



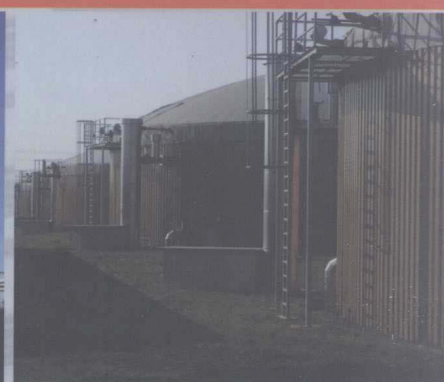
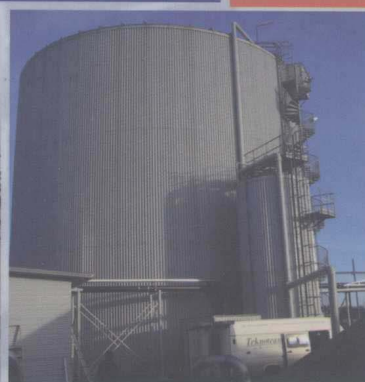
# 沼气工程与技术

## Biogas Engineering and Application

Volume 1

董仁杰 [奥]伯恩哈特·蓝宁阁 主编

Edited by: Prof. Dr. DONG Renjie  
Prof. Dr. Bernhard Raninger



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## PREFACE

China has a long tradition in using biogas in rural areas. Nowadays globally relevant topics, such as environmental pollution from the industrialization in the agricultural area, rapid urbanization through migration and climate change, are top issues on the international political agenda, and therefore also on the agenda of the Chinese Government. Large scale biogas technology is, in this context getting increasingly important as it is an instrument to tackle targets of circular economy, environmental protection, greenhouse gas emission reduction and renewable energy development within an emerging low carbon society.

Based on these drivers China has started within the recent years to set up middle-, large-and even mega-large biogas plants. Billions of RMB have been spent by the government to subsidize a first generation of middle and large scale biogas plants, which were mainly developed by up scaling traditional technologies with limited performance.

According to the “MOA National Agricultural Biomass Energy Industry Development Plan (2007-2015)”, the policy target for developing middle and large scale biogas plants (MLBGPs) at large scale livestock and poultry farms is 8 000 with an annual biogas production of 670 million m<sup>3</sup> by 2015. The “NDRC Medium and Long Term Program of Renewable Energy Development Plan (2006-2020)” anticipates 10 000 MLBGPs at animal husbandries and another 6 000 MLBGPs processing industrial organic wastewater with an overall annual biogas yield of 14 billion m<sup>3</sup> and an installed electricity generation capacity of 3 GW by 2020 as part of the 15% Renewable Energy target in 2020 (Renewable Energy Law, 2006). The enforcement of those policies is part of the 12<sup>th</sup> Five-Years Plan, but the biogas plant activities planned by the individual provinces are even going far beyond the national targets.

Novel business concepts are required and new technological solutions are emerging, such as multi-feedstock co-digestion at centralized biogas plants, using additional feedstock from straw, biomass grown on marginal and reclaimable land, biomass waste from urban sources. In terms of biogas use: the replacement of petroleum based fuels (CNG, LNG) by biogas as compressed bio-methane for vehicle operation, efficiently generated grid connected biogas power with high availability, biogas projects applied in climatically cold areas in China, viable biogas operation under carbon credit conditions, and so on. All that innovative approaches and objectives have to be seen as new challenges for the biogas technology industry development

and have to be joint by setting up a professional and academic training and education system for biogas experts, more research and development and the demonstration of the application of new technologies adapted to the Chinese conditions.

Related international technical cooperation is established to share the experience from developed countries with China and China spreads in contrary its own experience to other developing countries, in order to help them to meet their renewable energy development targets in the context of common global low carbon society development. The ‘giz’ (Gesellschaft fuer Internationale Zusammenarbeit, Deutschland) supports with its Sino-German Biomass Utilization Project the publication of this book series issued by China Agriculture University, *Biogas Engineering and Application*. This publication shall be a viable platform for scientific and applied biogas technology articles for biogas experts involved in technological and political project development, project implementation and operation. *Biogas Engineering and Application* should be an important information source not only China-wide, it should be as well a source and platform for the international biogas society interested in biogas in China.

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Beijing, January 2011

## 前 言

中国农村使用沼气有着悠久的历史。目前,全球普遍存在的农村工业化所造成的环境污染以及城市化进程加速带来的人口流动和气候变化等,已经成为国际政治热点,同时也提上了中国政府的议事日程。在这样的环境下,大型沼气工程技术就变得越来越重要,因为它有助于在未来低碳社会中实现循环经济、环境保护、减排温室气体和生产可再生能源等目标。

在上述因素的驱动下,中国近年来开始建设大中型甚至超大型沼气工程。中国政府为第一代大中型沼气工程项目补贴了数十亿元资金,但是当时的大中型沼气工程技术大多来源于传统沼气池的放大,沼气的性能有限。

根据农业部《农业生物质能产业发展规划(2007—2015年)》所提出的战略目标,到2015年,建成规模化养殖场、养殖小区沼气工程8000处,年产沼气 $6.7 \times 10^8 \text{ m}^3$ ;国家发展和改革委员会发布的《可再生能源中长期发展规划》提出,到2020年,建成大型畜禽养殖场沼气工程10000座、工业有机废水沼气工程6000座,年产沼气约 $1.4 \times 10^{10} \text{ m}^3$ ,沼气发电装机容量达到 $3 \times 10^6 \text{ kW}$ ,为到2020年使可再生能源消费量达到一次能源消费总量的15%(可再生能源法,2006)做出贡献。“十二五”规划中上述政策得到进一步强化,而且各省沼气工程建设任务将远超过国家的总体目标。

沼气工程发展的新商业模式和新技术不断涌现,例如集中沼气工程上的多原料联合发酵,就使用秸秆、边际土地的能源作物和城市有机废弃物作为沼气的原料。在沼气的利用方面,则有用压缩沼气源甲烷作为车用燃料代替化石能源(压缩天然气和液化天然气),在可行的地方实施沼气高效发电并网,在中国寒冷地区实施建设沼气工程,碳交易机制支持下的沼气工程建设等。上述各种创新的模式和技术都是沼气工程发展的机遇和面临的挑战,必须通过对沼气工程技术人员的培训、更多的研究、以及适合中国国情的沼气的开发和示范,实现沼气工程创新模式和技术的整合。

中国与发达国家之间已经建立了相关国际合作机制;中国也同时向其他发展中国家派遣自己的专家,帮助他们实现可再生能源的目标,以推动全球低碳社会的进程。德国国际合作机构(Gesellschaft fuer Internationale Zusammenarbeit, Deutschland—giz)的中德生物质能优化利用项目支持由中国农业大学出版社出版的本系列书籍《沼气工程与技术》。该出版物将成为沼气工程技术、政策、建设和运行等各个方面专家的科研和应用论文交流的平台,供沼气专家与学者交流讨论。《沼气工程与技术》不仅是中国国内沼气行业的重要信息来源,也是关注中国沼气发展的国际同行的信息资源平台。

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TABLE OF CONTENT

PREFACE

1. BIOMASS RESOURCES ASSESSMENT

DEVELOPMENT OF OPTIMIZATION MODEL AND CASE STUDY FOR BIOMASS  
ENERGY SYSTEM IN JAPAN ..... 1  
GAO Weijun, REN Hongbo, LI Haifeng, Yutaka Tonooka  
ENERGY EXPLOITATION FROM BIOMASS WITH THE-E-M-D-SYSTEM ..... 10  
Y. Liu, W. Bidlingmaier  
CREATING REGIONAL ADDED VALUE BY COMPARING AND UTILIZING  
DIFFERENT BIOENERGY OPTIONS FROM REGIONAL BIOENERGY RESOURCES ..... 21  
Dunja Hoffmann  
THE RRU-BMW PROJECT-FOUR YEARS PILOT TESTS ON BMW SOURCE  
SEPARATION IN SHENYANG, CHINA ..... 35  
Bernhard Raninger, YANG Guangzhong, LI Rundong, FENG Lei  
BIOGAS POTENTIAL OF SEWAGE SCREENINGS USING MESOPHILIC ANAEROBIC  
DIGESTION ..... 44  
L. S. Cadavid, N. J. Horan  
ASSESSMENT OF ENERGY POTENTIAL AND DISTRIBUTION OF ANIMAL MANURE  
RESOURCE IN CHINA ..... 54  
GENG Wei, CHEN Xiaoyu, CUI Jianyu, ZHANG Beibei, BU Meidong, HU Lin  
ASSESSMENT OF METHANE PRODUCTION POTENTIAL BY INDUSTRIAL  
ORGANIC WASTEWATER IN CHINA ..... 61  
BU Meidong, ZHANG Beibei, CUI Jianyu, PANG Changle, CHEN Xiaoyu, GENG Wei, Wu Li, HU Lin

2. ANAEROBIC DIGESTION PROCESS RESEARCH

EFFECT OF WATER FLUSHING ON THE ACIDIFICATION PROCESS IN  
ANAEROBIC DIGESTION OF SWINE MANURE ..... 67  
GUO Jianbin, CAO Wei, DONG Renjie  
EFFECT OF HRT ON THERMOPHILIC DRY ANAEROBIC DIGESTION OF RESIDUAL  
MSW AT SEMI-INDUSTRIAL SCALE ..... 75  
M. Carrere, H. Olczyk, F. Lebrisse, O. Lemaire, J. A. Cacho Rivero  
EFFECTS OF TEMPERATURE, INOCULUM AND MOISTURE CONTENT ON  
ANAEROBIC DIGESTION OF FOOD WASTE ..... 85  
Y. C. WANG, Q. X. YUAN, W. Q. ZHANG

SPECIFIC TRACE ELEMENT DEMAND IN THE ANAEROBIC DIGESTION OF BIOMASS AND SOLID WASTES .....	95
H. Lindorfer, Th. Fritz, D. Banemann, M. Nelles	
EFFECT OF COMPOST PRE-TREATMENT ON BIOGAS PRODUCTION FROM RICE STRAW .....	103
GAO Bairu, CHANG Zhizhou, YE Xiaomei, DU Jing	
SILAGES AS FEEDSTOCK FOR BIOGAS: NOVEL PERSPECTIVES FOR SILAGE ADDITIVES .....	111
D. Banemann, H. Lindorfer, T. Fritz, M. Nelles	
ENHANCEMENT OF BIOGAS PRODUCTION USING ADDITIVES IN CHINA: A REVIEW .....	118
CHENG Huicai, DONG Renjie, HUO Shuhao, JIN Mingjun, ZHANG Wanqin, PANG Changle	
PROCESS OF ANAEROBIC DIGESTION OF VEGETABLE WASTE .....	132
ZHANG Wanqin, HUO Shuhao, CHENG Huicai, DONG Renjie, PANG Changle	
<b>3. CO-FERMENTATION</b>	
CO-DIGESTION OF ANIMAL MANURE AND SOURCE SEPARATED BIOORGANIC MUNICIPAL WASTE FROM SHENYANG, CHINA .....	141
FENG Lei, Bernhard Raninger, LI Rundong, LI Yanji , YANG Guangzhong	
ANAEROBIC CO-DIGESTION OF LIGNOCELLULOSE AND LIVESTOCK MANURE TO PRODUCE BIOGAS .....	148
CHEN Guangyin, ZHENG Zheng	
UTILIZATION OF FRUIT WASTE AS CO-SUBSTRATE FOR PIG MANURE ANAEROBIC CO-DIGESTION—THE COD : N : P BALANCE .....	156
L. M. Ferreira, E. A. Duarte, D. Figueiredo	
EFFECTS OF WATER HYACINTH ON BIOGAS PRODUCTION CHARACTERISTICS IN CATTLE MANURE BY ANAEROBIC FERMENTATION .....	164
ZHANG Luo, HAO Minjie, GAO Hongli, ZHOU Wenzong, ZHUANG Songlin	
THE BIOGAS PRODUCTION EFFICIENCY OF ANAEROBIC FERMENTATION OF DIFFERENT DUNG AND STRAWS .....	170
CHU Lili, YANG Gaihe, LI Yibing, REN Guangxin, FENG Yongzhong	
STUDY ON MESOPHILIC ANAEROBIC CO-DIGESTION WITH MANURE, SLUDGE AND RURAL ORGANIC WASTE .....	179
ZHAO jun, LANG Xianming, LIU Yiwei, KE Xin	
<b>4. ANAEROBIC DIGESTION PROCESS TECHNOLOGY</b>	
BIOGAS STANDARDIZATION CONSTRUCTION AND DEVELOPMENT IN CHINA .....	185
LIU Geng	



FOSTERING GOOD BIOGAS PRACTICE BY THE PUBLIC ADMINISTRATION IN STYRIA (AUSTRIA) .....	190
I. Winter, W. Himmel	
ADVANCES IN EARLY-WARNING INDICATORS OF PROCESS IMBALANCE IN ANAEROBIC DIGESTERS .....	200
JIA Chuanxing, PENG Xuya, HUANG Yuanyuan, LI Xiaofeng	
CHANCES IN CLOSED-LOOP PROCESS CONTROL OF THE ANAEROBIC DIGESTION OF BIOMASS .....	211
S. Weinrich, M. Nelles C. Wahmkow	
BIOENERGY CONCEPTS IN THE RURAL AREA-DECENTRALIZED ENERGY SUPPLY AS AN OPPORTUNITY FOR REGIONAL ADDED VALUE .....	213
A. Schüch, M. Nelles	
AN ASSESSMENT OF THE AVAILABILITY OF HOUSEHOLD BIOGAS RESOURCES IN RURAL CHINA .....	223
CHEN Yu, YANG Gaihe, FENG Yongzhong, REN Guangxin, LI Yibing	
ON-LINE MONITORING AND CONTROL SYSTEM FOR TWO-PHASE ANAEROBIC DIGESTION .....	232
LI Qiuyan, PANG Changle	
SURVEY AND ANALYSIS ON LARGE AND MEDIUM SIZE BIOGAS PLANTS IN HILLY MUNICIPALITY .....	238
TANG Xuemeng, CHEN Li, DONG Renjie, PANG Changle	
SURVEY REPORT ON LARGE AND MEDIUM BIOGAS PROJECT INDUSTRY RESEARCH ...	244
LIN Nina, CHEN Li, PANG Changle, DONG Renjie	
DESIGN OF CHINA BIOGAS PLANTS GEOGRAPHIC INFORMATION SYSTEM BASED ON WEBGIS .....	251
TANG Xuemeng, CHEN Li, DONG Renjie	
<b>5. CLIMATE RELEVANT BIOGAS EMISSIONS</b>	
CURRENT PROBLEMS AND METHODS OF RESOLUTION ON COLLECTION AND UTILIZATION OF LANDFILL GAS IN GERMANY .....	256
S. Licht, M. Nelles	
WHY CHINESE MSW LANDFILLS DO NOT GENERATE THE EXPECTED AMOUNT OF CERTIFIED EMISSION REDUCTION (CERS) .....	265
CHEN Xiaoyan, Bernhard Raninger, FENG Lei, LI Rundong	
A COMPARISON OF STABILIZATION PROCESS IN THE LANDFILLS OF REFUSE AND MODIFIED SEWAGE SLUDGE .....	277
ZHAO Youcai, JIANG Jiachao, ZHEN Guangyin, HAN Dan, LOU Ziyang, ZHANG Hua, ZHU Ying	

MODIFIED METHANE OXIDATION MATERIAL BASED ON AGED REFUSE AS BIO-COVER  
IN REFUSE LANDFILL ..... 287  
HAN Dan, WANG Li, ZHAO Youcai, HE Yan, CHAI Xiaoli

6. DIGESTATE APPLICATION

THE STUDY OF THE EFFECT OF BIOGAS DIGESTATES ON PLANT STRESS-TOLERANCE  
..... 301  
HOU Bao chao, WEI Quanyuan, PANG Changle, WANG Renping, LI Xiaoping, GONG Hui, GUO Jianbin, DONG Renjie

FERTILIZER VALUE OF RECOVERED NUTRIENTS AND ORGANIC MATTER FROM  
ORGANIC WASTE ..... 307  
J. Clemens, U. Arnold, S. Antonini, J. Simons, S. Siebert, B. Kehres

MONITORING AND REDUCTION OF METHANE EMISSIONS FROM BIOGAS PLANTS ..... 318  
C. Cuhls, J. Clemens, XU Pan, GUO Jianbin, DONG Renjie

EFFECT OF ORGANIC NUTRITION BIOGAS SLURRY ON PHYSIOLOGICAL RESISTANCE  
OF CROPS ..... 323  
REN Yang

# 目 录

## 前言

### 1. 生物质资源评估

日本生物质能系统优化模型案例分析 .....	1
基于 E-M-D 系统的生物质能利用 .....	10
不同地区生物质附加值的比较与分析 .....	21
RRU-BMW 项目:4 年沈阳市生物垃圾源头分类中试试验 .....	35
剩余污泥中温沼气发酵潜力研究 .....	44
中国畜禽粪便资源能源分布及潜力评估 .....	54
我国工业有机废水产甲烷资源潜力评估 .....	61

### 2. 厌氧发酵过程研究

水冲洗对厌氧酸化过程的影响 .....	67
水力停留时间对半规模化城市固体废弃物厌氧干发酵的影响 .....	75
温度、接种物与湿度对食品废弃物厌氧发酵的影响 .....	85
生物质与固体废弃物厌氧发酵特定微量元素需求 .....	95
堆肥预处理对秸秆生物产气量的影响 .....	103
沼气青贮原料:青贮添加的新展望 .....	111
国内沼气发酵添加剂研究进展 .....	118
蔬菜废弃物厌氧消化工艺研究进展 .....	132

### 3. 联合发酵

中国沈阳动物粪便与源头分类有机生物垃圾的联合发酵 .....	141
木质纤维原料与畜禽粪便混合厌氧消化的研究 .....	148
水果废弃物与猪粪的联合发酵:COD:N:P 平衡 .....	156
添加水葫芦对牛粪厌氧产沼气的影响 .....	164
不同种类粪便与秸秆的沼气生产效率 .....	170
畜禽粪便、污泥、农村垃圾联合中温厌氧消化技术研究 .....	179

### 4. 厌氧发酵工艺

中国沼气标准化建设与发展 .....	185
STYRIA 公共管理系统的先进沼气生产经验 .....	190
厌氧反应器发酵过程失稳早期预警指标研究进展 .....	200
生物质厌氧发酵闭合过程控制 .....	211
农村地区生物能源概念:分散能源供应作为区域增加值增长契机 .....	213

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中国农村户用沼气池利用率评价.....	223
两相厌氧发酵系统的在线监测与控制系统.....	232
山区城市大中型沼气工程的调研与分析.....	238
大中型沼气工程产业化研究调研报告.....	244
基于 WebGIS 的中国沼气工程地理信息系统的设计 .....	251
 <b>5. 沼气的温室气体排放</b>	
德国垃圾填埋气收集与利用过程的问题与解决方案.....	256
为什么中国城市固体垃圾填埋场没有达到预期 CERS 数量 .....	265
垃圾填埋与改性城市污泥稳定化工艺比较.....	277
垃圾填埋场生物覆盖材料:基于改良老化废物的甲烷氧化材料 .....	287
 <b>6. 沼液、沼渣利用</b>	
沼液对提高作物抗害促生能力的研究.....	301
有机废物中提取的养分与有机物质的肥料价值.....	307
沼气工程甲烷气体泄漏的监测.....	318
有机沼液营养液对作物生理抗性的影响.....	323

# DEVELOPMENT OF OPTIMIZATION MODEL AND CASE STUDY FOR BIOMASS ENERGY SYSTEM IN JAPAN

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## EXECUTIVE SUMMARY

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To decrease global warming caused by increasing concentrations of CO<sub>2</sub> from burning fossil fuels, and to develop alternative energy sources, it has become desirable to construct alternative, renewable energy systems. Potential alternative energy sources include solar cells, wind turbines, biomass, etc. Among these, biomass is considered to be the most promising. For example, the current global energy consumption is estimated to be 8 000 MTOE (million tons of oil equivalent) per annum and will increase to as high as 15 000 MTOE by the year 2050. And it is estimated that by the year 2050 annual energy supply by biomass will amount to 4 400 MTOE. This comparison indicates that, in the future, biomass is expected to significantly contribute to the global energy supply. Industrial, agricultural livestock and forest residues can be used as a biomass energy source, or energy crops such as trees and sugarcane can be grown specifically for conversion to energy. Methods for utilizing biomass include direct burning, gasification, and liquefaction.

In Japan, biomass has been a relatively small portion of the overall energy budget, supplying about 1% of the total primary energy consumed in 2004. The Japanese government has tried to promote biomass energy use in an effort to solve global warming. For instance, The Ministry of Agriculture, Forestry and Fisheries (MAFF) has predicted biomass energy use of 110.5-210.1 PJ in the future energy demand and supply plan in 2010.

According to previous research, although having an obvious environmental benefit, the biomass energy system is not attractive from the view point of economy. However, it is believed that as the development of biomass fuel conversion technologies and the improvement of other aspects, the biomass energy system will become competitive with the conventional energy system in the future.

In this paper, a linear programming model is developed. The objective is to minimize annual cost of an energy system equipped with a biomass combined heat and power plant, combining with a back-up boiler. The model reports the optimal biomass system capacities that customers could employ given their energy requirements. As an illustrative example, using this model, an investigation is conducted of the introduction feasibility of the biomass energy system for the science and research park in Kitakyushu, Japan. According to the results, currently, although having a good environmental merit, it is not a good choice to introduce biomass energy system from the economic point of view.

**Key words:** Design; Evaluation; Biomass system; optimization; Economic effect; Environmental effect

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## 1 Introduction

To decrease global warming caused by increasing concentrations of atmospheric carbon dioxide (CO<sub>2</sub>) from

burning fossil fuels, and to develop alternative energy sources, it has become desirable to construct alternative, renewable energy systems. Potential alternative energy sources include solar cells, wind turbines, and biomass. Among these, biomass is considered to be the most promising. For example, the current global energy consumption is estimated to be 8 000 MTOE (million tons of oil equivalent) per annum. The energy consumption will increase to higher than 15 000 MTOE by the year 2050. And it is estimated that by the year 2020 the annual energy supply by biomass will amount to 1 600 MTOE and by the year 2050 to 4 400 MTOE. This comparison indicates that, in the future, biomass is expected to significantly contribute to the global energy supply. Industrial, agricultural livestock and forest residues can be used as a biomass energy source, or energy crops such as trees and sugarcane can be grown specifically for conversion to energy. Methods for utilizing biomass include direct burning, gasification, and liquefaction<sup>[1-2]</sup>.

In Japan, biomass has been a relatively small portion of the overall energy budget, supplying about 1% of the total primary energy consumed in 2004. The Japanese government has tried to promote biomass energy use in an effort to solve global warming. For instance, The Ministry of Agriculture, Forestry and Fisheries (MAFF) also predicts biomass energy use of 110.5-210.1 PJ in the future energy demand and supply plan in 2010<sup>[3]</sup>.

In this study, a linear programming model is developed, using a commercial software package LINGO<sup>[4]</sup>. The model evaluates the introduction feasibility of a biomass energy system in a specific district. It takes the customer's selections (e. g. system capacity, etc.), combines them with pre-collected data (electric rate schedules, carbon tax rate, government economic incentives, electric and thermal load profiles, and biomass energy system performance) and analyzes the information using time series analysis. Finally, overall evaluation results regarding economic, energetic and environmental effects can be obtained, according to the simulation for various scenarios.

As an illustrative example, using this model, an investigation is conducted of the introduction feasibility of the biomass energy system for the science and research park in Kitakyushu (KSRP), Japan. In addition, corresponding economic, environmental and energetic effects are determined.

## **2 Evaluation model of biomass energy system**

### **2.1 Description of the evaluation model**

In order to adopt the biomass energy system effectively, it is necessary to take into consideration various aspects including local conditions, energy demands, as well as technical and market information. As shown in *Figure 1*, firstly, the electricity and heat demands of the customer, regional energy tariffs (electricity and city gas), and the biomass energy utilization technologies should be investigated. Then the model is executed and the optimal results are reported. The objective of the model is to minimize annual total cost including investment cost and running cost. In addition, by analyzing the installed capacity, energy prices as well as supply share while considering the balance between supply and demand of energy resources, the operational characteristics of the integrated energy system are evaluated. The calculation is taken hour by hour in a total year (8 760 hours).

Furthermore, by fixing the installed capacity or the running schedules of an existed energy system, the economic, environmental and energetic effects of the biomass energy system can be evaluated through the execution of the model. In this study, the linear analytical model is constructed by using the optimization tool LINGO according to the objective function and various constraints.

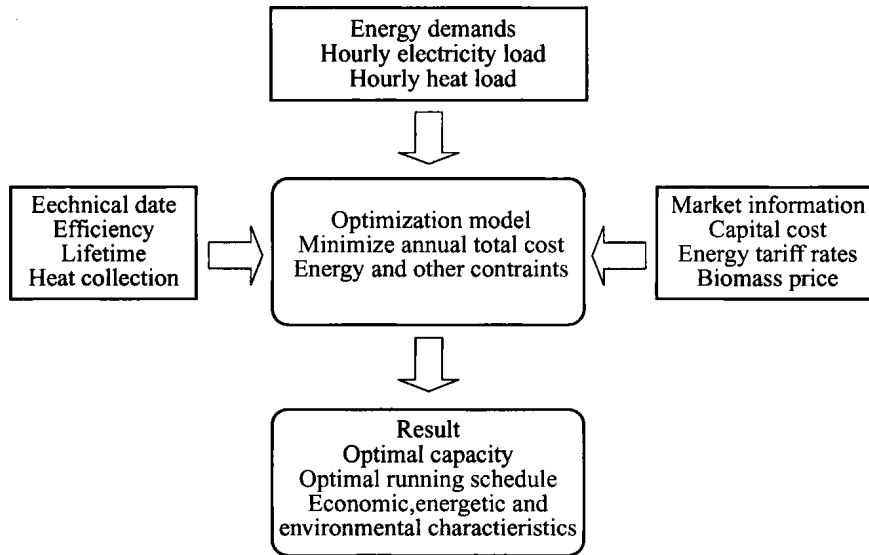


Figure 1 Flow chart of the model

## 2.2 Objective function and main constraints

The objective function of the biomass application process is to minimize annual total cost for the local customer, taking into account of the costs of the decision. Specifically, system investment cost  $C_{Inv}$ , running and maintenance cost  $C_{OM}$ , biomass fuel cost  $C_{Bio}$ , as well as natural gas cost  $C_{Gas}$  and grid electricity cost  $C_{Elec}$ . Thus, the overall objective to be minimized is;

$$\text{Min} \quad C_{total} = C_{Elec} + C_{Bio} + C_{Gas} + C_{Inv} + C_{OM} \quad (1)$$

Annualized investment cost is shown in Eq. (2).

$$C_{Inv} = Fmaxp \cdot FCost \cdot YF \quad (2)$$

$Fmaxp$  is the capacity of biomass equipments,  $FCost$  is the capital cost of the equipment, and  $YF$  is annualized coefficient.

The O&M cost is composed of fixed and variable cost, as illustrated in Eq. (3).

$$C_{OM} = \sum_m \sum_d \sum_h \sum_u EGen_{m,d,h,u} \cdot FOMv + Fmaxp \cdot FOMf \quad (3)$$

$EGen$  is the electricity generation from the biomass system,  $FOMv$  and  $FOMf$  are the unit cost coefficient for variable and fixed O&M costs, respectively.  $m$ ,  $d$ ,  $h$  and  $u$  are month, day, hour, and end-user, respectively.

The biogas fuel cost is calculated by multiplying total biogas consumption and the fuel price, as shown in Eq. (4)

$$C_{Bio} = \sum_m \sum_d \sum_h \sum_u PBio_{m,d,h,u} \cdot BPrice \quad (4)$$

here,  $PBio$  is the biomass consumption,  $BPrice$  is the price for biomass fuel.

The gas cost is composed of natural gas base service fee  $GBase$  and volumetric charge, as shown in Eq. (5).

The volumetric charge is calculated with cumulative gas consumption  $PGas$  for backup boiler use multiplied by the tariff rate  $GPrice$ .

$$C_{Gas} = \sum_m GBase_i + \sum_m \sum_d \sum_h \sum_u PGas_{m,d,h,u} \cdot GPrice_m \quad (5)$$

The electricity purchase cost is described by Eq. (6).

$$C_{Elec} = \sum_m EBase + \sum_m \sum_d \sum_h \sum_u PElec_{m,d,h,u} \cdot EPrice_{m,d,h} \quad (6)$$

$EBase$  is the base charge for electricity purchase,  $PElec$  is the amount of electricity purchase,  $EPrice$  is the

electricity tariff rate.

A balance of supply and demand has to be achieved for both heat and electric power at each point in time, as shown in Eq. (7).

$$\begin{aligned} Load_{m,d,h,u} = & EGen_{m,d,h,u} + PElec_{m,d,h,u} + \mu \cdot PGas_{m,d,h,u} \\ & + \gamma_u \cdot RHeat_{i,m,d,h,u} \quad \forall m,d,h,u \end{aligned} \quad (7)$$

$RHeat$  is the amount of recovered heat from on-site power generation.  $\mu$  and  $\gamma$  are the efficiencies for direct gas use and recovered heat, respectively.

Another key performance constraint is that the biomass plant must operate below maximum operating capacity of the units, as illustrated in Eq. (8).

$$\sum_u EGen_{m,d,h,u} \leq Fmaxp \quad \forall m,d,h \quad (8)$$

Constraint is also set to how much heat can be recovered from the biomass CHP plant, as described in Eq. (9).

$$\sum_u RHeat_{m,d,h,u} \leq \alpha \cdot \sum_u EGen_{m,d,h,u} \quad \forall m,d,h \quad (9)$$

$\alpha$  is the heat to power ratio of the CHP plant.

### 3 Illustrative example

#### 3.1 Research object

In this study, the residential area in KSRP, Japan is selected for a case study by considering a biomass energy system. Figure 2 is the project plan and shows the area comprising 19 Detached Houses (DH), 16 Terrace Houses (TH) and 34 Apartments (APT), whose total floor areas are 2 626 m<sup>2</sup>, 1 075.2 m<sup>2</sup> and 2 740 m<sup>2</sup>, respectively<sup>[5]</sup>.

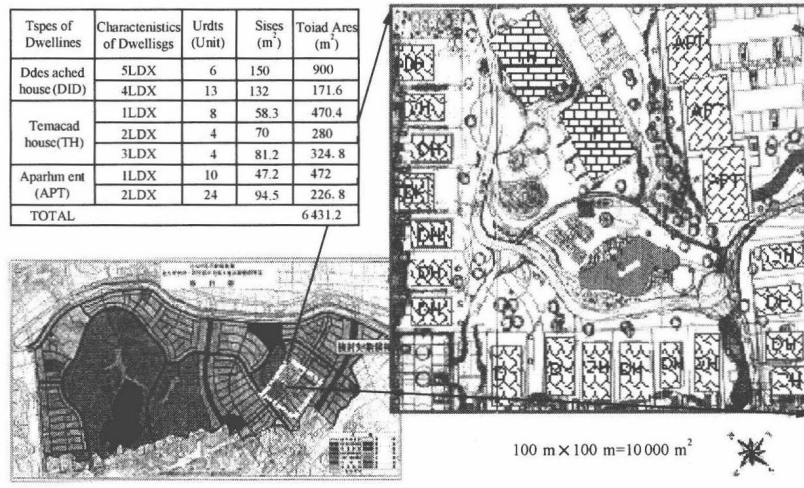


Figure 2 Outline of the housing complex development

#### 3.2 Load assessment

According to the energy consumption unit data in Kyushu, it is possible to assess the unit load per square meter for heating, cooling, hot water and electricity for different months for various types building<sup>[6]</sup>. Figure 3 illustrates the mean value of electricity and thermal loads in winter and summer. From the data, it can be concluded that: on one hand, peak loads for thermal demand for various dwellings in winter is about 3 times that in summer; on the other hand, the electricity load for various dwellings in winter is approximately the same as in summer.



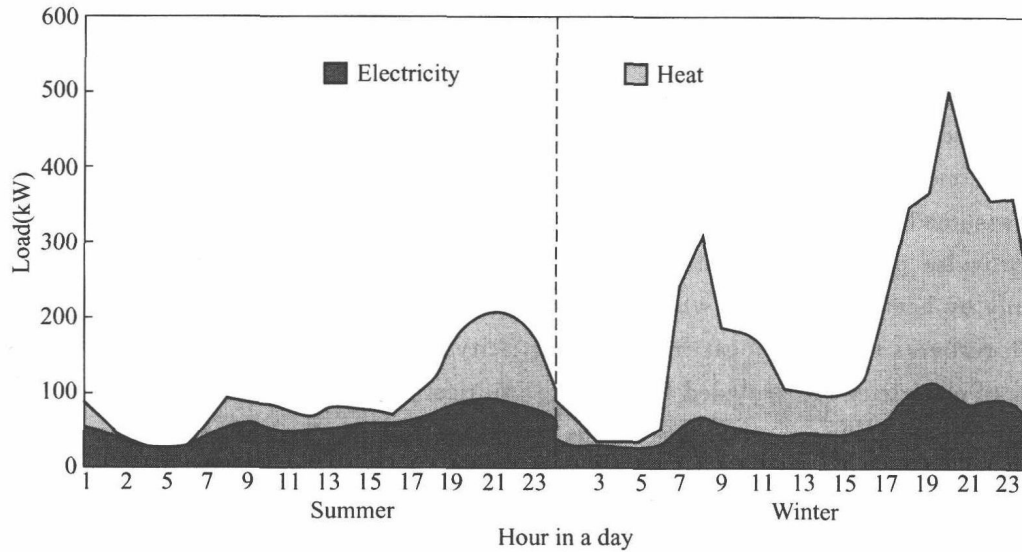


Figure 3 Electricity and thermal demands

### 3.3 Market information

In the paper, a time of use electricity tariff for residential buildings is employed, as shown in Table 1. Besides the basic charge, different rates are set for peak-time, day-time and night-time, respectively<sup>[7]</sup>. The gas tariff is composed of basic charge and flow charge, which are 1 501.50 Yen/month and 196.76 Yen/m<sup>3</sup>, respectively<sup>[8]</sup>.

In this study, a biomass gas engine CHP system is assumed for adoption. Various characteristics about the equipment are assumed according to previous study, as shown in Table 2<sup>[9-11]</sup>. The parameters of grid electricity and city gas are determined according to the investigation of local companies<sup>[7-8]</sup>.

Table 1 Electricity tariff

Season	Load period	Base Charge (Yen)	Energy charge(Yen/kWh)
Summer	on-peak	1 155	32.01
	mid-peak		20.13
	off-peak		7.19
Winter	on-peak		26.70
	mid-peak		20.13
	off-peak		7.19

Table 2 Other parameters

Item		Value
Electric Utility	Efficiency (%)	38
	Carbon intensity (kg/kWh)	0.375
City gas	Carbon intensity (kg/kWh)	0.18
	Electricity efficiency (%)	32
Biomass CHP system	Heat efficiency (%)	52
	Capital cost (10 <sup>4</sup> Yen/kW)	70
	Lifetime (a)	20
Boiler	Efficiency (%)	80
Heat exchanger	Efficiency (%)	95