4-IN-1 BIOGAS SYSTEMS

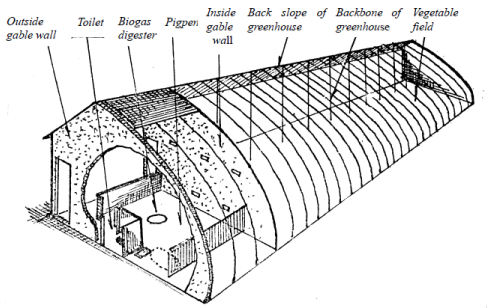
A Field Study on

SANITATION ASPECTS & ACCEPTANCE ISSUES

in Chaoyang and Shenyang Municipalities, Liaoning Province

On behalf of

CHINA NODE FOR SUSTAINABLE SANITATION (CNSS)



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Centre for Sustainable Environmental Sanitation

University of Science and Technology Beijing

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Mr.Cheng Shikun (Master Student), Ms.Du Xinling (Master Student), Mr.Xing Jingjing (Master Student), Mr.Mario Lucas (Junior CIM erpert), Mr.Justin Shih (Student from UC Berkley) were involved in the field visit and also prepared the draft report. Mrs.Elisabeth Huba took a lot of time to review this draft report and finalized it. Without their active involvement this report could not be realized.

Director of CNSS: Prof. Dr. Zifu LI

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1. Executive Summary

China plays a leading role in the development and dissemination of household biogas technology. One of these technologies is the 4-in-1 biogas system, which has been promoted and implemented in colder regions of China. A survey on the acceptability of 4-in-1 biogas systems in two townships in Liaoning Province was undertaken in July, 2010. The purpose of the survey was to clarify the status of 4-in-1 biogas systems and to learn more about people's attitude and behavior towards them. The study looks specifically at the economic, social, technical, and environmental aspects of these systems, and discusses the advantages as well as the challenges that the systems currently face.

The survey revealed that slurry is more accepted and used than biogas. Farmers are neutral towards the sanitation condition of the pigsty and toilet. Breeding pigs is becoming less common, which restricts the further dissemination of 4-in-1 biogas systems. The greenhouse aspect of the system greatly supports the farmer's crops, which generates considerable more income for farmers. While the environmental benefits of 4-in-1 biogas systems are often promoted by governmental agencies and environmental groups, the economic incentive is a much stronger motivator for farmers. In addition, it became obvious that the multipurpose benefits of biogas need to be further popularized.

From 2001 to 2004, the dissemination of 4-in-1 biogas systems increased sharply. However, as time went by, this model was no further developed according to the needs of farmers and the potential benefits they could have drawn from this system. This downturn could be summarized in 5 points[1]: (1) a limitation of sub-urban gardening land: with the development of market economy, the trend goes to large-scale and intensive management of farmland; (2) strict regulations of the gardening area of the residential house besides the green house in order to protect arable land; (3) pig breeding as economic activity has significantly reduced during the past years; (4) vegetable farmers don't use 4-in-1 systems, but "ordinary" greenhouses, because their income mainly originates from vegetable production, so breeding pigs would be an extra workload without significant economic benefits; (5) breeding pigs is counterproductive to a clean environment because it causes odour nuisances.

In addition, in the winter cold regions of Northern China, the biogas production in winter is limited but farmers won't complain as long as the digester could get over the winter and the digester content doesn't freezes.

[1] Notes taken during the interview with Ms. Wang Ying from Liaoning Rural Energy Office (LREO)

In general, the most successful aspect of the 4-in-1 system lies in the utilization of the fermented slurry as fertilizer because it improves vegetable production thus brings larger income to farmers. Second benefit lies in biogas utilization for cooking, and the third benefit is seen in the sanitation aspect with the attached improved toilet.

2. Purpose and Location of the study

The purpose of this investigation, prepared and financed by the China Node for Sustainable Sanitation (CNSS) was multiple: to evaluate (1) the sanitation impact of 4-in-1 biogas systems, and (2) the acceptance of this ecological model by the users, as it is embedded in several socio-economic, technical and agricultural activities. In order to make proper recommendations, further and more detailed research on health and hygiene impacts should be done. Also, the relevance of fresh water use in the toilets, and water saving potential should be analysed.

The present study does not claim to be a statistically relevant investigation, because compared to a scientific project less households were interviewed. However, within the limited framework of the on-site investigation, the study led to significant findings. It is further important to let the reader know that the Province of Liaoning, where data collection and interviews have been carried out, is home to the first ever and original 4-in-1 biogas system. The study therefore may claim to be relevant as monitoring assessment after a long period of dissemination and use of 4-in-1 biogas systems.

The survey covered two townships located in two different cities in Liaoning Province; in each township, two villages were selected for on-site investigation; 15 households were interviewed - 5 in Shenyang and 10 in Chaoyang.

Table 1: Locations of the on-site investigation

Municipality	**Township**	**Village 1**	**Village 2**
Shenyang	Lengzibao	Shejia	Pijiapu
Chaoyang	Xiyingzi	Liujiazi	Changgao

Figure 1: Map of Liaoning Province displaying cities and townships of on-site investigation

3. Basics of a 4-in-1 biogas system

Liaoning Province is the original home to 4-in-1 biogas systems nowadays distributed all over China. The model integrates (1) biogas digester, (2) pour flush squatting toilet, (3) pig shed or poultry house and (4) greenhouse into one system, which altogether stand for the “4-in-1”. The system is based on the combined principles of ecology, economics and system engineering, developed specifically for rural agricultural (fertilizer) and energy needs in North China.

When perfectly constructed, operated and maintained the 4-in-1 system makes complete use of organic resources, absorbs solar energy as power, takes biogas as link, and combines plant production with animal husbandry, thus performing an integrated agricultural bio-energy system. Since the early 1990ies, wherever they have been installed, 4-in-1 systems have delivered significant contributions to the increase of energy supply in rural areas, the increase of farmers’ income, and the improvement of rural environment.

The greenhouse permits continued agricultural production even during cold winter. Survey results indicate that the average temperature in the greenhouse is about 16^{o}C in winter, compared to -15^{o}C ~-25^{o}C ambient temperature, which enables the farmers to planting off-season and to generate additional income; The pigpens are built in the greenhouse, so the pigs can grow faster than normal; farmers can sell pigs 3 times a year, which is one times more than without operating a 4-in-1 system. Both, the toilet and the pig pen are linked with the digester placed under the pig pen; pig dung and human excreta are the main raw material for biogas production. The biogas is used for cooking and lighting.

Besides production of biogas for cooking and lighting energy, the use of a “4-in-1” system results in various social-economic impacts, including increased income and reduced expenditures, additional investments, agricultural productivity, reduction in application of mineral fertilizer, lower inputs in pest control, improvements in soil and water quality, human and animal health, and sanitized of household environment.

4. Biogas system type 4-in-1 in Shenyang and Chaoyang

The two places selected in Liaoning Provinces as study sites are Lengzibao Township in Shenyang Municipality and Xiyingzi Township in Chaoyang Municipality. The model disseminated in the villages in these cities is the common 4-in-1-model in North China, including a bio-digester, a pigpen, a latrine and a greenhouse. All these components interact and complement each other to form an ecologically balanced,

small-to-medium-scale agricultural energy system. Often the greenhouse is built in the yard; at one side of the greenhouse, a biogas digester is constructed underground; the pig pen is built on top of the digester, and in one corner attached outside of the pigpen, the toilet for the household. Thus, human and animal wastes directly flow into the bio-digester to generate biogas and organic fertilizer. The greenhouse produces vegetables and fruits by benefitting from sunshine and indirect solar heating; the digester provides biogas for lighting and additional heating if required, and organic fertilizer. The presence of pigs under the same greenhouse roof, and the burning of biogas in gas lamp for lighting inside the green house help to increase the CO_2 concentration in in the greenhouse, thus supporting plant productivity.

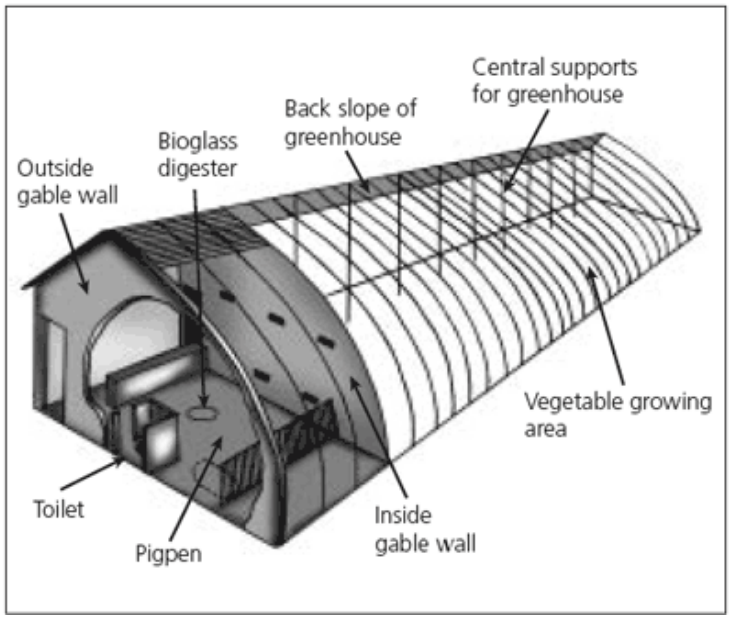

Figure 2: Overview on complete 4-in-1 system

Source:

http://www.hedon.info/UsingIntegratedBiogasTechnologyToHelpPoorCommunitiesInBaimaSnowMountainNatureReserve

The biogas reactor functions in the hydraulic pressure mode. Construction costs for a 4-in-1 biogas system are in the range of CNY30,000 to CNY60,000; governmental subsidy per family about CNY3,000. Investigation in Shenyang confirmed that one family operates not more than 2 or 3 biogas 4-in-1 systems, because the government limited sub-urban vegetable cultivation area since end of 2006.

4.1 Household Profiles

After having analyzed the on-site visits and the interviews to 15 households in the villages of Shejia and Pijiapu, both in Shenyang Municipality, and Liujiazi and

Changgao, both in Chaoyang Municipality, the following profiles have been elaborated:

Table 2: Socio-economic profile of sampled households

	Farms before using "4 in 1" system	Farms after using "4 in 1"system
Household size (persons)	3.4	3.4
Number of labour (persons)	2.1	2.5
Annual household income (CNY)	21,330	43,400
Annual household expenditure (CNY)	10,500	19,730
Household net income (CNY)	10,830	23,670
Household net income per person (CNY)	3,185	6,962

4.1.1 Income & Expenditures

While there is little difference regarding household size and labour before and after use the 4-in-1 system, a significant change in household net income is confirmed. Households operating a 4-in-1 system on average earn more than twice as much income as before having invested in the 4-in-1 system. Reflecting the effect of higher income, farmers using 4-in-1 systems have higher expenditures, too; however, their net income is more than doubled.

In Shenyang, households have often installed 2 or more additional greenhouses beside the 4-in-1 system, as they experienced that their biogas digester could produce sufficient fertilizer to manage several greenhouses even if they are not directly connected with the 4-in-1 unit. Saving money otherwise spent for chemical fertilizer, and at the same time reducing the workload by working "inside", they also tend to hire up to 2 people during harvest time.

In Chaoyang Municipality, households stay with the traditional 4-in-1 system, using the integrated greenhouse, which often is even smaller than the greenhouses installed in Shenyang. The advantage: almost one person can manage whole system, so the other household members can acquire paid work outside the farm. Interviewed families confirmed that the income based on the operation of the 4-in-1 system is reliable and permanent, even more than working outside of the village, and they have more money available for their daily needs than before. It therefore can be concluded that the installation of 4-in-1 systems significantly improves economic conditions of households in Liaoning Province.

Most of the household incomes in Shenyang are generated by agricultural activities, whereas in Chaoyang household income from agricultural activities accounts for about 50% only. Expenditures for agricultural activities after installing 4-in-1 biogas systems stand for about 70% of household's expenses, including a certain decrease in fertilizer and agro-chemicals, but an increase in material cost esp. for maintenance of the greenhouse.

Using biogas slurry as fertilizer as well as the separation of the greenhouse from other planting areas reduces insect attacks. But probably due to increased temperatures in the greenhouse more plant diseases are observed by the farmers; the treatment of these diseases requires in average CNY1000 per year.

As pigpens are integrated into the greenhouse, the pigs grow fast also during winter time, about as much as during comfortable ambient temperatures. This increases the selling rate of pigs per year: each household can sell 6 to 9 pigs, 2 to 3 pigs each time; one pig is sold for about CNY2000. The net income from one sold pig is about CNY400 to 500.

Thus benefits and disadvantages of a 4-in-1 system are balanced: they reduce insects and accelerate the growth of the pigs, but potentially increase plant diseases.

Table 3: Household income in 4-in-1 Biogas Villages, Liaoning Province 2010

Using 4-in-1	Total Household Income (CNY)	Agricultural Activities (%)	4-in-1 related Agricultural Income (%)	Income from other activities (%)
Before	21,330	40%	-	60%
After	43,400	70%	60%	30%

Table 4: Household expenditure in 4-in-1 Biogas Villages, Liaoning Province 2010

Using 4-in-1	Total Household Expenditures (CNY)	Expenses for Agricultural Activities (%)	4-in-1 system-related Agricultural Expenses (%)	Other expenses (%)
Before	10500	45%		55%
After	19730	>80%	>70%	<30%

Expenditures - details	***Before "4 in 1":*** *0.5 mu (333m^2)/year* **(CNY)**	***After "4 in 1"*** *0.5 mu (333m^2)/year* **(CNY)**
Chemical fertilizer (CNY)	700-800	500~600
Pesticides (CNY)	300	60-100

Plastic for greenhouse (CNY)	0	1500

4.1.2 Educational Level

The educational level in the investigated villages is comparatively high. All household heads have received education above the level of primary school. More than 50% of the household heads surveyed have completed middle school, but there are no household heads that received education at high school level or above.

4.1.3 Household Size

The average family size in Shenyang Municipality ranges between 4 and 5 persons. Except some children at schooling age most of the family members are working at home. 4 of the 5 families raise pigs; one family is raising a cow (outside the greenhouse, but the cow manure is filled in the biogas plant). Most families say they earn little money from animal husbandry, because they raise pigs just for assuring enough biogas production.

In Xiyingzi Township, Chaoyang Municipality, all farmer families raise pigs; however in summer most of the families have jobs outside of their home, because greenhouse vegetables are generally cultivated in winter and spring.

Table 5: Family size of pig breeders with 4-in-1 systems in Chaoyang Municipality

Household No.	Family members	Pigs per year
1	5	6
2	3	3
3	3	8
4	2	6
5	3	3
6	4	6
7	3	2
8	4	2
9	2	4
10	2	8

4.1.4 Agricultural Productivity and Commercialising of Produce

In general, most farmers in Liaoning generate income from traditional cultivation of cereals, oil-bearing plants, vegetables, fruits and domestic animals, mainly hogs. In addition, some households generate income from job acquired outside of the village.

Our survey revealed that these households with 4-in-1 biogas systems plant vegetables and fruits only in their greenhouse. The earning from selling fruits is just a

little bit higher than that from vegetables, but vegetables can be planted more often (up to 6 times per year) than fruits, so the revenues are more or less equal. The primary agricultural revenue of farms with 4-in-1 biogas systems is obtained from production yields achieved in the greenhouse. On average, 85% of total household revenue from agricultural activities is greenhouse based production.

Survey data indicate further that well operated 4-in-1 systems contributes to the increase of revenues from livestock; in the case of the investigated area the average revenue from pig breeding in the surveyed farms is about CNY16800.

Most of the vegetables produced in greenhouses attached to 4-in-1 biogas systems are sold to brokers or small scale dealers; this commercialisation method does not allow for a permanent and stable income. If vegetable and fruit dealers do not show up in time at the farm gate, people sell directly to the local market.

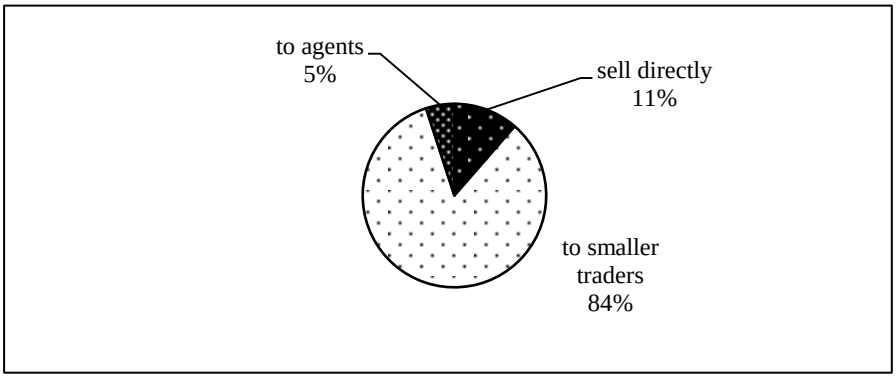

Figure 3: Fruit and vegetable marketing in Liaoning, 2010

To start a profitable vegetable marketing, farmers would have to switch to “mass produce” farming systems. Currently the conditions in the villages are not favourable to enter in long term supply contracts: every family cultivates different vegetables or the same vegetables at different periods. To promote cooperative marketing, stringent coordination of tasks and responsibilities is needed, and the commitment of those actors who really could impact on the local market.

Nutrient and Energy Flow

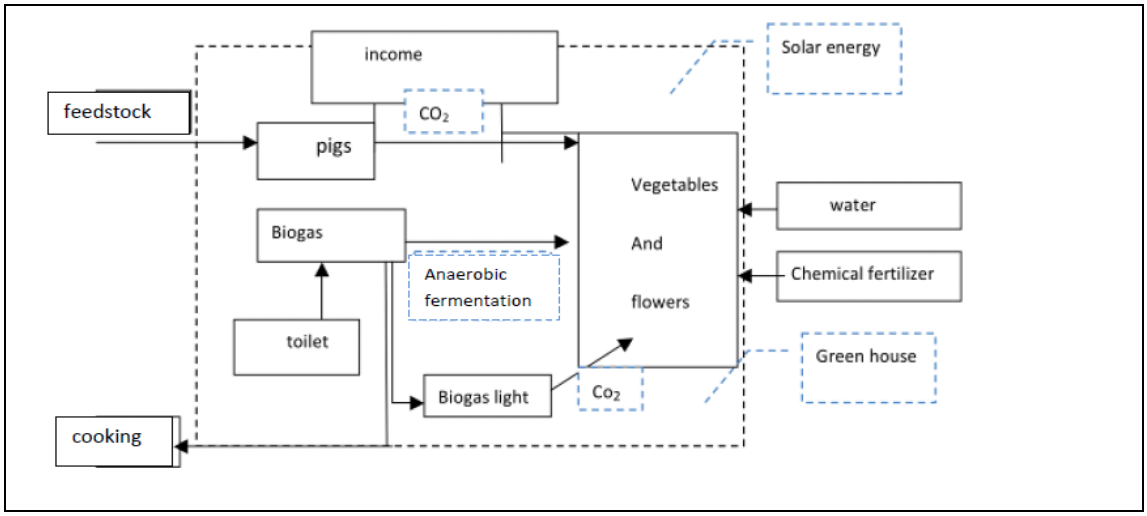

Figure 4: Mass flow diagram of 4-in-1 biogas systems implemented in Liaoning Province

Feedstock for 4-in-1 biogas systems developed and implemented in Liaoning Province mainly consists of human excreta and pig manure.

Table 6: Human excrement per capita: amount and resource content

Parameter	Manure	Urine	Excreta
g/per day (wet)	250	1200	1450
g/per day (dry)	50	60	110
Organic (g)	92	75	83
Carbon (g)	48	13	29
Nitrogen (g)	4-7	14-18	9-12
P_2O_5 (g)	4	3.7	3.8
K_2O (g)	1.6	3.7	2.7

4.2 Use of fermented slurry

Literature data indicate that N (Nitrogen) losses of up to 5% in form of NH_3 (Ammonia) are to be considered after anaerobic fermentation and storage of the slurry for three months up to its use as organic fertilizer. The recovery rate of K (Potassium) and P (Phosphorous) is 100%. Anaerobic fermentation produces simultaneously biogas and fertilizer. In order to produce transportable and marketable fertilizer, slurry as fluid component of the fermentation residues requires post-treatment and an intensive marketing campaign to make farmers understand its specific value.

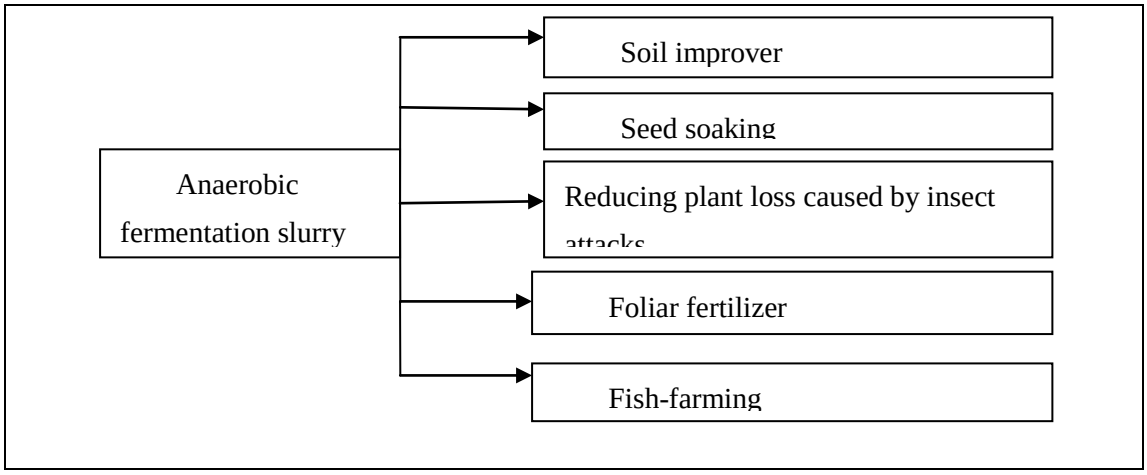

Figure 5: Potential applications of Fermentation Slurry

Anaerobic fermentation residues from typical 4-in-1 systems contain 30 - 50% organic matter, humic acid 10 - 20%, 0.8 - 2.0% N, 0.4 - 1.2% P, and 0.6 - 2.0% K. In the process of anaerobic fermentation, some chemical elements are converted to CH_4 and CO_2. Most of the plant nutrients are kept in the anaerobic fermentation residues, mainly in the liquid part, and are therefore highly valuable substrates for soil fertility in vegetable and fruit production throughout the year.

Table 7: Sampling in Chaoyang

Parameter	Values
Temperature (^{0}C)	30
TN (mg/l)	1107
TP (mg/l)	36
NH_4-N (mg/l)	2072
pH	7.07
electric potential (V)	-37
E. coli bacillus (cfu/ml)	$33*10^4$

According to own sample analysis, Total Nitrogen (TN) and Total Phosphorous (TP) are quite high in the solid fraction, higher than in the liquid fraction of settled slurry (60% in solid, 40% in liquid form). Both pH are neutral. In the analysed sample a slightly elevated presence of E.coli was observed; this may cause by the prolonged sample storage time of 2 days before starting the lab analysis. The slurry is without any doubt appropriate for agriculture, as it was confirmed that the amounts of N, P, and K are considerably high.

4.3 Energy Consumption

Analysing the expenses for energy borne by the surveyed farm-households was important for measuring potential and real benefits from 4-in-1 systems. Survey data result in an overview on energy sources and consumption patterns by types of farm energy systems. Besides biogas, commercial energy sources are widely used in Liaoning: electricity for lighting and cooking; coal, straw and wood for cooking and heating; LPG and biogas for cooking.

Changes in the usage pattern of energy sources before and after the installation of a biogas 4-in-1 system are displayed in the following table. After the construction of a 4-in-1 system, households use biogas for cooking, saving CNY300 to CNY500 energy expenditures per year. In Chaoyang all residential houses attached to greenhouses of 4-in-1 models are built with a passive solar heated thick wall, which supports house heating in winter. Electricity is used for lighting in any place of the compound. If enough biogas remains after cooking, biogas lamps are used in the greenhouse to enrich the atmosphere with CO_2 to enhance vegetable growth.

Table 8: Household energy use by type of farm energy system (%)

Use	4-in-1	electricity	coal	straw & wood	LPG	biogas	solar
Cooking	Before	20	0	30	50	0	0
	After	10	0	10	0	80	0
Heating	Before	0	40	60	0	0	0
	After	0	0	30	0	15	55
Lighting	Before	100	0	0	0	0	0
	After	99	0	0	0	1%	0

5. Socio-economic impacts

5.1 Investment and loan

Survey results revealed that up to CNY60,000 has to be spent for the set-up of the complete 4-in-1 system. The greenhouse accounts for about 85% of the total investment, whereas the cost of the digester accounts for only 5% of total capital costs. The following tables present an overview on average initial capital requirements for a 4-in-1 model, including one greenhouse with integrated pig pen, the residential house adjacent to the greenhouse, one digester and one toilet.

Table 9: Average initial capital need for a 4-in-1 biogas system in Shenyang

Total cost	**CNY 40,000 – 60,000**

Cost for Greenhouse with integrated pig pen	CNY 30,000 – 40,000
Cost for attached living house	CNY 7,000 - 15,000
Toilet	CNY 300
Cost for Digester (including plumbing, biogas stove, lighting upgrade)	CNY 3,000

Table 10: Sources for investment (average) in 4-in-1 systems in Shenyang

Financial sources	Average CNY/Household	Percentage
Self-financing	CNY 17,000	35.4
Commercial loan	CNY 28,000	58.3
Government subsidy	CNY 2,800 + 200	6.25

In Shenyang, greenhouses are simpler constructed than in Chaoyang; their cost accounts for 20% of the total investment.

In Chaoyang, however, construction of residential houses follows basically the same energy efficient greenhouse concept: they built a passive solar heated thick wall to warm the living space especially in winter, so house construction is more expensive than in Shenyang, but people are satisfied with the long-term benefits. Costs of toilet integration are just CNY300, which represents less than 1% of the total cost. Further details are given in the following tables.

Table 11: Average initial capital need for a 4-in-1 biogas system in Chaoyang

Total cost	**CNY 60,000 – 80,000**
Cost for Greenhouse with integrated pig pen	CNY 30,000 – 40,000
Cost for attached living house	CNY 20,000 - 30,000
Toilet	CNY 300
Cost for Digester (including Plumbing, biogas stove, lighting upgrades):	CNY 3,000

Table 12: Sources for investment (average) for 4-in-1 systems in Chaoyang

Financial sources	Average CNY/Household	Percentage
Self-financing	CNY 25,000	30.5
Commercial loan	CNY 46,000	56.1
Government subsidy	CNY 2,800 + 200 + 8,000	13.4

The access to commercial loans in rural areas of China is very limited. Most investments (30~35%) in Liaoning are self-financed, according to survey responses. Households rely on their own savings, and in addition borrow money from friends or relatives. 50~60% of the surveyed farms obtained loans from local banks, such as the China Agricultural Bank, or China Rural Credit Union. Our survey also revealed that 100% of the 4-in-1 users received government subsidies for setting up their systems.

The government subsidy is basically CNY3,000, including CNY200 from the county government, and CNY2,800 from provincial and national government level. In Chaoyang an additional subsidy of CNY8,000 is given to families moving from erosion sensitive mountain areas to the plain and to build up a 4-in-1 system. Most of the subsidy is directly supplied for the construction material of the biogas digester including plumbing and biogas stove.

5.2 Use of biogas from 4-in-1 systems

Biogas contains 50-70% CH_4, 30-40% CO_2, and fractions of CO_2, H_2S, H_2, O_2 and N_2.

All families surveyed in Chaoyang and Shenyang use biogas only as cooking fuel. Moreover, all interviewed families use biogas for cooking, regardless if it sufficient whether in winter or in the summer. About 50% of the households have never maintained the delivered and installed H_2S filter (purifier) because of knowledge deficiency of biogas; most farmers do not know that H_2S may harmful. As the investigation took place in summer, most of the greenhouses were open. Data provided by local government officials show that in winter time the temperature in the greenhouses varies between 10 and 28°C, although outside temperature falls below -10°C. Given the fact that the digester is built without any additional insulating material, but well humidity protected in dry soil under the pig pen concrete platform, biogas production during winter depends mainly on this humidity free packing in soil, and on solar radiation passing through the greenhouse, heating up the greenhouse heat storage wall. Due to low ambient temperature biogas production is significantly lower in winter than in summer. However, all families confirmed that biogas is used for cooking, even in winter.

The entire biogas installation is subsidized by the government; each household receives about CNY3000 for a uniformly installed biogas system; each village and township offers regular training biogas use. The on-site visit revealed that in about 90% the biogas pipelines of the households has no problems, they are tight and do not leak. Not all farmers using biogas lamps although these could improve CO_2 content and temperatures in the greenhouse while burning biogas; moreover, excess biogas is sometimes not used but just released into the air. Although it could be stated that

the overall use of biogas is well organized, farmers still lack knowledge about the multifold benefits of biogas technology; more information is required especially from those governmental services that help at any time to resolve farmers' problems with 4-in-1 systems.

5.3 Cultivation of vegetables

In Shenyang, most farmer families cultivate in 3 summer seasons vegetables mainly tomatoes, cucumbers, and grapes. In each village, farmers focus on the same kind of vegetable cultivation. Most farmers still apply chemical fertilizers and chicken manure. The majority of farmer families have 2 to 3 greenhouses, and their main revenues depend on selling additional off-season vegetable production in winter. The revenue per year per famer family reaches CNY40,000-50,000 CNY. In general, vegetables are sold at farm gate to dealers.

In Chaoyang most vegetables cultivated in greenhouses are tomato, cucumber, aubergine and pumpkin. As local living standard is low, most farmers earn about CNY30,000 per year. The majority of the farmer families cultivate different kinds of vegetables, as it is difficult to sell large amounts of one variety.

Greenhouse vegetable production provides the most important source of revenues. The following table compares benefits and costs of vegetable farmers in Chaoyang and Shenyang.

Table 13: Comparison of revenues from, and costs for 4-in-1 systems in Shenyang and Chaoyang

Parameter	Shenyang	Chaoyang
Revenue from 4-in-1	50,000 CNY	15,000 CNY
Revenue from work outside of the village	0	15,000 CNY
Maintenance cost for 4-in-1	15,000 CNY	10,000 CNY
Total revenue	50,000 CNY	30,000 CNY
Rate of 4-in-1 revenue	100%	50%

The analysed households in Liaozhong County, Shenyang Municipality basically depends on the 4-in-1 system to earn their living; otherwise family members would need to leave the village for work.

6. Maintenance Requirements

All households with 4-in-1 biogas systems are receiving training before the system is put into operation. This is a one-time-training, but obviously not enough to give to

each family a general understanding of how to operate, maintain and use the installation. An analysis of farmers' demand shows that about 50% of the interviewed households suggest more training on biogas technology. In addition, respondents would like to have training on how to improve marketing channels for their products and knowledge about appropriate planting of greenhouse vegetables. 100% of the interviewed households emphasized that if government would provide similar subsidy for toilet construction just like for the biogas digester, they would like to rebuild and improve their toilet.

Figure 6: Safety and general maintenance rules for household biogas digesters

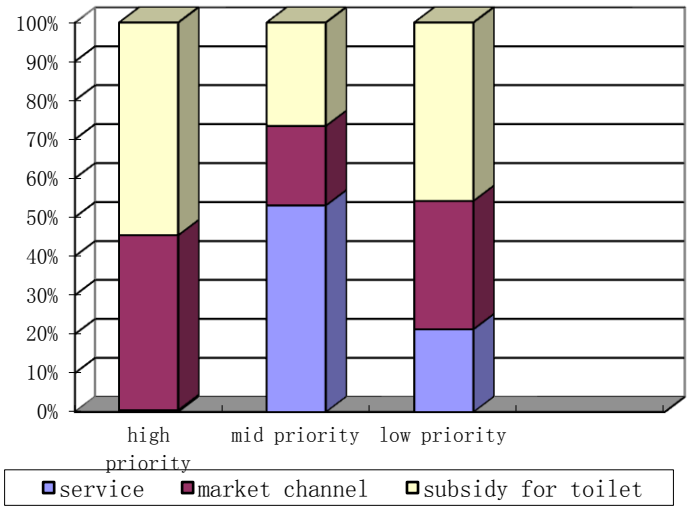

Figure 7: Demand for policy support in Liaoning

System maintenance requirements

According to our investigation, in both places farmers apply still some additional chemical fertilizer to increase the greenhouse vegetable production. About 50% of the farmers still apply pesticides, but the amount is reduced because the fermented

slurry also functions as insect prevention. Maintenance costs mainly are required for the replacement of the plastic film and the straw curtain of the greenhouse. The plastic film needs to be changed at least once per year, and the straw curtain needs to be changed every 3 years.

From the manure and agricultural residues that enter a biogas digester, about 97% can be returned as fertilizer to the farm land (Wang, 2001). However, poor operation could significantly reduce the biogas plant performance. 35% of the visited families experience gas leakages in the digester construction, but they don't know how to fix it. 95% of the toilet flush water containers were broken, nobody repaired it. Although a biogas desulfurizer device is installed at all 4-in-1 systems, most of the households don't use it. Investigation shows that they lack knowledge about the hazardous impacts of sulphur dioxide. A regular professional service (like sludge emptying service, livestock raising service) to facilitate optimal functioning is not available.

Table 14: Comparison of costs for agricultural inputs for 4-in-1 systems per year

Category	Shenyang (CNY)	Chaoyang (CNY)
Feedstock	1,200 – 2,000	400 – 1,000
Chemical fertilizer	3,000 – 4,000	600 – 1,000
Piglet and seed	2,000 – 3,000	2,000 – 3,000
Maintenance	6,000 – 8,000	5,000 – 6,000

7. Environmental Impacts

The operation of 4-in-1 systems results in several environmental impacts: reduced application of chemical fertilizer; lower demand for pest control; and improvement in soil and irrigation water quality, human and animal health, and village environment.

7.1 Fertilizer

Respondents indicated that 4-in-1 systems lead to reduced application of chemical fertilizers: 91% reported a reduction of chemical fertilizer use, of which 54% indicated they require much less chemical fertilizer. However, in some cases there is obviously not enough K available in the digested slurry, so most of the respondents say that they need to purchase Potassium (K) fertilizer. In order to assure the intended vegetable yields, 25% of the farmers buy additional chicken manure as P_2O (Phosphor) fertilizer source; 75% reported that their biogas digester produces enough fertilizer for the greenhouse vegetable production.

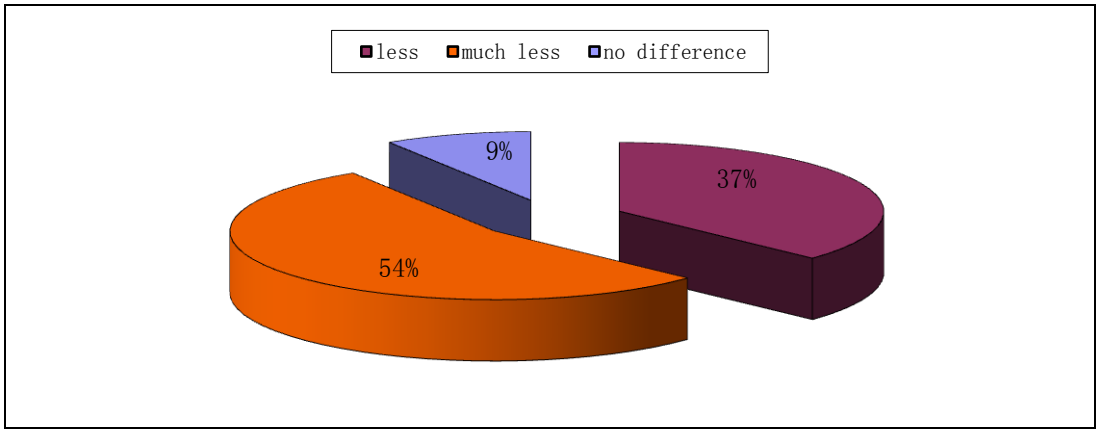

Figure 8: Impact of 4-in-1 biogas systems on fertilizer utilization in Liaoning

7.2 Pest & Insect Control

Referring to pest and insect problems during cultivation, all respondents operating 4-in-1 systems indicated that such problems have been significantly reduced since the installation of the system. 17% reported that pest and insect problems were reduced, and 83% reported that they were significantly reduced. The application of the digested slurry, the separation from other plants and the cultivation in the greenhouse as a protected space could be the main reasons for this observation.

In contrast, all farmers observed that after the installation of the 4-in-1 system there are much more plant diseases than before, and that they have to spray more products to prevent and control the diseases (mainly fungus diseases due to high humidity and temperature in the greenhouses). Thus control of the aeration (airflow) in the greenhouse may provide a solution to this problem.

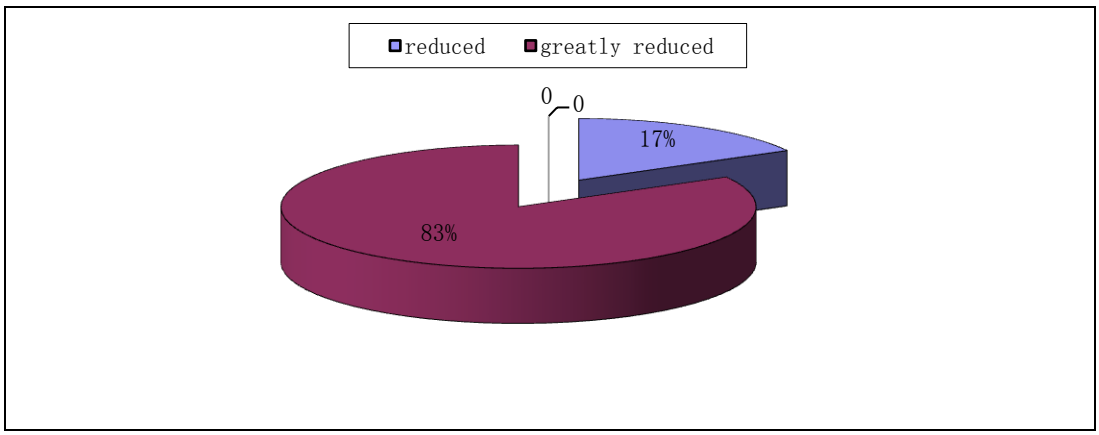

Figure 9: Impact of 4-in-1 biogas systems on pest and insect problems in Liaoning

7.3 Impacts on water and soil quality

Respondents reported that their 4-in-1 system contributes to improved soil quality. About 50% have noticed some level of improvement and about 50% indicated that improvements were substantial. Impacts on water quality were less evident, with 83%

reporting no remarkable effect, and 90% reporting that they use more water for stable cleaning than before operating a biogas digester. Rainwater is generally not used as adequate collection devices and storage facilities have not yet been constructed.

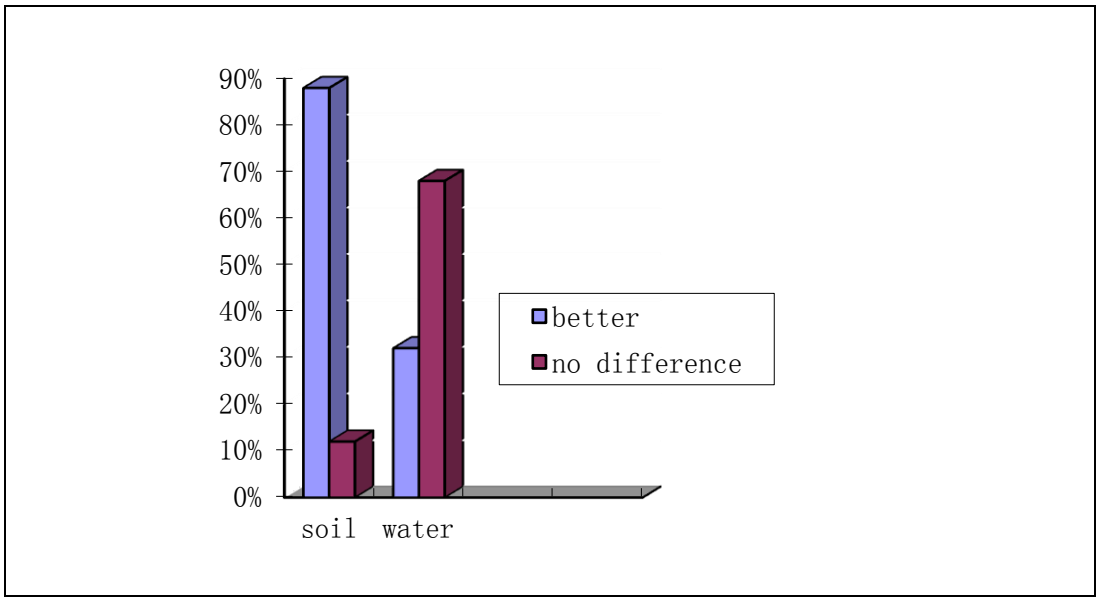

Figure 10: Perceived impacts of 4-in-1 biogas systems on soil and water quality in Liaoning

7.4 Health effects and living conditions

More than 50% of the interviewed farmer families experienced significant improvements in animal health. The same group mentioned that positive impacts on family health are true but less obvious. Overall, the family living environment seems to be greatly improved, especially in the kitchen where smoke and combustion residues are avoided due to the use of biogas. Pig manure and human excreta are directly fed into the digester, thus no longer exposed to the open air, producing smell and attracting flies.

However, during winter most of the households still have to use fire wood for heating the traditional bed (kang); and therefore some families are also cooking with fire wood in these months, thus smoke and residues still are very common. Outside the greenhouse, there are obviously less smell and flies, but in the greenhouse, close to the pigpen, and in most cases also close to the toilet, flies cannot be avoided. The living environment would be much better, if bed heating would not needed to be done with fire wood, and if the toilet could be separated from the pig pen, i.e. through outside greenhouse connection with an attached inlet pipe.

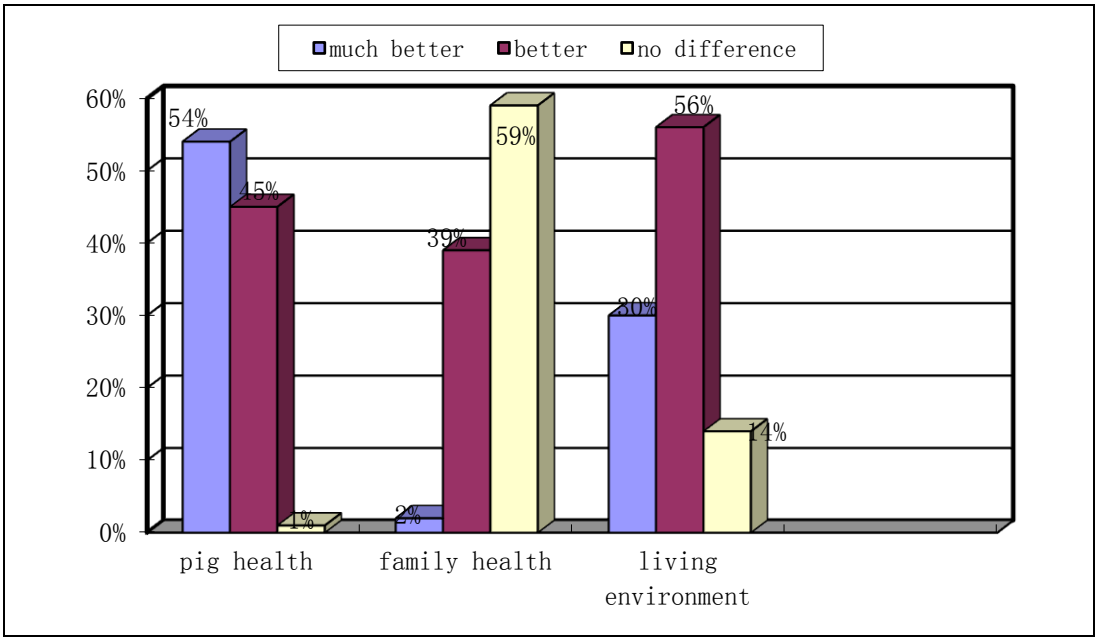

Figure 11: Perceived impacts of 4-in-1 biogas systems on environment and health in Liaoning

8. Technical Analysis

8.1 Greenhouse

Greenhouse cultures receive the digested slurry. At the time of our on-site visits, most of the greenhouses were openly used due to the season; some were completely emptied. The only greenhouse fully covered in operation was used for breeding mushrooms, which only needs slurry as inoculum. The biogas from this 4-in-1 system was used for cooking. The slurry was taken to farmland outside of the greenhouses or given to other farmers for fertilizer application.

The greenhouse for all the 4-in-1 systems is a uniform model: width is usually 7m while the optimal length is approximately 80m. In reality, the length may vary: some greenhouses count less than 50m while others measure more than 100m. Bute even expenditure for the construction of a greenhouse is high; in Shenyang, an average household could own 2 or 3 greenhouses, but often one of them is also used for living purpose. Therefore at least one greenhouse could not be used completely for production purposes. At the programme start, in order to encourage farmers to adopt 4-in-1 systems, there was no limitation of houses to be added to the greenhouse. During the following years of programme implementation, an increasing number of farmers enjoy this benefit. Even if nowadays the house area is less, they still like to use this system. In the beginning the area could be up to 70m^2, now the limit was set at 48m^2. In fact, besides the house next to greenhouse, farmers still maintain their

original village house. Nevertheless, farmers would like to live in the house besides the greenhouse to use biogas for cooking and to enjoy the comfort of a nearby toilet.

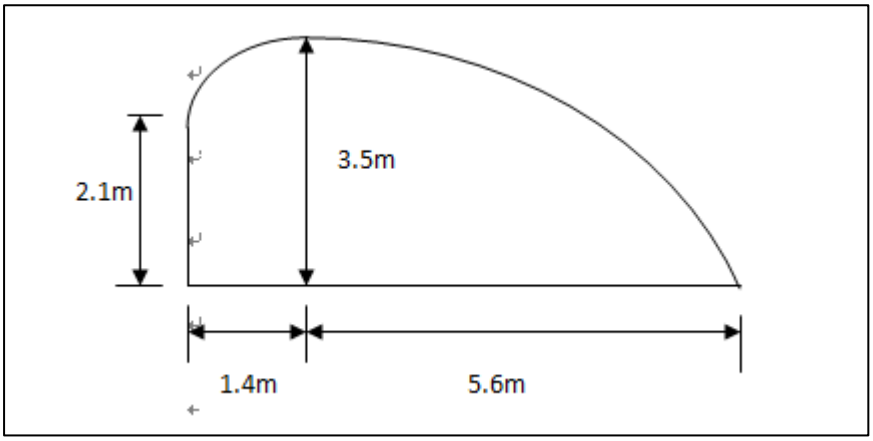

Figure 12: Dimensions of model greenhouse on top of a biogas digester in a 4-in-1 systems

Figure 13: Greenhouses in Liaoning province

8.2 Biogas digester

During the on-site visits most of the digesters functioned very well; owners confirmed that due to the greenhouse even in winter biogas production is satisfactory. When temperatures are high or the number of pigs is large, biogas production is too much, and farmers release biogas without any treatment or utilization.

8.3 Toilet

Three main types of toilets were installed: Step flush toilets and pour flush toilets with platforms were both found in Shenyang and Chaoyang, while slanted channel toilets were only found in Chaoyang. There are not enough data available to conclude which option in which place is the most popular. It has to be stressed that this study does not conclude that slanted channel toilets do not exist in Shenyang, considering that only 5 of the 15 sampled households were visited in Shenyang.

Table 15: Remarks on different toilet types in use in 4-in-1 systems

Toilet type	**Number of households using the toilet type** (out of 15)	**Observations**	**Picture** *(1.-Shenyang, 2.-Chaoyang)*
Step flush toilet:	4	The step flush toilet uses a step that serves as a pump that draws water out of a storage container placed near the toilet. This water then flushes the excreta into the toilet hole, which is pipe-connected to the biogas digester. Variations in the stepping technology could be found: some of the steps are mounted with a cylinder while others are not.	 
Pour flush toilet with platform:	6	The flushing mechanism of a pour flush toilet with platform is a less sophisticated version of a step flush toilet. Instead of stepping on a pump to flush the toilet, the user must manually pour water into the toilet via a bucket or plastic shovel. Excreta are flushed into the hole, which is pipe-connected to the biogas digester.	 
Slanted channel toilet:	5	A slanted channel toilet does not have a squatting platform; it provides a small narrow channel that leads directly to the biogas digester.	 *(Chaoyang)*

Some families - because the stepping mechanism of their step flush toilet broke and they could not fix it - now use the toilet as a pour flush toilet with platform. The recorded number of pour flush toilets with platforms includes these households.

In terms of smell, the slanted channel toilets tend to develop stronger smells than those with platform and syphon, both step flush and pour flush. This is probably caused by the temporarily open storage of solid and liquid excreta in the digester inlet pipe.

There has been some discussion within our working group about the location of the toilet relative to the pigpen. In order to prevent long pipes and pipe blockages, it is necessary to position the toilet close to the digester. In 4-in-1 biogas systems, the digester is placed under the pigpen for keeping the temperature within the dry soil packed digester at the required level, and for convenience to feed the digester when cleaning the stable. This leads to the fact that the toilet, too, has to be located close to the pigpen. However, in terms of the height of separating walls and final positioning of the toilet, a great variability could be observed in the households. The following pictures reveal these differences.

Figure 14: Different styles and locations of toilets (indicated by arrows)

This positioning leads to a number of hygienic concerns. Although the pigpens have been clean in the moment of our investigation, the potential disease transmission through flies attracted by pig waste has to be considered; especially children are very susceptible to this hazardous environment.

In addition, many households informed us that as soon as there is too much biogas produced but not used, the pressure pushes pig dung and human excreta back and through the toilet connection pipe or channel. Although this amount is not enough to overflow or spill out of the toilet, this waste push-up is very inconvenient (smell) and affects a hygienic use of the toilet. In terms of smell and cleaning the toilet given these conditions, the toilet may be easier to manage outside attached to the greenhouse. However, it is difficult to make any conclusions with such a small data set.

In summer, both pig house and latrine are totally open to air and rain, no toilet room roof has been found. When the toilet platforms have been installed, there was a water tank besides the squatting pan which supplied the water for flushing. Once the tank was stepped upon, the water came out. This is more or less similar to flushing toilet. However, as time goes by, most are out of action and once broken, nobody repair any more. Or in some area, these water tank was not installed at all when cost was taken into consideration. So on the site, most are flushed by manpower.

In spite of sanitation condition almost all interviewees reflected that animals' health and people's health conditions improved a lot compared with their situation before. If farmer families are more concerned with their toilet, they should be cleaner and more comfortable compared to the observed ones.

Before the "4 in 1"system was build, most of the families used a defecation hole as latrine, which was exposed to the street, dirty, smelly and without privacy. All of the respondents report that comparing with the former latrine; they prefer the "4in1". Not only because the faeces are used for biogas, but mainly for the improved privacy, the reduction of the diseases and the clean environment.

8.4 Insulation

Insulation of the greenhouse is very important for plant and biogas production. If during winter time temperatures drop too low (soil temperatures under 10^{o}C), biogas production will stop. However, if the greenhouse is heated up, even in winter sometimes the temperature is too high, and heat must be released.

Two main issues concerning the insulation are the characteristics of the north facing solar passive heated wall, and the material used for roof insulation. In general the greenhouse consists of different types of walls: (1) made by bricks (width is about 1.4m), (2) made by bricks with a foam layer inside (width is about 0.9m), (3) heated by a chimney. The north facing thick wall is of special importance for the temperature inside the greenhouse; however, it was difficult to exactly identify the different layers combined to set-up the wall of generally 3m width, since they are covered up and well protected. In Shenyang, a clayish cement material is used on the outside to cover the internal structure; information about this internal structure has not been disclosed by the farmers. In Chaoyang, holes in a greenhouse wall allowed for identification of the integrated material consisting of a mixture of bricks, thin plastic, Styrofoam, and old clothes. Some passive heat storage walls were well maintained on the inside of the greenhouse, while others looked worn down.

In terms of the insulation material for the roof, the use of straw, wood, Styrofoam and plastic sheets was noted. Many of the greenhouse roofs have been opened in the days of our on-site visits. When operated the roofs are covered with plastic sheets

and during night time with additional straw curtains. In some cases a motor on the top helps to roll up the straw curtain.

The following figures display materials used for the north facing walls and roof insulation.

North facing wall:

Shenyang *Chaoyang*

Chaoyang

Roof insulation:

Shenyang *Chaoyang*

Chaoyang

Figure 15: North facing wall and roof insulation

8.5 Biogas appliances

Many reports about 4-in-1 systems present household burners for cooking and biogas lamps for lighting as the two main biogas appliances. All of the sampled houses had one household burner for cooking, but only one sampled household had a biogas lamp in his living area, though broken and out of use. Biogas lamps inside of the greenhouse not only provide heating, but increase the levels of carbon dioxide inside the greenhouse, which promotes higher crop yields. Biogas lamps have only 3 - 5% light efficiency, but heating with 95 - 97% of the supplied biogas the surrounding area. Often these lamps are lacking in the greenhouses and this raises concerns about farmers' knowledge about biogas and the related training and support they receive.

As the main energy for cooking, biogas is welcomed by each family we interviewed. However, this biogas utilization is a single action choice in spite of its multi-purpose character, but almost all the interviewees made no use of biogas for other purposes. Some farmers acknowledged that they were informed about biogas lamps but they never used them. Other farmers once used a biogas lamp but they do not use it any

more mainly because the biogas production volume is limited, or because their biogas lamp was broken and nobody could repair it. Other farmers even have never heard about biogas lamps or any other biogas appliances. This clearly indicates that know-how on biogas use needs to be popularized further.

8.6 Pig pen

The pig pen is one of the key components of the 4-in-1 system, because the pig manure provides the majority of the digester input material. There is a hole in the pigpen that directly feeds to the digester, and the pig manure must be regularly swept into this hole. Even though most of the households had just seasonally sold their pigs, some still had some left. In one case, a pig was observed urinating in a corner of the pigpen where faeces were amounted. However, the digester input hole was on the opposite side of the pigpen. This observation raises issues of the correct slope of the floor of the pigpen, and how to improve it so that maintenance and cleaning are more convenient.

During our on-site investigation we encountered the situation that most households had just seasonally sold their pigs. We observed that the sanitation condition of pigpen corresponds more or less to the conditions of the latrine. As a matter of fact, farmers obviously don't pay much attention to breeding pigs, because compared with the income from the greenhouse production the income from pig breeding is neglectable. Therefore some 4-in-1 system farmers don't breed pigs, what they need is just manure as feedstock for the digester which they receive from other households for free.

Figure 16: Pigpens

8.7 Slurry

The slurry normally is pumped onto the farmland; according to interviewees the fertilizer effect of slurry is excellent. In some households, farmers only want to get slurry for fertilizer but neglect the biogas use, which seems to make slurry the most popular outcome of 4-in-1 systems.

Figure 17: Biogas system components

8.8 Desulfurizer

Another problem may be the desulfurizer because we even found that even there is a desulfurizer for H_2S removal, biogas is piped to the burner shortcutting without passing desulfurizer. One household reflected that the biogas volume is good but

biogas stove can't be ignited, the desulfurizer was blocked due to humidity and not being maintained every 30 days as requested.

8.8.1 Gas pipelines

Leakages in flexible gas pipelines are common problems in biogas systems. They can significantly lower gas pressure, greatly affecting its use. About one third of the sampled households reported experiences with gas leakage in the past, but they identified and repaired on their own. For prevention purposes, gas pipes should be installed in such a way that they are protected against potential damages.

Systems in Shenyang tended to be simpler in design. The kitchen and the room with the biogas digester were separated by just one wall. Due to this, the outside gas pipeline is short and leads straight to the kitchen. Piping systems in Chaoyang seem to be a bit more complicated. The biogas digester and the kitchen were separated by several rooms, so gas pipelines were found climbing and navigating through multiple rooms, sometimes with water-jackets hindering a constant gas flow. In terms of indoor pipelines, similar setups were found in both counties. The following photos show gas pipelines both outside and inside the house.

Shenyang: The red arrow points to where the gas pipe goes through the wall into the kitchen.
The yellow arrow points at the pigpen.

Chaoyang

Chaoyang

Figure 18: Outside gas pipelines

Shenyang: The biogas digester is on the other side of the wall.

Chaoyang

Chaoyang

Figure 19: Inside gas pipelines

It appears to the investigation team as if farmers only change the biogas pipelines when they are definitively broken or corroded, but they do no maintenance work and they don't care for the safe condition of the pipeline.

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Annex 1: Survey impressions

On site survey

Sampling

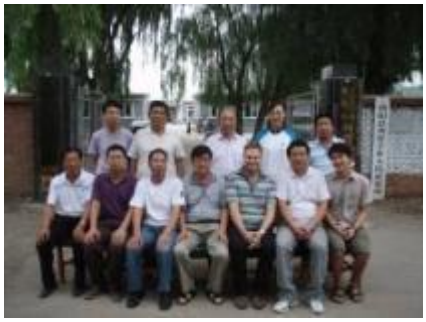
Indoor interview

4-in-1 under construction

Gasification stove

Solar house

Instruction for using biogas



Group photo with local officials

Personal Remarks from the Study Team: It is very interesting to make a field survey because we could find something new except for related topics. From our point of view, we are glad to see that renewable energy systems are well developed in rural area of North China. For

instance, most famers use solar house and solar water heater. Biomass gasification station can be seen in many places. They even use solar to heat the bed during winter time. The living conditions are getting better and better. The scale of greenhouse in Shenyang is obvious larger than Chaoyang, so income is more. We think a market of standardization is needed to instruct farmers. For instance, farmers had better not to sell products by themselves. Instead, agents should help them to build unified marketing channels. Besides, more funds should be on loan to farmers by commercial banks for a period.

Through all the cycle of material and energy, we can see that the system of 4 in 1biogas improve the revenue of farmers, reduce the pollution of the air, reduce greenhouse gases. The system also improves the progress of ecological agriculture and reduces the waste of energy. But it also has some problems, in Liaoning lots of farmers lack the knowledge of biogas system, and it lacks unity management. Also its sanitation system is not so good.

This study analysed the technical components of these 4in1 biogas systems. There was not enough data collected to be able to make specific technical recommendations. The nature of these systems is that they attempt to address multiple needs of the farmers: agricultural benefits, sanitation, household heating, and overall income generation. Given that these farmers have a limited income, there is an inherent give and take of what farmers are willing to spend time on and what they are not. This results in the variability of systems that have been observed. If this is the case, there must be a strong, accessible technical support system for the farmers, or they will not be able to effectively and efficiently manage their systems.

From the sanitation perspective, as stated before, more in depth investigations are needed in order to make specific conclusions about the systems. The study found that the toilets are in use. However, there is still a lot of potential for ensuring that the sanitation option is comfortable and accessible to both the young and the old. Health, a potential indicator of sanitation, can also be used to add another perspective on the system. Finally, water management and usage can also be analysed to understand the different sanitation options that are available. Sanitation encompasses many different fields; it must be analysed in this way.

Annex 2: Household-scaled biogas & integrated farming system (http://wenku.baidu.com/view/45a85868011ca300a6c3909f.html)

Agricultural standard: Household-scaled biogas& integrated farming system-specification on design, construction and use for northern model (NY/T 466-2001)