of utilization of biogas as vehicle fuel in China.

5.3.3 Digested residue

The successful utilization of digested solid and liquid residue is critical for the operation of biogas plants, which can not only reduce the fines for environmental pollution, but also generate extra income. At present, new policies must be designed to encourage the use of digested residue as organic fertilizer. For example, price subsidy can be provided for purchasing organic fertilizer. Moreover, considering the current low price of chemical fertilizer doesn't reflect its real cost to the society, taxes should be levied. For instance, there is a tax on the nitrogen in commercial fertilisers in Sweden (Lantza, et al., 2007). Besides, the subsidy for manufacturing chemical fertilizer must be cancelled.

It is of great importance to strengthen the communication and education on the use of digested residue as organic fertilizer, so that farmers are willing and can use it correctly. New research needs to be carried out to make the utilization and transportation of digested solid and liquid residue more convenient, for example, the design of the special vehicle for spraying liquid residue on farm, or reduce the water content of liquid residue etc (G. Z. Zhang, et al., 2009).

In addition, the sanitation and safety of utilizing digested residue should be taken care of in China. It is found that for most biogas plants built for intensive livestock and poultry farms, the digested liquid can hardly meet the requirement of *Discharge standard of pollutants for livestock and poultry breeding (GB18596—2001)*, since most of them use medium and normal temperature fermentation and the hydraulic retention time(HRT) is short, which can't effectively kill the bacteria and parasitic ovum (Q. C. Hu, 2006a). Besides the organic fertilizer, the digested residue can also be used as feedstock for fish, pig and soaking seeds etc in rural China which have the positive effects, however, there is lack of the research on the sanitation and safety of such utilization (Q. C. Hu, 2006a).

The sanitary and safe use of digested residue has been taken seriously in European Union. For example, in Germany, there is Fertilizer Law to regulate the safe use of digested residue as fertilizer. The digested residue must be disinfected under 70°C for one hour before it is used as organic fertilizer (S. X. Zheng & Li, 2009). In Sweden, a certification system is used to control the quality of digested residue, which provides a certificate for qualified digested residue and regularly checks the contaminated contents such as infectious bacteria and heavy metals etc (SBGF, et al., 2008). Therefore, more research must be done to analyze the safety and sanitation of using digested residue in China and corresponding regulations must be issued to control the safe utilization.

5.4 Conclusion

Biogas plants can treat organic wastes and produce biogas and digested residue, which are clean renewable energy and organic fertilizer respectively. Due to its multi-benefits for rural development, renewable energy, climate change mitigation and environmental protection, Chinese central government has made great efforts to promote the construction of household biogas plants and medium and large scale biogas plants in rural China in recent years.

By the end of 2008, 30.5 million household biogas plants have been built, the largest number in the world, with an increased number of 2-3 million per year since 2005. The main feedstock for household biogas plants in rural China are livestock and poultry manure, crop residues and human excrement. 90% of household biogas plants are hydraulic biogas digester, which is built of clay, brick and concrete, usually 8 m³ and operated at normal temperature. Biogas produced by household biogas plants is mainly used for cooking, heating and lighting. Several ecological models have been applied to make full use of digested residue, including pig-biogas-fruit system, Four in One model and Five in One model in different parts of China.

There were only 700 medium and large scale biogas plants built for intensive livestock and poultry farms in 2005, accounting for only 6% of total medium and large scale intensive livestock and poultry farms (MOA, 2007). The main feedstock is livestock and poultry manure. Most of medium and large scale biogas plants use vertical tanks for fermentation and a few of them use underground installations. Almost all the fermentation technologies have been applied in China, including CSTR, ASBR, etc. Generally fermentation process is at normal temperature without mechanical stirring and biogas production is approximately 0.5-0.6 m³/m³.day (L. W. Deng, et al., 2008). The main use of biogas is for cooking and heating in the farm. Only 2.53% total biogas has been used for generating electricity and 1% for centralised biogas supply (L. W. Deng, et al., 2008). Three models have been developed to treat the digested residue, including comprehensive utilization model, ecological model and anaerobic-aerobic model.

There are a number of driving forces and barriers for the development of household biogas plants. A set of policy objectives, laws and regulations with regard to rural development, renewable energy, and climate change are in favour of household biogas plants. Besides, large amount of investment from the central government, which was more than 17 billion Yuan from 2001 to 2009, has been provided for the promotion of household biogas plants and recently the subsidy was even further increased for farmers. Another incentive is that biogas plant can improve farmer's income on fruit farming and animal husbandry. In addition, the CDM has provided new channel of finance for household biogas plants. The mature technology for building household biogas plants and associated facilities, as well as the established administrative network also favour the development of household biogas plants.

However, there are big challenges for the development of household biogas plants, especially the social change. The rapid urbanization and large amount of migrant workers will reduce the users. The building of socialist countryside, the separation of crop planting and animal farming, and the change from scatter breeding to intensive livestock and poultry farming in rural China will result in the shortage of fermentation material for household biogas plants. In addition, the current transnormal development of household biogas plants has caused a series of problems. Qualified biogas technicians are in short resulting in the poor quality of household biogas plants. The poor follow-up service and management as well as the lack of education and training for farmers make more biogas plants break down. Besides, the current household biogas plants can't use in cold seasons and are not convenient to manage. Furthermore, many poor farmers still can't afford building household biogas plants even with the support of subsidy.

There are also several incentives and barriers for the development of medium and large scale biogas plants. Compared with household biogas plants, the policies and laws related to environmental protection are key incentive for medium and large scale biogas plants, apart from renewable energy, climate change and rural development. From 2001-2005, 81.15

million Yuan were invested to build 120 medium and large scale biogas plants for intensive livestock and poultry farms by central government in China. And the subsidy has been further increased recently. In addition, to reduce fines for environmental pollution is also an incentive for farmers. The potential income from selling biogas or electricity generated by biogas and saving cost on cooking and heating can attract farmers to build biogas plants too. Besides, recently CDM can provide extra economic return for owners of biogas plants. The current social change including the transition from scatter breeding to intensive livestock and poultry farming and its induced serious environmental problems as well as the building of new socialist countryside have become the strong incentive for developing medium and large scale biogas plants.

However, several major problems exist. The lack of coordination between different government departments and the poor enforcement of environmental protection law have weakened the incentives of farmers to build biogas plants. Besides, the initial investment of medium and large scale biogas plants is high and farmers lack channels to get the investment money. Moreover, there are few taxation policies in favour of the development of biogas plants and economic return of biogas and digested residue is low, thus further reducing the incentives of farmers. The current technology needs to be further improved to guarantee the quality of biogas plants as well as the auxiliary facilities so as to increase the biogas production. Currently there are few policies in favour of the utilization of biogas, the electricity produced by biogas, biogas vehicle fuel and the digested residue.

In order to improve the biogas system in rural China, a series of measures have been suggested to strengthen the incentives and weaken the barriers. The policy advice for the development of household biogas plants in rural China is to slow down the development step, strengthen the education and training of farmers on the proper utilization of biogas plants, improve the rural biogas service network and ensure the quality of biogas plants as well as the associated facilities, and provide more funding for the research and development of household biogas plants.

As for medium and large scale biogas plants, in order to promote the further expansion, it is important to strengthen the enforcement of environmental protection law, develop multi-channels to raise the investment, set up the market for the products of medium and large scale biogas plants, and provide more funding for the capacity building of qualified technicians and improve the technology of biogas plants and auxiliary equipments for industrialization.

With regard to utilization of biogas and digested residue, subsidy for the use of biogas should be provided, so that owners of the biogas plants can make profits for using or selling biogas. New policies should be introduced to increase the subsidy for power price of biomass power projects so that profits can be made. Biogas power must be guaranteed to be fully purchased by power grid companies. Besides, there should be a production bonus to encourage CHP implementation. In addition, the electricity efficiency of biogas generating set needs to be improved, and technical standards and regulations with regard to biogas power project should be issued as soon as possible. Using biogas as vehicle fuel can be explored in big cities such as Beijing and Shanghai, with new policy instruments to support the development of biogas as vehicle fuel.

In order to promote the use of digested residue, new policies need to be designed such as price subsidy for purchasing organic fertilizer. For chemical fertilizers, the current subsidy for manufacturing must be removed. Furthermore, taxes such as tax on the nitrogen should be

introduced on chemical fertilizer. The communication and education on the use of digested residue as organic fertilizer is very important. Besides, new research needs to be carried out to make the use and transportation of digested residue more convenient.

The promotion of biogas plants in rural China is a complicated undertaking involving multiple policy objectives with regard to rural development, renewable energy, climate change, and environmental protection etc. The prospects of the biogas system, especially the household biogas plants and medium and large scale biogas plants in rural China will depend on how the current incentives are strengthened and how the existing barriers are weakened or overcome. Therefore careful analysis needs to be done in order to achieve the multi-benefit effects when implementing a variety of policy instruments in various policy domains.

5.5 Further Study

The rapid urbanization, the building of new socialist countryside and the transition from scatter breeding to the intensive livestock and poultry farming, will restrain the development of household biogas plants; while at the same time provide the opportunity to construct centralized medium and large scale biogas system in the village. However, the design, operation and management of such centralized biogas system at the village level need to be further studied.

Market-based policy instruments can provide a way to promote the utilization of biogas and digested residue, thus resulting in the expansion of medium and large scale biogas plants in rural China. However, how such market-based policy instruments can be designed and effectively implemented requires further research.

At present, household biogas plants and medium and large scale biogas plants are the focus of the development of biogas system in rural China. Therefore, for the majority of intensive livestock and poultry farms, the small scale farms, there are no incentives for them to build biogas plants to deal with the manure. Most of them choose household biogas plants, which can only treat part of the waste and still lead to serious environmental problems(Peng, 2007). How to build biogas plants for those small scale intensive livestock and poultry farms should be further analyzed.

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Appendix

Appendix 1 Policies, Laws and Regulations with regard to biogas development in China

Policies with regard to agriculture, farmer, rural area:

- *Circular of CPC Central Committee and State Council on Agriculture and Rural Work* (No.3 [2003]) [中共中央国务院关于做好农业和农村工作的意见（中发〔2003〕3号）]
- *Circular of CPC Central Committee and State Council on Increasing Farmers' Income* (No. 1 [2004])[中共中央国务院关于促进农民增收若干政策的意见（中发〔2004〕1号）]
- *Circular of CPC Central Committee and State Council on Further Strengthening the Work in Rural Areas to Raise the Overall Agricultural Production Capacity* (No. 1 [2005])[中共中央国务院关于进一步加强农村工作提高农业综合生产能力若干政策的意见（中发〔2005〕1号）]
- *Circular of CPC Central Committee and State Council on Promoting the Building of New Socialist Countryside*(No.1 [2006])[中共中央国务院关于推进社会主义新农村建设的若干意见（中发〔2006〕1号）]

Law and regulation with regard to renewable energy:

- Agriculture Law of the People's Republic of China, 2002[中华人民共和国农业法]
- Energy Conservation Law of the People's Republic of China,2007[中华人民共和国节约能源法]
- Renewable Energy Law of the People's Republic of China,2005[中华人民共和国可再生能源法]
- Regulation on Returning Farmland to Forest of the People's Republic of China, 2002[中华人民共和国退耕还林条例]
- Animal Husbandry Law of the People's Republic of China, 2005[中华人民共和国畜牧法]
- National Development and Reform Commission (NDRC). (2007). Mid-Long Term Development Plan for Renewable Energy.[可再生能源中长期发展规划]

Policies with regard to climate change:

- National Development and Reform Commission(NDRC). (2009). *China's Policies and Actions for Addressing Climate Change—The Progress Report 2009*.
- Information Office of the State Council of the People's Republic of China, (IOSC). (2008). *China's Policies and Actions for Addressing Climate Change*. Beijing.

Regulations with regard to the pollution prevention of intensive livestock farming:

- Ministry of Environmental Protection (MOEP).(2001).Administrative measures of pollution prevention for livestock and poultry farms,[畜禽养殖污染防治管理办法]
- Ministry of Environmental Protection (MOEP).(2001).Discharge standard of pollutants for livestock and poultry breeding(GB18596—2001), [畜禽养殖业污染物排放标准(GB18596—2001)]
- Ministry of Environmental Protection (MOEP).(2001).Technical standard of preventing pollution for livestock and poultry breeding, [畜禽养殖业污染防治技术规范(HJ/T 81-2001)]
- Ministry of Environmental Protection (MOEP).(2009).Technical Specifications for Pollution Treatment Projects of Livestock and Poultry Farms, [畜禽养殖业污染治理工程技术规范(HJ 497-2009)]

Plans with regard to Biogas development in rural China:

- Ministry of Agriculture (MOA), & National Development and Reform Commission (NDRC). (2007). *Development Scheme for Service System of Rural Biogas in China (Tentative)*.[全国农村沼气服务体系建设项目方案（试行）]
- Ministry of Agriculture (MOA). (2007). *China's rural biogas project planning (2006–2010)*,[全国农村沼气工程建设规划（2006—2010年）]
- Ministry of Agriculture (MOA). (2003). *Regulations on Rural Biogas Projects Supported by National Bond (Tentative)*.[农村沼气建设国债项目管理办法]
- /Ministry of Agriculture (MOA). (1999). *Plan for construction of energy environmental engineering for medium and large scale livestock farms*.[大中型畜禽养殖场能源环境工程建设规划]

National standard and criteria with regard to biogas plants:

- GB/T 3606-2001 Household Biogas Stove [家用沼气灶]

- GB/T 4750-2002 Household Biogas Digester Standard Collection of Drawings [户用沼气池标准图集]
- GB/T 4751-2002 Quality Assessment of Household Biogas Digester [户用沼气池质量检查验收规范]
- GB/T 4752-2002 The Operation Rules for Construction of Household Biogas Digesters [户用沼气池施工操作规程]
- NY/T 344-1998 Household Biogas Lamp [家用沼气灯]
- NY/T 465-2001 Rural Household Energy-Ecology Engineering: The Regulation on Design, Operation and Utilization for Southern Model [户用农村能源生态工程 南方模式设计施工与使用规范]
- NY/T 466-2001 Rural Household Energy-Ecology Engineering: The Regulation on Design, Operation and Utilization for Northern Model [户用农村能源生态工程 北方模式设计施工与使用规范]
- NY/T 667-2003 the Classification of the Scale of Biogas Engineering [沼气工程规模分类]
- NY/T 858-2004 Biogas Pressure Meter [沼气压力表]
- NY/T 859-2004 Household Biogas Desulfurizer [户用沼气脱硫器]
- NY/T 860-2004 Sealed Coating for Household Biogas Digester [户用沼气池密封涂料]
- NY/T 1220.1-2006 Technical Regulations of Biogas Engineering Part 1: Technological Design [沼气工程技术规范 第1部分：工艺设计]
- NY/T 1220.2-2006 Technical Regulations of Biogas Engineering Part 2: Design for Air Supply [沼气工程技术规范 第2部分：供气设计]
- NY/T 1220.3-2006 Technical Regulations of Biogas Engineering Part 3: Operation and Inspection [沼气工程技术规范 第3部分：施工及验收]
- NY/T 1220.4-2006 Technical Regulations of Biogas Engineering Part 4: Operational Guidance [沼气工程技术规范 第4部分：运行管理]
- NY/T 1220.5-2006 Technical Regulations of Biogas Engineering Part 5: Quality Assessment [沼气工程技术规范 第5部分：质量评价]
- NY/T 1221-2006 Technical Regulations on Operations, Maintenance and Safety of Biogas Engineering for Intensive Livestock Farms [规模化畜禽养殖场沼气工程运行、维护及其安全技术规程]
- NY/T 1222-2006 Regulations on the Design of Biogas Engineering for Intensive Livestock Farms [规模化畜禽养殖场沼气工程设计规范]
- NY/T 1223-2006 Biogas Generating Set [沼气发电机组]

Source: (MOA, 2007)

Appendix 2 Different classification of the scale of intensive livestock and poultry farms

Technical Specifications for Pollution Treatment Projects of Livestock and Poultry Farms

Type	Pigs	Diary cows	Beef cattle	Hens	Ducks and geese
Numbers	>300	>30	>100	>4000	>2000

Source: (MOEP, 2009)

Discharge standard of pollutants for livestock and poultry breeding(GB18596—2001)

Type	Pigs	Diary cows	Beef cattle	Hens	chickens
Numbers	≥3000	≥200	≥200	≥100 000	≥200 000

The conversion rate:

30 hens=1 pig; 60 chickens=1 pig; 1 dairy cow= 10 pigs; 1 beef cattle= 5 pigs; 3 goats= 1 pig

Source: (MOEP, 2001b)

Administrative measures of pollution prevention for livestock and poultry

Type	Pigs	Diary cows	Beef cattle	Hens	chickens
Numbers	≥500	≥100	≥100	≥30 000	≥30 000

Source:(MOEP, 2001a)

China's rural biogas project planning (2006–2010)

Type	Pigs (sale)	Diary cows (stock)	Beef cattle (sale)	Sheep (sale)	Hens (stock)	chickens (sale)
Intensive	≥50	≥5	≥10	≥30	≥500	≥2000
Medium and large scale	≥3000	≥200	≥500		≥50 000	≥100 000

Source: (MOA, 2007)