Handbook

Decision Support System (DSS)
for the application of
RENEWABLE ENERGY (RE)
from Biogas and Biomass
Combustion

under particular consideration of
framework conditions in
VIETNAM and THAILAND

Version 1.0

June 2005

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List of abbreviations

ASEAN	Association of South East Asian Nations
BOD	biological oxygen demand
CH_4	methane
CHP	combined heat and power
CO_2	carbon dioxid
COD	COD concentration of the substrate
DOC_F	fraction dissimilated DOC
DS	dry substance
EFB	empty fruit branches
EVN	Electricity of Vietnam
FFB	fresh fruit branches
GWh	giga watt hours
HAPUA	Heads of ASEAN Power Utilities/Authorities
hrt	hydraulic retention time
IE	Institute of Energy of Vietnam
kg	kilogram
kWh	kilo watt hours
m_S	mass to be disposed after treatment
MOI	Ministry of Industry
MWh	mega watt hours
oDS	organic dry substance
OLR	Organic Loading Rate
PC	Power Company
P_{CO2}	biomass combustion project
RE	renewable energy
REAP	Renewable Energy Action Plan
t	tonnes
WG	Working Group
€	Euro

1 Introduction to the Decision Support System (DSS)

1.1 Funding of this project

The production of this Decision Support System and handbook has been co-funded by the European Union, within the framework of the ASEAN-EU University Network Programme (AUNP) (Contract: ASE/B7/1997/0178-06).

The AUNP Programme was launched in January 2000 as a six-year programme with a total budget of € 7.767.500. This initiative by the European Union (EU) and the ASEAN University Network (AUN) aims to enhance co-operation between higher education institutions in the two regions, to promote regional integration within ASEAN countries, and to strengthen the mutual awareness of European and Asian cultural perspectives.

For further information regarding the AUNP and the European Union, please see the following websites:

- AUNP
  http://europa.eu.int/comm/europeaid/projects/aunp/index_en.htm
- European Commission
  www.europa.eu.int
- EuropeAid Cooperation Office
  www.europa.eu.int/comm/europeaid
- European Commission External Relations
  www.europa.eu.int/comm/external_relations
- European Commissions DG Development
  www.europa.eu.int/comm/development
- European Commission DG Education and Culture
  http://europa.eu.int/comm/dgs/education_culture/index_en.htm
- European Union in the World
  www.europa.eu.int/comm/world .

1.2 The project “BiWaRE - Biomass and Waste for Renewable Energy”

This handbook represents the major result of the joint applied research project BiWaRE “Biomass and Waste for Renewable Energy” which has been carried out within the framework of the AUNP Programme. The project was conduced by an EU-ASEAN consortium, consisting of

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The project started in December 2003 and finished in December 2004.

Further information on BiWaRE and all results and publications (downloads) can be obtained from the project website: www.biware.hs-bremen.de.

1.3 Objectives of the Decision Support System (DSS)

Reliable, cost-efficient und sustainable energy supply is one of the main factors for development and economic growth. Therefore the identification of potential energy options and their careful selection are of utmost importance.

Many factors need to be considered for the selection of energy options, e.g. energy demand, site conditions, socio-cultural framework, socio-economic implications, legislation and policy, and the economic feasibility. In addition, with biogas and biomass combustion, even more factors need to be evaluated, e.g. the quality and quantity of suitable substrates, seasonal distributions, shelf life and logistics, etc.. Therefore the assessment of the feasibility of potential projects is complex, especially for decision-makers or planners, who are not familiar with renewable energy from organic substrates.

The Decision Support System (DSS) shall assist decision-makers and planners with an initial evaluation, whether biogas or biomass combustion could be a feasibility option for their energy project, e.g. the electrification of a particular community or the supply of an industrial firm. The DSS should also serve the purpose to promote the idea of renewable energy and to overcome inhibitions.

The DSS is intended to be applied during the first stages of the project development. Its application represents a pre-feasibility study and leads to an initial decision, whether or not biogas or biomass combustion is potentially suitable for the project in question and whether it is worth to proceed with the costly further project development (Figure 1.3-1).

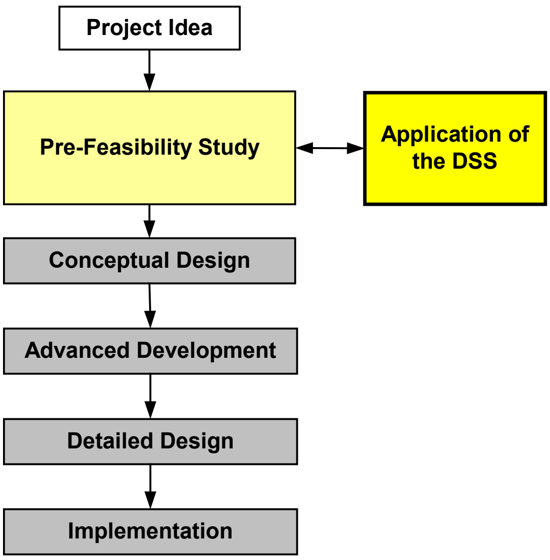

Figure 1.3-1: Scope of the Decision Support System (DSS)

The overall objectives of the DSS are:

- to promote the increased use of biogas process and biomass combustion
- to promote the transfer of knowledge and know-how in the field of renewable energy
- to promote environmental awareness with decision-makers and students
- and to provide the basis for training.

1.4 Target group of the DSS

The Decision Support System is useful for a wide range of professionals and students:

- ASEAN and European decision-makers, who are involved in energy supply, waste management, agriculture
- ASEAN and European planners/suppliers, who are involved in energy project development
- ASEAN and European undergraduate or postgraduate students, who can use the Decision Support System as a reference for renewable energy applications and integrated planning.

The DSS is developed under particular consideration of the framework conditions in Vietnam and Thailand, providing a wide range of background information for those countries. **However the major parts of the DSS are applicable for renewable energy projects in every country.**

1.5 Content overview

The Decision Support System handbook consists of

- Introduction to renewable energy
    - Introduction to the relevant of renewable energy by biogas and biomass combustion (Chapter 2)
    - Introduction to biogas and biomass combustion (Chapter 3)
    - State of the art of renewable energy plants (biogas and combustion) (Chapter 8)
    - Glossary (Chapter 10)

- Information on renewable energy for Vietnam and Thailand
    - Framework conditions for renewable energy production by biogas and biomass combustion in Vietnam and Thailand (Chapter 4)
    - Evaluation of the potential for renewable energy from organic substrates in Vietnam and Thailand (Chapter 5)
    - Address List (Chapter 8)

- Decision tree
    - Decision Tree flow-chart (Chapter 6.2), which guides the user systematically through the decision-making process, step by step. In total the tree consists of 29 steps
    - Explanatory notes (Chapter 6.3) which explain all relevant steps of the Decision Tree and provide necessary background information and tools.
    - Result summary sheet (Chapter 6.5) which represents a standard template designed for the user to fill in the results of the pre-feasibility study, which also can be used for further planning purposes.
    - Excel-based application aid for the decision tree (Chapter 6. 4) The digital excel-version is provided on the attached CD-Rom, or can be downloaded from www.biware.hs-bremen.de.
    - Case studies for the application of the decision tree and for renewable energy in Vietnam and Thailand (Chapter 7)

1.6 Technical scope

The Decision Support System is applicable to

- renewable energy from organic substrates
  i.e. biogas process or biomass combustion processes

- **medium to large-scale applications** (not for household systems), i.e. for biogas plants > 70 kW_{el}

- biomass combustion plants:
  - Electricity plant: > 5.000kW_{el}
  - Combined heat and power (CHP) plant: >500kW_{el}
  - Heat plant: 1.000kW_{th}

- a wide range of substrates, including
  - biomass, e.g. energy plants,
  - waste, e.g. organic fraction of household waste
  - manure
  - high strength industrial wastewater.

  for further details see table 6.3-1, Chapter 6

2 The Relevance of Renewable Energy

2.1 Definition

Renewable energy
Renewable energy can be defined as energy resources that are replaced rapidly by natural processes, e.g. solar, geothermal, wind and biomass energy.
Figure 2.1-1 gives an overview over renewable energy sources in form of thermal, chemical and electrical energy.

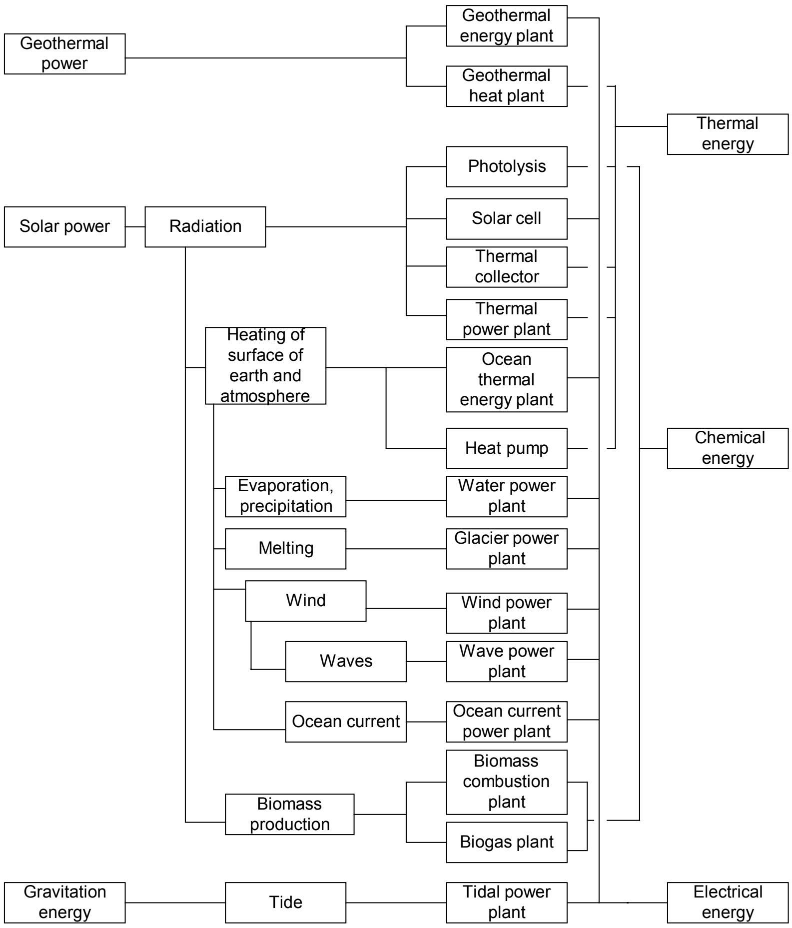

Figure 2.1-1: Options of renewable energy [Kaltschmitt, M., Hartmann, 2001]

Biomasse
The term biomass encompasses all those substances of organic origin (i.e. carbon containing materials). According to Kaltschmitt (2001) biomass includes all living animals and plants, dead (but not fossilised) animals and plants, the resulting residues, and generally all those materials that result, for example, from their technical conversion and/or use (for example, paper, wood pulp, abattoir waste, domestic kitchen waste, vegetable oils, alcohol). The line between biomass and fossil fuels begins with peat, the initial fossil product of incomplete organic degradation, whereby, strictly speaking, peat is not considered as biomass.

For the production of renewable energy the following biomass fractions are available (Figure 2.1-2):

- Energy crops (rapidly growing trees, grasses, etc.)
- Harvest residues (Straw, waste wood from forestry, etc.)
- Organic by-products (e.g. liquid manure, industrial wood)
- Organic waste (sewage sludge, abattoir waste, etc.).

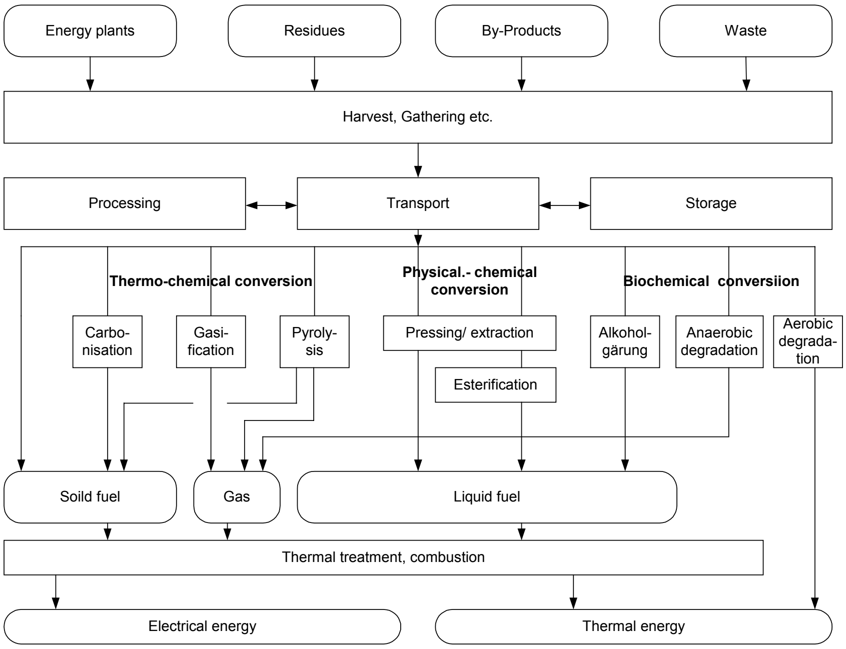

Figure 2.1-2: Overview of renewable energy production from organic substrates [Kaltschmitt, M., Hartmann, 2001, changed]

2.2 Benefits and impacts of Renewable Energy

2.2.1 Introduction

There is now wide international consensus about the need to make far greater use than at present of renewable sources of energy. The arguments are complex, ranging from the need for the long-term provision of energy in view of dwindling reserves of fossil fuels to more current political considerations relating to the economy and labour market. Particularly urgent, however, is the further expansion of renewable energy for ecological reasons, especially in respect to meeting the challenge of climate change. Within the scientific community there is now little doubt that global warming is a reality and that it is closely associated with the burning of fossil fuels. Thus, in most countries today, at local, national and international levels, various measures and mechanisms (statutory and economic) are being implemented to reduce emissions of greenhouse gases and to encourage the use of renewable forms of energy.

Renewable energy production using biomass is particularly interesting for decentralised applications in tropical countries like Vietnam and Thailand, either by the production of biogas or directly by burning as a fuel. Due to climatic conditions and economic structures, organic substrates from agriculture, forestry, households and industry are very abundant. Biomass can provide an environmentally, economically and socially sound energy supply for private households and industry alike. Furthermore, residues from biogas production can be utilised as high quality fertiliser, containing valuable substances such as phosphate.

2.2.2 Economic benefits from Renewable energy

This subsection will look at economic or financial effects and issues on the increased use of RE and especially from RE generated from biomass. It will give a general picture and it should help to better understand the economic background and implications of the use of RE from biomass. This subsection gives some general applicable information and important arguments for politicians, decisions makers and investors to promote RE from biomass.

2.2.2.1 Macroeconomic considerations

<u>Reduction of import and world market price dependency on fossil energy</u>

Increasing energy production from renewable sources has not only local social and economic effects. It brings also several economical changes and benefits to the whole country. Most countries depend very much upon import of fossil energy. Use of RE brings less dependence upon energy import and therefore less dependence upon world market prices and price volatility of fossil energy. This reduction of dependency increases short and long term economic stability, especially regarding the fact that energy prices will increase in future because of production constraints and demand increases (especially from Asian countries). Energy price fluctuations lead in highly energy dependent countries repeatedly to political discussions and to economic disruptions. Sudden energy price hikes hamper economic growth. In traditional analysis this overall risk reducing effect of RE is overlooked. If price and economic risk of fossil energy is properly considered prices for electricity should be higher by at least 3 US cents/kWh (*Awerbuch 2003*). Currently this risk is paid for by society in economic and social losses through energy price induced business fluctuations.
Linked to energy prices are prices for chemical fertiliser (because their production is very energy intensive). Biogas technology especially helps to save countries expenses for chemical or mineral fertiliser.
The use of RE saves foreign exchange and improves the trade balance of a country. This gives a country the opportunity to import more other needed products or to stabilise the value of the currency.

Reserves of fossil energy from oil and gas

Oil and gas production has grown in the last decades considerably. Superficially seen it seems that oil and gas reserves also have grown and that therefore no shortage of oil and gas will be in future. Price volatility's occur only because of political instabilities, temporary shortage of investment or some influence of OPEC.
But the picture is not as bright as it seems to be. Official statistics are often cluttered. There is an apprehension that some countries (esp. OPEC countries) overstated their reserves. More and more countries cannot increase their oil and gas production any more. For example, US oil production has been diminishing for more than 30 years; the OPEC country Indonesia now imports oil. Physical constraints lead to a reduction of the production of oilfields many years before they are finally depleted. Some experts expect that the world maximum of oil production could be as soon as 2010 or even earlier. The world maximum of gas production will be some years later.
Especially when energy demand of big fast growing countries like China and India will increase there will be a supply shortage and further remarkable price increases of fossil energy will come. The market which is now more supply driven will change to a market which is more demand driven and prices will increase.[1]

Income, tax and purchasing power generation
With local production of RE income, taxes and purchasing power within the country is generated. In some European countries RE is now an important market and generates billions of EURO turn-over every year. Imports of energy in form of oil, gas or coal generates income mainly abroad. Home industry will create less turn-over. Through the production of biomass used for RE new local added value chains be created.

Job creation or destruction?
There is a debate in European countries if the increasing production of RE will harm or boost the economy and therefore create or destroy jobs. Reason for this debate is the argument that RE is often more expensive than conventional energy. Therefore appears the fear that energy prices will increase and overall (international) competitiveness of industries will decrease. No definite simple answer to this very complex subject can be given. Much depends upon the very special situation. Studies who claim that RE cost jobs, do not regard negative external effects and environmental and economic risks of fossil energy properly.

For Asian countries some additional arguments are important: energy is in many places scarce and any energy generation will help the economy (or more simply, better expensive energy than no energy), labour is relatively cheap and therefore RE which is usually more labour intensive will be relatively cheaper than in Europe and the high demand of fossil fuel (esp. from India and China) will increase prices of fossil energy in Asia even more than elsewhere.

Choice of technology and machinery - import or not?
One important technical but also economical issue arises from the choice of technology and machinery. Use of imported technologies has advantages and disadvantages. On the one hand it is worth choosing technology and machinery which is developed and produced within the own country. It is often cheaper, it has the advantage that it can be maintained easier by local technicians and most works and services can be done with local manpower and by local firms. Production generates local income and boosts local machinery producers and suppliers, increases their experiences and knowledge. In the long run these firms can improve their quality. The disadvantage of this approach is that efficiency and reliability are often lower than of products from established and well experienced firms which produce technically mature products. It is therefore necessary to find a good choice between higher efficiency and maturity of technology and machinery from mostly foreign firms and less reliable local products which are easier to maintain and give an impetus for income and knowledge generation in other firms within a country.

RE - an investment in the future
Beside the direct ecological advantages of RE the mentioned economic arguments should be sufficient to show that it is advantageous to promote investment in RE even if

they seem to be more expensive. RE will play a more important role in future and the market for machinery supply and knowledge about RE increases every year world-wide.

2.2.2.2 The electricity sector

Small power producers - a new challenge for established power companies
RE is usually produced decentralised by mostly smaller power plants. RE production from biomass depends on its local availability and transport costs set a limit to plant size. Therefore a widespread use of RE needs a national wide power grid which is able to absorb the energy produced by many small power plants and to transmit it to the consumers. This means there is a need for an economical and institutional framework with power purchasing agreements and regulations and probably incentive schemes. There is also a need for a proper technical framework to stabilise voltage and to ensure reliability of electricity provision. In general it seems that it is easier to regulate a few big power plants than many small ones, from a technical as well as from an institutional and economical perspective. Therefore introduction of RE especially from small decentralised sources will be very often hampered by big power companies. They may fear loss of control and influence. Additionally there is the problem that big power companies used to be monopolies. Introduction of RE needs some deregulation in energy sector. So much depends upon the governments' ability to introduce useful regulations and create a technical and institutional framework which enables SPP to sell their energy.

The costs of producing RE
Very often it is said, that energy production from biomass is more expensive than from fossil fuel. From a pure business point of view and on condition that all external costs (e.g. environmental pollution etc) are not taken into account, this is often true. For instance, in Germany, the range for the guaranteed purchasing price is currently 8.4 Eurocent/kWh for big plants to 11.5 Eurocent/kWh for very small biogas plants. Depending on the framework conditions, technological and substance related revenues can be possible. As labour is much cheaper in Asia than in most countries and fuel is the same price, it seems that biogas produced energy is an even better option in Asia than in developed countries. Furthermore very tough technical and safety standards increase necessary investment in countries like Germany.

External costs

External costs also sometimes called 'externalities' or external effects arise when activities carried out by an individual or a company have an impact on another group and this impact is not fully accounted for. This impact can be e.g. noise, air, water, soil pollution etc. This means that some effects, and therefore also some costs involved in an activity will be borne by other persons not directly involved or profiting from it. No proper compensation is paid by the polluter. Environmental problems are usually closely linked with external effects. Because the polluter do not have to pay the true costs for it's activity there will be a gap between the costs of an activity from business perspective of the polluter and from a perspective of the whole economy.

One example is the burning of coal to produce electricity. The power plant pollutes the air with dust, CO_2 and SO_2 and other pollutants. These emissions cause environmental damage and have an effect on human health, leading to higher costs in healthcare. These costs should be added to price of electricity from this plant. Regarding the impact on the entire economy the price of electricity produced by a coal burning plant should be higher than the direct cost of the power plant.

It is the task of the government to find solutions to internalise these external effects and so give environmental sensitive activities a real price. This internalisation can be done in different ways e.g. with taxes on polluting activities or subsidies for environmental friendly activities.

For a long term and comprehensive economic view to costs external effects have to be considered. Energy production from fossil sources causes external costs which are usually much higher than external costs from RE. External costs include local effects and global effects e.g. through GHG emission and the long run dangers and damages caused by it. The use of coal especially correlates with much environmental damage through coal mining: which means destruction of landscape, intervention in the water household, health problems of miners and residents, dust and SO_2 emissions will impair the surroundings of a coal burning plant etc. All these external costs have to be burden by the people surrounding a mine or a power plant and by the taxpayer. An extensive study to this topic for Vietnam was undertaken by *Nguyen Van Song and Nguyen Van Hanh 2001***.** They found that external costs add 171 VND/kWh at the distribution stage. *EU 2001* found external costs up to 2-8 Eurocent/kWh for electricity production from coal. *Hohmeyer 2002* calculates even up to 20 Eurocent/kWh less external costs in using biomass for energy production. These values are higher because they consider also global external costs. Considering external costs gives a very strong argument in favour of RE. Reduction of energy producing activities which cause many local external effects will benefit a country immediately through less health costs and less degradation of soil and water. Reduction of energy producing activities which cause global external effects will benefit all countries.

Economies of scale
For biomass using plants economies of scale are very important and should be considered in the planning process. For instance plants with 50 MW may produce electricity about 3 cent/kWh cheaper than plants of 100 kW. Big plants may even produce energy cheaper than coal power plants (*Batthacharya 2000, p.21*).

Capacity costs and generation costs

Costs in energy sector are distinguished in capacity costs and in generation costs. Capacity costs are the costs to build the capacity of a new power plant and therefore to enable the electricity sector to produce electricity. Capacity costs are long run costs. They are also called sunk costs because even when the power generation capacity is not needed the money is gone. Generation costs are the costs per produced kWh. Sometimes they are also called variable costs. They are short run costs; they correlate highly with the amount of energy produced. They depend also much upon fuel prices.

Operation time during the year
An important influence on operational costs comes from the operation time or capacity use during the year. Because of high fixed costs and relatively low variable costs, the price of electricity will be lower the more the installed capacity is used. This has to be considered especially when biomass is only available during a certain season. The following picture gives a rough idea about the correlation between energy costs and capacity use. Capacity use of 1 means that the plant is in operation for 8760 hours per year.

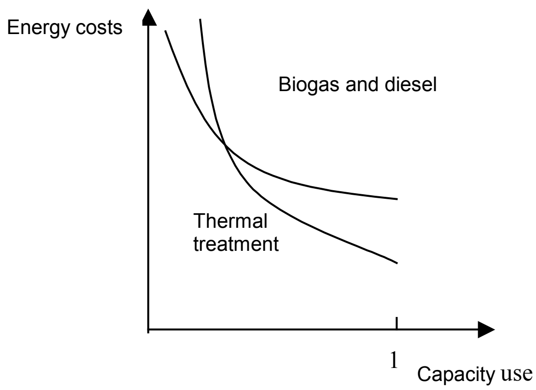

Figure 2.2-1: Correlation between energy costs and capacity use

Cost effect of decentralisation
Another possible cost reducing effect of RE comes through the decentralisation of power generation. It can save some investment in transmission infrastructure and reduce electricity loss in power transmission and transformation from big power stations to the user. With smaller plants the distance from the producer to the consumer of energy is shorter. But to gain the full cost saving effect it is necessary to plan long time ahead. It is

more efficient and cheaper to extend the electricity network with consideration of SPPs, instead of replacing existing power plants by RE power plants somewhere else.
In remote or sparsely populated areas (e.g. mountains or islands) without electricity grid the use of RE from smaller plants can save a lot of investment in electricity connection lines to the grid. Especially the connection of small islands to the national grid is very often (prohibitively) expensive. Mini-grids are in some areas the most efficient solution for electricity provision. For generation of electricity in mini-grids RE is often economically the best choice because otherwise fuel has to be transported to this area.

Easy regulation of produced amount of energy
Energy generation from biogas has the big advantage that it is easy to regulate and very reliable. Depending upon the storage capacity of biogas, such power plants for instance can be used to produce especially for peak hour demand or can even be combined with other less reliable RE sources like wind or solar power. Depending upon the needed scope of energy regulation the storage capacity can be adopted (which means of course some additional capacity costs - but brings also more valuable energy for high demand peak hours). Biogas plants which produce energy mainly for peak hours and produce nothing during low load hours will be more expensive but they save investment in other power plants for peak load.
Thermal treatment plants (and biogas plants) have to operate around the clock. But there is the possibility to reduce electricity production during low demand times. So there exists a similar possibility to increase the overall capacity and produce more valuable electricity at peak hours.
RE from biomass has the advantage that it is quite reliable and manageable (in contrast to wind and solar energy which depends much upon the whether) and therefore need less investment in the energy transmission and control system.

Investment in energy sector is a long run decision
Investment in power generation is a very long run investment with high sunk costs. For decisions it is necessary to consider the long run development of fuel prices. With use of fossil fuel the price of produced electricity depends much upon fuel costs. Considering the amount of resources for the next years it can be expected that the price of oil and other fossil energy fuels will increase even more. Beside this expected cost increase for fossil energy fuels it can be expected that CO_2 emissions will play a bigger role in future. In Europe an emission certificate system is starting in 2005 which will increase the price of electricity from fossil fuels. In 2008 more countries will join the emission trading system. For any long term investment this has to be taken into account and it will lead to a relative generation cost advantage for RE.

Clean Development Mechanism (CDM)

This is a tool developed within the Kyoto protocol to facilitate GHG abatement efforts. The Kyoto protocol aims global GHG reduction with different abatement goals for certain countries. Most of those countries have already made considerable efforts to reduce GHG emissions, so that further reductions will be rather expensive for them. It is cheaper and globally more efficient to reduce GHG emissions in other countries with lower abatement costs. GHG are globally harmful, it does not matter at which country they are emitted. The idea behind CDM is to enable a monetary transfer system within the Kyoto protocol to facilitate the implementation of efficient solutions for GHG abatement to reduce costs. Framework conditions for CDM are not finished yet (because the Kyoto protocol is not ratified yet). First pilot projects are starting now with Thailand and Vietnam rated under the top 10 countries.[1]

In future it may be possible to generate additional income with RE by Clean Development Mechanism. Some estimations expect prices of 3-6 $/tCO_2$equivalent (*CD4CDM*)[1]. Energy production from biomass or biogas has rather low costs for CO_2 reduction and therefore it may be a competitive solution for CDM *(Tuan and Nguyen 2002)*. But because of the expected rather low price, unclear framework conditions, the need for control and certain transaction costs it seems currently CDM will be an option only for big projects. Conditions for CDM may change quickly; it is worth observing the actual situation.

[1] Emission trading takes also place at the European Energy Exchange see: http://www.eex.de/index_e.asp (current price 8.72 €)

2.2.2.3 Financing and investment

Investors and banks lack of experience

Because larger scale use of RE is relatively new, investors and banks are inexperienced. In many countries not many projects exist so that investors are not able to rate the risk properly. Often RE technologies are perceived as commercially unproven. A learning curve for technical improvements and a learning process for investors exists. Technology develops and will be less risky now than some time ago but investors rely on the available data from the past. Information about RE is scarce; this leads to imperfect markets and market entry barriers. The information and lack of experience, together with the fact that RE projects are typically small, will also increase transaction costs to higher levels compared with those of conventional infrastructure projects. All together this will have the effect that money lenders are usually over cautious when rating RE projects, they will not give credit at all or will rate the project risk higher which leads to a higher interest.

This perceived higher risk of RE will also affect insuring companies. If it is necessary to take out an insurance policy companies may be reluctant or demand high premiums.

Problems of short term planning horizon

One of the biggest problems of investment in RE is the short term planning horizon of investors and banks compared to the ultimate lifetime of an investment. In countries like Vietnam and Thailand this is even truer because investors plan for a very short period. As a rule of thumb the payback period for any investment should be no longer than 5 years. The payback period for RE is very often longer. Usually RE needs rather high investment cost combined with quite low running costs because of no or very low fuel costs. Conventional energy production very often needs less investment but causes more running costs especially because of high dependence upon fuel costs. The problem can be shown in the following diagrams:

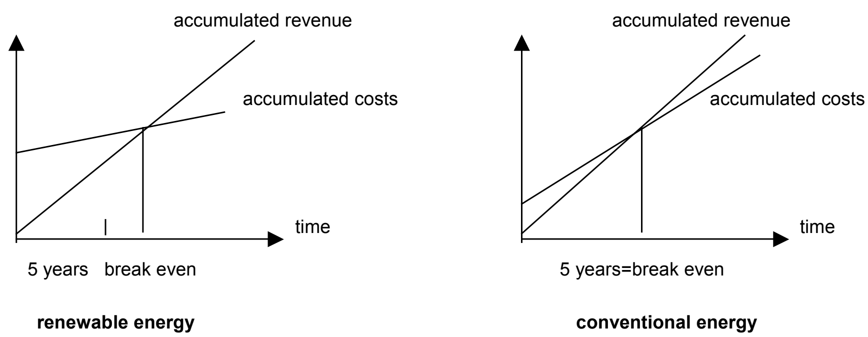

Figure 2.2-2: Payback period of renewable energy and conventional energy

RE brings an investor in the long run often a higher return than conventional energy. But in the short run the difference between costs and revenue is higher. The high initial costs of RE are one of the most important investment barriers.

Kartha and Larson 2000 give example calculations for biomass using energy production. For a small biogas plant they calculate 57% of production costs are capital costs (based on a 25 year operating lifetime and 12% discount rate). For a medium size thermal treatment plant they calculate that 63% of costs are capital costs.

Higher risk and higher interest

This cost structure with the big gap between costs and revenues in the first years means a higher risk for investors and money lenders. This is often a reason why investors decide for a technology which combines lower fix and higher variable costs even if it is not favourable in long run. In many countries there is currently a tendency to build gas power plants. This has different reasons e.g. environmental reasons but the important point for the investors is also that they are relatively cheap to build compared to other plants.

Because of the greater time shift between costs (especially the high investment costs) and revenue, investment in RE is more interest sensible than energy production with lower investment costs and higher variable costs. In economies with higher real interest rates, like fast growing economies in Asia, therefore investment in renewable energy is hampered simply because of its relatively high initial investment costs.

High interest has another negative side effect. Any delay in planning and construction will have a big negative effect on economical success. High interest rates demand careful planning so that investment will not be idle for any time.

Some implications of this cost structure
The cost structure of RE shows that it is favourable for investment to have economic stability with moderate interest rates and a banking sector which is willing to lend money for longer periods. Subsidies could of course relieve this problem. A very good and not necessarily expensive assistance could come through a guarantee program which reduces the risk for investors and banks and so removes this obstacle which comes from the cost structure.
Contrary to the higher risk from the perspective of business RE brings a lower risk for the economy. RE relies usually more on countries own sources (manpower, biomass, construction) than fossil energy. Conventional energy depends much more on world markets and world market prices and price volatility even when fossil energy is abundant in own country. This could give the government an incentive to promote investment in RE.
One important possibility to promote RE is to offer any potential investor long term contracts for purchasing energy. This is risk reducing for the investor. This is the way some European countries like Germany or Spain promote RE. Any purchasing contract should have a duration of at least the pay back period of the investment. This helps to calculate revenues and removes most of the economic uncertainties for investors.

2.2.2.4 Ecological impacts

Ecology is closely linked with economy
As shown in the paragraph about external effects any ecological impact has also indirectly economical consequences. Therefore it is useful to look at some ecological impacts of use of energy from biomass and get some information about the economical effects.

GHG and other air pollution
The use of biomass is CO_2 neutral because it emits only this CO_2 which was previously absorbed by plants. Also, using waste as a substrate for biogas plants or biomass combustion plants can lead to additional reductions in GHG, because GHG emissions from disposal dumps are minimised. GHG emission reduction helps to stabilise the world climate. Therefore biogas and biomass combustion processes represent a vital advantage over energy production from fossil fuel. It will be more and more important to use this kind of energy production to reduce negative climate change effects.

The problem is that it does not give a direct immediate financial benefit to the country. This means there is a lack of economic incentive. Probably the Kyoto protocol will change this through CDM or emission trading systems.
Beside GHG reduction the use of RE and thereby substitution of fossil energy will diminish other environmental harms like dust, smoke and SO_2 emissions from coal power plants which cause health problems and damages in agriculture and forestry and thereby economic costs.

Waste cleaning and removal
An important positive environmental and health impact of biogas plants evolves from the cleaning and sanitation effect. Fermentation reduces smell and makes the substrate less harmful. Water will be less polluted. Thereby this technology reduces hygienic dangers and the substrate can be better handled. Through this sanitation effect biogas technology can save some costs in the medical sector and improve wellbeing of people.
Because biomass using technology makes bio-waste more valuable than before more bio-waste will be collected and so the environment will be cleaner.

Transport
One important impact on the environment may occur through the transport of biomass. Transport causes negative external effects like air pollution or noise. For environmental and social reasons this negative impact should be kept as small as possible. Transport costs and external effects will therefore limit the size of biomass using power plants - in contrast to economical demand of economies of scale to build plants as big as possible. When planning a plant it is necessary not only to find just a financial optimal solution between economies of scale and transport cost of biomass. External effects should also be put into the calculation to find a solution which is well balanced not only from a business view.

2.2.3 Socio-cultural and socio-economic framework of RE

This subsection gives information which goes beyond economical issues. It looks on different economical, social and cultural issues people may be confronted with when a biomass using power generation activity is started. This subsection deals more with small scale, local issues and problems which are connected directly and indirectly with the use of biomass for RE. Some of the issues may be caused by every more or less similar economic activity, some of the issues are connected more specifically to the use of RE from biomass.
Compared with other energy projects, bioenergy projects are likely to have large socioeconomic and environmental impacts for two reasons. Biogas and thermal plants can be realised on a relatively small scale and are therefore suitable for decentralised solutions. New added value chains can be developed in rural areas.

2.2.3.1 Stakeholders

<u>Many groups are directly and indirectly involved in a project</u>
Any economic activity involves a lot of stakeholders who are directly or indirectly involved or affected. Stakeholders could be the operator, employees, residents, local government and authorities, the state owned or private electricity provider, a non-profit-organisation or farmers which use or produce the biomass you need. As more people and groups are involved the more complicated the realisation of the project will be. It is advantageous to regard every stakeholder and its demands and its stake. This helps to satisfy them sufficiently and prevent potential protests, improve social effects and strengthen support. A careful consideration of all stakeholders ensures also the longevity of a project.
Even people who are not directly involved through a contract may be affected and hamper or even thwart the project through passive or active protests. The following picture is not necessarily complete but it gives an impression how complicated interests are entangled. It can be extended to apply to every project.

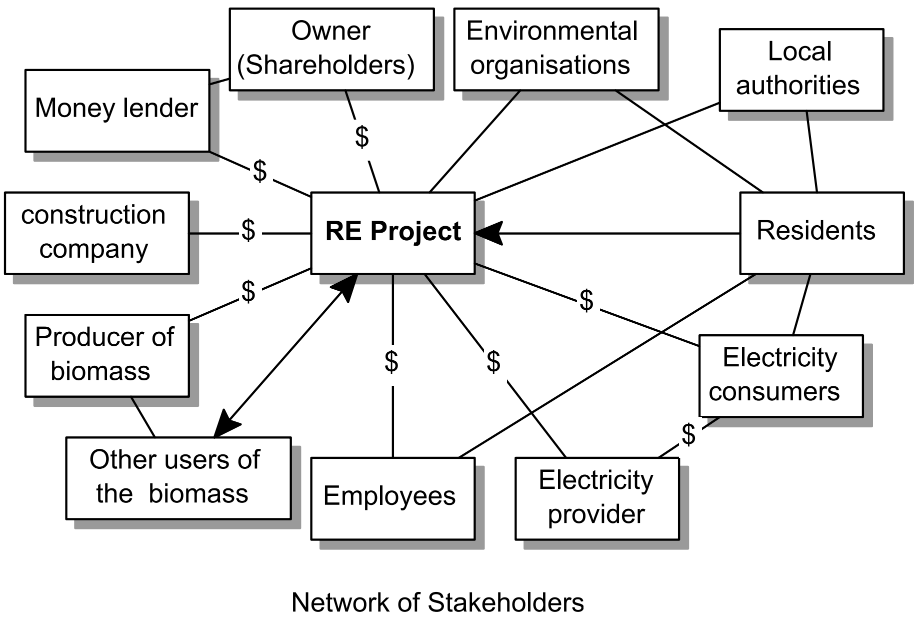

Figure 2.2-3: Network of project's stakeholders

<u>Ownership one of the key issues</u>
The most important stakeholder is the owner. He wants to achieve success and gain profit from the project. If the owner is a single person he has to deal with the other stakeholders to find solutions which are suitable for everybody. If the owner is a group containing people from different stakeholder groups the picture is different. The stakeholder network shows that some groups have contrary interests. These interests have to be considered, conflicts may arise or this constellation could help to reduce conflicts.
A group of owners may simplify the project because other stakeholders are involved and they have common interest to achieve success with the project. So these stakeholders will be more responsible and co-operative and may participate more into the project. If

employees own the plant they will be much more careful and they will feel responsible for proper maintaining and operating. If the supplier of biomass owns the plant he will be reluctant to sell his biomass elsewhere even when prices there are higher because he wants his plant to operate. These are arguments for e.g. a community based ownership or a co-operative. Ownership by different groups will bundle interests and secure participation from different stakeholder groups.
But there may be also a danger with a group of owners. The bigger the group the more communication problems will arise and it will be difficult to come to decisions because interests diverge by some degree. Every members responsibility within a big group may diminish because everybody think someone else will do it, - why should I do it. For small hydropower based grids in Vietnam it has been shown that commercially operated systems are far less likely to fail than community-operated *(UNDP-SSC 2003)*. A similar result can be found for biogas plants in India, where community based plants are less likely to fail as the number of participants is smaller (*Planning Commission 2002*, p. 9).
No definite answer can be given to a preferred type of ownership. It depends too much upon local conditions. But sometimes small changes in ownership lead to more involvement of important stakeholders, improvements in responsibility which then will lead to a higher success for the project.

2.2.3.2 Knowledge problems

The lack of knowledge and acceptance raises problems even in countries with a high ly educated population. Three knowledge and information barriers are often identified which have to be overcome to lead a project to success:

1. Technical barriers and knowledge
It is necessary to adopt a technology which is suitable to the existing level of knowledge in this region. The operator itself has to have full knowledge about physical, biological, technical and financial aspects to build and operate a plant. But also the personnel, maintenance engineers, building companies and other subcontractors have to have a certain level of knowledge. Especially in remote areas the lack of knowledge may be a serious impediment for the successful implementation of an RE project.
Probably technology has to be adapted to a level which can be handled with local available knowledge. Some technology which looks more primitive and is less efficient from a pure technical point of view may be better suitable for the project and more sustainable because it can be better maintained. The use of too sophisticated technologies may lead easily to losses. If it takes a long time to find a maintenance engineer or when spare parts have to be ordered from far away big cities or even from abroad it involves high costs and delays the availability of the plant.
It is useful to look in the neighbourhood for other similar projects and their experience with certain technologies. It saves a lot of time, hassle and costs not to choose the globally best available technology but to choose the locally best available technology.
Carefully chosen technology is also necessary to gain confidence in a project and to convince others of its benefits. A plant which does not work or does not work properly will be a negative example in the whole region and other projects will also lose credit. Negative examples will be more impressive for the people than positive examples.
To overcome knowledge barriers continuous training of staff and experience exchange with other similar projects is necessary.

2. Institutional barriers
Much depends upon the role of institutions. RE and its technologies is often not very well known or understood. If institutions and authorities do not know and understand RE they may be too cautious and hesitate to support a project or demand many expert opinions or impose additional requirements which cause costs. Often it lacks co-ordination between authorities and organisations and long term strategic planning for biomass development. To reduce these barriers locally a lot of information is necessary. A good political framework reduces institutional barriers.

3. Information barriers
Commonly not much is known about the production of RE, about chemical, physical and technical aspects. This will lead to an unspecific fear and to barriers for everybody who is more or less concerned in the project. This leads very quick to an acceptance problem, to protests and to a lack of support.

2.2.3.3 Acceptance problems

Beside barriers which come mainly from a lack of knowledge there are other barriers which are more originated in structure of society and culture:

Social and class barriers
Problems may arise because of the social structure of the society. Especially from India this is known from the caste system. But also classes (e.g. crop or animal farmers), ethnic or religious groups may play a role within societies and often there are barriers between them. So especially with plants which are community operated it may happen that barriers between different groups within a village hamper the project. But experiences show that such barriers can be overcome if everybody gains trough the project (see C.W. Lewis: Biotechnological practices in integrated rural development in *DaSilva E. J. et al 1987, p 115*).--
In rural areas social structure can play an important role when assigning jobs, functions or responsibilities to certain persons. Often this social structure is not recognisable by strangers and people may not be much aware of it. Social regulations for the division of labour can have different reasons: Certain groups have some privileges. Privileges can stem from belonging to a certain social, ethnic, age or sex group. Some kind of labour division is caused by economical or political dependency. The assignment of jobs has to take care of this traditional division of labour and functions within a society to ensure responsibility and acceptance. (For more information about social and cultural problems see *GTZ*)

Cultural barriers and taboos
In some rare cases problems may arise from cultural, social or religious reservations against the used materials (e.g. human faeces or animal manure) or technologies. Taboos and acceptance problems can be solved. It is not possible to give general recommendations; too much depends upon local situation. As a rule of thumb it is useful to contact local persons with authority which could be the elders of the community, leaders of influential groups, priests or other persons with a religious function. If they are willing to support a project they have some influence to change the attitude of the people. But also they depend upon the people and they can not change everything.

Start the information process as early you can - let people participate
Proper and early information is often crucial for the success of the whole project. In Europe some projects die because of the protest of the people concerned (a hot issue is now e.g. wind power). It could be helpful first to start information campaigns before the project planning is completed and official. Sometimes it can help to involve possible stakeholders (esp. the residents) very early to find together solutions. Acceptance problems occur because relevant people do not know about the specific goals of a project and how they may profit from it. Experiences show that for critical projects where people may be negatively affected early discussion is very useful even if it seems to be more work in the first moment. Of course if there are proposals from the community they must be considered but not accepted blindly.
When confronting people with final solutions it could happen that there are verbal agreements because people see no chance to intervene but in reality they undermine the project behind its back.
In the long run the planning and implementation process and involvement of many groups from the community can strengthen institutional capabilities of authorities and private enterprises. Participation increases democratic awareness and strengthens responsibility of people towards the duties of the community.

Information increases overall environmental awareness
Use of biogas or thermal treatment needs not only knowledge. During the planning process it is necessary to inform authorities, to give people and communities all the necessary information. So the process brings a lot of information to all people concerned. It helps to understand some health aspects, ecological and environmental aspects and energy issues. So indirectly the introduction of RE from biomass increases overall knowledge about crucial topics like environment, waste and energy and will so facilitate other environmental projects.

2.2.3.4 Local economic effects

The following paragraphs look in more detail at the local economic effects through different channels. They give valuable information for local decision makers and politicians, they provide arguments to overcome the mentioned lack of information and they help to understand the positions of different stakeholder groups.

Job and Income creation

RE from biomass brings employment
One important advantage of energy from biomass is its employment generation. Based on a study in the Netherlands it is estimated that energy generation from biomass

generates double the amount of employment as compared to energy generation from coal (*Bhattacharya 2001, p.20).* Based on experience in California, *Kartha and Larson 2000* estimate for a 10 Mw_e thermal plant two employees per Mw_e and for a 30 Mw_e plant one employee per Mw_e. Regarding the fact that labour in Asian countries is usually cheaper than in Europe it can be expected that employment generation is even higher. A general analysis about bio-energy based on data from Latin America and Southeast Asia comes to the result that employment up to 800 person years/PJ or income up to 700,000 $/PJ will be generated (*IEA Bioenergy 2003*). To these directly generated jobs indirect employment generation can be added.
It is also estimated that the investment requirement per job is much lower in biomass energy industries than in other branches. This means with the same amount of money more employment can be generated than in other sectors. So especially in regions with high unemployment, energy from biomass can more easily create jobs than investment in other sectors.
This kind of investment brings employment not only to well educated people like engineers. Some unskilled labour is also needed for the handling of biomass. Different social levels can profit from job creation. *Kartha and Larson 2000* estimate for thermal treatment that 20% of jobs need high and managerial skills, 75% need moderate skill levels and 5% low skill levels.

<u>RE from biomass generates income locally</u>
Energy production from biomass in rural areas brings additional advantages. There it can generate some income (for the owner and for the employees) and make this areas more attractive. D. Nianguo Li (Biogas production in China: an overview (in *DaSilva E. J. et al 1987, pp 205*) mentioned a case where village income doubled within two years (not only, but also because of biogas introduction).
RE energy from biomass can make agriculture more attractive and thereby make a contribution against urbanisation which is a huge problem in all fast developing countries. Any income generation in rural areas and any promotion of farming should be welcomed. With SPP the money which is paid for the electrical energy from consumers comes directly back to the region. With energy production in big power plants the money for the electrical energy flows only into the areas with power plants (or abroad to pay for the fuel).
Biomass use in rural areas diversifies the economic structure. This gives this region a better stability against economic disruption. Electricity demand and electricity price will change less than other economic indicators and prices. Farmers who sell their biomass are also less vulnerable to crop failures or declining crop prices.

Improvement of energy supply

<u>Better energy supply is advantageous but not automatically beneficially for all</u>
Energy supply is the key for rural development. People are usually willingly to pay a high proportion of their income for energy services. Electricity is the highest valuable form of energy. Because households which are not connected to the grid have to buy dry cells, use charged batteries or diesel generators they have to pay higher per kWh prices and often even a higher proportion of their income than households which are connected to the grid.
Access to modern energies like electricity helps to mitigate problems of the poor. But just increasing energy supply is not enough to alleviate poverty it is only one part of necessary actions. To reap the full benefits from introduction of electricity supply it should be considered to bundle it with other activities like water, sanitation and education services because services complement each other: the availability of one service reinforces and increases the benefits of another.

[Kartha and Larson 2000] gives a general picture how the use of bio-energy influences human development:

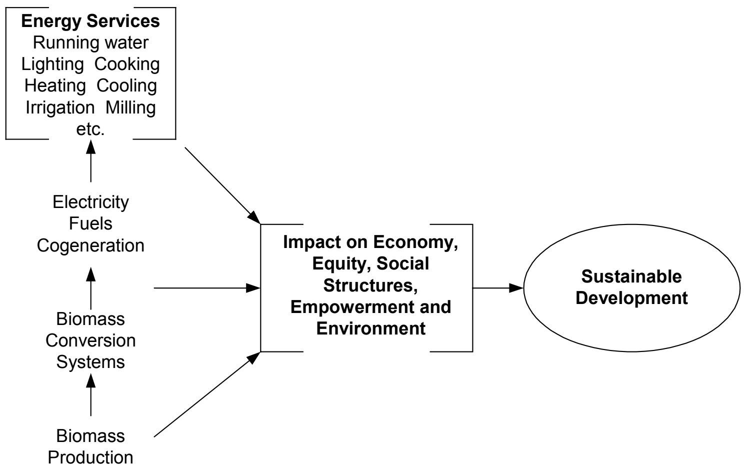

Figure 2.2-4: Conceptual presentation of biomass energy systems and linkages to stustainable human development [Kartha and Larson, 2000]

Introduction of electricity may favour already wealthy households because they can pay more for electricity, connection to the grid and for complementary inputs (like lightning, pumps). Energy access depends upon availability (this can be improved by a biomass project) and affordability. Biomass produced energy has the big advantage that most of the money which is paid for energy will remain in the local community. This can help to increase affordability. For more comprehensive information about energy and poverty alleviation see *ESMAP 2000 and Worldbank 2001.*

Improvement of energy supply enhances the local economy

In some remote regions electricity is scarce, the network unstable or electricity is not available at all. This shortage is a factor which hinders economic development and job and income creation in this region. In this case the use of biomass generated energy will improve energy supply and can hereby create additional jobs through better business and employment opportunities. But bear in mind that new energy services will support development only to the extent that they expand employment opportunities. It is not completely ruled out that new energy service may also displace workers.
It is possible to discern two different levels of improvement. The first level is the creation of a general energy supply where nothing was before. Effects are difficult to estimate because completely new business opportunities could emerge. Existing business could change technology (e.g. electric bulb instead of kerosene lamp, using electric engine instead of manual power) and thereby change or improve products or improve productivity. The second level is an influence on the price if an energy supply already exists but is very expensive (e.g. because it is produced by a diesel generator). Here the influence on business can estimated more easily. This will be mainly be through saving of energy costs and more reliability. Technology or products may not change much.

Improvement of energy supply will enhance quality of life

Not only the economic and income situation may be improved by a better energy supply, but also the quality of life and well being. This will happen through different channels: Improved lighting allows more time to study, use of radio, television or telecommunications improves access to information; health services can be improved through better lighting, equipment and refrigeration.

Surveys have shown that rather high prices for energy are accepted by people who do not have sufficient supply to energy (For an extensive study of this topic in Vietnam see e.g. HIFAB 2000).

Demand and supply effects on different markets

Other business will be affected indirectly

Any energy production plant using biomass acts on different markets and thereby influences the prices on these markets. Not only consumers will be affected, also other producers, merchants or farmers can be positively or negatively affected (see also the subsection about stakeholders). The most important markets are described in the following. These are markets in which the influence of the biomass power plant is large. Influence in other markets on prices (like the labour market) will usually be negligible.

It is important to understand the economic effects which are channelled through the different markets. Some people will gain and some will lose. This creates support or protest from certain groups. To reduce negative social impacts and resistance it could be advantageous to involve concerned groups very early in the project.

1. As an output there will be supply to the **electricity** market. In cases of a supply to the national grid it will not have any influence on the price because the plant will be too small.
   The situation can be different where there is no grid or only a very unreliable mini-grid. Some effects on the electricity users have already been mentioned, they are usually positive. But also electricity producers are affected. The operator of a diesel generator or battery charging station for example could be negatively affected because of his business becoming inefficient and expensive. People may switch from batteries or kerosene lamps to electricity from the grid. The merchants of these goods may be affected negatively.

2. Biogas plants may have an additional output: **fertiliser**. An additional supply of fertiliser will influence this market. Prices may differ locally because of transport costs. It can be expected that existing prices for fertiliser will fall locally (it is important to take this into consideration in project calculations).
   This price reduction may have negative effects on already existing fertiliser producers and traders. The price change on the fertiliser market can also have positive effects on agriculture. Farmers will benefit from lower fertiliser costs. This price reduction is an important reason why they should support the project.

By utilising biowaste or biomass in renewable energy plants new markets can be created. If there are competing utilisation paths for the organic substrates, prices for the substrates may increase. It is important to take this effect into consideration for project calculation. A long run calculation of available substrates considering all possible local and regional prices and demand changes is essential.

The price increase of substrates may have negative effects on some other businesses or private households using this biomass because their costs will also increase. Resistance against the project will come from these people. It is possible that other businesses may suffer because of higher input prices. Sometimes poor people are especially affected because biomass is the energy being used by them. A biomass utilising project could have the effect that people who previously used biomass freely will now have to pay for it.
On the other hand producers of biomass will profit because of the higher demand for their product. They may support the project. This biomass market may cause important economic and social changes. Because the biomass supply is crucial in the long run this topic has to be considered very carefully to avoid economic and social failure of the project. *Any pre-existing uses of biomass should be identified and satisfied through other means or integrated into the proposed bio-energy system. (Kartha and Larson 2000)*

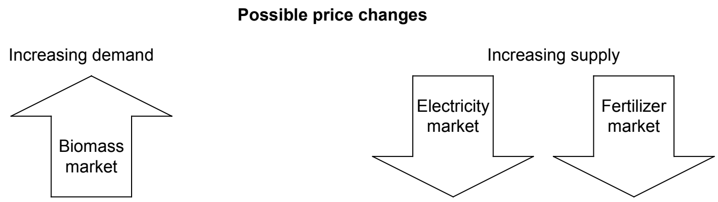

Figure 2.2-5: Price changes affecting the application of renewable energy

Figure 2.2-6: Price changes affecting the application of renewable energy

It is very important to look at all relevant markets. The people involved in these markets will be directly or indirectly affected. These people usually do not have a contract with the plant operator and therefore there is a danger of them being overlooked. They may however, have the power to thwart the whole project. Authorities may be prone to look mainly at the disadvantages of these people and so refuse to accept the project. Early involvement of all those who may suffer losses is vital. Compensation may probably even be necessary to get support from the community and from the authorities to give the project a positive social and economical impact.

<u>Households using biomass may be indirectly affected</u>
In some countries small scale household size biogas plants are already used to produce cooking gas. This is a very good opportunity to use biomass (biowaste). It involves the whole population, it increases environmental awareness and responsibility and it improves the quality of live (especially of women) considerably through different channels. From a pure technical point of view these plants may sometimes have a low efficiency. A bigger scale biogas plant may be more technically efficient and more economical but it would also have considerable effects on current producers of biogas. Biomass would increase in price. So people may change to another fuel (e.g. firewood) andl sell their biomass. As compensation they would get some income from their biowaste. But they would have some losses in that they would have expenses for other fuel. Even if the other fuel is virtually costless (e.g. firewood) it incurs costs in the form of working hours (usually done by women).
A very complicated process of social change may occur if the biomass is already being used within the household. Small scale biogas plants are only one example. Households would get some income from the biomass but they would lose the utilisation opportunities of the biomass which involves monetary and non monetary losses. A comparison of different options may be difficult because it is necessary to take the non-monetary effects into consideration.

2.2.3.5 Experiences in Europe and other developed countries

Bioenergy is quite well accepted - burning technologies more problematic

In Europe modern RE have a long tradition and in some countries further expansion is much in discussion. The following diagram gives some indication about the positioning of different kinds of RE within the dimensions of acceptability and understanding.

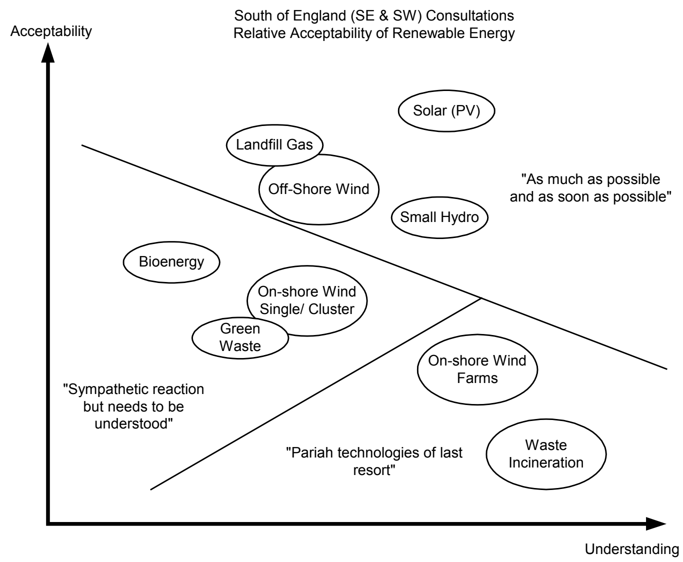

Figure 2.2-7: Positioning of different kinds of renewable energy [Community Preferences for Bioenergy Development in the South East of England Keith Richards and Annette Deveson in J. Domac and K. Richards (eds.) 2001]

It is very likely that this diagram could also be transferable to other regions of the world. The main issue is that positioning of people is very not based on facts alone, but also on emotional aspects. As a consequence, the provision of information might be of limited use only.
The picture shows that bioenergy is not necessarily well understood but nevertheless accepted. Waste incineration produced a different picture. People understand more (or at least they seem to understand more) but acceptance of this technology is lower. In general the use of burning technology will meet more resistance than the use of biogas technology. Burning of harmless biowaste will be more acceptable than incineration of waste from different sources.
In most developed countries extensive permit procedures for any (plant) building activities exists. Residents are involved in the permit procedures so they can claim their concerns. This can lead to expanded permission procedures, or to the rejection of projects.

2.2.3.6 Experiences from other developing countries

Some experience already exists with the use of small biogas plants for cooking or lighting gas generation. There are millions of these small plants in operation especially in Asian countries. But experiences are only partially transferable because the small scale utilisation of biomass within household is in many aspects different from its use on a larger commercial scale. Larger plants are more complex but are usually also better managed.

In China biogas has been used extensively since the 1950s. Now it is widespread. The simplest version for home use has a payback period of 1 1/2 year. Bigger plants which also produce have a payback period of about 5 years. Some important points of the Chinese strategy are (D. Nianguo Li: Biogas production in China: an overview in *DaSilva E. J. et al 1987, pp 205*):

- clustered development because it favours extension of services, financial support and collective operation,
- focus on implementation in areas of fuel shortage and where epidemic diseases are prevalent, because in these areas the benefits are highest
- supply of both domestic and community methane digesters
- self-support with proper government back-up. Because resources and consumption are small-scale and scattered, constructions for rural energy should rely mainly on self-support. Preferably those who built the digesters should own, manage and profit from them.
- Institution and educational courses. An office should disseminate information, supervise technology transfer and allocation of funds and subsidies, organise training courses and an exchange of experiences.

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http://wbln0018.worldbank.org/esmap/site.nsf/pages/AnalysisPovertyReductionStrategyPapers

Further information:

Energia http://www.energia.org/ (Network on gender and sustainable energy)

ESMAP (Energy Sector Management Assistance Programme)
http://www.esmap.org/

ESMAP 2003 Monitoring and evaluation in rural electrification projects : a demand-oriented approach http://www-wds.worldbank.org/servlet/WDS_IBank_Servlet?pcont=details&eid=000012009_20031121125428
(This paper gives tools for an approach in rural electrification which is more oriented to the real needs of the community)

IGES (Institute for Global Environmental Strategies)
http://www.iges.or.jp/en/cp/output_all/aboutiges/index.html (comprehensive scientific information about clima change and CDM in Asia)

Nielsen L.H, Hjort-Gregersen K. 2002: Socio-economic Analysis of Centralised Biogas Plants, 12th European Conference on Biomass for Energy, Industry and Climate Protection, Amsterdam, June 17-21.
http://www.lr.dk/planteavl/informationsserier/biogas/samfundsoekonomi_engelsk.pdf
(shows for an example calculation for Denmark the approximated true costs of energy from biogas)

REAP 1999 (Renewable Energy Action Plan for Vietnam)
http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2003/01/07/000094946_02121704045588/Rendered/PDF/multi0page.pdf

3 Introduction to biogas and biomass combustion

3.1 Introduction to biogas technology

3.1.1 Definition of biogas

Biogas
Biogas is a gas mixture of 50-75% methane, which is generated by anaerobic, microbial degradation of organic substrates (anaerobic digestion, fermentation). Besides the valuable component methane, other constituents are 25-45 carbon dioxide (CO_2), as well as traces of hydrogen sulfide (H_2S), Nitrogen (N2) and carbon monoxide (CO) (Table 3.1-1).

Table 3.1-1: Average composition of biogas [Kaltschmitt, Hartmann, 2001]

Component	Concentration
Methane (CH_4)	50-75 Vol.-%
Carbon dioxide (CO_2)	25-45 Vol.-%
Water (H_20)	2-7 Vol.-% (20-40 °C)
Sulfide hydrogen (H_2S)	20-20.000 ppm
Nitrogen (N_2)	< 2 Vol.-%
Oxygen (O_2)	< 2 Vol.-%
Hydrogen (H_2)	< 1 Vol.-%

Biogas can be used for electricity and heat generation. The energy content directly depends on the methane content. One m³ methane has an energy content of ca. 10 kWh. Therefore the energy content of typical biogas (60% methane) lies in the range of 6 kWh. The average energy content of one m³ biogas is equivalent to 0,6 l fuel oil.

The biological methane generation is a process, which occurs in nature, where wet organic material is available and free oxygen is absent, e.g. in the digestive tract of cows, wet composting plants, landfills or flooded paddy fields.

3.1.2 Basic principle of anaerobic metabolism

Knowledge of the fundamental processes involved in methane fermentation is necessary for planning, building and operating biogas plants. Methane bacteria are obligate anaerobic, i.e. they are only active under oxygen free conditions. Under these conditions, the energy generation represents only 1/7 of the aerobic bacteria [Bilitewski et al., 1994]. Therefore anaerobic bacterial have a longer growth rate, respectively. Their metabolism depends on the preparatory steps and symbiosis with other bacteria. The following figure (Figure 3.1-1) shows the different phases of the methanogenesis, involving three different bacterial communities.

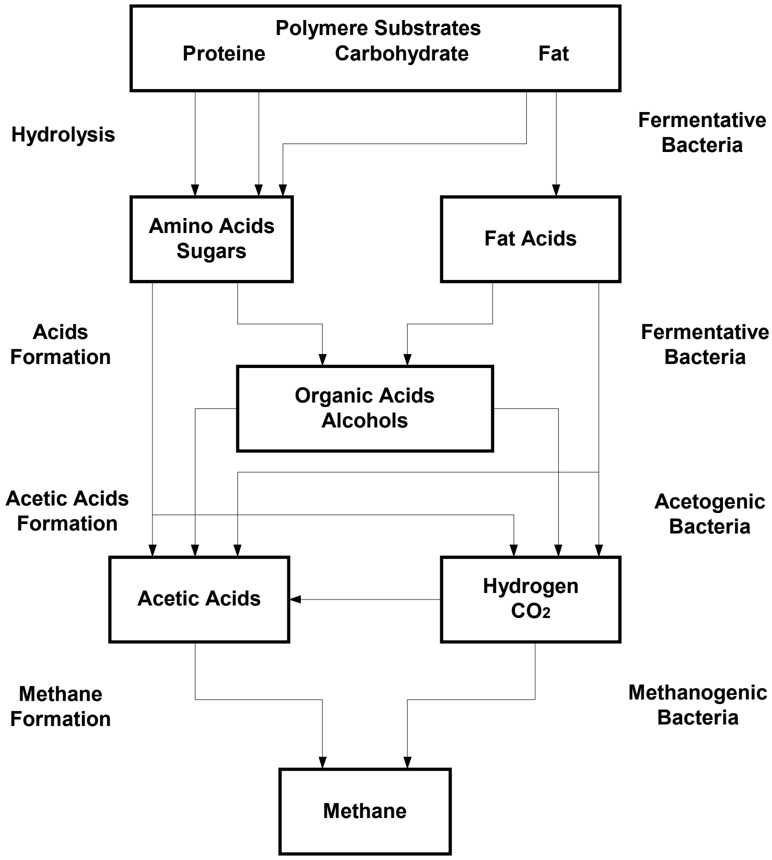

Figure 3.1-1: The phases of methane production

The biogas process consists of three phases:

- **1. Hydrolysis:**
  In the first phase, high molecular compounds like carbohydrates, fats and proteins are degraded into simpler compounds (monomere, like aminoacids, glucose, fatty acids) and solved in water.

- **2. Acidification:**
  Acid-producing bacteria convert the solved compounds to organic acids (butyric acid, and propionic acid), alcohol, hydrogen and carbon dioxide.

- **3. Acetogenic phase and methane formation:**
  In the acetogenic phase are the compounds converted into acetic acids. The methane formation is carried out by methane bacteria, which only can utilise C-1 and C-2 compounds.

  Methane- and acetogenic bacteria act in a symbiotical way. The latter creates and atmosphere with ideal parameters for methane producing bacteria (anaerobic conditions, compounds with a low molecular weight), the former us the intermediates of the acid-producing bacteria. Without consuming them, acid would accumulate, resulting in toxic conditions for acid-producing bacteria.

In nature as well as in biogas plants, the metabolic actions of the different bacteria act in concert.

3.1.3 Parameters and process optimisation

Overall, the methane yield depends on many factors, which relate to the substrate, the pre-treatment or conditions of the substrate and the fermentation process (Figure 3.1-2).

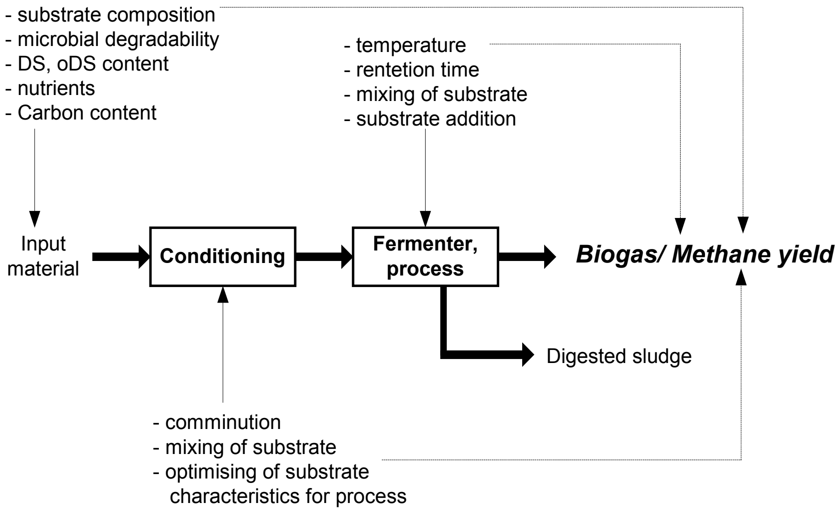

Figure 3.1-2: Factors which influence the biogas and methane yield [Weiland, 2001].

3.1.3.1 Substrate requirements

Substrates used for biogas production often are residues, by-products or residuals from agricultural, commercial and industrial activities, and also from households. See Table 3.1-2 for examples for typical substrates and possible methane yields, or tool 1 for a comprehensive list of suitable substrates and their characteristics.

Table 3.1-2: Typical substrates and biogas yield

	Methane yield [CH_4 m^3/kg o DS]
cattle manure	0,1-0,35
pig manure	0,18-0,64
Maize silage	0,22-0,5
Grass silage	0,3-0,6
Food waste	0,3-0,6
Sewage sludge	0,19-0,44

The quantity of biogas and methane produced mainly depends on the composition of the substrate. In practice it is often not possible to calculate the methane yield, as the composition not known and the degradation is not complete. Table 3.1-3 shows the theoretical, specific biogas yield. The different methane concentrations result from the differences of the relative carbon ratio.

Table 3.1-3: Specific biogas yield and methane concentration

	Biogas yield [l/kg oTS]	Methane content [Vol.-%]
Digestable proteine	600-700	70-75
Digestable fat	1.000-1.250	68-73
Digestable carbohydrates	700-800	50-55

Degradability
Suitable substrates for biogas production are basically all kinds of organic matters and biomass containing carbohydrates, proteins, fats, cellulose or hemicellulose. Generally, easy degradable substrates with low molecular compounds, e.g. wet organic kitchen waste, can be degraded quicker and more complete. In contrast to this, wooden substrates, containing a lot of lignin, are not suitable.

Inhibiting substances
Inhibiting substances can be toxic to the bacteria involved in anaerobic digestion, so that the processes can be reduced or stopped. Antibiotics or disinfectants in household waste can have these effects. Also, heavy metals or salts from certain concentrations act toxic.

Nutrients

The substrate must contain certain concentrations of nutrients, a certain carbon/nitrogen ratio, as well as trace elements for the bacteria to grow. The demand for nutrients can be estimated according to composition of the micro-organisms (Table 3.1-4). The optimisation of the nutrient supply must be carried out on an empirical basis, considering the mechanical, chemical and physical framework conditions.

Table 3.1-4: Typical Constitution Of Biomass (Bindlingmaier, 1985)

Component	Bacteria		Yeasts		Molds	
	Average	Range	Average	Range	Averge	Range
Organic Constituents (% dry wt)						
Carbon	48	46 - 52	48	46 - 52	48	45 - 55
Nitrogen	12,5	10 - 14	7,5	6 - 8,5	6	4 - 7
Oxygen		22 - 28				
Hydrogen		5 - 7				
Protein	55	50 - 60	40	35 - 45	32	25 - 40
Carbohydrate	9	6 - 15	38	30 - 45	49	40 - 55
Lipid	7	5 - 10	8	5 - 10	8	5 - 10
Nucleic acid	23[a]	15 - 25	8	5 - 10	5	2 - 8
Ash	6	4 - 10	6	4 - 10	6	4 - 10
	Bacteria		Fungi		Yeast	
Inorganic Constituents (g/100 g dry wt)						
Phosphorus	2.0	to 3.0	0.4	to 4.5	0.8	to 2.6
Sulfur	0.2	to 1.0	0.1	to 0.5	0.01	to 0.24
Potassium	1.0	to 4.5	0.2	to 2.5	1.0	to 4.0
Magnesium	0.1	to 0.5	0.1	to 0.3	0.1	to 0.5
Sodium	0.5	to 1.0	0.02	to 0.5	0.01	to 0.1
Calcium	0.01	to 1.1	0.1	to 1.4	0.1	to 0.3
Iron	0.02	to 0.2	0.1	to 0.2	0.01	to 0.5
Copper	0.01	to 0.02			0.002	to 0.01
Manganese	0.001	to 0.01			0.0005	to 0.007
Molybdenum					0.0001	to 0.0002
Total ash	7 to 12		2 to 8		5 to 10	

[a]Values this high are observed only with rapidly growing cells

3.1.3.2 Process parameters

A number of parameters have an influence on anaerobic digestion and can be adjusted in technical processes, to optimise the gas production, methane yield, the degradability (desintegration) of substrates, the hygienic situation, and fertilising qualities of the residual digested matter.

Temperature
The temperature is a major factor for the activity of bacterial communities. Three ranges of temperature can be distinguished:

- physchrophile : around 10°C
- mesophile: 32-50 °C
- thermophile: 50-70 °C.

Generally a thermophilic process results in an quicker metabolism and degradation. It is often preferred if the substrate contains high levels of fat, or if pathogenic micro-organisms shall be destroyed. However most biogas plants are operated under mesophilic conditions as the process is biologically more stable and less costs for energy are involved [Bilitewski, 1994]. Generally biogas plants can be operated on all temperature levels within 30-55°C.

pH-Value
The pH-value plays an important role for all microbial processes. The optimum pH-value for the methanogenesis lies in the range of 6,8- 7,5. In contrast to this, the pH-value of the previous phases (Hyrolysis and acidformation) lie in the range of 4,5-6,3 [FNR, 2004]. PH-values which are too low should be prevented as they have an inhibitory effect on the micro-organisms of the methanogenesis.

Retention time
The duration depends on the temperature, the capacity of the digestion-tank, the concentration of substrate in the reactor, the concentration of active biomass and the desired degree of degradation. The duration period can vary from a few hours (waste water clarification technology) to up to 2 months (agricultural biogas plant).

The above mentioned, slow bacteria growth creates the problem that in order to shorten the duration period the active biomass must be retained or enriched. This can be achieved by immobilising the carrying materials in a solid or whirl bed or by adding sludge or processing water. The addition of inert solid fillers or inert particles, which through adhesion can retain the bacteria, is only possible in waste water clarification. This is because by the addition of solids or sludge type waste, the solid bed can become blocked or the carrying materials in the whirl bed process also be transported out. In fermentation of clarification sludge, waste or agricultural substrates, with normal duration periods of between 15 and 60 days, continual injection or enriching of micro-organisms of the fermentation suspension is not necessary. All known continual processes do not need additional injection after the start up phase. Special types of micro-organisms are not required.

3.1.4 Technical application

Development of anaerobic processing technology comes traditionally from wastewater clarification. In reactors suitable for wastewater treatment, industrial organic waste, wet and bio-waste can lead to deposits, blockages and build-up of sediment and floating layers. Therefore this had lead to the development of two principle solutions which are suitable for other substrates than wastewater:

- Dry fermentation
- Wet fermentation.

With dry fermentation the substrate is fermented to a dry substance content of up to 65%, whilst with wet fermentation it is mashed with water into sludge of approx. 5% to 12 % dry substance content. In two stage wet fermentation the solid substance goes through a hydrolysing stage in which a large part of the organic substance is dissolved in water. This is then treated in a normal anaerobic reactor as is used in waste water clarification. With dry fermentation the advantages of having a lower water requirement and a higher sludge-digestion tank load can be expected. Wet fermentation promises fewer problems in the handling of a homogenous sludge, a possible separation of floating or sinking substances at the liquefying stage and sludge reduction. In two phase wet fermentation it is hoped that higher capacities can be reached by having the possibility to attain optimum conditions for the separate phases and the use of high capacity reactors as used in waste water clarification plants. The biogas generated is of higher value with higher methane content as it is mostly rejected in the carbon dioxide generated in hydrolyses. The specific biogas yield in dry and wet fermentation plants varies depending on the duration period, tank capacity etc. In principle, the same level of specific biogas yields can be reached from a substrate in both dry and wet fermentation plants. Dry fermentation plants can be made very resistant to interfering materials depending on how they are technically equipped.

Substrate handling and storage of biogas substrates is done similar to substrates used for biomass combustion (compare Chapter 3.2.1.3, 3.2.1.4). The storage and transport of liquid substrates are done using agricultural equipment and machines.

In Chapter 8, a number of existing biogas plants for different substrate characteristics, process temperature, etc. (Table 3.1-5) are presented as an example.

Table 3.1-5: Features of different types of biogas plants for solid and sludge-like substrates [Institut für Energetik gGmbH, quoted in BMU, 2003]

Criterion	Features
TS-content of substrate	• Dry fermentation (TS from 15 to 65%) • Wet fermentation (TS up to 15%) • Anaerobic wastewater treatment (for wastewater)
Type and source of substrate	• Agricultural mono-fermentation plants (manure fementatio) or Co-fermentation plants (manure plus additional substates) • Biowaste fermentation plants • wastewater
Temperature of process	• Psychrophile (below 20°C) • Mesophile (25 to 43°C) • Thermophile (below 55°C)
Charging clearance	• batch • Intermittent • Semi- or quasi continuous
Method implementation	• Single-stage - All degradation stages simultaneous • Two-stage - Separation of hydrolysis • Multi-stage - Separation of hydrolysis and formation of acid
Principle of mixture	• Mechanical - Propeller agitator • Hydraulic - Pumps • Pneumatic - Gas injection

3.1.5 Biogas utilisation

Biogas processing

For the utilisation of biogas in unit power stations, heating boilers etc, it must be treated to varying degrees depending on the energy utilisation system. During the anaerobic microbial transformation processes in a biogas plant, the existing various forms of sulphur (sulphate, organic sulphur compounds etc) will be converted to sulfide (S_{2-}). The sulfide will then be as hydrogen sulfide (H_2S) in the biogas. During the oxidating of biogas in a unit power station, heating boiler or other energy conversion plant, H2S is converted into SO_4^{2-}. In the form of sulfuric acid (eg. in exhaust gas heat exchanger in a unit power station) can lead to significant corrosion problems in the condensation zones. The removal of H_2S from the biogas can be achieved through biological or chemical purification.

Chemical de-sulphuring is generally carried out by precipitation of H_2S to bog iron ore (as FeS) or gas purification with sodium hydroxide.
In biological treatment, which can take place in the fermenter head itself or in a connecting reactor (gas purifier), the biogas is supplemented with oxygen (O_2). On the surfaces in the fermenter or in external reactors, micro-organisms will grow which can oxidise H_2S, S and $S_2O_3^{2-}$ to SO_4^{2-}. H_2S is removed from the gas phase (biogas). A significant decrease in pH values on the H_2S oxidising micro-organism growing surfaces will result, and so these should be regenerated from time to time.

If silicon compounds are added (eg. those used as de-foamers in some lemonade) in the fermentation process, Silan (SiH_4) will be generated by the biological conversion. Silan is gaseous similar to methane. On burning of biogas containing silan, for example in unit power stations, silicone oxide (silica sand) will be generated. This will lead to significant damage in the internal combustion engine. It is assumed that silan causes approx. 50% of damage to unit power stations in German waste water purification plants converting biogas from sludge digestion. Silan can be removed from biogas using various different methods. A process most generally used in biogas plants is adsorption on activated carbon.

In a fermenter the relative humidity of biogas is 100%. The biogas humidity must be reduced in order to protect the e.g.unit power stations from high wear and damage. This can be brought about for example by installing a pipeline system between the fermenter and the unit power station (heating boiler etc.). On installing the pipeline it must be ensured that any condensation created in the pipeline can be drained off into condensation collectors and that no pools of condensation can result from lower points in the pipeline caused by settling for example. If the pipeline system is not long enough or the outside temperature is too high for part condensation of the water vapour in the biogas, then external cooling (air conditioning system, water cooling with ground water or cold surface water etc.) must be used to reduce the relative humidity of the biogas.

Depending on the quality of the biogas and its proposed use further specific treatment processes may be necessary. To feed biogas into the natural gas grid, its methane content must be increased. As this and other similar processes are not yet economic and are only individually applied, they do not require to be further discussed here. If required, refer to current specialist literature.

Biogas utilisation

Utilisation of biogas generally takes place in heating boilers (heat utilisation) or in unit power stations. This will briefly be discussed in the following. Other innovative processes for the conversion of biogas into energy using fuel cells, gas turbines, steam engines, organic rankine plants or stirling engines are generally not yet economic and will not be further discussed here.

In the conversion of biogas in heater power stations, depending on the type and size of the plant, electricity will be generated with an output of 30 to 40 %. In partial load areas the output is decreased. The rest of the energy is precipitated in the form of heat. Heat in the form of hot water can in be absorbed and used at a temperature of 90°C. The thermal output (usable heat) from unit power stations generally ranges from 20% and around 50% depending on the specification of the individual plant and according to the application with or without exhaust heat exchanger. When the alongside electricity also heat utilised, this is referred to as power-heat-coupling.

Unit power stations consist of an internal combustion engine and a generator for the generation of electricity. Gas-Otto engines or gas-diesel engines are used for the internal combustion engines. Whilst gas-Otto engines (Figure 3.1-3) can be run on biogas alone, with gas-diesel engines (Figure 3.1-4) require an oil-ignition part alongside the biogas (eg. diesel; approx. 10 % the combustion heat output). Gas-diesel engines are generally installed in unit power stations with an electrical output of 20 to 300 kW. Gas-Otto engines with an electrical output of between 100 kW and 2 MW. Gas-Otto engines normally have better exhaust values and a longer serviceable life.

Gas-diesel engines are suitable for operation at lower outputs and can be purchased more inexpensively. On selecting a suitable aggregate, the economic and investment costs in each individual case as well as the availability of spare parts, serviceability etc. must be taken into account.

Figure 3.1-3: Unit power station with gas-Otto engine with an electrical output of 375 kW.

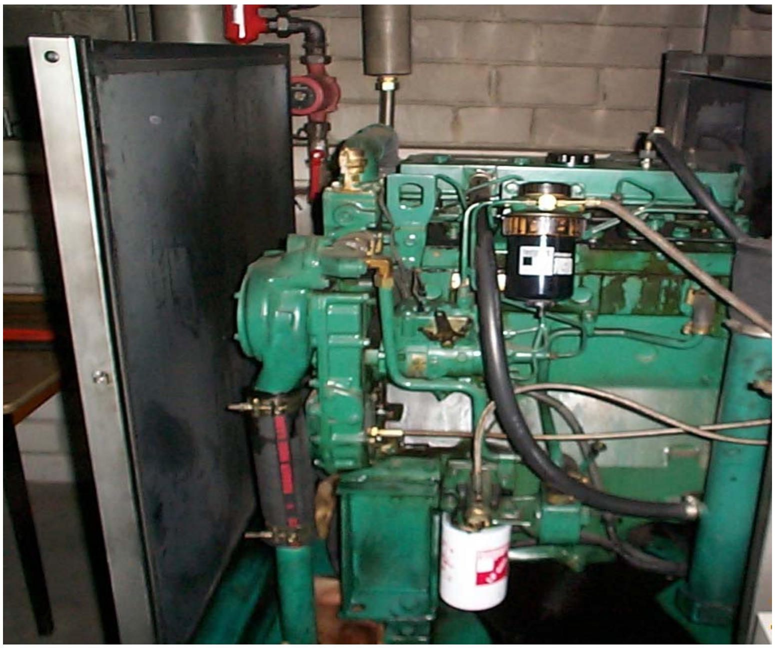

Figure 3.1-4: Unit power station with gas-diesel motor with an electrical output of 60 kW

3.1.6 Benefits

The development and operation of biogas plants opens up a variety of developmental perspectives, particularly also in rural areas. Alongside the reduction of GHG emission, the provision of infrastructures for the disposal of waste and substrates from waste water clarification, and agriculture in certain aspects stand here in the foreground, and relate to a generation of new added value chains in rural areas.

Biogas plants create jobs, increase economic power, and produce decentralised fertiliser and energy in the form of electricity and heat, thereby making a region less dependent on external resources.

The positive perspectives of biogas plants have been well discussed. For this reason, only a table of some of the advantages have been listed below (see Table 3.1-6).

Table 3.1-6: Benefits of biogas plants

Area	Benefits
Waste treatment	• natural waste treatment process • infrastructure for waste treatment • reduces disposed waste volume and weight to be landfilled • reduced the long term hazards of landfills • sanitation of waste and substrates from waste, waste water treatment or agriculture
Energy:	• generates biogas which can be used for the production of electricity, heat or cooling (heat exchange) • net energy producing process • proven in numerous end-use applications
Environmental	• significantly reduces carbon dioxide and methane emissions (Greenhouse effect) • eliminates odour • produces a sanitised compost and nutrient fertiliser • maximises recycling benefits, reduces resource depletion
Other benefits	• cost-efficient • decentralised applicable • flexible process for a wide range of substrates • new value creation chain for the waste management sector and agricultural sector • generates jobs, tax revenue, revenues • reduces the dependency from external energy supply

3.2 Introduction to biomass combustion

3.2.1 Biomass production und handling

3.2.1.1 Harvesting, supply and transport

Biomass which can be used for energetic utilisation is generated in the form of waste from different industrial sectors or can be directly grown for this purpose. Typical sectors of the producing industry where this material is generated are for example:
agriculture (farmyard manure, straw), food industry (rapecake, fruit pulp) and wood processing industry including forestry itself (wood residues and offcuts, sawdust). For energetic utilisation fast-growing biomass can also be cultivated. Some common examples are elephant grass and other „energy"-grasses known as Topinambur. The harvesting technologies used are adapted to the kind and specific use of the biomass. For the harvest of elephant grass, a row-independent chopper harvester for maize or harvesting aggregate called Häcker[2] can be suitable.
The waste as well as the grown biomass are generally not readily available in the way as the energetic utilisation processes (continuous or discontinuous) demand for. This fact makes a temporary storage of the biomass indispensable. Together with the storage process, an improvement of the material quality for fuel purposes (homogenization of different batches by mixing, further drying) can be achieved.
The transportation to the combustion facility can be done in a lose way (e.g. chopped like in the case of Miscanthus), in a compressed state (bales, like in the case of straw) or using a pre-conditioned product (e.g. pellets, briquette like in the case of sawdust), respectively.

3.2.1.2 One site handling at the combustion facility

Power plants and combustion facilities normally posses of a storage area and a hold-up bunker for feeding the combustion process. From the storage area (e.g. flat bunker, storage hall, silo) the material is send to the hold-up bunker from where it is taken to feed the combustion chamber as required.

3.2.1.3 Fuel storage

<u>Temporary storage of biomass for energetic utilisation</u>
A temporary storage of biomass for energetic utilisation is necessary where a continuous supply of this biofuel cannot be guaranteed. The manner in which the fuel product can be stored depends on its moisture content, the requirements it has to fullfil (fuel requirements) and the transportation distances.
Dry solid biofuels (< 15-20[3] % moisture content), e.g. pellets, dry wood chips
Flat bunker, silos and bigbags are most commonly used for the temporary storage of dry biofuels.
The outdoor storage on flat surfaces is basically possible with and without coverage or under a roofing with or without side walls. To maintain the fuel properties and keep the moisture content low outdoor storage without coverage cannot be recommended, however. Likewise unsuitable for outdoor storage are dust-like fuels, such as saw dust, because of the occurence of emissions[4].and the risk to be blown away.
Water penetration into the stored matter during outdoor storage can be prevented through the coverage with a foil or similar. The storage area should be paved or of other impermeable underground (e.g. concrete) in order to avoid foreign matter such as soil or stones to get mixed up into the biofuel[5].
The flat bunker at the combustion facility should be roofed at least but most often it is set up in form of a hall or other closed construction. The bunker can be filled by simple tipping wagons and subsequent stockpiling with the help of wheel loaders or crane systems, or by means of aggregates which blow the biomass (in the appropriate grain size) from the outside into the bunker. The storage height of wood chips[6] can reach up to 7 meters. The same kind of storage can also be used for baled fuels.

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[2] Quelle: Interessengemeinschaft Miscanthus Schweiz
[3] According to Önorm M 7133 up to 20 % for air-dry wood chips, up to a moisture content of 30 % wood chips are considered suitable for storage.
[4] Koppejan, Jaap, van Loo, Sjaak; Handbook Biomass – Combustion and Co-Firing, Twente University Press, Enschede 2002
[5] Jiris, R.: Storage an drying of biomass – new concept. In: Proceedings of the 2. Biomass Summer School, Institute of Chemical Engineering (Ed.), Technical University of Graz, Austria
[6] without aeration a dumping height of less than 2 metres is recommended for e.g. coarse wood chips (fresh) (Fachagentur für nachwachsende Rohstoffe)

Where physical properties and grain size of the dry biofuels allow a discharge without problems, the storage can also be undertaken in silos. The feeding of the silos is usually done with blower aggregates or conveyor systems. The advantages of storage in silos in comparison to flat bunkers are found in the smaller basal area consumed and, for smaller silo types, the possibility to have them carried to other places and thus a flexibility in their use. The advantages of flat bunkers as in comparison to silos are the possibility of larger storage quantities and lower costs due to the reduced equipment needs and technical expenses.

Given the self-heating and slowly progressing micro-biological degradation of the biomass, to a certain extent a drying effect takes places during the storage of the dry solid biofuels.

Calculation example flat bunker: A basal area of 25 x 65 m and an average storage height of 3.5 m for wood chips (bulk density: 200 kg/m³) results in a possible storage quantity of 1,138 Mg.

Solid biofuels (> 15-20 % moisture content)

Regarding the storage of this fuel category the same facts like for the dry solid biofuels apply. Solid fuels with a moisture content above 15-20 % show the following problems:

Stronger self-heating of the stored matter with a risk of self ignition

Degradation of the carbon

Danger of mildew formation and ill-smelling emissions

In dependence from moisture content and grain size of the biofuel product specific precautionary measures may have to be applied such as forced aeration, reduction of storage height and constructional modifications of the side walls.

Biomass with a high moisture content does not hold steady during storage. Aside from a risk of self-ignitation, micro-biological degradation of the material, the formation of odours and mildew development are taking place to a larger extent. Either the biomass is being dried (for example by means of exhaust heat from the combustion facilities) before the energetic utilisation or a biological pretreatment undertaken (see wet biomass).

Wet biomass (e.g. turnip, grass, maize, mustard)

Wet biomass can basically be stored in silos as well as in flat bunkers under anaerob conditions. However, appropriate conditions need to be created for the anaerob degradation processes. In the degradation, a certain amount of carbon gets converted and is furthermore not any longer available for the energetic utilisation. It is for this reason that a storage of wet biomass is not very much advisable, especially that prior to its energetic utilisation a mechanical dewatering with a subsequent thermal drying must be undertaken first.

Fluid biofuels (rape oil)

Fluid biofuels such as rape oil etc. can be stored in semi-mobile tanks up to a volume of 1 m³ or in ordinary tank farms. In tank farms using single-walled tanks up to a volume of 10 m³ additional storage volumes have to be kept aside for possible leakages and spills.

Tanks and other storage devices with a potential volume capacity above 10 m³ should in any case dispose of a double-walled construction[7].

According to the expert agency for renewable resources (Fachagentur Nachwachsende Rohstoffe e.V.), rape oil does not fall into the category of water-polluting substances and with its flashing point above 220 °C must not be considered under the regulations for the handling of inflammable goods, respectively.

Further influencing factors

Fuel properties:

In case that the process for the energetic utilisation demands for a conditioning of the fuel product (e.g. generation of pellets), the conditioning will have to take place before the storage. In this context, storage properties such as moisture content but also mechanical properties like resistance to deformation and abrasion can be positively influenced (e.g. by adding binders or other additives).

Transport distances

Depending on the distance between the place where the biomass has been generated and the place of its use for energetic processes a compression of the biofuel can be useful for enhancing the efficiency of transportation. Usually this is achieved through the baling of the lose dry biomass (e.g. hay/straw).

Transportation/storage costs

[7] Source: Expert agency for renewable resources (Fachagentur Nachwachsende Rohstoffe e.V.)

The costs for the transportation/storage differ strongly in dependence from the biomass used, the way of its processing, the transportation distances and other related factors.

3.2.1.4 Handling and feeding

To operate the storage units, wheel loader, gripper and crane equipment of different types are in use. Likewise suitable for material forwarding are walking-floor systems, and in the case of silos, pneumatic or otherwise operated conveyor systems.

Wheel loader

Wheel loader (Figure 3.2-1) have the advantage of being also available for other uses beside the operation of the storage area. This is of particular relevance if other waste management facilities, such as landfills or composting sites are close by and need to be managed at the same time. The operation with wheel loaders is especially suited to combustion facilities of small to medium size.

Figure 3.2-1: Wheel loader[8] in operation

Gripper and crane systems

For operating the storage bunkers of waste management facilities, gripper and crane systems (Figure 3.2-2) are the most common. Also facilities for the energetic utilisation of biomass avail of such systems. The advantages are the robust and little failure prone construction of these systems and the possibility to use the storage space in the most optimised way and to mix the material. The use of this technique furthermore allows disturbing materials to be easily accessed and removed from the storage area. Gripper and crane systems in larger storage facilities are usually double secured, i.e. set up in a way that a second aggregate can take over when a breakdown occurred on the first one, and their operations are programmable and remotely controlled.

Figure 3.2-2: Crane system in operation[9]

Walking-floor systems

The operating principle of walking-floors systems (Figure 3.2-3) is as follows: Weight and friction of a material against the surface area of two sets of planks is greater than the

[8] www.radlader.bau-portal.com
[9] www.energie-beratung.at

weight and friction of a material against a single, third set of planks. This allows an individual set of planks to move underneath the material as the other two sets hold the material in a stationary position. After all planks have individually moved backward beneath the material, they then move together, in the unloading direction, conveying thus the material[10] forward. The planks are made of aluminium or stainless steel.

Figure 3.2-3: Walking-floor system[10]

The walking-floor system permits the continuous discharge of the fuel product from the storage area. Depending on the properties of the product to be transported, a walking-floor system can be more failure prone than gripper or crane systems, however. Also the targeted removal or discharge of a disturbing material is not possible with this technique.

Pneumatic or otherwise operated conveyor systems

Pneumatic or other, mechanically operated conveyor systems (conveyor belts, screw-conveyor- Figure 3.2-4-, etc.) are specially suited to the storage in silos and for fuel products with a small (e.g. sawdust) or a defined particle size (wood pellets). With this equipment it is possible to forward the fuel material directly from the delivery truck into the hold-up bunker set up before the combustion chamber or also via a temporary storage unit to this place.

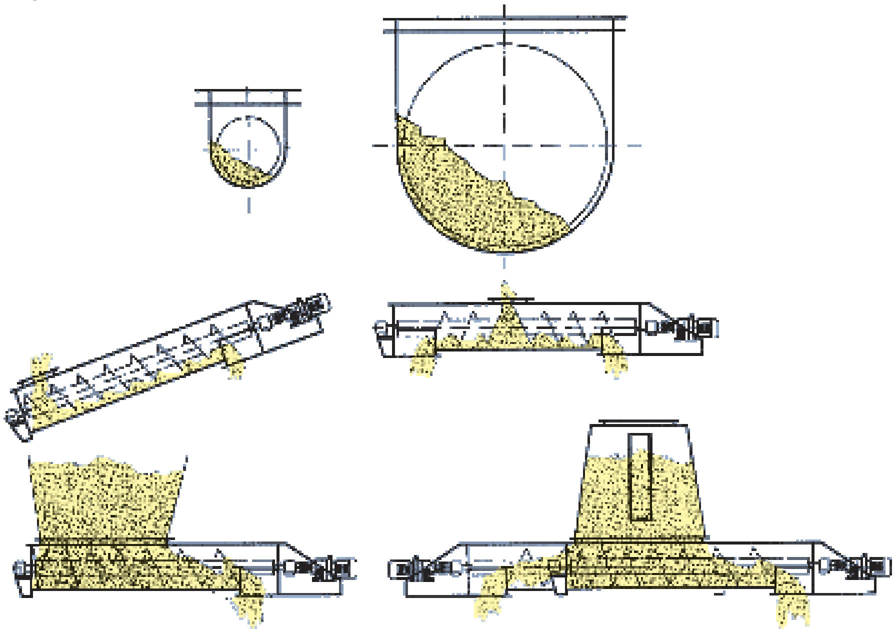


Figure 3.2-4: Options for forwarding processes with screw-conveyor [11]

3.2.2 Drying

A conditioning of the fuel materials must be undertaken in dependence on the kind and manner of the combustion process (e.g. particle size, calorific value and moisture content). An essential criterion for the storage persistence of fuel products, beside general fuel properties, is the moisture content.

[10] www.keithwalkingfloor.com
[11] www.gefa-konstanz.de

The objective of drying the fuel material lies in an increase of the calorific value and thus the creation of an optimal state for a direct combustion or the further processing into high-quality fuels (pellets). Drying prevents mildew and the contamination of the fuel material with bacteria reliably. Following options for drying exist and shall be briefly described hereafter.

3.2.2.1 Open air drying

One possibility for the drying of biomass is presented in the ***air drying***. In this drying method, physical (wind, sun energy) as well as biological processes (self-heating due to biological decomposition) are used. The time period for drying is influenced from the moisture content of the air and the fuel material and the material properties mainly.
In wood chips, water is present in the binded (due to the molecular binding forces in the wood cells) and free form. Depending on the tree species, the fibre saturation point (FSP) varies between 18 % and 26 % water content[12]. By means of air drying, water content can be decreased up to a level of 15 % to 20 %.
The height of stockpiling the fuel material for air drying must be limited and a restacking ensured in order to obtain the same result of drying throughout the entire pile.

3.2.2.2 Biomass drying by flue gas

A technically supported drying process can help to decrease the water content of the biomass in much shorter time and at a larger extent than a natural drying method can do. Depending on the quantity of the material which need to be dried in a certain time span, the appropriate technolgy has to be chosen.
Different aggregates for the drying of wood chips, animal manure, straw and other biomass with the potential for energetic utilisation are offered at the market. Within the spectrum of available equipment one can distinguish between staionary and mobile aggregates.
The drying is technically realised by means of separate heat flows generated from gas burners. There are also drying aggregates available which operate on the basis of various low calorific heat transfer media such as exhaust air, flue gases, hot (process) water and steam. Additional heat needed for the drying can be generated through the combustion of gas (natural gas, propan, fermentation gas) or heating oil.
In principle it is possible to put biomass at a certain thickness and density on a special grating and let the exhaust heat pass through it so that the natural drying process will be accelerated. The moist air generated in that way condenses at the colder side walls from where it is collected and taken out from the drying chamber. Very often special drying systems are used, however. Three different types shall be described here in more detail:
Special drying systems, for example those offered by the company Stela[13] , allow the water content in fresh wood chips of originally 40 % to 60 % to be reduced up to 10 % to 12 % and thus the calorific value of the material to rise from 2 kWh/kg up to 4.5 kWh/kg. The equipment used here are predominantly of the ***drum dryer*** type (Figure 3.2-5). Most often this kind of aggregate is used for the drying of chopped potatoes and turnip chips, chicken manure, sewage sludge, tree bark, wooden offcuts and chopped green fodder.

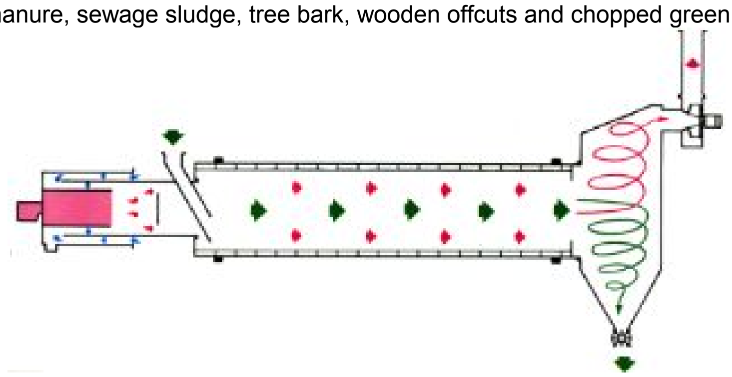


Figure 3.2-5: One-way drum dryer

[12] State Agency for Forestry (Landesanstalt für Wald- und Forstwirtschaft), „Partly mechanised supply, storage and logistics of wood chips. (Teilmechanisierte Bereitstellung, Lagerung und Logistik von Waldhackschnitzel)", www.lwf.bayern.de
13 Laxhuber GmbH –http://www.stela.de

The shear-and-turn drying aggregate [*Schubwendetrockner*] (Figure 3.2-6) from Stela is used for drying foliate plants, herbal material, grasses, pellets, granule, wood chips, different pulp and many other materials.

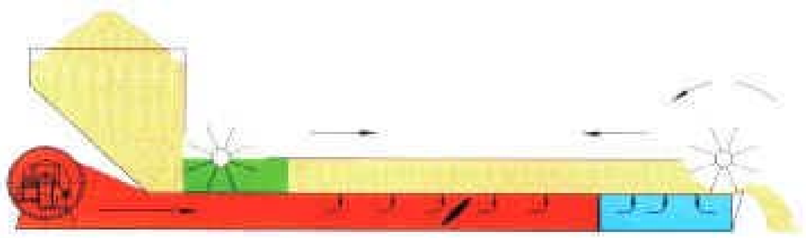


Figure 3.2-6: Shear-and-turn aggregate for drying (pass through drying – yellow; biomass – green; pre-heating zone (warm air) – red; cooling air - blue)

In this aggregate, warm air is blown through the double-layer flooring set up in form of a grating and passes through the drying material. A moveable paddle wheel forwards and mixes the whole material throughout the entire drying time. This simple process arrangement ensures almost care-free and undisturbed drying operations. A trolley moves the paddle wheel several times across the drying area. The change of direction is initiated automatically by an end-off limit switch and a steering panel. This way a good restacking and consequently a steady and homogenous drying is being achieved. Once the desired state of drying has been reached, a cooling process can be initiated, if necessary.

Some plant construction companies do also offer equipment which can be used to dry baled material. In a pilot test program round bales from hay with a original water content of 30% to 35% have been dried with a RTS-aggregate[14] (Figure 3.2-7). After a period of 20 hours, the dry matter content had reached 90 % already. A precondition for the successul drying is that the bales have not been in a too dense state so that a penetration of air is still possible. Contrary to other technologies, the RTS-aggregate does not work with the external heating of air but sucks in air from the surroundings which is then dehumified from a high power heat pump and blown through the material.

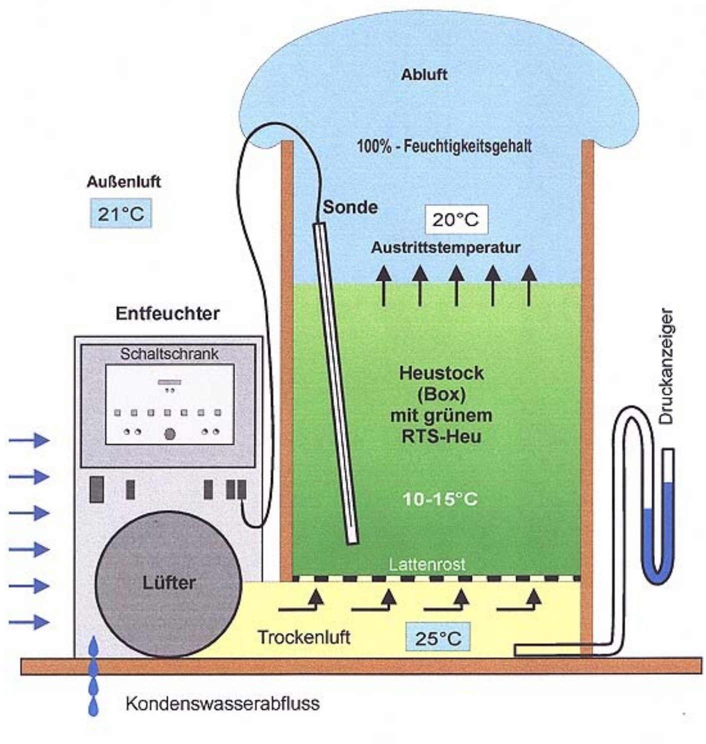


Figure 3.2-7: Principle of drying biomass with the RTS-aggregate

[14] RTS Trocknungstechnik GmbH A - 9654 St. Lorenzen 117

With the exemption of the RTS-process, exhaust heat coming from combustion facilities and power plants can basically be used with a minimal technical modification in all the drying processes described beforehand. Dry exhaust heat can be applied directly. It has to be noted, however, that a direct drying process with exhaust heat from combustion processes must be combined with a subsequent treatment (cleaning) of the flue gases.
The drying of biomass by technical means represent a considerable cost factor in the frame of the energetic utilisation of this type of material. The application of this process step should therefore be preceded by a thorough examination whether simple drying methods are available (natural drying, solar drying) and what drying intensity is at all required for the subsequent combustion.

3.2.2.3 Biomass drying by steam

Where steam shall be used for the drying of wet biomass a dehumidification of it must be undertaken beforehand. Such can be achieved by means of heat pumps or in that the hot steam is used in a heat exchanger to heat up dry air which is then forwarded to the drying system. In terms of the aggregates employed for drying, the same applications as shown in 3.3.2 are being used.

3.2.3 Fuel processing

Depending on the combustion technology used fuel products must fulfill different requirements. The demand to get the fuel product either powdered or as fluff, in pelletised form,or as briquettes or chips of defined size is not uncommon.

3.2.3.1 Powdered fuels

Fuel material of small particle size (e.g. sawdust) is being generated by many production processes. With the appropriate combustion technology in place, such fuels can be directly utilised. Special requirements exists when the material is considered as waste. The German „Technical ordinance for dangerous matter-553“, for example describes essential security measures that must be undertaken while dealing with sawdust. The storage of fuel products with a small particle size can be done in flat bunkers and in silos. However, special provisions are also made with respect to fire protection and prevention of explosions during the storage of these materials (e.g. 7. BImSchV[15]).

3.2.3.2 Briquetting

Briquetting presses operate as piston compressors with a fly wheel, slider crank, crosshead and plunger or with a hydraulic drive. After initial compression in a screw conveyor the material passes under pressure batch wise through the compression tools, cone for pre-compression and the press nipper. Within the press nipper a heating or cooling can be done. The briquette is wedged from the pneumatic press nipper in a pressure variable way [16].
Piston rod presses are being used for the compression of sawdust, splinter, straw, paper fibres and similar materials. Figure 3.2-8 shows rod briquettes.

Figure 3.2-8: Rod briquettes[17]

Through the production of briquettes in various shapes, a optimal burning (burnout, burning duration) of the fuel material can be achieved.

15 7 BImSchV: BGBL. I S. 3133, Dezember 1975
16 Bilitewski, B., Härdtle G., Marek K.: Abfallwirtschaft-Handbuch für Lehre und Praxis- 3., neubearbeitete Auflage, 2000
17 www.holzpellets.com

3.2.3.3 Pelletising

A pelletising of fuel material (Figure 3.2-9) permits higher throughput rates as in comparison with briquetting. Often pelletising is also preferred because of the additional comminution which takes place in the pan grinder. Bilitewski et. al. states the following advantages of fuel pelletising:

- Reduced storage volume through an increased bulk density of the lose fuel material,
- Better flow properties and dosage,
- Avoidance of bridges and clumping in silos and conveyor aggregates
- Enhancement of the energy density and calorific content by pressure and heat.

Three basic types of pelletising aggregates can be differentiated:

- John-Deere-press,
- Ring stencil press
- Flat stencil press

Aside from compression pressure and grain size, also water content plays an essential role in the process. Adding binding agents can help to improve the physical and chemical quality and enhance the burnout. Kiesewalter[18] studied the effect different additives have in the pelletising of fibrious biomass (melasse, modified starch, wood splinter) on the example of a pan grinder-flat stencil press. Investigations done from Röhricht et al[19]. show on the example of topinambur, that binding agents (in the specific case dried sewage sludge) can improve the fuel properties significantly.

Common standards and quality certificates exist for wood chips (e.g. Germany DIN 51731, Gütesiegel „Deutscher Energie Pellet Verband [DEPV], e.g. Austria Ü-Norm M 7135, Gütesiegel des Pelletverbandes Austria [PVA]).

Figure 3.2-9: Wood pellets[20]

Essential requirements on the quality of wood pellets and procedures for their assessment have been compiled from Schubert[21] . Quality attributes are for example.

- surface finish
- durability
- abrasion
- share of fine material
- ash content
- calorific value
- heavy metal content
- content on sulphur, nitrogen and chlorine.

18 Kiesewalter,. S., Röhricht, Ch.: Pelletproduktion aus halmgutartiger Biomasse, Vortrag zur Tagung im Landwirtschaftszentrum Haus Düsse, Bad Sassendorf; Wohlige Wärme aus Land- und Forstwirtschaft -Stand der Technik und Perspektiven; 2004

19 Röhricht, Ch., Beier, Th, Brix, B., Groß-Ophoff A.: Untersuchungen zum Einsatz land- und forstwirtschaftlicher Biomasse als Energieträger im Freistaat Sachsen, Abschlußbericht 12/200 zum Forschungsprojekt

20 Quelle: www.holzpellets-online.de

21 Schubert, A.: Holzpellets-Qualität erkennen in: www.rhoen-hessen-forstconsulting.de

3.2.4 Combustion technology

3.2.4.1 General remarks – Overview

The fuel properties essentially influence the course of the combustion of biomass and the process of emission. For the energetic use the elemental composition, the combustion process conditions and physical-mechanical properties are of importance.

3.2.4.1.1 Chemical composition of biomass

Herbal biomass mainly consists of carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S). Besides them there are elements like potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), chlorine (Cl). Furthermore, they consist of a number of trace elements like e.g. sodium (Na), silicon (Si), iron (Fe), zinc (Zn) and copper (Cu).

Solid herbal biomass primarily comprises carbon, hydrogen and oxygen. Carbon and hydrogen are the components assigning the released energy by oxidation; meanwhile oxygen is only supporting the oxidation.

3.2.4.1.2 Moisture content

The moisture content of biomass fuels varies considerably, depending on the type of biomass and biomass storage. It essentially influences the calorific value of the fuel. During the combustion less or more water has always to be evaporated hence biomass without moisture is not naturally occurring. The required heat is taken from the converted and released energy and is therefore reducing the net energy efficiency.
Besides, the moisture content influences the storage possibilities of the fuel. A moisture content of >16% causes biological degradation and consequently the calorific value is reduced.

3.2.4.1.3 Calorific value (H_U)

The calorific value is the amount of heat generated by a given mass of fuel when it is completely burned. It is measured in joules per kilogram. Calorific values are measured experimentally with a bomb calorimeter.
The calorific value of biomass fuels is much more prejudiced by the moisture content than by the kind of biomass. For this reason only calorific values of absolutely dry biomass are compared. The net calorific value of biomass fuels usually varies between 16,5 and 19 MJ/kg [Kaltschmitt, 2001].

3.2.4.2 Most common combustion principles/systems

There are different biomass combustion systems available for mid- and large-scale plants. Each system needs to be properly designed for a specific fuel type in order to guarantee adequate combustion quality and low emissions.

Furnaces are generally equipped with mechanic or pneumatic fuel-feeding systems.
The following combustion principles can be distinguished:

- fixed-bed combustion (underfeed stoker or grate furnace)
- fluidised-bed combustion (bubbling or circulating)
- dust combustion

The basic principles of these technologies are shown below in Figure 3.2-10. Variations of these technologies are available but not further described here.

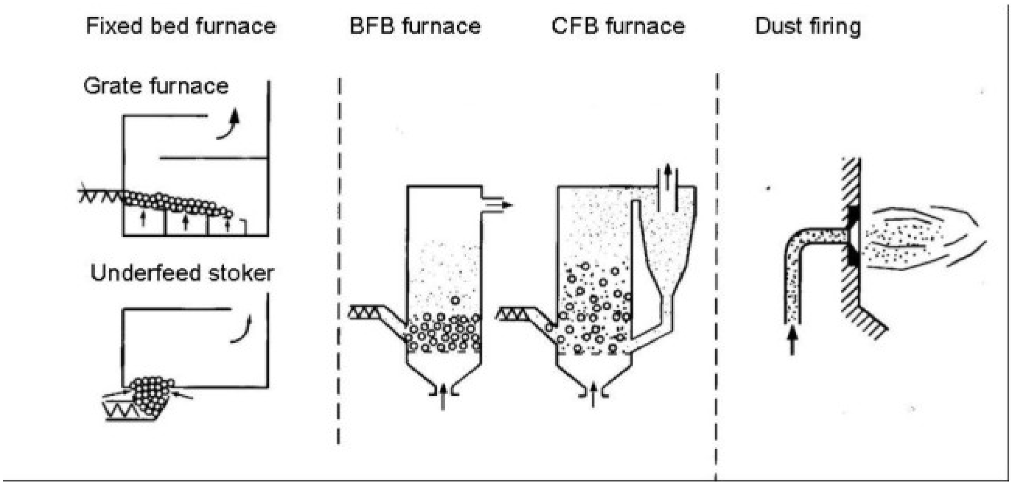


Figure 3.2-10: Principle combustion technologies for biomass [Loo, 2003]

3.2.4.2.1 Fixed-bed combustion

Fixed-bed combustion systems include grate furnaces (Figure 3.2-11) and underfeed stokers (Figure 3.2-12). Primary air passes through a fixed bed where drying, gasification and charcoal combustion takes place. The combustible gases produced are burned after secondary air addition has taken place (usually in a combustion zone separated from the fuel bed).

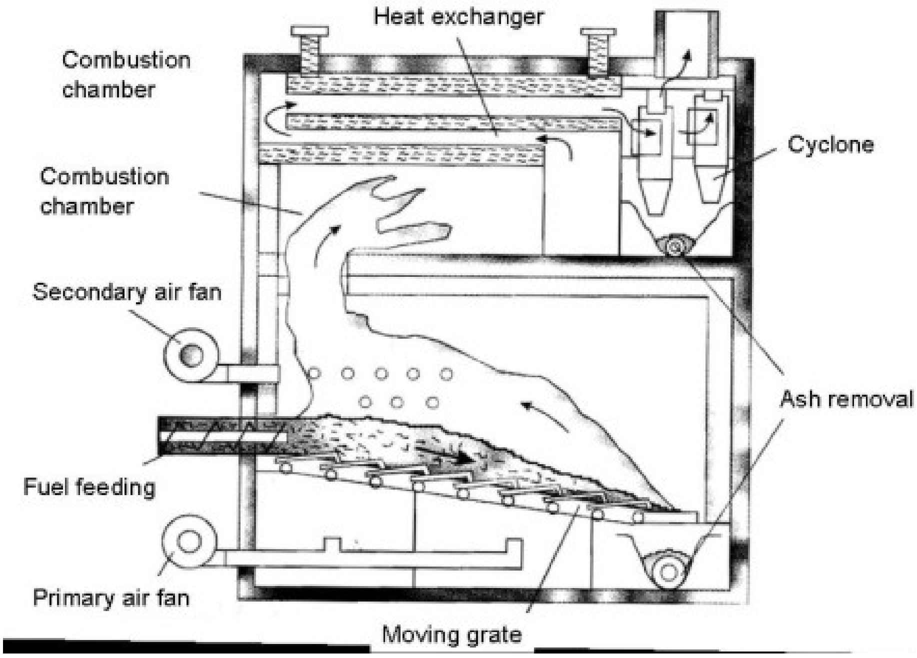


Figure 3.2-11: Grate combustion with counter-current flow (flame in the opposite direction as the fuel → suitable for wet biomass) [Kaltschmitt, 2001]

Grate furnaces are suitable for biomass fuels with high moisture content, varying particle sizes and high ash content. Mixtures of wood fuels can be used but current technology does not allow mixtures of wood fuels and straw, cereals and grass due to their different combustion behaviour, low moisture content and low ash melting point. A homogenous distribution of the fuel and the bed of embers over the whole grate surface have to be guaranteed to assure an equal primary air supply over the various grate areas. If not, slagging, higher ash amounts and excess of oxygen may increase.
The technology needed to achieve these aims includes continuously moving grates, a height control system of the bed of embers (e.g. by infrared beams) and frequency-height controlled primary air fans for the various grate sections.

Another important aspect of grate furnaces is that a staged combustion should be obtained by separating the primary and the secondary combustion chambers in order to avoid back-mixing of the secondary air and to separate gasification and oxidation zones.

The geometry of the secondary combustion chamber and the secondary air injection have to guarantee a mixture of flue gas and air that is as complete as possible. The better the mixing the lower the excess of oxygen that is necessary for complete combustion and the higher the efficiency. [Loo, 2003]

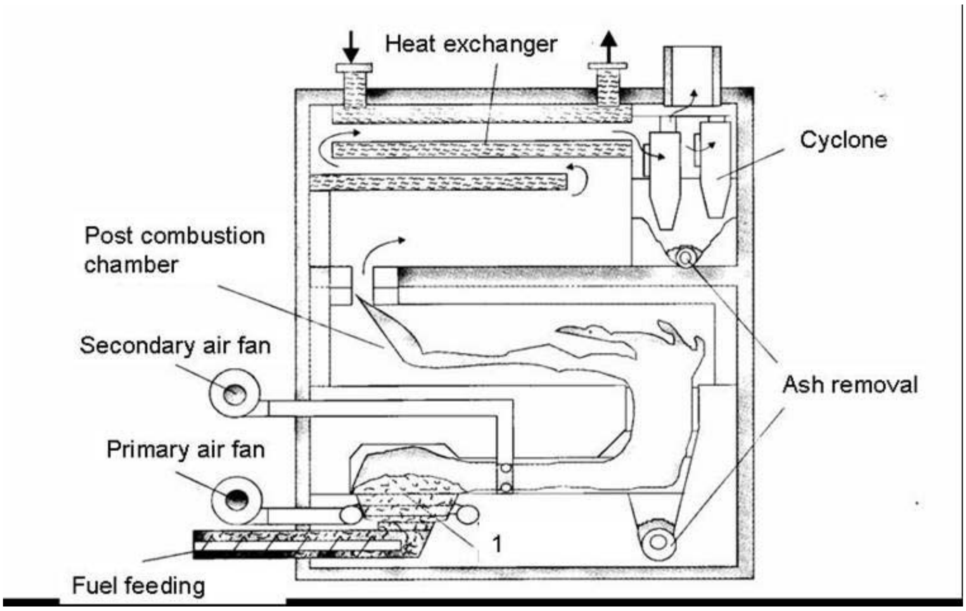
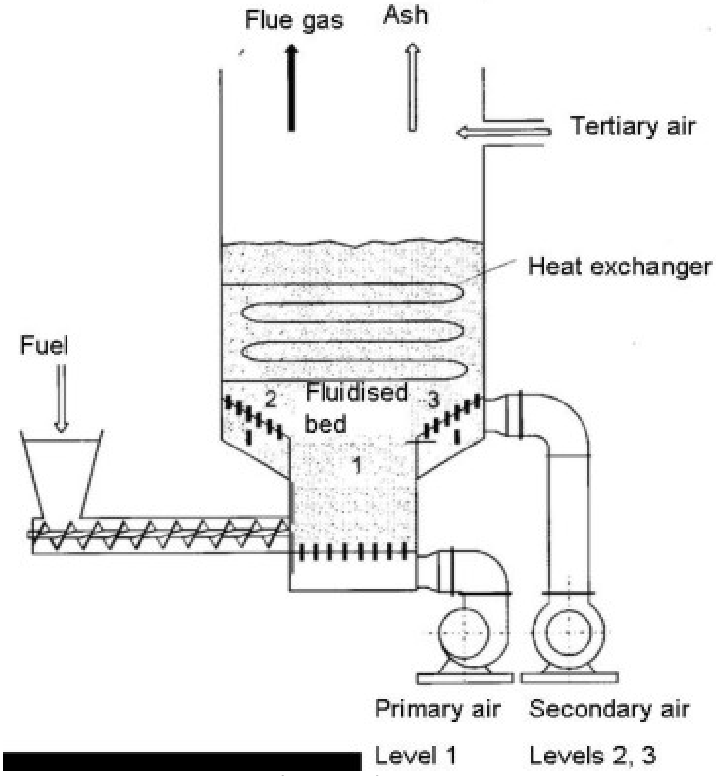


Figure 3.2-12: Diagram of an underfeed stoker furnace (1 = understoker zone with glow bed) [Kaltschmitt, 2001

Underfeed stokers represent a cheap and operationally safe technology for small- and medium-scale systems up to a nominal boiler capacity of 6 MW_{th} [Loo, 2003]. The fuel is fed into the combustion chamber by screw conveyers from below and is transported upwards to an inner or an outer grate. Outer grates are more common because they allow a more flexible operation and an automatic ash removing system can be attained easier. Primary air is supplied through the grate and secondary air usually at the entrance to the secondary combustion chamber.

3.2.4.2.2 Fluidised-bed furnace BFB

Within a fluidised-bed furnace (Figure 3.2-13), biomass fuel is burned in a self-mixing suspension of gas and solid-bed material into which combustion air enters from below. Depending on the fluidisation velocity, bubbling fluidised bed and circulating fluidised bed can be distinguished. A fluidised bed consists of a cylindrical vessel with a perforated bottom plate filled with a suspension bed of hot, inert and granular material. The common bed materials are silica, sand and dolomite. Primary combustion air enters the furnace from below through the air distribution plate and fluidises the bed so that it becomes a seething mass of particles and bubbles. The combustion temperature has to be kept low (800-900°C) in order to prevent ash sintering in the bed.



[redacted]

Figure 3.2-13: Diagram of a BFB furnace with three air introduction zones [Kaltschmitt, 2001]

Due to the good mixing achieved, fluidised-bed combustion plants can deal flexibly with various fuel mixtures but are limited when it comes to particles size and impurities contained in the fuel. Therefore, appropriate fuel pre-treatment (particle size reduction, separation of metals) is necessary.
The low excess air quantities necessary increase combustion efficiency and reduce flue gas volume flow. That is why it is especially interesting for large-scale applications (boiler capacity > 30 MW_{th}) [2]. Investment and operation costs are very high for small plants compared with fixed-bed systems.

A disadvantage is that high dust loads entrained with flue-gas make efficient dust precipitators and boiler cleaning systems necessary. Bed material is lost with ash, making it necessary to ad new material to the plant periodically.

For **bubbling fluidised bed combustion (BFB)** particle size below 80 mm is recommended. Mostly for plants with a boiler capacity > 20 MW_{th}, BFB furnaces are of interest. The fluidisation velocity of the air varies between 2,0 and 2,5 m/s. The secondary air is introduced through several inlets in the form of horizontal arranged nozzles at the beginning of the upper part of the furnace to ensure a staged-air supply to reduce NO_x emissions. The fuel amounts only 1-2% of the bed material and the bed has to be heated before the fuel is introduced. The advantage of BFB is their flexibility concerning particle size and moisture content of the biomass fuels. It is also possible to use mixtures of different biomass fuels. One disadvantage are the difficulties they have at partial load operation. It is solved by splitting or staging the bed.

By increasing the fluidising velocity to 5 to 10 m/s and using smaller sand particles (0,2 to 0,4 mm in diameter) a **circulating fluidised bed combustion (CFB) (**Figure 3.2-14**)** is achieved. The sand particles will be carried with the flue gas, separated in a hot cyclone or U-beam separator and fed back into the combustion chamber. The higher bed temperature in CFB furnaces leads to a better heat transfer and a very homogenous temperature distributing in the bed. This is of advantage for stable combustion conditions, the control of air staging and the placement of heating surfaces right in the upper part of the furnace.

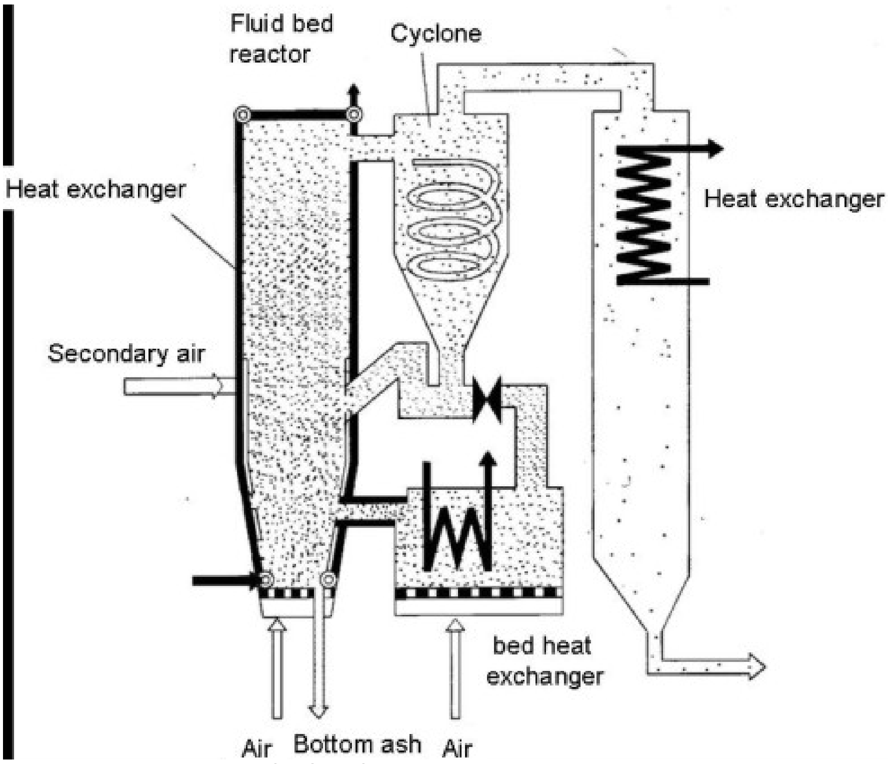


Figure 3.2-14: Diagram of a CFB furnace with steam boiler [Kaltschmitt, 2001]

The disadvantages are the larger size and therefore the higher price, the even greater dust load in the flue gas leaving the sand particle separator than in BFB systems, the higher loss of bed material in the ash and the small fuel particle size (0,1-40 mm in diameter) required. These systems are of interest for plants of more than 30 MW_{th}.[Loo, 2003]

3.2.4.2.3 Dust combustion

Dust combustion is suitable for fuels available as small particles (average < 2 mm) like sawdust and fine shavings. A mixture of fuel and primary combustion air is pneumatically injected into the combustion chamber (Figure 3.2-15). Combustion takes place while the fuel is in suspension and gas burnout is achieved after secondary air addition. Fuel quality has to be quite constant. A maximum particle size (10-20 mm) has to be maintained and fuel moisture content should not exceed 20 wt%. Due to the explosion-like gasification of the fine and small biomass particles, the fuel feeding needs to be controlled very carefully.

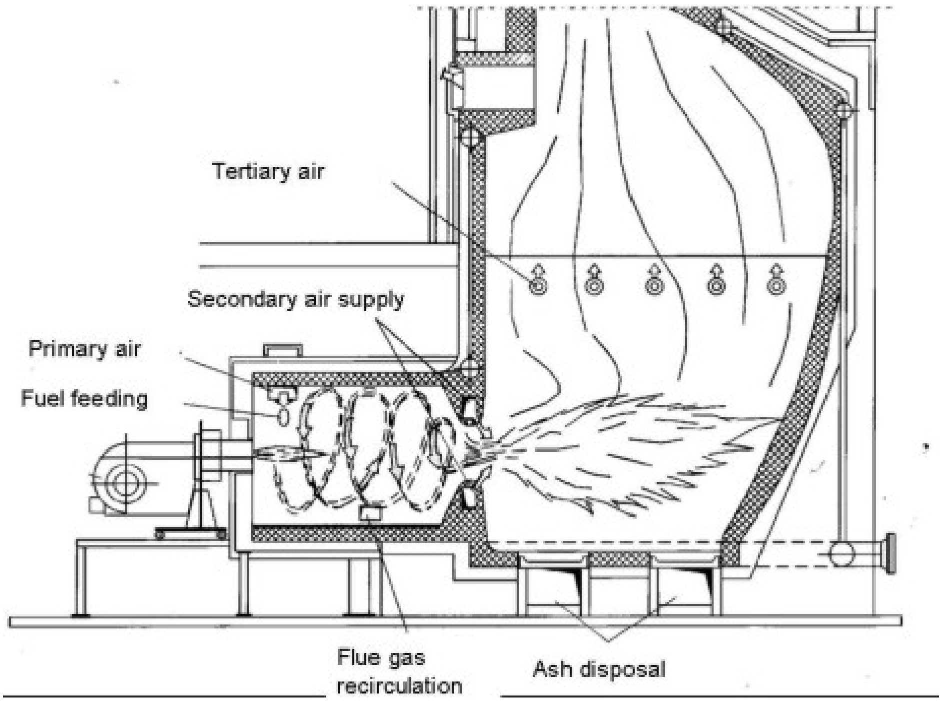


Figure 3.2-15: Diagram of a dust combustion plant [Kaltschmitt, 2001]

The fuel/air mixture is usually injected tangentially into the cylindrical furnace muffle to establish a rotational flow. Fuel gasification and charcoal combustion take place at the same time because of the small particle size. Therefore, quick load changes and an efficient load control can be achieved. A disadvantage is that insulation bricks wear out quickly due to the thermal stress and erosion.

3.2.4.2.4 Summary

The following tables provides an overview of relevant advantages and disadvantages (Table 3.2-1, Table 3.2-2), and fields of application of different biomass combustion technologies (Table 3.2-3).

Table 3.2-1: Overview of advantages, disadvantages and fields of application of different biomass combustion technologies [Loo, 2003]

Advantages	Disadvantages
underfeed stokers	
• low investment costs for plants < 6 MW(th) • simple and good load control due to continuos fuel feeding • low emissions at partial load operation due to good fuel dosing	• suitable only for biofuels with low ash content and high ash-melting point (wood fuels) • low flexibility in regard to particle size
grate furnaces	
• low investment costs for plants < 20 MW(th) • low operating costs • low dust load in the flue gas • less sensitive to slagging than fluidised bed furnaces	• no mixing of wood fuels and herbaceous fuels possible • efficient NOx reduction requires special technologies • high excess oxygen (5 - 8 Vol%) decreases efficiency • combustion conditions not as homogeneous as in fluidised bed furnaces • low emissions level at partial load operation is difficult to achieve
dust combustion	
• low excess oxygen (4 - 6 Vol%) increases efficiency • high NOx reduction by efficient air staging and mixing possible if cyclone or vortex burners are used • very good load control and fast alternation of load possible	• particle size of biofuel is limited (< 10-20 mm) • high wear out of the insulation brickwork if cyclone or vortex burners are used • an extra start-up burner is necessary

Table 3.2-2: Comparison of the most important combustion technologies with automatically fuel-feeding systems (ash content referred to dry substance) [Kaltschmitt, 2001]

BFB furnaces	
• no moving parts in the hot combustion chamber • NOx reduction by air staging works well • high flexibility concerning moisture content and kind of biomass fuels used • low excess oxygen (3 - 4 Vol%) raises efficiency and decreases flue gas flow	• high investment costs, interesting only for plants > 20 MWth • high operating costs • low flexibility with regard to particle size (< 80 mm) • high dust load in the flue gas • operation at partial load requires special technology • medium sensitivity concerning ash slagging • loss of bed material with the ash • medium erosion of heat exchanger tubes in the fluidised bed
CFB furnaces	
• no moving parts in the hot combustion chamber • NOx reduction by air staging works well • high flexibility concerning moisture content and kind of biomass fuels used • homogeneous combustion conditions in the furnace if several fuel injectors are used • high specific heat transfer capacity due to high turbulence • use of additives easy • very low excess oxygen (1 - 2 vol%) raises efficiency and decreases flue gas flow	• high investment costs, interesting only for plants > 30 MW(th) • high operating costs • low flexibility with regard to particle size (< 40 mm) • high dust load in the flue gas • partial-load operation requires a second bed • loss of bed material with the ash • high sensitivity concerning ash slagging • loss of bed material with the ash • medium erosion of heat exchanger tubes in the furnace

Table 3.2-3: Main characteristics of the main combustion technologies

Type	Capacity range	Fuel	Moisture content [%]
Underfeed stoker	10 kW – 2,5 MW	Wood chips (ash content ≤ 1%), wood pellets	5 – 50
Grate furnace	150 kW – 15 MW	All woody fuels (ash content ≤ 50%)	5 – 60
bubbling fluidised bed combustion	5 MW – 15 MW	Fuel size ≤ 10 mm in diameter	5 – 60
Circulating fluidised bed furnace	15 MW – 100 MW	Fuel size ≤ 10 mm in diameter	5 – 60
Dust furnace	2 MW – 10 MW	Fuel size ≤ 5 mm in diameter	Mainly < 20

3.2.4.3 Flue gas cleaning (FGC)

3.2.4.3.1 Flue gas cleaning overview

Biomass combustion influences the environment mainly through emissions. The amount of pollutants emitted to the atmosphere from different types of biomass combustion applications is highly dependent on the implemented combustion technology, the primary and secondary emission reduction measures and the fuel properties.
Emissions from biomass combustion can be divided into two different groups:

- emissions from complete combustion (Carbon dioxide - CO_2, Nitric oxides - NO_X, Sulphur oxides - SO_X, Hydrogen chloride - HCl, particles, heavy metals)

- emissions from incomplete combustion (Carbon monoxide - CO, Methane – CH_4, particles)

Reduction of harmful missions through flue gases and effluents can be obtained by either avoiding generation of these substances (primary treatment) or removing the substances from the flue gas (secondary measures).

3.2.4.3.2 Primary emission reduction measures

Preventing or reducing the formation of emissions and/or reduction of emissions within the combustion chamber are primary emission reduction measures. Several possible measures are:

- modification of the fuel composition, particle size or moisture content
- improved construction of the combustion application
- selection of type of combustion equipment
- combustion process control optimisation
- staged-air combustion
- staged fuel combustion and reburning
- catalytic converters

In practice these measures mostly are interrelated.

First of all, fuel characteristics such as fuel composition, moisture content and particle size are important. Substantial emission reduction can be achieved for emissions from incomplete combustion and NO_X emissions by the best possible combustion technology for a given fuel and by optimising the combustion process.
A high **moisture content** in the fuel makes it difficult to achieve s sufficient high temperature in the combustion chamber. To ensure a low level of carbon monoxide (CO) often a temperature above 850 °C is desired, otherwise an incomplete complete combustion occurs with high emissions as result.
Typical **process control parameters** for biomass combustion are the CO, C_XH_Y and O_2 concentrations in the flue gas, as well as combustion chamber and boiler temperatures. Process variables, which can directly be adjusted to achieve the targets for the mentioned process parameters are usually the amount of fuel fed into the furnace and the amount of primary and secondary combustion air supplied.
Staged-air combustion is widely applied in biomass combustion plants, also in small scale applications. It is possible to reduce simultaneously emissions from incomplete combustion and NO_X through a separation of devolatilisation and gas phase combustion. In the first stage, primary air is added for devolatilisation of the volatile fraction of the fuel and in the second stage, sufficient secondary air is supplied to ensure a good burnout.
Staged fuel combustion and reburning are other possible measures to reduce NO_X during biomass combustion.
Catalytic converters are used to some degree in small-scale biomass combustion plants. Placed in the flue gas channel after the combustion chamber, the catalytic converter introduces the possibility for heterogeneous reactions on the surface. Hence the emissions from incomplete combustion can efficiently be removed

3.2.4.3.3 Secondary emission reduction measures

Secondary measures are applied to remove emissions from the flue gas once it has left the boiler. For virgin wood combustion, particle removal is of particular relevance. For other types of biomass, depending on the elementary composition, the fuel characteristics and the combustion technology, additional measures may be necessary.

The following rules may be helpful in selecting particle control technologies for biomass combustion applications [Loo, 2003]:

- Sticky particles have to be collected in a liquid, as in a scrubber or in a cyclone, bag filter or an electrostatic filter whose collecting surfaces are continually coated with a film of flowing liquid
- Particles that stick to each other but not to solid faces are easy to collect.
- The electrical properties of the particle are of dominant importance in electrostatic filters.
- For non-sticky particles smaller than 5 μm a cyclone separator is probably the only device to consider.
- For particles much smaller than 5 μm electrostatic filters, bag filters and scrubbers are considered.
- For large flows pumping cost makes scrubbers very expensive, other devices are preferable.
- Corrosion resistance and drew point must always be considered.

Table 3.2-4 summarizes the typical sizes of particles removed by several proven particle control technologies and removal efficiencies.

Table 3.2-4: Summary of typical sizes of particles removed by various particle control technologies [Loo, 2003]

Particle control technology	Particle size (µm)	Efficiency (%)
Settling chambers	> 50	< 50
Cyclones	> 5	< 80
Multicyclones	> 5	< 90
Electrostatic filters	< 1	> 99
Bag filters	< 1	> 99
Spray chambers	> 10	< 80
Impingement scrubbers	> 3	< 80
Cyclone spray chambers	> 3	< 80
Venturi scrubbers	> 0.5	< 99

<u>Settling chamber</u>

Principle of operation: Particle separation is based on the principle of gravity but the disadvantage is the low collection efficiency. However, it has the ability to extinguish the flame. The advantages and disadvantages are summarised below (Table 3.2-5)

Table 3.2-5: Advantages and Disadvantages of a settling chamber [Loo, 2003]

Advantages	**Disadvantages**
Low pressure High capacity Low costs Simplicity of design and maintenance	Much space required Low collection efficiency

Cyclone

Principle of operation: Particle separation is based on the principle of gravity in combination with centrifugal forces and therefore it has higher collection efficiency than settling chambers. Gas and solid particles are exposed to centrifugal forces. Gas either flows in axial or tangential direction into the cyclone. Particles hit the wall and slide down into the container. The advantages and disadvantages are summarised below (Table 3.2-6).

Table 3.2-6: Advantages and Disadvantages of a cyclone [Loo, 2003]

Advantages	Disadvantages
simplicity of design and maintenance little floor space required dry continuous disposal of collected dust low to moderate pressure lost handles large particles and high dust loads temperature independent ability to extinguish the flame low costs	much head room required low collection efficiency of small particle sensitive to variable dust loadings and flow rates tars may condense

Electrostatic filter

Principle of operation: In this filter the particles are first charged and then exposed to an electrical field, where the particles are attracted to an electrode. Periodically, this electrode is cleaned through vibration – dust falls of the electrode into a collection unit. The advantages and disadvantages are summarised below (Table 3.2-7).

Table 3.2-7: Advantages and Disadvantages of an electrostatic filter [Loo, 2003]

Advantages	Disadvantages
99 % efficiency obtainable very small particles can be collected particles may be collected wet or dry pressure drops and power requirements are small compared with other high efficiency collectors maintenance is nominal unless corrosive or adhesive material is handled few moving parts can operate at high temperatures (< 480°C) applicable for high flue gas flow rates	relatively high initial costs sensitive to varying particle loadings or flow rates resistivity causes some material to be economically uncollectable precautions are required to safeguard personal from high voltage collection efficiencies can <gradually and imperceptibly voluminous

Bag filter

Principle of operation: the simple construction consists of a filter or cloth, tightly woven from special fibres and hung up in a closed construction through which flow gas passes. The advantages and disadvantages are summarised below (Table 3.2-8).

Table 3.2-8: Advantages and Disadvantages of a bag filter [Loo, 2003]

Advantages	Disadvantages
> 99% efficiency obtainable dry collection possible decrease of performance is noticeable collection of small particles possible	sensitive to filtering velocity high-temperature gases must be cooled affected by relative humidity (condensation) susceptibility of fabric to chemical attack voluminous operating temperature limited to 250°C tars may condense and clog the filter at low operating temperatures limited lifetime of the cloth (2-3 years)

Scrubber

Principle of operation: The particles are scrubbed out from the flow gas by water droplets of various size (depending on the scrubber used) and then removed by collision and interception between droplets and particles. The particles are wetted and carried out by the water droplet, thus effecting removal. The more droplets are formed the more efficient is the unit, hence, droplets must be small. The advantages and disadvantages are summarised below (Table 3.2-9).

Table 3.2-9: Advantages and Disadvantages of a scrubber [Loo, 2003]

Advantages	Disadvantages
simultaneous gas (SO_2, NO_2, HCl) absorption and particle removal ability to cool and clean high-temperature, moisture-laden gases corrosive gases and mist can be recovered and neutralised reduced dust explosion risk efficiency can be varied	corrosion, erosion problems added cost of wastewater treatment and reclamation low efficiency on submicron particles contamination of effluent stream by liquid entrainment freezing problems in cold weather reduction of buoyancy and plume rise water vapour contributes to visible plume under some atmospheric conditions

NO_X control technologies

The secondary NO_X reduction measures are mainly Selective Catalytic Reduction (SCR) or Selective Non-Catalytic Reduction (SNCR). Both utilize injection of a reducing agent, mostly ammonia or urea, to reduce NO_X to N_2, with or without a catalyst.

SCR reduces NO_X by reactions of ammonia or urea in the presence of a platinum (also titanium or vanadium) oxide catalyst. A reduction of 80-95 % NO_X at about 250 °C is reported in fossil and wood firing systems [Loo, 2003].

SNCR require no catalyst for activation for the reaction. Usually at a temperature between 850 and 950 °C, ammonia or urea is injected into the flue gas. Due to the high temperature, no catalyst is needed to initiate the reactions. About 60-90 % NO_X reduction can be reached with SNCR [Loo, 2003]. The process requires an accurate temperature control, because if the temperature is to high ammonia is oxidised to NO and if the temperature is to low ammonia does not react and is emitted with the NO_X.

Furthermore, catalytic converters can be optimized for NO_X reduction can be utilized after the combustion chamber in small-scale biomass combustion applications, like the catalytic converters discussed before (reducing emissions from incomplete combustion).

3.2.4.4 Ash/Slag disposal and ash utilisation

During the combustion of biomass ash is generated. For a sustainable biomass utilisation, it is essential to integrate biomass ashes within the natural cycles. Therefore the natural cycle of minerals should be as completely as possible. But since the deposition of heavy metals caused by environmental pollution, this natural cycle is disturbed and not the whole amount of ashes produced during combustion can be recycled. The main question is, which ash fractions can be utilized. The origin and the composition of the different ash fractions from biomass combustion plants are essential. In biomass combustion plants three ash fractions must be distinguished (Figure 3.2-16):

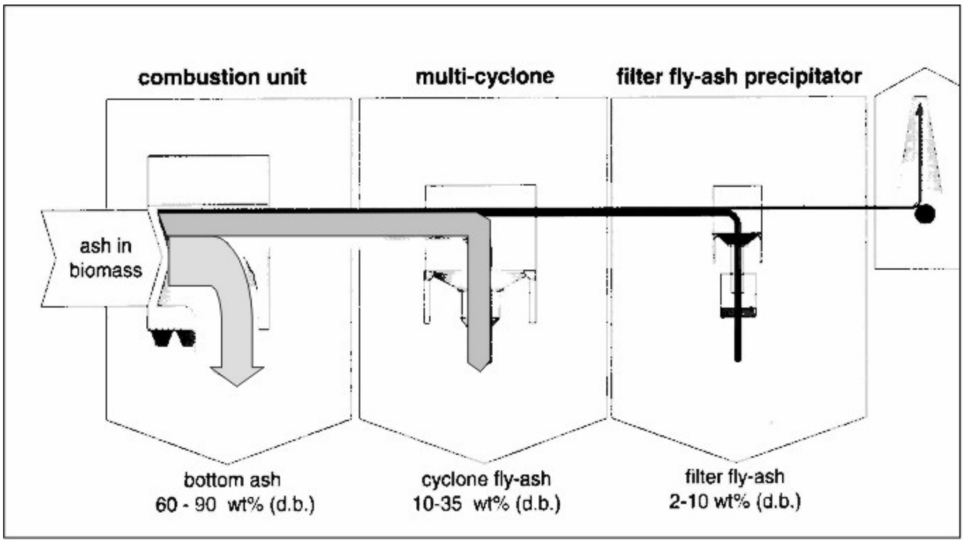


Figure 3.2-16: Various ash fractions produced in a biomass combustion plant (data are valid for fixed bed combustion units. In fluidised bed combustion units fly-ash is quantitatively dominant) [Loo, 2003]

Bottom ash: Fraction produced on the grate, often mixed with impurities contained in the biomass fuel like sand, stone and earth. These impurities can cause the formation of slag and sintered ash particles.
Cyclone fly ash: Fine mainly inorganic ash particles carried with the flue gas and precipitated in the secondary combustion zone, in the boiler and especially in multicyclones placed after the combustion unit.
Filter fly ash: Second and finer fly ash fraction precipitated in electrostatic filters, fibrous filters or as condensation sludge in flue gas condensation in flue gas condensation units. In plants without this efficient dust precipitation technology, this fraction is emitted with the flue gas.

The amount of ash produced mainly depends on the type of substrate/ fuel (Table 3.2-10). Also the combustion technology is influencing the amount of ash produced (compare Chapter 3.2.4.2.2: Fluidised bed furnace).

Table 3.2-10: Average ash content in different fuels [Loo, 2003]

Fuel	ash content (%)
Bark	5.0 – 8.0
Wood chips with bark	1.0 – 2.5
Wood chips without bark	0.8 – 1.4
Sawdust	0.5 – 1.1
Straw and cereals	4.0 – 12.0

For utilisation or disposal of ashes the following options can be considered:

- secondary raw material (fertilizing and improving soil properties in agriculture and forestry)
- disposal or landfilling
- industrial utilisation (e.g. row material for concrete and chemicals)
- road construction.

Mostly ashes are utilized to fertilize and improve soil properties or they are disposed. The industrial utilisation is only applicable in large scale combustion plants. Slagged bottom ash can be used for road construction. But the fine fractions contain water soluble substances and an increased heavy metal concentration and are therefore unsuitable for this purpose.

The following figures show the heavy metal (Figure 3.2-17) and nutrient concentration (Figure 3.2-18) in various ash fractions.

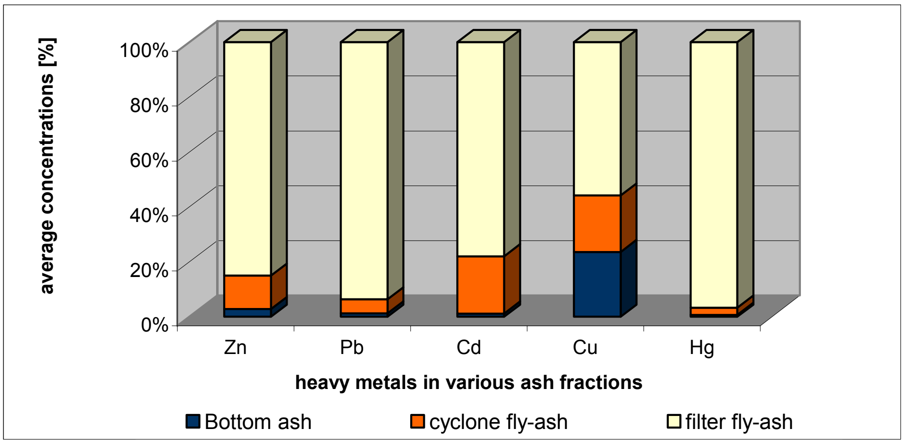
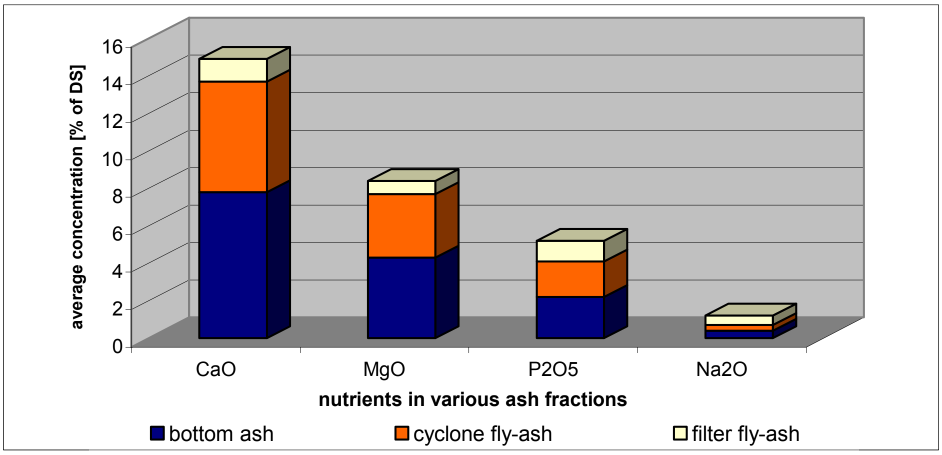


Figure 3.2-17: Average concentrations of heavy metals in various ash fractions of bark, wood chips and sawdust incinerators [Kaltschmitt, 2001]

Figure 3.2-18: Average concentrations of nutrients in various ash fractions of straw incinerators [Kaltschmitt, 2001]



For the utilization or disposal of biomass ashes he following principles and conclusions can be derived:

- A mixture of cyclone and bottom ash is used to close the mineral and nutrient cycle and therefore lead back to agricultural areas and in the forest.
- The filter fly ash is disposed, due to the high concentration of heavy metals.
- The concentration of heavy metal is increasing with a decreasing size of the fraction.
- Cadmium (Cd) and zinc (Zn) cause most problems in ashes of biomass combustion plants.
- In the finest fraction (5-10% of the ash) are 35-65 % Cd and 35-55 % Zn of the original concentration in the biomass.
- In the cyclone and bottom ash are approximately 80-95 % of the plant nutrients, which have been supplied with the biomass.

3.2.4.5 Heat / Power generation

To fulfil its purpose combustion plants pass the generated heat as much as possible to a circulating transfer medium. This takes place in the boiler. As process medium water or steam is used. The more complete the heat is transferred and the lower the losses of heat and unburned ash or flue gas the better the efficiency of the boiler.

You have to distinguish between the following modes, depending what you are aiming to produce:

- Heat

- Power
- Heat and power.

3.2.4.5.1 Heat generation

It is always intended to cool down the flue gas as much as possible to secure a high efficiency. The most important force is the difference of the temperature of the flue gas and the process medium. Depending on the utilisation of the process medium (e.g. process water) heat of the flue gas is transferred less or more.

In combination with combustions plants for biomass fuels, 2 kinds of boilers are used. In smaller plants of up to 1 MW_{el} fire tube boilers which allow steam pressures of only 20-30 bar are applied instead of water tube boilers for economic reasons. [Kaltschmitt, 2001]

3.2.4.5.2 Power generation

Power generation by combustion can be divided into closed and open processes. Open cycles are used for gaseous and liquid fuels.
In closed thermal cycles, the combustion of fuel and the power generation are separated by a heat transfer from the hot combustion gas to a process medium used in a secondary cycle. Due to this separation the engine is only in contact with the clean process medium. Process and engine types are:

- **Steam turbines** used as expansion engines in the Rankine cycle with water as process medium; water is evaporated under pressure and superheated;
- **Steam engines**;
- Steam turbines used in an **organic Rankine cycle (ORC)** with evaporation of an organic medium in a tertiary cycle separated from the heat production
- **Stirling engines**
- **Closed gas turbines**

Power generation with steam turbines is a highly developed technology for applications in thermal power stations and in combined heat and power production plants (CHP). Heat generated in a combustion process is used to produce high-pressure steam in a boiler (20-200 bar) and in cases of steam turbines superheated to increase efficiency and to achieve dry steam. The steam is expanded through to expansion engine and delivers mechanical power to drive an electricity generator.

Steam turbines are applied in medium- and large-scale power plants ranging from 5 to 500 MW_{el} [Loo, 2003] and operating as condensing plants. Sometimes there are also steam turbines with a capacity with 0.5 – 2 MW el used, but often they have a reduced efficiency.

The electric efficiency in the cycle depends on the enthalpy difference before and after the turbine and therefore on the inlet and outlet temperature and pressure: high pressures are needed to achieve high efficiencies. On the other hand, high pressure and temperature increase the investment costs and the risk of corrosion.
The temperature in the condenser should be as low as possible for a high electric yield. If no heat recovery after the condenser is applied and the condenser is operated with ambient air, the condenser temperature is typically 30°C to approximately 0,04 bar. This enables efficiencies of more than 40 % in large thermal power plants (>50 MW_{el}) with high steam pressures (>200 bar) where feed water pre-heating and multistage turbines are applied. [Loo, 2003] Large steam turbines allow a certain concentration of droplets in the turbine (10-15 % of wetness). Small turbines have to be operated with dry steam which limits their efficiency (η_{el} = 20-25% → 5-10 MW_{el}) [Loo, 2003].

3.2.4.5.3 Combined Heat and Power (CHP)

In the range from 0,5-5 MW_{el} [Kaltschmitt, 2001] steam turbines are used as **back-pressure plants** with heat extraction for thermal use and hence reduced electric efficiency. These are combined heat and power plants. The temperature in the condenser is usually between 90 and 140°C with a back pressure of approximately 1 to 5 bar. This leads to a reduced electrical efficiency of about 10 %, since the enthalpy difference is only partly used for power production. However the overall efficiency indicated as the sum of electric and heating efficiency can be increased by co-generation reaching up to 80-90 % [Loo, 2003; Kaltschmitt, 2001]. This technology is called back-pressure steam turbine.

The produced amount of heat is only orientating to the demand of heat. The generated electricity and heat have a defined proportion. The lower the demand for heat, the lower is the produced amount of steam and the lower is the generated electricity. Hence, these back-pressure steam turbines are called heat controlled CHP. If there is a high heat demand all over the year, this process is most interesting.

To enable heat production allowing a varying heat demand, **condensing plants with use of steam at intermediate pressure for heat production** are applied. This allows an operation of the plant at maximum overall efficiency in winter with high heat production and at maximum electric efficiency in summer with low heat production. Using the steam turbine as condensing plant, the produced heat has to be removed (e.g. with a cooling tower). Because of the technical expenditure this system is suitable for large scale plants. The electrical efficiency is lower compared to a real condensing plant due to the waste heat which is not needed.

3.3 References for chapter 3

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- Loo, S. v.; Koopejan, J.: Handbook of Biomass Combustion and Co-Firing. Twente University Press, Enschede (2003)

Recommendations for further reading:

English:
GTZ: Biogas digest

Volume I: Biogas Basics
http://www5.gtz.de/gate/publications/BiogasDigestVol1.pdf

Volume II: Biogas-Applications and Product Development
http://www5.gtz.de/gate/publications/BiogasDigestVol2.pdf

Volume III: Biogas-Cost and Benefits; Programme Implementation
http://www5.gtz.de/gate/publications/BiogasDigestVol2.pdf

Volume IV: Biogas-Country Reports
http://www5.gtz.de/gate/publications/BiogasDigestVol4.pdf

German:

FNR Fachagentur Nachwachsende Rohstoffe e.V., 2004: Handreichung Biogasgewinnung und –nutzung.
http://www.bmu.de/de/1024/js/sachthemen/ee/biomasse/biomasse_leitfaden/

4 Framework conditions for renewable energy production by biogas and biomass combustion processes in Vietnam and Thailand

4.1 Framework conditions for renewable energy production by biogas and biomass combustion in Vietnam

4.1.1 General Facts

Geography
Vietnam lies on the eastern seaboard of the Indochina Penisula, has a total area of 329,560 km^2, bordering China (1,281 km) to the north and Laos (2,130 km) and Cambodia (1.228 km) to the west. the Gulf of Thailand to the South and the Pacific Ocean to the East. The country stretches from latitudes 8°30' to 23°30'N and has an 3,444 km long of coastline, over 3,000 islands. Mountains and hill cover four-fifths of Vietnam's territory with the Truongson range stretching over 1400 km. Mount Fansipan (3,142) is the highest peak in Southeast Asia. The country's two main cultivated areas are the Red River Delta (15,000 sq. km) in the north and the Mekong Delta (40,000 sq. km) in the south.

Climate
Vietnam is essentially a tropical country with a humid monsoon climate. The annual mean temperature is over 20 degrees Celsius through out the country (Hanoi 23.4 C, Hue 25.1 C, Ho Chi Minh City 26.9 C). Low land areas receive around 1,500 mm of rain per year, while mountainous areas receive 2,000 mm to 3,000 mm. Humidity can reach 90 percent in rainy season.
Vietnam has two season: cool and dry from November to April and hot and rainy from may to October. The difference between summer and winter temperature is dramatic in north (varying up to 20 or 30 degrees Celsius). The south is warm all year round, with seasonal variations in temperature averaging just three degrees Celsius.

Inhabitants

Vietnam has a population of an estimated 82.069 million people (Table 4.1-1) of which the Viet people comprise 85%. The minority of the population consists of 54 ethnic groups who live mostly in the mountainous areas in the Central Highlands and the north. Ethnic groups in the north generally live between altitudes of 25m and 2,000m above sea level. The most well known of these are the Tay (also the most populous), the White Tai and Black Tai (distinguished by the colour of their clothes) and the Hmong (Meo). In the south, geographic locations of ethnic hilltribes are much more distinct with some living in the plains as well as the hills. The most well known of these are Hoa, Khmer, Cham.

Table 4.1-1: Vietnam inhabitants profiles

Population (2004)	82.069 million
Urban (2003)	24.8%
Rural (2003)	75.2%
Annual population growth rate (2003)	1.47%
Population density (persons per square kilometer)	247.9

Economic, industry
Vietnam is a developing, densely-populated country that has had to recover from the ravages of war, the loss of financial support from the old Soviet Bloc, and the rigidities of a centrally-planned economy. Substantial progress was achieved from 1986 to 1996 in moving forward from an extremely low starting point - growth averaged around 9% per year from 1993 to 1997. The 1997 Asian financial crisis highlighted the problems in the Vietnamese economy, but rather than prompting reform, reaffirmed the government's belief that shifting to a market-oriented economy would lead to disaster. GDP growth of 8.5% in 1997 fell to 6% in 1998 and 5% in 1999. Growth then rose to 6% to 7% in 2000-02 even against the background of global recession. These numbers mask some major difficulties in economic performance. Many domestic industries, including coal, cement, steel, and paper, have reported large stockpiles of inventory and tough competition from more efficient foreign producers. Since the Party elected new leadership in 2001,

Vietnamese authorities have reaffirmed their commitment to economic liberalization and have moved to implement the structural reforms needed to modernize the economy and to produce more competitive, export-driven industries. The US-Vietnam Bilateral Trade Agreement entered into force near the end of 2001 and is expected to significantly increase Vietnam's exports to the US. The US is assisting Vietnam with implementing the legal and structural reforms called for in the agreement. The following table shows the nation´s economic profile in 2003.

Table 4.1-2: Vietnam economic profiles in 2003

GDP per capita (2003)	US$ 485
Real growth of GDP (2003)	7.3%
Annual average GDP growth rate (1996-2003)	7.03%
Sectoral share of GDP (2003)	
Agriculture	21%
Industry	38.5%
Services	40.5%
Balance of payments in convertible currency (2003)	
Exports (f.o.b.)	US$ 20.176 billion
Imports (c.i.f.)	US$ 25.227 billion
Trade Deficit	US$ 5.051 billion
Principal exports(2004) : crude oil (26%), garments and textiles (21.8%), sea products (10.6%), footwear (12.7%), rice (5%), coffee (3%), others (20.9%).	
Principal imports (2004) : capital equipment (21.6%), refined petroleum (14.6%), textile (8%), steel (9.6%), Motorbikes (1.7%); electronic components (5%), fertilizers (2.8%), others (36.7%).	
Principal export markets (2004) : US (19%), Japan (13%), China (10%), Singapore (5%), Australia (6%), Taiwan (3%), Germany (4%), UK (4%), France (2%), Netherlands (2%), others (32%).	

Land use

After regulation of general department of land management of Vietnam, on using aspect, land is classified into 5 groups: (1) Agricultural land, (2) Forestry land, 3) Land for special use, (4) Residential land, (5) Not yet used land (see Table 4.1-3).

Table 4.1-3: Vietnam land use in 2002 (statistical yearbook 2003)

			Total area
	WHOLE COUNTRY		32929,7
Agricultural land			9406,8
	Annual crops land		5977,6
	Miscellaneous gardens		623,2
	Perennial crops land		2213,1
	Weed land for animal raising		39,5
	Water surface land for fishing		553,4
Forestry land covered by trees			12051
	Natural forest		9989,6
		Productive forest	3597,8
		Protective forest	4883,4
		Specially used forest	1508,4
	Planted forest		2036,8
		Productive forest	1360,9
		Protective forest	610,2
		Specially used forest	65,7
	Land for breeding of trees		24,6
Specially used land			1615,9
	Construction land		145,3
	Transportation land		466,6
	Irrigation land		572,5
	Historical & cultural relics land		6,9
	Security and defense land		153
	Mineral exploitation land		17,8
	Brick and tile productive land		16,7
	Salt productive land		18,4
	Cemetery		94,7
	Other specially used land		124
Homestead land			451,3
	Urban		79,2
	Rural		372,1
Unused land and river, spring, mountain			9404,7
	Unused flat land		535,7

	Unused mountainous land	7136,5
	Unused water surface land	150,3
	River and spring	748,9
	Non tree rock mountain	618,3
	Other unused land	215

Environment issues
Like many other developing countries, the environment in Vietnam is deteriorating, particularly in densely populated areas, in industrial regions or base, and in sea port.
Various kind of Environment problems have been meet with: logging and slash-and-burn agricultural practices contribute to deforestation and soil degradation; water pollution by industrial refuse or waste; overfishing threaten marine life populations; groundwater contamination limits potable water supply; growing urban industrialization and population migration are rapidly degrading environment in Hanoi and Ho Chi Minh City (air pollution, noise pollution and water pollution); acid rains have also detected, toxic chemical pollution too; the use of chemical fertilizers and insecticides in agriculture certainly affects the surface and underground water, but its consequences are still not clearly understood.

Natural resources
Vietnam’s most valuable natural resource is its land, particularly the fertile, alluvial soils in the Red and Mekong deltas. Some 26 percent of the land is currently being cultivated
Most mining activities take place in the northern provinces of the country, where anthracite coal, phosphate rock, gypsum, tin, zinc, iron, antimony, and chromite are extracted. Coal and apatite are mined extensively. The total coal production in 2001 was 10 million metric tons.
In recent years, large petroleum and natural gas deposits have been discovered along the continental shelf in the South China Sea. With assistance from the Soviet Union, Vietnam began extracting oil from its first oil field in the mid-1980s. Additional oil fields have since become productive. In the late 1990s petroleum accounted for nearly one-third of Vietnam’s export revenues.
Socio-cultural issues:

Language
More than 80 percent of the population speaks Vietnamese, the national language. Many ethnic minority people speak kin and their own native language.
Religion: Buddhism is the dominant religion in Vietnam usually combined with elements of Confucianism and Taoism. About 10% of the country's population are Catholic and there are also communities of Protestants and Muslims. Vietnam is also home to a unique religion called CAO Dai, a religious cocktail of all the world's major faiths.

4.1.2 Economic framework for renewable energy

4.1.2.1 Macroeconomic considerations

Rapid economic growth
Vietnam is a country of rapid economic growth. This growth needs an expansion of the electricity production. Currently energy consumption is rather low. Increasing industrialisation and foreign industry investment will need more electricity production in next time.

Changes in agriculture sector
Agriculture is under change. There is e.g. a programme to increase rice quality in Mekong delta. There will be investment in more modern technologies for rice processing. With this structural change it is also possible to introduce biomass using energy production technologies more.
Livestock farming is currently done by very small farmers. It can be expected that this situation will change. Under pressure of competition farming size has to increase and farming has to become more intensive. But bigger scale livestock farming will create bigger problems with the manure. This is a change to use biogas more as it is done in Thailand already in some farms.

4.1.2.2 The electricity sector

Main target in the electricity sector: extension of the electricity grid
Main target of the electricity sector in Vietnam is to improve and to extend the electricity network. This goal is formulated in the " Rural Electrification Master Plan". The role of RE is mentioned there but it is not given an extra strong position. This attitude to RE seems to change slowly. So in the Prime Minister's Decree No.102/2003/ND-CP about Energy Conservation from September 2003 was stated that it is necessary to conserve fossil fuels (coal, oil, natural gas) through the promotion of renewable energy.

But there is not yet an official special detailed plan for promotion of RE. A first step did World Bank together with EVN, ministry of industry and some other participants with start of implementation of "Renewable Energy Action Plan" (REAP) (see *ASTAE 1999 and REAP 1999*). But until know it seems that this plan does not show much effect. Currently there is a need for a legal framework and funding. This plan does not see energy from biomass as a priority instead it expect more from hydro and wind energy.

There are some Research & Development programs initiated from the Ministry of Science, Technology and Environment which also focus on the development of small scale furnaces/boilers using agricultural wastes and agro-industries residues as fuel.

Vietnam has started to realise the benefits of RE. This helps to reduce the institutional barriers. Much has to be done to implement this attitude in concrete regulations.

Energy production costs will increase because of much necessary investment
Marginal cost of electricity of hydro power is very small. Marginal costs from other sources of energy is more expensive and depends much upon world market prices of energy. Because of the big share from depreciated hydro power, energy production in Vietnam is currently relatively cheap. But because of the quick growing demand of electricity a lot of investment in new capacities is necessary in the near future.

To the cost of producing energy add the cost of transmission and distributing electrical energy. Because of the extension of the grid a lot of investment in the electricity network is necessary within the next years. Therefore it is estimated that the long run marginal costs of electric energy in Vietnam are higher than the short run marginal costs (which don't include costs to increase capacity). So it is estimated that official prices are now about two thirds of marginal costs for production, transmission and distribution *(GEZ 2003)*. Either the taxpayer will bear this costs or prices of energy in Vietnam has to increase in future. There are estimations that long run marginal costs are at least 980 VND/kWh and will increase in future (see *HIFAB 2000, vol.1 p.23*)

Current avoided cost and purchase price of EVN
Following the *REAP* (p.50) and based on 1999 prices the avoided or short run marginal costs for electricity generation are 427 VND. The avoided costs for capacity and generation, the long run marginal costs are estimated with 750 VND in this study. Furthermore there is a need to differentiate between the wet and the dry season. In dry season avoided costs are higher. Since the study came out inflation, price increase for fossil energy and heavy need for capacity investment should have augmented avoided costs for generation and capacity.

Because no official regulation exist, individual agreements with EVN are necessary for feeding energy into the grid. For this negotiations avoided costs should be the base. If avoided generation or capacity and generation costs apply depends upon reliability of the plant. When the plant is very reliable than EVN can avoid some investment in new power capacity and it should pay avoided generation and capacity costs to the electricity producer.

Energy selling to EVN will currently yield only rather low revenues. There are only a few examples for independent private producers which sell energy to EVN. In 2001 11 IPPs sold energy to EVN. Biomass produced energy is sold by three sugar mills for 4,35 US-cent/kWh, 400-440 VND/kWh and 400 VND/kWh *(GTZ 2004, p.15)*. In 2002 7% of the countries electricity demand was produced by IPPs. In 2002 in total purchased power reached 2.1 billion kWh at an average rate of 923.6 VND/kWh *(Truong and Cu 2004)*. Because much investment is necessary it seems that EVN tries now more to encourage IPPs.

Region may matter in determination of avoided costs
To compare costs it is also necessary to look for geographical divergences. Because of the size of the country electrical energy transmission add some considerable costs and the geographical distribution of power plants matters. It is estimated that transmission losses will be go down from a currently very high rate of 14% to 10% in 2010 through some improvement in the grid. But this rate is nevertheless high (compare to e.g. 4.3% for Germany).

Especially in mountainous areas hydro power will be further developed in the next years. This means an energy with high investment costs and very low variable costs. In the south of Vietnam are gas reserves and it is planned to build thermal gas power plants, plants which are quite quick and relatively cheap to build but have high variable costs which depend upon the world market price of energy. In North Vietnam are coal reserves which will increasingly exploited. Some coal fired power plants are planned. They will be also depend upon the world market price for fossil energy but less then the gas power plants. As a big disadvantage they have high external costs and high CO_2 emission which could probably cause some additional cost in future. From an economical view it may be useful to distinguish different avoided costs in different regions because of transmission capacity constraints between the north and the south and the locally different type of electricity production.

Energy generation from biomass is in some cases dependend upon the seasons. Harvest of sugar cane ist during the dry season. So it is a complement to water power which is less available during dry season. It can help to stabilize power supply and reduce investment for other power plants.

Power plants from biomass a rather small scale compare to other electricity plants. They will produce energy at a low or medium voltage level and can deliver it directly to a customer. This will save transmission losses and costs for transformation of electricity which emerge for big size power plants. Because energy is produced near the place of energy consumption and transformation and transmission costs can be saved, decentralised power production can be more efficient than central power production.

Official prices give a benchmark
Prices are determined by the State Pricing Committee (SPC). The current tariff was introduced on 1 October 1999. For productive use there are different tariffs for low load hours, of peak and peak hours. There are also slightly higher prices for foreigners and foreign companies from 560 VND up to 2550 VND at peak hours for companies in services, trade and tourism. Special tariffs exist for public use like administration or hospitals. For residential use exist an escalation tariff with cheaper prices for lower use. For communities which distribute energy by themselves exist a bulk power tariff. *(see www.aseanenergy.org)*[22] This price starts with 327 VND (incl. VAT) for residential use in rural areas and goes up to 690 VND for other purposes in community centres. Presently, the ceiling price of 700 VND/kWh mandated by the Government to rural households is strictly being applied to 81.4 percent of the communes.[23]

These in general rather low prices make build up an impediment for the use of RE up to now because energy which is produced for own use or direct selling to other consumers compete with low prices for buying energy from EVN.
Because a lot of investment in electricity sector is necessary it is expected that power tariff will be increased and reach about 7 US-cent/kWh (approx. 1000 VND/kWh) by 1. January 2006 (*Truong and Cu 2004*). Necessary adjustment of tariffs are also demanded by Asian Development Bank and World Bank. This will help much to improve possibilities to sell RE.

[22] for details see
http://www.aseanenergy.org/publications_statistics/electricity_database/vietnam.htm
[23]
http://www.aseanenergy.org/energy_sector/electricity/vietnam/current_organisational_structure_evn.htm

4.1.2.3 Financing and investment

Financing - a big bottle neck
In general there is a shortage of capital availability in Vietnam. Existing firms have difficulties to invest capital. It seems their main investment objective is to reduce costs and to improve their product quality. Investment in RE seems to be not very attractive especially regarding the relatively long pay back period. Beside this lack of available capital there is also a lack of experience with energy projects in the financial sector.

The banking system in Vietnam is adequate developed. But in remote areas only Vietnam Bank of Agriculture and Rural Development (VBARD) together with the Vietnamese Bank for the Poor have branches. The interest rate was 12.6% in 2000. VBARD has also experience in some renewable energy projects.

Private lending systems are not uncommon. Especially for people who have no access to normal banking system.

Group lending e.g. with help of Women's Union is in some areas known. It has engaged already successfully for home solar systems. The Vietnam Association of Gardeners has been active in promoting biogas.

In the energy sector international donors are very active: to the most important multilateral organisations and countries count the World bank, UNDP, Japan and some European Countries.

Use of CDMs
For comprehensive information about GHG emission reduction in Vietnam see *UNEP 1999*. Use of energy from biomass is only one of several options. Use of CDMs seems to be possible especially for bigger plants. CDMs need more external control and supervision which involves more costs but will also help to secure success.

4.1.3 Socio-cultural and socio-economic framework for RE

4.1.3.1 Knowledge and acceptance

Education and training
Vietnam has a high literacy rate, more than 90%. This is a good base to give information to stakeholders and train people. In remote villages illiterate rate is much higher which could cause some problems.

Lack of experience
There is only some small scale use of biogas technology for cooking gas. So in some areas people know about the principle of this technology. This may reduces fears and give some basic insights. People may have heard about the technology and therefore be more willingly to adopt them. But small scale use of biogas is a much simpler technology than energy production in a bigger plant. Large plants may be rather complex because of higher safety requirements and additional electrical machinery.

Therefore it can be expected that lacking knowledge will be an huge problem. This problem applies to the operator who has to acquire necessary knowledge, to employees who need training, for any construction and engineering company, for financing institutions or insurances. Universities like CTU may play an important role to disseminate the knowledge.

With burning technologies exist already some experience. There are some example plants.

One big danger with such projects is, that there exist a good support for building and starting the plant but later when problems during the operation arise there is partly no adequate support. This happens often when foreign groups or companies support a project. After the closure of the initial project phase help is far away. Therefore it is highly recommended especially for biogas plants to establish a long run partnership between the operator and local available people with the necessary knowledge! Furthermore regional establishment of adequate Know-How and capacities is essential.

Good base for community projects
Because of the structure of the society, especially a big importance of villages communities and high degree of organisation it could be a good idea to set up a community project. In rural areas such a community project could help to strengthen responsibility for community and environment and it could help to overcome financial constraints.

For larger projects and projects in or near cities this will be not a option. There it can be expected that private investors or enterprises have more financial and organisational capacities for a biomass project.

Many groups and organisations could be involved
In developing of energy supply options especially for rural areas a lot of actors beside direct local stakeholders and EVN are involved, including ministries such as Ministry of Science, Technology and Environment, Ministry of Construction, Ministry of Industry, semi-independent institutions such as the Institute of Energy, Hydropower Centre and NGOs such as the Vietnam Association of Gardeners, Vietnam Sustainable Energy Development and mass organisations such as the Vietnam Women's Union. Ministry of Agriculture and Rural Development seems to show little interest in developing RE *(HIFAB 2000)*. Local governments are relatively strong and for economic activity and development provinces play an important role.

No acceptance problems expected
Nothing is known about acceptance problem in form of religious, ethnic or social taboos.
Unemployment and employment in informal sector is very high all over the country. Therefore it can be expected that people will accept even dirty jobs. Problems may arise to find people with the necessary engineering knowledge and experience.

4.1.3.2 Local economic effects

There are many remote areas which could profit from better electricity supply
In 2001 about 85% of the urban and 77% of rural households where connected to the grid. This means about 20 million people have to access to grid electricity. The plan is in 2010 to reach 90% of rural population with electricity from the grid *(GTZ 2004).* This means there is a huge potential to improve live and business opportunities in remote areas also in future years. So especially remote areas the use of biowaste may be a chance to introduce electricity at all.

Off grid households have a very high willingness to pay. *HIFAB 2000* found that households currently spend between 16,000 and 106,000 VND for Kerosene, dry cells or car batteries. All these households would be happy to get access to electricity and are willing to pay for it. Electricity access means for them usually not only more also cheaper energy. (For more details about effects of rural electrification see *HIFAB 2000)*.

Small power plants can help to stabilise economic growth
Economic growth will increase demand for electricity in next years. Every opportunity to improve electricity supply will secure business activities. It is worth to look at China where power cuts now impede the economy even in rural areas. Some decentralised power plants help the area to secure long run economic success. Together with expected general increasing prices for fuel the high demand will increase prices for electrical energy and make RE more competitive. Small power plants give a region more independence.

Biomass is used in different ways
Different kinds of biomass are already used. Local situation has to be observed carefully. E.g. in the south there exist a seasonal market for straw (it is used for mushroom growing). During the mushroom season straw has a price outside the season it has now price. If this straw should be used in thermal treatment it will have effects on the mushroom business. Least negative impact will be when using biowaste like market or municipal waste e.g. for landfill gas.

4.1.4 Legislative, regulatory and policy framework conditions for renewable energy

4.1.4.1 Legislation, regulation

The Vietnamese Government takes the particularly interest on production of electricity from renewable resources in remote area and the area where the grid line cannot be installed for improving the living standard of the inhabitant there.

Decision 22 and the Rural Electrification Policy adopted by the MOI provide a foundation for renewable electricity development in Vietnam. According to the Renewable Energy Action Plan for Vietnam`s Summary Report 71% of rural households have access to electricity from the grid. The ratio is expected to increase to 90% by 2005. Nevertheless, one million rural households will remain without access to electricity.

4.1.4.2 Policy and programmes, action plans

In recent years, Vietnam has established some important programmes and action plans on Renewable Electricity: On 17th December 2003 the Heads of ASEAN Power Utilities/Authorities (HAPUA) have approved Vietnam as the coordinator of the working group (WG) No. 4 on Renewable Energy and Environment. The First Meeting of HAPUA WG No.4 helt in Hanoi, Vietnam, from 23 - 24 June 2005 discussed the roadmap for RE development in the ASEAN region. In order to the petition of the ASEAN Energy Ministerial Meeting and the ASEAN Summit Meeting, Vientian 29 November 2004 the target of the roadmap is to implement, “at least 10% RE in electricity generation” in 2010.

The above decisions are based on the results of the preparation in the year 1999 and 2000 of EVN and IE with the support of WB to develop the Renewable Energy Action Plan (REAP). The REAP was endorsed by participants during the Workshop held in October 2000. Subsequently, the Ministry of Industry (MOI) and EVN agreed that the REAP report would provide a framework for implementation of a program to be led and coordinated by the Ministry of Industry (MOI).

Renewable Energy Action Plan (REAP).

Objective. The objective of the REAP is that renewable energy will provide cost-effective and reliable electricity to help rural people improve their standard of living and increase their income. Renewable electricity will:

(a) supply isolated households and communities that cannot be reached economically by the grid; and

(b) augment grid supply in remote areas.

Strategy and Phasing. MOI, with support from national and international agencies, will facilitate and coordinate the implementation of the REAP. Priority will be given to providing energy services in poor isolated communes and villages, with particular attention to stimulating income-generating activities through electricity services. The Program will be carried out in two five-year phases, a capacity building phase and an implementation phase. The capacity building phase would put in place the decrees, regulations and incentives needed to create a positive environment for renewable electricity activities to expand. It would also build capacity at all levels, while carrying out pilot activities in particular provinces, to test the proposed implementation arrangements. Phase 2 would scale-up implementation.

4.1.4.3 Institutional framework

The key organizations in the power sector are MOI and EVN. MOI is responsible for energy policy and planning. EVN is a state-owned utility responsible for production, transmission, distribution and supply of electricity. Under EVN, the seven regional power companies in charge of power distribution and retailing through the country are:

- Power Company (PC) Hanoi,
- PC Ho Chi Minh City,
- PC1 (North),
- PC2 (South),
- PC3 (Central),
- PC Dong Nai and
- PC Hai Phong.

In several provinces, especially in the south, electricity distribution companies exist at provincial and district level. For example in order to sell renewable energy for the grid line of Phu Quoc island, the investor has to get the permission of PC2. Before that PC2 has to discuss with Phu Quoc people committee, KienGiang people committee and Kien Giang electricity distribution company (belong to PC2) to give Phu Quoc the first priority of the special economic region of Vietnam as the frame conditions of government promulgated.

4.1.5 General potential for renewable energy production from biomass

Main barrier: lack of knowledge and information
Main barrier seems to be a lack of knowledge and therefore technical and institutional barriers. (See e.g. *Truong and Cu 2004*). Thermal treatment seems to be easier to bring into operation because their exist already some plants and basic technology is rather simple. For energy generation from biomass a large potential exist but it can only be used if knowledge will be spread further.

Waste problem will increase - opportunity landfill gas
It is useful to understand biogas technology and thermal treatment not only as an electricity generating technology. They reduce also amount of biowaste and make this waste more easy to handle. Beside the agriculture sector which will produce more biowaste, in cities more waste will produced. Waste collection in cities is under development. The common way for disposal is now dumping in a landfill. Usually a big part of this waste is organic waste. This gives a big opportunity to use gas from the landfill or, an even better opportunity, to perviously treat the waste in biogas plants. Growing cities and quick growing landfills may make this energy production more economically.

Agriculture structure will change
Vietnam is a country with a big agriculture sector and therefore a huge potential for use of biomass and biowaste. But small scale agriculture makes the use for electricity generation often not economically. The amount of residues from agriculture and farming are usually low and this make it difficult to use it in a bigger biogas plant because of the necessary transport. With a change of the agriculture sector to bigger farms the opportunities to use biogas may increase. Especially bigger animal farms have a waste and wastewater problem which can be reduced by biogas plants. So the increase of farm size may promote the use of biogas in future. With bigger farming environmental problems will increase and protests can be expected because of deteriorating water and air quality. With bigger farming protests can be targeted more easily. As long everybody is a farmer protests make no sense. Biogas plants can help much to reduce this protests because they reduce bad smell and water pollution. Thereby they can smooth a structural change in agriculture.

Recommendations

Observation of changing political and regulatory frameworks
There are some beginnings to change the political framework to increase the supply of RE. The current problem is the lack of a regulation for IPPs with special benefits for IPPs and SPPs from RE. Future politics of more privatisation may create some helpful regulation.[24] Hopefully with some special support for RE. The quick economic growth demand for more investment in energy sector. Changing regulation will surely reflect this need to facilitate energy generation to smooth and ensure the process of economic

[24] http://pepei.pennnet.com/Articles/Article_Display.cfm?Section=CURRI&ARTICLE_ID=184465&VERSION_NUM=1&p=17

growth. The expected general electricity price increase will improve competitiveness of RE compare to energy from fossil fuel.

Dissemination of knowledge and information networks are needed
Dissemination of knowledge is the main task which has to be fulfilled because lack of knowledge seems to be the main impediment for using technologies for energy generation from biomass:

- EVN and the government could enhance electricity supply in Vietnam through broader promotion of RE.
- Every constructed plant should serve as a place to disseminate experience and knowledge. The best option is to found a network to exchange experiences and to create a stronger lobby to promote RE from biomass. For the operator there are several positive effects:
- • Exchange of experience will improve the construction and maintenance process. Hereby everybody who participate in the network will gain in the long run.
- • Dissemination of experience facilitates the development of RE and thereby economic growth and prosperity in whole Vietnam - it shows responsibility for the whole society
- • With a broader use of RE this technology will be better known and understand and political influence will increase to improve future regulation and framework in energy sector - this helps to ensure long term success and sustainability of the project
- • There may be even a direct financial benefit through selling of acquired experience and knowledge
- Intensive on the job training of the staff is absolutely necessary. Much problems arise because of insufficient maintenance. Partly it is a fault of the owner who want to save money partly it is a fault of the staff because of a lack of insight into the processes of the plant.
- More knowledge about bioenergy should be transferred to the whole population in agriculture areas. This facilitates any biomass RE project and improves general environmental awareness and responsibility.

Financial accountability is necessary
Business must be given a better economic environment to overcome capital constraints and to reduce risk. The financial sector needs more information about RE. Purchasing power regulations should be improved.

Electricity production
There is currently a lack of regulation concerning electrical energy from independent and small private power producers. In existing cases contracts are negotiated on case to case base and yield a rather low revenue for electricity production. It could be difficult to sell electricity to EVN at a cost covering price. Politics, procedures and regulations are to level the playing field with conventional energies. Situation seems to change slowly now. EVN is in a restructuring process. In 2003 EVN announced that it will treat power plants which belong to EVN and other power plants in the same in offering the power selling price.

One opportunity to sell energy is in remote areas like islands or mountains. The extension of the national grid to this areas is (prohibitive) expensive. EVN will not have connected all villages to the national grid in 2010. This means to give this areas some economic and social advance it is necessary to produce energy decentralised for a minigrid. The use of a minigrid saves the investment for connection to the national grid and gives decentralised energy production a cost advantage. If energy access exist at all in this remote areas it is currently very often done by a diesel generator. In this case RE has usually a cost advantage because of the high fuel and fuel transportation costs to this areas. Biogas plants could use infrastructure of an existing diesel generator and investment is only necessary for the fermenter and the gas storage.

Regarding the current electricity tariff one other option is to sell electricity directly to consumers who have to pay a higher price, like foreign owned companies or to the trade, service and tourism sector. The tariff for this consumers seems to be higher than the general marginal cost of electricity production in Vietnam and therefore the willingness to pay is for this consumer higher than for EVN.

Another option to gain better prices is to sell electricity especially at peak hours. This option is quite feasible for biogas plants which can regulate energy production through a flexible gas reservoir. For thermal treatment plants this option apply less but some regulation should be possible. With production at peak hours even EVN may be willing to pay higher prices.

Foreign assistance improves success
Foreign support and the development of CDMs could overcome some financial constraints. Furthermore foreign support will help to build knowledge. But the effect should not be overestimated. In many countries are experiences about too much dependency upon foreign money and knowledge. Any foreign help should only be an initial impetus and superfluous in the long run.

Biogas and biowaste burning helps to solve the waste problem
The framework to sell electricity is currently underdeveloped. So it is necessary to understand these technologies also as waste treatment technologies. Both technologies will help to reduce waste problems and should therefore promoted by local governments and communities. As mentioned especially biogas plants can be very helpful to reduce environmental problems of growing animal farms. Therefore the extension of farms should be close tied to biogas plants to reduce environmental concerns of residents around growing animal farms. In future tightened environmental legislation will make use of bioenergy more attractive.

Proper design and maintenance
It can be expected that in Vietnam similar to Thailand problems arise because of a lack of knowledge and thereby a negligence of the necessary design and maintenance. It is really indispensable to use the proper design to ensure a working plant. Construction should not changed to save costs and hereby to thwart the whole project. The same apply to maintenance. Some minor mistakes in maintenance ruin the whole plant. Everybody who support the project (especially financially) and has a strong stake in it should urge that the proper design will be kept and should control maintenance.
To save maintenance costs and to make the system simpler moving parts or mechanical equipment should be avoided or reduced. To ensure good maintenance technology should be kept simple and tolerant. So it can be ensured that it needs not so much attention. This is especially important for small plants who can not employ extra skilled technicians.

4.2 Framework conditions for renewable energy production by biogas and biomass combustion in Thailand

4.2.1 General Facts

Geography
The kingdom of Thailand, lying off the southeast coast of Asia, is a gateway to Indochina, Myanmar and Southern China. The country comprises 76 provinces that are further divided into districts, subdistricts and villages. Bangkok is the capital city and centre of political, commercial, industrial and cultural activities. Its shape and geography divide into four natural regions -- the North, the Central Plains, the Northeast plateau, and the peninsula South. Each of the four geographical regions differs from the others in population, basic resources, natural features, and level of social and economic development. The diversity of the regions is in fact the most pronounced attribute of Thailand's physical setting.

During the winter months, in the mountainous North the temperature is cool enough for the cultivation of fruits, such as lychees and strawberries. These high mountains are incised by steep river valleys and upland areas that border the central plain. A series of rivers, including the Nan, Ping, Wang, and Yom, unite in the lowlands to form the Chao Phraya watershed. Traditionally, these natural features made possible several different types of agriculture, including wet-rice farming in the valleys and shifting cultivation in the uplands. The forested mountains also promoted a spirit of regional independence. Forests, including stands of teak and other economically useful hardwoods that once dominated the North and parts of the Northeast, had diminished by 2000 to 165,000 square kilometers. In 1961 they covered 56 percent of the country, but by the year 2000 forestland had been reduced to less than 30 percent of Thailand's total area.

The Northeast, with its poor soils, is not favored agriculturally. The region consists mainly of the dry Khorat Plateau and a few low hills. The short monsoon season brings heavy flooding in the river valleys. Unlike the more fertile areas of Thailand, the Northeast has a long dry season, and much of the land is covered by sparse grasses. Mountains ring the plateau on the west and the south, and the Mekong delineates much of the eastern rim.

The "heartland" of the Central Thai, the Center is a natural self-contained basin often termed "the rice bowl of Asia." The complex irrigation system developed for wet-rice agriculture in this region provided the necessary economic support to sustain the development of the Thai state from the thirteenth-century kingdom of Sukhothai to contemporary Bangkok. Here the rather flat unchanging landscape facilitated inland water and road transport. The terrain of the region is dominated by the Chao Phraya and its tributaries and by the cultivated paddy fields. Metropolitan Bangkok, the focal point of trade, transport, and industrial activity, is situated on the southern edge of the region at the head of the Gulf of Thailand and includes part of the delta of the Chao Phraya system.

The South, a narrow peninsula, is distinctive in climate, terrain, and resources. Its economy is based on rice cultivation for subsistence and rubber production for industry. Other sources of income include coconut plantations, tin mining, and tourism, which is particularly lucrative on Phuket Island. Rolling and mountainous terrain and the absence of large rivers are conspicuous features of the South. North-south mountain barriers and impenetrable tropical forest caused the early isolation and separate political development of this region. International access through the Andaman Sea and the Gulf of Thailand made the South a crossroads for both Buddhism, centered at Nakhon Si Thammarat, and Islam, especially in the former sultanate of Pattani on the border with Malaysia.

Area: 513,115 square kilometers

Climate
Thailand has a tropical monsoon climate with three distinct seasons-hot and dry from February to May (average temperature 34 degrees Celsius and 75% humidity); rainy with plenty of sunshine from June to October (average day temperature 29 degrees Celsius and 87% humidity); and cool from November to January (temperatures range from 32 degrees Celsius to below 20 degrees Celsius with a drop in humidity). Much lower temperatures are experienced in the North and Northeast during nighttime. The South has a tropical rainforest climate with temperatures averaging 28 degrees Celsius almost all year round.

Neighboring countries
1) Myanmar - west and north,
2) Lao P.D.R. - north and northeast,
3) Cambodia - southeast and
4) Malaysia - south.

Population
Since 1911, Thailand has taken frequent national censuses organized by the National Statistical Office. A large majority of the population (80%) are ethic Thai, along with strong communities whose ethnic origins lie in China (10%), Malay (3%), India and the rest (Mons, Khmers, hilltribes). About 6 million people reside in the capital city of Bangkok.

From the 2000 National censuses, Thailand had in 2000 about 61 million people. This total was divided about equally between males and females. The regional breakdown was approximately 20.5 million in the Center (which included the Bangkok metropolitan area), 20.8 million in the Northeast, 11.4 million in the North, and 8.1 million in the South. As in most Southeast Asian nations, the population was youthful and agrarian; approximately 25 percent of the population was between the ages of 15 and 29.

Language
Thailand's official language is Thai. The core Thai--the Central Thai, the Northeastern Thai (Thai-Lao), the Northern Thai, and the Southern Thai--spoke dialects of one of the languages of the Tai language family. The peoples who spoke those languages--generically also referred to as Tai--originated in southern China, but they were dispersed throughout mainland Southeast Asia from Burma to Vietnam.

In terms of language and culture, both the Northeastern Thai and the Northern Thai are closer to the people of Laos than to the Central Thai. Speakers of the Tai language of Kham Mu'ang (known as Yuan in its written form) made up the majority of the population of the 9 northernmost provinces from the Burmese-Lao border down through the province of Uttaradit, an area of about 102,000 square kilometers. The Tai-speaking people of the Northeast, known as Thai-Lao or Isan, live on the Khorat Plateau. Historically, this area relied heavily on border trade with Laos and Cambodia; in 1987 the Thai government permitted increased Laotian border commerce and lifted a ban on the export of all but 61 of 273 "strategic" items previously barred from leaving Thailand. Also, traditional handicrafts, e.g., silk weavings and mats, increasingly are being sold outside the region to produce extra income. Still, approximately 82 percent of the region's labor force is involved in agriculture.

Religion: Buddhism (93.8%), Muslim (4.6%), Christian (0.8%), and others (0.8%)

Theravada Buddhism, the form of Buddhism practiced in Sri Lanka, Burma, Cambodia, and Laos, is the religion of more than 90 percent of the Thai people. Buddhism's place in Thai society was by no means defined solely by its relation to the state. The religious beliefs and behavior of most Thai are compounded of elements derived from both formal doctrine and other sources. The latter either developed during the long history of Buddhism or derived from religious systems indigenous to the area. Implementation of the same Buddhist rite and tradition often varied from region to region.

The practice of Islam is concentrated in Thailand's southernmost provinces, where the vast majority of the country's Muslims, predominantly Malay in origin, are found. The remaining Muslims were Pakistani immigrants in the urban centers, ethnic Thai in the rural areas of the Center, and a few Chinese Muslims in the far north. Education and maintenance of their own cultural traditions were vital interests of these groups.

Except in the small circle of theologically trained believers, the Islamic faith in Thailand, like Buddhism, had become integrated with many beliefs and practices not integral to Islam. The country has more than 2,000 mosques in 38 Thai provinces, with the largest number (434) in Narathiwat Province. All but a very small number of the mosques are associated with the Sunni branch of Islam; the remainders are of the Shia branch. Although the majority of the country's Muslims were ethnically Malay, the Muslim community also included the Thai Muslims, who were either hereditary Muslims, Muslims by intermarriage, or recent converts; Cham Muslims originally from Cambodia; West Asians, including both Sunni and Shias; South Asians, including Tamils, Punjabis and Bengalis; Indonesians, especially Javanese and Minangkabau; Thai-Malay or people of

Malay ethnicity who have accepted many aspects of Thai language and culture, except Buddhism, and have intermarried with Thai; and Chinese Muslims, who are mostly Haw living in the North.

The National Council for Muslims, consisting of at least five persons (all Muslims) and appointed by royal proclamation, advises the ministries of education and interior on Islamic matters. Its presiding officer, the state counselor for Muslim affairs, is appointed by the king and held the office of division chief in the Department of Religious Affairs in the Ministry of Education. Provincial councils for Muslim affairs exist in the provinces that have substantial Muslim minorities, and there are other links between the government and the Muslim community, including government financial assistance to Islamic education institutions, assistance with construction of some of the larger mosques, and the funding of pilgrimages by Thai Muslims to Mecca. Thailand also maintains several hundred Islamic schools at the primary and secondary levels.

During the sixteenth and seventeenth centuries, Portuguese and Spanish Dominicans and other missionaries introduced Christianity to Siam. A high percentage of the Christian community was Chinese, although there were several Lao and Vietnamese Roman Catholic communities, the latter in southeastern Thailand. About half the total Christian population lives in the Center. The remainders are located in almost equal numbers in the North and Northeast. More than half the total Christian community in Thailand is Roman Catholic. Some of the Protestant groups had banded together in the mid-1930s to form the Church of Christ in Thailand, and nearly half of the more than 300 Protestant congregations in the country are part of that association.

Other religions represented in Thailand included Hinduism and Sikhism, both associated with small ethnic groups of Indian origin. Most of the Hindus and Sikhs lived in Bangkok.

Government

Thailand has had a constitutional monarchy with His Majesty King Bhumibol Adulyadej, or King Rama IX, the ninth king of the Chakri Dynasty, the present king. Parliament is composed of 2 houses, The House of Representatives and the Senate. Both representatives and senators are elected by the people. A prime minister elected from among the representatives leads the government. The country is divided into 76 provinces. The Bangkok Metropolitan Administration comes under an elected governor. Appointed provincial governors administer the other 76 provinces (Changwat), which are divided into districts (Amphoe), sub-districts (Tambon) and villages (Mu Ban).

Land Use

Roughly two-fifths of Thailand is covered by mountains and hills, the steepness of which generally precludes cultivation. Nevertheless, perhaps as much as a tenth of this area might also be converted to agricultural purposes once detailed information was obtained through surveys. Estimates in the 1970s of overall land-use suitability classified roughly 58 percent of mountainous and hilly regions as cultivable (compared with 24 percent 2 decades earlier), of which about 19 percent was usable for paddy, 28 percent for upland crops, and 11 percent for both paddy and upland agriculture. Actual holdings of agricultural land--not all of which was under cultivation at any one time--were estimated in the mid-1970s to occupy about 43 percent of the total land area.

Soils throughout most of the country are of low fertility, largely as a result of leaching by heavy rainfall. Differences between the various soil types are the result of differences in parent rock material, variations in the amount of rainfall, length of wet and dry seasons, type of vegetable cover, and other natural factors. In general, stony and shallow soils characterize the hill and mountain terrain of the North. Large portions of this mountainous area were traditionally used by hill peoples for shifting cultivation. The Lua (also called Lawa) and Karen cultivated for short periods, then permitted the land to lie fallow for long periods, which allowed forest regrowth and restoration of soil fertility. As a result of population pressures, however, other groups sometimes failed to follow this practice. The principle crop of many hill peoples was upland rice; maize was an important secondary crop. The Hmong, Lisu, and certain other hill peoples cultivated the opium poppy as a cash crop , but this activity had important implications for internal stability as well as major international repercussions. Thai authorities, with substantial international assistance, increased efforts in the 1980s to redirect these people to other cash crops, including tobacco and coffee.

Many inhabitants of the lowlands in the North also practiced shifting cultivation in hill areas lying not far above the valleys. The valleys usually had better soils, some of fairly high or moderate fertility, which were used mainly to grow irrigated rice. In places where population pressures had developed, the higher areas were often turned to shifting cultivation to supplement lowland production. The principal crop was usually upland rice, although other crops were also grown.

Shallow sandy loams cover a large part of the Khorat Plateau. Their generally low fertility partly explains the lower economic level of the region. Soils along the main rivers are more fertile, and alluvial loams of high fertility are found along the Mekong River. Lowland soils covering about a fifth of the Northeast (some 3.5 million hectares) had been converted to rice paddy.

The central plain rice-growing area and the delta of the Chao Phraya river has clayey soils of high to moderate fertility. Low-lying and flat, much of the area is flooded during the rainy season. Higher areas on the edges of the plain are generally well-drained soils of high to moderate fertility that are suitable for intensive cultivation. These lands are used extensively for maize and sugarcane. Among other highly useful soils are the well-drained clayey and loamy soils in parts of the peninsula where rubber is grown.

Economy

Thailand’s economy is heavily agricultural, with rice by far the leading crop. Other commercial crops include rubber, corn, tapioca, cotton, tobacco, and sugarcane. Marine and freshwater fisheries are important, and some of the deep-sea catches (mackerel, shrimp, and crab) are exported. In addition, Thailand is a major exporter of farmed shrimp. Tin, tungsten, lead, zinc, and antimony are mined for export. Industries are centered mainly in the processing of agricultural products, such as rice milling, followed by sugar refining, textile spinning and weaving, and the processing of rubber, tobacco, and forest products. During the 1980s and 1990s, electronics became important, causing a substantial rise in the per capita GDP. Thailand also has a small steel mill, oil refineries, tin smelters, and vehicle and machine assembly plants.

The economy has experienced strong growth over the past 3 years. The country’s real gross domestic product (GDP) grew 5.3% in 2002, up from only 1.9% in 2001. Real GDP growth for 2003 is projected at 6.4%. Longer-term annual growth rates in 2004 and beyond are projected in the range of 5.8% - 6.6%.

Environment

The 1997-1998 Asian financial crisis brought an end to Thailand's economic boom and turned the spotlight on to the effects of rapid industrialization on the country's environment. One of the most visible environmental side effect of Thailand's industrial development is the growing problem of air pollution, where thick smoke often chokes city streets in Bangkok. Although traffic congestion has proven to be a difficult problem to tackle, the Thai government has instituted a number of measures to address urban air pollution problems, including phasing out leaded gasoline. In addition, the country suffers from increased levels of industrial wastewater, a dramatic rise in domestic sewage and hazardous wastes, and severe degradation of its water and coastal resources. Marine pollution is another threat, with increased risks if an offshore gas pipeline linking Thailand and Malaysia proceeds as planned.

Carbon Emissions

Although slowed by the 1997-1998 financial crisis, Thailand's rate of energy consumption has picked up speed once again, continuing to grow at a fast pace. Thailand's carbon emissions have mirrored the growth in energy consumption. In 2001, the country emitted approximately 48 million metric tons of carbon equivalent – more than twice its carbon emission level in 1990, the baseline year for the group of mostly industrialized countries that are required to reduce their greenhouse gas and carbon emissions by an average of 5.2% between 2008 and 2012.

Thailand is a non-Annex I country under the 1997 Kyoto Protocol, meaning it has no binding obligation to reduce its carbon emissions below 1990 levels by 2008-2012. However, owing to concerns for Bangkok and the other low-lying coastal areas in the event of rising oceans due to climate change, the Thai government ratified the Kyoto Protocol in August 2002.

Energy and Carbon Intensity

Thailand's energy intensity (energy consumption per $) is on par with energy intensity levels of other countries in southeast Asia. However, the country's energy intensity has nearly doubled since the mid-1980s, following the regional trend among countries in the region that have boosted their energy consumption during the years of rapid economic expansion. The 1997 financial crisis did not slow the increasing level of energy intensity in Thailand, demonstrating the necessity for Thailand to implement energy conservation and efficiency measures.

Similarly, Thailand's carbon intensity (emissions per $) is on the rise, although not at the same rate as the country's energy intensity. Still, the country's carbon intensity has become more pronounced since the start of the 1990s, with increases in industrial development matched by growth in carbon emissions, as well as greater vehicle exhaust with the boom in motor vehicles. The contraction of Thailand's economy in the wake of the 1997 financial crisis did, however, result in a downturn in the country's carbon intensity, although this appears to be merely a temporary slowdown as Thailand's economic rebound appears to have put the country's carbon intensity levels back on an upward path.

Thailand hopes to reduce its carbon intensity by diversifying its fuel share of energy consumption to emphasize more renewable energy sources, chiefly solar power. A number of solar-powered projects are in development, and the Thai government has given incentives for other non-conventional, alternative energy production. Thailand's environmental outlook is improving, especially as the government conducts required environmental impact assessments (EIAs) and allows for more public participation in the development of infrastructure projects. Still, better enforcement of existing environmental laws and regulations will be necessary to boost Thailand's environmental record.

4.2.2 Energy and renewable energy in Thailand

4.2.2.1 Energy Sector and Energy Production

Thailand’s energy sector is undergoing a period of restructuring and privatization. The Thai electric utility and petroleum industries, which historically have been state-controlled monopolies, are currently being restructured. Currently, there are six energy-related state enterprises, i.e.

- Electricity Generating Authority of Thailand (EGAT)
- Metropolitan Electricity Authority (MEA)
- Provincial Electricity Authority (PEA)
- Petroleum Authority of Thailand (PTT)
- PTT Exploration and Production Co.,Ltd. (PTTEP)
- Bangchak Petroleum Public Co., Ltd. (Bangchak)

Additionally, the energy-related businesses, which are not state enterprises, but in which the government or state enterprises hold shares, include

- Thai Oil Co.: PTT holds 49%.
- Electricity Generating Public Co., Ltd. (EGCO): EGAT holds 25.8%.
- Fuel Pipeline Transportation Co., Ltd. (FPT): PTT, Bangchak, Thai Airways International Public Co., Ltd. and Airports Authority of Thailand altogether hold 44%.
- Thai Petroleum Pipeline Co., Ltd. (THAPPLINE): PTT holds 30.6%.
- Thai LNG Power Co., Ltd. (TLPC): PTT holds 40%.
- Esso (Thailand) Public Co., Ltd.: the Ministry of Finance holds 12.5%.
- Rayong Refinery Company (RRC): PTT holds 36%.
- Star Petroleum Refining Co., Ltd. (SPRC): PTT holds 36%.
- Bangkok Aviation Fuel Services Co., Ltd. (BAFS): PTT, Thai Airways and, Airports Authority of Thailand hold 49%.

This list excludes a number of petrochemical companies in which PTT is also a shareholder, for example, National Petrochemical Public Co., Ltd. and Thai Olefins Co., Ltd. (TOC).

Crude Oil and Condensate

Thailand contains 583 million barrels of proven oil reserves. In 2003, Thailand produced about 96,322 and 57,032 barrels per day (bbl/d) of crude oil and condensate, respectively, an increase of about 21,000 and 9,000 bbl/d from the previous year. Oil consumption in 2003 was 623,000 bbl/d, up from 589,000 bbl/d in 2002. Preliminary figures indicate that consumption has continued to grow rapidly in 2005, despite the Thai government’s moves to increase taxes on petroleum products.

The oil industry in Thailand is dominated by PPT, formerly the Petroleum Authority of Thailand. PTT Exploration and Production (PTTEP) is the main upstream subsidiary of PTT. Thai Oil, the country's largest refiner, is also controlled by PTT. The company underwent a partial privatization in November 2001, in which 32% of its equity was sold through the Bangkok Stock Exchange. The Thai government still owns a 68% stake in PTT, and does not plan to sell its controlling interest in the near future. Unocal announced in September 2003 that new investments in developing its offshore fields in the Gulf of Thailand should double current production, reaching 40,000 bbl/d by mid-2005.

Thailand has four oil refineries, with a combined capacity of 703,100 bbl/d. The three main refineries are Shell Co. of Thailand Ltd. (275,000 bbl/d) located in the province of Rayong, Thai Oil Co. Ltd. (192,850 bbl/d), in Sriracha District, the province of Chonburi, and Esso Standard Thailand Ltd. (173,500 bbl/d), also located in Sriracha District.

Natural Gas

Thailand contains approximately 13.3 trillion cubit feet (Tcf) of proven natural gas reserves, of which it produced 936 billion cubic feet (Bcf) in 2003. Much of the country's natural gas is used for generating electricity. Bongkot is Thailand's largest gas field, located 400 miles south of Bangkok in the Gulf of Thailand. Thailand began imports of gas from Burma in late 2000, used mainly at the Ratchburi power plant. PTT also is in the process of building an extensive gas distribution network around Bangkok, which will provide fuel for power plants as well as large industrial consumers.

Unocal Thailand is the country's largest natural gas producer, and has continued to increase its production with the development of new reserves. The Pailin gas field, which came onstream in August 1999, added 165 million cubic feet per day (MMcf/d) to Thailand's gas production. Unocal also started production at the Trat field in 1999. Unocal is undertaking a second phase of development at its Pailin field, which will eventually incease its production to around 330 MMcf/d.

Chevron is currently producing about 145 MMcf/d from its offshore Block B8/32. The company has put its estimated gas reserves in the block at 2.5 Tcf, and has plans to expand production in the future to about 250 MMcf/d. Amerada Hess reported a new onshore natural gas find in northeastern Thailand in early 2003, which currently is under evaluation. The company has projected a startup date for production from the Phu Horm field sometime in mid-to-late 2005.

The $1 billion, 416-mile Thai-Burmese natural gas pipeline, running from Burma's Yadana gas field in the Andaman Sea to an Electricity Generating Authority of Thailand (EGAT) power plant in Ratchburi province, was completed in mid-1999. A new connecting line also has been built linking Ratchburi to the Bangkok area, which provides for other uses for imported Burmese gas in addition to the Ratchburi power plant.

Lignite and Coal

Domestically produced coal is mostly lignite and sub-bituminous and has played an important role as a major energy source for decades. In 2001, the total reserve was 2,155 million tons. Of this, 1,124 million tons, or 52.2% was from the Mae Moh basin operated by the Electricity Generating Authority of Thailand (EGAT). The Krabi basin has a measured reserve of 112 million tons. In southern Thailand are the Saba Yoi basin in Songkhla Province, with a measured reserve of 350 million tons, and the Sin Pun basin, with a measured reserve of 91 million tons. In the north, there are the following basins: Wiang Haeng, Ngao and Mae Tha, with a measured reserve of 93, 48 and 25 million tons, respectively.

In 2004, lignite production was 18.5 million tons, 82% of which came from the Mae Moh Mine of EGAT and was used in power generation. The remaining 18% was produced by private mines and used by the industrial sector, including cement, pulp & paper, food processing and tobacco-curing industries. More than 70% of coal consumption by the industrial sector was used as fuel in cement manufacturing.

Electric Power

Thailand had 21 gigawatts (GW) of power generation capacity as of January 2001, from which it produced approximately 98 billion kilowatt-hours (Bkwh) of electricity. The decline of the Thai economy as a result of the Asian financial crisis resulted in a decline in domestic demand for electricity of about 3 Bkwh in 1998, before rebounding in 1999.

This situation compelled EGAT, the state-owned electricity company, to revise its electricity demand projections. EGAT postponed or delayed a number of projects including: delaying the commissioning of the third and fourth 300- 400 MW thermal units of the Ratchaburi power complex by three years to 2004 and 2005, respectively; postponing the start-up of the second 300-MW thermal unit at the Krabi power plant from 2001 to 2005; and delaying power purchases from three Laotian projects - the lignite-fired Hongsa project and the Nam Ngum 1-2 hydro projects to 2004 and 2005, respectively. While demand growth has recovered in step with Thailand's economic recovery, EGAT decided to lower its planned generating capacity reserve from 25% to 15%, which has diminished the immediate need for additional generating capacity. In recent months, reserve capacity has still been over 25%, though demand growth forecast at 4% is expected to produce requirements for additional power plants.

The Ratchaburi power plant, Thailand's largest power project, has moved forward despite the slowdown in power demand growth. The complex eventually will have a capacity of 3,200 MW, including 1,800 MW in six combined cycle gas-fired generators and 1,400 MW in two conventional thermal units which can burn either natural gas or fuel oil. The first combined-cycle unit began operation in January 2000, and the current capacity of the plant is 2,125 MW. Ownership of the plant was transferred from EGAT to Ratchaburi Electric Generation in October 2000, and successful initial public offering of stock was carried out, only the second IPO on the Thai market since the crisis of 1997-98.

One other independent power producer (IPP) also began operation in August 2000, Tri Energy, which has a 700-MW plant at Ratchaburi. The company is owned by a consortium including Edison Mission Energy, Texaco, and local Thai firms. Additional IPP capacity may be added later in the decade, once the power generation capacity reserve ratio declines. The Thai government has stated that it plans to eventually privatize EGAT, but it is still studying the options for structuring the privatization process. EGAT selected six firms in July 2003 to provide advice on structuring the privatization process, and current plans call for the initial public offering (IPO) of stock in EGAT to take place in March 2003.

The Thai government announced a decision in May 2002 to postpone two new coal-fired power projects in southern Thailand at Bo Nok and Hin Krut by at least two years. The two projects, originally scheduled for completion in 2002, had been met by opposition from local communities and environmentalists. The Thai government also announced its intention to assess the possibility of changing the location of the new power plants and switching to natural gas as a fuel. The question of possible overdependence on natural gas, however, is a growing concern for the Thai government.

Technical Considerations

EGAT develops, owns and operates the national transmission network. Its grid system covers the entire country, mainly operating at 500 kV, 230 kV and 115 kV voltages. The power system operation is divided into five geographical areas: metropolitan, central, northeastern, southern and northern regions. From the National Control Center based at EGAT’s Headquarters and other five regional control centers. The grid system is presently linked to Laos by 115 kV and 230 kV lines and to Malaysia by 115 kV, 132 kV and the new 300 kV HVDC lines.

EGAT is obliged to supply and sell virtually all of the energy output from its own generation facilities and from private power sources to two distributing authorities, namely the metropolitan Electricity Authority (about 35% of the total supply) and the Provincial Electricity Authority (about 63%) which then deliver electricity to and users across the country. EGAT’s direct customers also include a small number of large industries prescribed by the Royal Decree. Cross-border power trades are also made with Laos and Malaysia.

Energy Demand and Consumption
Per capita commercial energy consumption of the country was 43 gigajoules (GJ) (1,028 kg oil equivalent) and electricity generation capacity was 19,000 megawatts (MW) in 2000. Primary commercial energy consumption of Thailand has been increasing rapidly in recent years: the increase during 1991-2001 was 89%.

A new renewable energy program has been formulated in Thailand, stipulating that 3% of the new electricity capacity over the next five years would come from renewable substrates. For this purpose, a fifth of the country's newly approved 30-billion baht national conservation program has been earmarked for the promotion of renewable energy. Renewable energy now accounts for an estimated 26% of Thailand's total energy consumption; however, most of this is in the form of wood for domestic use, such as cooking.

Thailand had an energy-related carbon emission of 45.2 million tons, representing a per capita carbon dioxide emission of 2.5 tons in 2000. The sectoral share of carbon emissions was: industrial (41%), transportation (36%), residential (12%), and commercial (11%).

Renewable Energy
Although renewable energy consumption makes up only about 3% of Thailand's fuel share of energy consumption, with hydropower accounting for the majority of that percentage, alternatives to fossil fuel-fired energy production are making up an increasing share of the country's energy production. Since Thailand does not have the luxury of domestic natural resources on the scale of neighbors, such as Malaysia and Indonesia, Thailand is forced to import much of its energy for domestic use. Oil imports cost the Thai government an estimated 300 billion baht ($7.3 billion) each year.

Solar Energy
In an effort to reduce this dependence on foreign oil, Thailand is turning to another source of energy: the sun. Thailand is constructing a 42.5 MW solar power plant in the northern province at Mae Hong Son. The plant, which consists of six solar-cell generating units, is the largest solar-powered station in the Association of Southeast Asian Nations (ASEAN) completed in April 2004. EGAT says that the plant, which has the ability to generate 500 kilowatt-hours (kWh) of power in the first phase, but eventually will be able to produce 1,750 kWh. Thai government plans to increase its solar power production capacity to 30 MW by 2006. The Thai government also is kicking off a project aimed to supply 300,000 homes with solar cells in a bid to generate additional solar energy.

The use of solar energy for power generation, using solar cells or photovoltaic (PV) cells, has been promoted by the government. So far, about 5 megawatts of PV power generation systems have been installed in Thailand; most of them are in remote areas beyond the grid systems, and solar cells have to be imported. Government support has also been given to demonstration projects on solar energy
utilization and integrated systems of PV/hydropower and PV/wind energy.

The Electricity Generating Authority of Thailand (EGAT) has developed several projects demonstrating power generation using the PV technology, PV power generation without use of batteries, and rooftop PV grid-connected systems. Development has also been undertaken on the integrated use of solar/wind energy for power generation at Phromthep Cape in Phuket Province, and the integrated use of solar/hydro energy at Klong Chong Klum in Sakaew Province.

The Energy Policy and Planning Office (EPPO) is the government agency monitoring the Energy Conservation Promotion Fund (ENCON) allocation for renewable energy projects. Grants have been given to encourage R&D on solar energy. Examples of funded projects are: the development of solar radiation measuring station network for Thailand; the demonstration project of electricity generation and distribution system using solar cells in Mae Hong Sorn Province in northern Thailand where most areas are mountainous with scattered population; and the establishment of "Solar Energy Park" to serve as the center for demonstration and information dissemination on solar energy.

Besides, the Thailand Research Fund (TRF), an independent organization under the Office of the Prime Minister, is another institute undertaking R&D and facilitating information on solar cells. In 2001, TRF approved a research project on the production of silicon from paddy husks, which can be eventually used for solar cell production and thus promoting development of solar cells using indigenous resources.

Wind Energy
The average wind speed in Thailand is moderate to rather low, usually lower than 4 meters per second; therefore, wind energy is currently used almost exclusively for propelling rooftop ventilators and water-pumping turbines. High wind speed along the coastline, however, may have the potential for power generation.

Fuel Cells
Study has been undertaken in Thailand on the feasibility and potential to use the fuel cell technology for power generation, using a process that transforms chemical energy of fuel into electrical energy via electrochemical mechanism. The fuel source for fuel cells is hydrogen and the output from the chemical reaction in the production process is water, which has no impact on the environment. Moreover, since no transformation into thermal energy occurs in the fuel cell process, there is no combustion and hence no generation of CO_2 and other greenhouse gases from the use of this technology. However, one major hindrance of the development of this technology is the high production cost and the technology is still under ongoing development.

In Thailand, the information on fuel cells has been compiled from both domestic and foreign sources. Cooperation has also been made with various laboratories so as to establish a fuel cell technology center. R&D and demonstration projects on molten carbonate fuel cell (MCFC) and phosphoric acid fuel cell (PAFC) have been undertaken, aiming to improve efficiency and to reduce the production costs to be affordable by the general public.

Geothermal Energy
Geothermal energy is natural energy from the internal heat of the earth; the temperature varies with respect to the distance from the earth surface (geothermal gradient) - the deeper from the earth surface, the higher temperature. At the depth of about 25-30 kilometers, the average temperature will be around 250-1,000°C.

There are approximately 64 geothermal resources in Thailand, but major ones are in the north of the country, especially the geyser field at Fang District in Chiangmai Province. Survey on the potential of geothermal energy development at Fang District commenced in 1978, with technical assistance and experts from France later in 1981. Currently, EGAT is operating a 300-kW binary cycle geothermal power plant at Fang District, generating electricity at about 1.2 million kWh per year, which helps reduce oil and coal consumption for power generation.

In addition, other benefits can be derived from the waste heat of hot water used in the power plant. The temperature of hot water, after being used in the power plant, will decrease from 130°C to 77°C, which can be used for drying agricultural products and feeding the cooling system for EGAT's site-office space. Some other non-energy uses of hot water from geothermal sources are for physical therapy and tourism.

Hydro-Electricity
Hydropower has been developed for power generation since 1964. The potential of hydropower in Thailand is estimated at 15,155 megawatts (MW). As of December 2003, EGAT produced 7,240 GWh of hydropower, which accounted for 6% of the total power generation by fuel type. As part of the rural electrification program, having already brought electricity to 99% of villages in Thailand, small hydropower sites have been identified as economically suitable for more accurate cost estimates and detailed engineering work.

Bio-Liquid Fuels
Apart from the use of biomass residues and wastewater containing organic matters for energy production, in recent years several efforts have been made to explore the potential to use biomass to produce bio-liquid fuels for engines and vehicles, which can be alternatives to use of gasoline and diesel oil and thus help reduce dependency on oil import.

Ethanol - The use of agricultural products, such as cassava and molasses, for ethanol production has been given particular attention since ethanol, which is 99.5% pure alcohol by volume, can replace the use of Methyl Tertiary Butyl Ether (MTBE), a fuel additive. Each year Thailand spends more than 2 billion baht on MTBE import. Therefore, the use of domestically produced ethanol can contribute to foreign currency saving as well as mitigation of pollution problems resulting from fossil fuel combustion.

The annual production of cassava in Thailand is estimated at 18 million tons while only about 4 million tons are used for domestic consumption and the rest is exported. To increase added value of cassava, about 2 million tons per year can be used for ethanol production of up to 1 million litres per day.

Gasohol - Gasohol is an alternative fuel for vehicles. It is a mixture of ethanol and regular gasoline at the ratio 1:9. The properties of derived gasohol are the same as Octane 95 gasoline. However, the use of gasohol will not only reduce oil consumption and air pollution from vehicle exhaust but also help farmers through the purchase of agricultural products, i.e. sugarcane and cassava.

In order to support and promote the production and use of ethanol and gasohol, the government has approved in principle the exemption of excise tax imposed on the ex-plant ethanol and on the ethanol mixed with gasoline, the deduction of contribution rates to the Oil Fund and to the ENCON Fund for gasohol; and the pricing of gasohol to be cheaper than that of Octane 95 gasoline within a range of not exceeding one baht per litre.

Moreover, the government has approved several supportive measures. For example, a policy will be established for government agencies and state enterprises to give priority to gasohol for their vehicle fleets. Promotion and support will be made to enhance preparedness of the automobile and oil refining industries to accommodate the production and use of fuel ethanol, by provision of tax privileges, for instance. Besides, potential SME practitioners and farmer organizations or entities will be encouraged to establish ethanol producing plants so that production of ethanol from agricultural products could be distributed across the country. Such measures as provision of financial assistance, in the form of concessional loan or soft loan, and provision of technical assistance from the government agencies will also be introduced for this purpose.

Biodiesel or Ester - Biodiesel, or ester, another alternative fuel for vehicles, can be produced from oil plants such as coconut, soy bean, palm and sunflower via a chemical process (Transesterification or Alcoholysis), using alkaline as a catalyst to transform fatty acid into ester or biodiesel, which has similar properties to those of diesel oil. In Thailand, biodiesel standards are yet to be established. The current mixtures vary, for example, between diesel and ester extracted from palm oil, diesel and ester extracted from coconut oil, or diesel and ester extracted from used cooking oil.

Currently, several institutes have undertaken studies and development of the quality of biodiesel and "blended oil" (a mixture of diesel and crude plant oil or that of diesel and refined plant oil without any chemical process) compared with the specified diesel standards. It has been reported that blended oil has advantages over diesel in that it contains lower sulfur content and helps with lubrication; however, the quality of different bulks of blended oil varies although it is sold at the same distribution station. Research is being carried out on biodiesel production from crude coconut oil ("cocodiesel") and on the impact of cocodiesel utilization on the environment.

Similar to the promotion and support to ethanol and gasohol, ester can be mixed with diesel, at a ratio no greater than 1:9, and the excise tax and the contribution to the Oil Fund are exempted for the portion of ester produced from plant oil and mixed with diesel. As a long-term measure, through use of the ENCON Fund, the government will continue supporting R&D to improve biodiesel efficiency as well as research on other oil plants to diversify sources of production; the standards for engine adjustment to enable them to run on biodiesel will be established.

Biogas and Biomass

In Thailand, there has been development of the biogas technology using biogas generated from animal manure, especially that of pigs and cows, as fuel in power generation and in cooking. Development has also been undertaken on power generation from landfill biogas. The major financial resource is the Energy Conservation Promotion Fund (ENCON) of the government. Several biogas projects have been supported by the ENCON Fund, such as the biogas from animal manure for power generation in livestock farms, R&D on the feasibility of biogas generation from wastewater treatment systems in factories, and the development of a biogas map providing information on pig farms and diary farms nationwide in order to facilitate the planning of biogas utilization in the future.

As for biomass, or biomass energy, it is a kind of fuel derived from organic substances, such as agricultural residues like woodchips, bagasse and paddy husks, animal manure from livestock farms, wastes from agricultural product processing, and wastewater from factories. Biomass can be an important energy resource, and the resources of biomass are distributed across the country. For instance, paddy husks are burned to produce steam for turbine operation in rice mills; bagasse and palm residues are used to produce steam and electricity for on-site manufacturing process; and rubber wood chips are burned to produce hot air for rubber wood seasoning. Moreover, the remaining biomass can be used for power generation, with the following potential:

Paddy husks, biomass from rice mills: each ton of paddy requires 30-60 kWh of energy for all stages of processing, yielding about 650-700 kilograms of rice and residue, that is, about 220 kilograms of paddy husks which can be used to generate 90-125 kWh of energy.

Bagasse, biomass from sugar mills: each ton of sugarcane requires 25-30 kWh of energy and 0.4 ton of steam for all stages of processing, yielding about 100-121 kilograms of sugar and residue, that is, about 290 kilograms of bagasse, which can be used to generate about 100 kWh of energy.

Palm outer-covering fiber, shells and empty bunches, biomass from palm oil extracting plants: each ton of palm requires 20-25 kWh of energy and 0.73 ton of steam for all stages of processing, yielding about 140-200 kilograms of palm oil and residues, that is, about 190 kilograms of palm outer-covering fiber and shells and 230 kilograms of emptied palm bunches which can be used to generate about 120 kWh of energy. In addition, there will be about 20 cubic meters of wastewater from the processing which can be used for biogas generation.

Woodchips, biomass from sawmills: one cubic meter of wood requires 34-45 kWh of energy for all stages of processing, yielding about 0.5 cubic meters of processed wood and residue, that is, about 0.5 cubic meters of woodchips which can be used to generate about 80 kWh of energy.

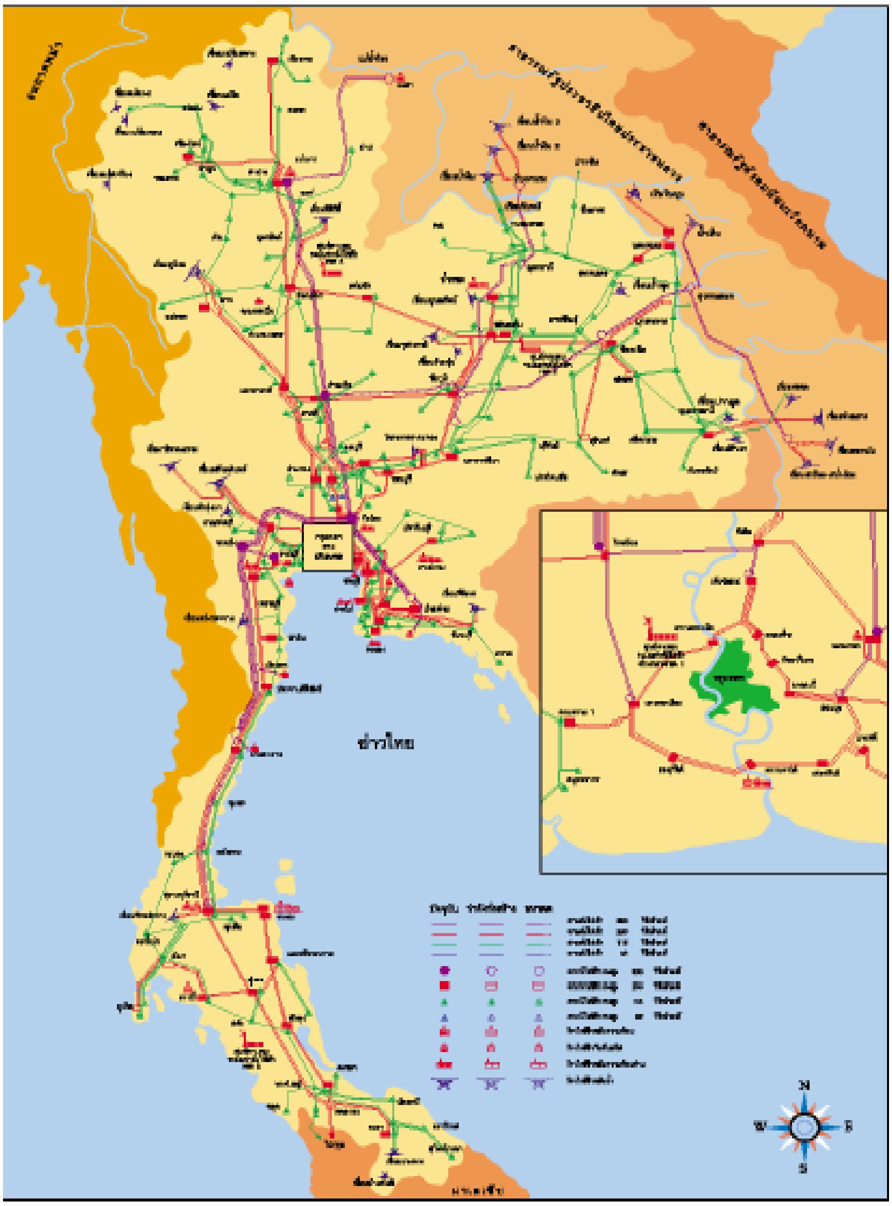
Table 4.2-1 summarizes the different types of energy described above, which are used to generate electricity and illustrates their development over five years from 1999 onwards.

Table 4.2-1: Electricity Generation by System Type, Year 1999-2003

TYPE (Unit: GWh)	**1999**	**2000**	**2001**	**2002**	**2003**
HYDRO	3444.2	5913.1	6205.4	7398.6	7240.0
THERMAL	37146.2	35665.6	30853.1	30422.6	31043.3
COMBINED CYCLE	25859.6	24252.3	23199.3	22490.8	19438.2
GAS TURBINE	1147.5	1151.0	1122.5	1104.8	1075.3
DIESEL	3.4	2.7	2.5	5.7	3.4
GEO-THERMAL	1.5	1.6	1.5	1.6	1.6
NON-CONVENTIONAL	0.2	0.2	0.2	0.2	0.2
SPP	8317.8	10170.9	11645.4	12548.0	13299.8
ENERGY PURCHASED	2255.7	2966.3	2881.8	3260.7	2473.4
IPP	14259.6	18211.9	27945.3	33595.9	44332.8
TOTAL	92435.5	98335.6	103857.0	110828.8	118908.1

Source: Energy Policy and Planning Office, updated March 26, 2004

Figure 4.2-1: Thailand’s National Grid



4.2.2.2 Biogas in Thailand

Biogas technology has been introduced in Thailand since 1960. During this period, the use of biogas was limited mainly to demonstration plants in rural applications aiming at hygienic disposal of animal manure and the production of energy for cooking. During the oil crisis between 1975 and 1980 the Department of Agricultural Extension [DoAE] started a biogas promotion program in response to the government policy towards energy self-sufficiency and also as a means to solve the environmental problems from livestock farms. However, the initial outcome was far from satisfactory. Out of 2816 biogas plants built between 1980 and 1988, only 35% were in use. The reason for rejection of the technology or disuse of the plants were attributed to bad construction techniques, lack of experience and awareness of the DoAE officials and the lack awareness on the part of the farmers.

In September 1988, the Thai-German Biogas Program [TG-BP] commenced, partly evolving from prevailing problems and shortcomings. The program was jointly implemented by the DoAE and Chiang Mai University [CMU], and assisted by the Deutsche Gesellschaft fuer Technische Zusammenarbeit [GTZ]. The Second and Third Phase were terminated in 1993 and 1995, respectively.

Aimed at increasing the utilization of biogas technology in 5 provinces in Northern Thailand [Chiang Mai, Chiang Rai, Lamphun, Lampang and Payoa], The TG-BP pilot project consisted of two major parts, [1] the dissemination of small household biogas digesters [8, 12 and 16 cubic meters volume] under the responsibility of the DoAE and [2] applied research and development at CMU, including the provision of consultancy services for anaerobic waste water treatment, mainly to specialized pig farms. The target group for household biogas plants comprises small mixed farms with crop production and livestock [at least 3-4 cattle and/or 3-6 buffaloes and/or 10-12 pigs]. The total number of these farms, in the five Northern provinces only, is estimated at 40,000 to 50,000. For this group, the utilization of biogas for cooking purposes and slurry utilization for fertilizer replacement is of primary interest.

To ensure a high quality of further dissemination of biogas plant, the TG-BP has set up a selection criteria for biogas farmers. If criteria mainly fulfilled: the contract for the construction of new biogas plants will be signed. This includes clarification of cost distribution between TG-BP and the farmer. Moreover, the biogas farmers are given provision of loans for the construction of biogas plants if certain conditions are fulfilled. The Biogas Demonstration Loan Scheme is managed by local farmer groups or cooperatives under advice of the DoAE. Investment costs for the standardized biogas plants of 12, 16 and 30 cubic meters digester volume range from 540 to 1,000 Euro (see Table 4.2-2).

Table 4.2-2: Standard Costs of a Construction of a Fixed-Dome Biogas Plant (DoAE, 2004)

Fixed Dome Size (m^3)	Total Construction Cost (Baht)	Project Subsidy (Baht)	Owner Pay (Baht)
12	27,000	12,150	14,850
16	33,000	14,850	18,150
30	48,900	22,000	26,900
50	86,000	38,700	47,300
100	160,000	72,000	88,000

Note: Approximately 1 EURO = 50 baht.

Operation costs are usually 5 to 7% of the initial investment. Under normal operation, gas yield per day is 0.35 cubic meter/cubic meter reactor/day. In farms with high energy demand, they utilize biogas not only for cooking purposes, but also for hot water preparation in order to clean dairy cows and milking equipment.

The pay-Back-Period for 49% of the small biogas plants surveyed [8, 12 and 16 cubic meters] is under 6 years. Whereas, for the remainder the pay-back period exceeds 6 years and even extends, in some cases, the assumed technical life span of the system. Concerning the International Rate of Return [IRR], 54% of the BGP observed record an IRR of more than 8%. For 46% of the small plants, the IRR is below 8%.

The Energy Conservation Promotion Fund (ENCON Fund)

In 1992, the Thai Government established the Energy Conservation Promotion Fund (ENCON fund) for the purpose of encouraging efficient utilization of energy as well as the use renewable energy to replace imported fossil fuels. The National Energy Policy Office (NEPO, then), or the Energy Policy and Planning Office (EPPO, now), is the body set up to manage the fund, which derives from oil taxes. Biogas, being a renewable form of energy with good potential, fits into EPPO's target.

It is on the medium and large farms where the prospects for biogas generation are promising in the short term as many of these farms will have to comply with environmental regulations which stipulate that waste water will have to be treated, e.g. there is a need for the installation of waste water treatment systems. Biogas systems can be used as an alternative and are attractive to farmers as gas is generated which can be used on the farm for various purposes such as piglet heaters. In 1995, EPPO supported the program called "The Biogas Dissemination Programme in Livestock Farms: Medium and Large Size Farms," in order to show that the biogas system for large farms was economically feasible. The program was divided into three phases (cp.Table 4.2-3).

Table 4.2-3: Details of the three phases of "The Biogas Dissemination Programme in Livestock Farms: Medium and Large Size Farms."

Phase	Entire Biogas System Volume (m^3)	Financial Support (% of investment cost)	Number of Farms
Phase I (1995 – 1998) *Pilot Phase*	10,000	47%	6
Phase II (1997 – 2003) *Demonstration Phase*	46,000	33%	14
Phase III (2002 – 2008) *Full Scale Expansion Phase*	130,000 (large farms) 150,000 (medium farms)	18%	80 (large farms) 500 (medium farms)

The current version of biogas system developed under the program basically comprises a channel digester, an upflow anaerobic sludge blanket (UASB) reactor, a drying bed and a post treatment system. The influent is normally diluted by cleaning water and has a COD of 18,000-37,000 mg/l and a BOD of 9,000-18,000 mg/l. After a post-treatment system the COD is reduced to less than 200-300 mg/l, which is acceptable for release to natural waters or to storage ponds for reuse.

Biogas Technology in Agro-Industries

The use of biogas technology to treat industrial waste water and to produce energy started in early 1984 in Thailand. During that time the application is mainly for distillery slop from cane molasses. One of the biggest anaerobic digesters in Thailand is at the Ayuthaya distillery plant. The system is of the anaerobic contact process with total volume of 9,000 cubic meters [3 chambers with 3,000 cubic meters each]. It was designed to operate at thermophilic range. In 1988, the loading rate was 10 kg COD/cubic meter/day and the biogas production was 27,000 cubic meter per day [30 cubic meter/cubic meter slop]. Methane content was 50-55%. The biogas was used as a fuel for the boilers. Normal fuel oil usage for the two boilers, without biogas, is 18,000-23,000 liters/day. Boilers have a gas burner, oil burner and pilot burner.

Interest in the use of anaerobic treatment in a closed digester to treat both solid and liquid wastes and to produce methane is increasing. Table 3 shows the list of biogas plants in Thailand. The many advantages of anaerobic waste treatment with concomitant production of energy are well known. Yet the number of new and successful industrial applications is disappointingly small. Nevertheless, the present trend indicates that the use of biogas in industries and farms in Thailand is increasing in particular in connection with environmental regulations which stipulate the treatment of waste water in order to reduce environmental pollution. The implementation is still limited as a result from high investment cost.

The economic feasibility of an anaerobic digestion system for waste water treatment and energy production was studied for the starch producing factory, which produced 100 tons of starch/day. The factory uses 2,200 litres of fuel oil for drying starch and 300 kilowatts electricity/day. The energy bill is about 14,000 US$ per month. If the factory wants to use biogas to supplement fuel oil, a 2,000 cubic meter reactor is enough to produce

6,000 biogas equivalent to 3,120 liters of fuel oil. IRR and pay back period are 34% and 4 years, respectively. To be energy self sufficient, 9,000 cubic meter biogas is needed to substitute for fuel oil and to generate electricity. The construction of 4,000 cubic meter reactor is recommended. In both cases, only part of the waste water is treated to produce biogas. To treat 2,000 cubic meter waste water discharged each day, 8,000 cubic meter reactor should be built. The IRR increases to 4.5% and the pay back period reduces to 3 years.

Moreover, the biggest brewery plant in Thailand [Boon Rawd Brewery LTD.] changed their treatment system from activated sludge to anaerobic-aerobic treatment. The anaerobic reactor is Upflow Anaerobic Sludge Blanket [UASB with a 2,200 cubic meter volume]. The system has been operated since March, 1995. The produced biogas is used in boiler as a supplementary fuel oil. The substitution is 20%. BOD removal efficiency is 91% as June 1996 and effluent after aerobic treatment is 20 mg BOD/ml. This saves about 8.5 million baht a year for operating cost. With a value of 5 million baht biogas/year, the UASB plus activated sludge gives an advantage totally13.6 million baht a year over activated sludge treatment used in the past. The investment cost of the project is 32.45 million baht.

Recently, there are more biogas reactors, such as UASB and high-rate anaerobic fixed film reactors, in use in the tapioca starch factories. The researchers at King Mongkut's Institute of Technology Thonburi (KMUTT) have been working extensively on the treatment of tapioca starch waste water. In addition, the biogas technology for industrial application has been promoted through the pilot plant demonstration and several training workshops under the project entitled "Utilization and Treatment of Tapioca Starch Waste water" supported by the National Center for Genetic Engineering and Biotechnology. The project has been divided into 3 phases. In phase I, a study of Thai tapioca starch factories investigating production processes, the quantity and quality of the waste water, and existing treatment processes was carried out. Biogas production was selected and tried on a laboratory scale. In phase II, the promising technology for implementation was tested on a pilot scale in order to evaluate its technical and economic feasibility. The last phase involved transfer of suitable technology to industry to improve the efficiency of waste treatment and utilization.

In December 2004, the Thai Government under the ENCON fund decided to subsidize 166 million baht (or, equivalent to 30% of capital cost) to 4 agencies to construct biogas plants for twelve cassava starch producing factories as a biogas demonstration project. The four responsible agencies are the Department of Energy Development and Promotion (DEDP), the Department of Factory, the Biogas Advisory Unit (BAU) of Chiang Mai University, and King Mongkut's University of Technology Thonburi (KMUTT). Each agency uses different biogas technology, i.e., UASB, H-UASB, and Anaerobic Fixed Film. In addition of the COD reduction of 90 million kg COD a year, the project targets to produce 36 million cubic meters of biogas, which can replace 22 million liter of fuel oil or produce 44 million KWh a year.

4.2.2.3 Biomass Combustion in Thailand

Biomass is an important renewable source of energy and has been used to provide energy to human activities. In the rural areas of Thailand where energy markets do not exist, biomass fuels are not traded and are mostly home-grown or collected by family labor. In energy markets where modern technology and competition dictates the use of more efficient and clean fuels, biomass is gaining an increased commercial value.

The Food and Agriculture Organization cites that biomass (including wood fuels) contributes more than one-third of the energy in Thailand, wherein two-thirds are consumed in the residential sector (mostly rural households for domestic energy needs) and the rest in industries. The sugar, rice and oil palm sectors are the three major potential biomass energy sources in the country. Sugar and rice are mostly concentrated in the North and North-eastern provinces of the country, while palm oil is found mostly in the Southern provinces. Residues obtained from the harvesting and milling of the agricultural produce can be utilised as fuel for energy generation (either in the form of power, heat, or both power and heat).

The processing of biomass in the industrial mills in Thailand results to a large production of residues. Technological developments in the energy sector now allow for the utilisation of these residues in a more efficient and clean manner. Proven technologies for heat and power generation in industrial mills are now available in the market, and the uptake of these technologies in Thailand could result to energy self-sufficiency in the mills. Based on Crop-to-Residues-Ratios (CRR) for rice husks, straws, bagasse, palm oil residues (except palm oil mill effluent), and wood, it has been estimated that about 16 million tons of residues were produced from the rice, sugar, palm oil and wood industries of Thailand in 2003. This is summarised in the table below (Table 4.2-4).

Table 4.2-4: Residues produced in 2003 and Potential Energy

Sector	Residues (10^3 tons)	Potential Energy (TJ/year)
Sugar - bagasse	4,473	64,412
Rice - rice husk	2,955	42,162
Rice – straw	7,967	81,581
Palm Oil - fibre + shells + empty fruit bunch	1,250	22,215

Biomass conversion technologies can be classified into three categories: traditional, state-of-the-art, and emerging technologies. Traditional technologies are conventional technologies which have been used for a long time without any technological barrier. Most of the existing technologies employed in Thai industries belong to this category. System (boiler) efficiencies may range from 50% to above 80% and may have none or minimal environmental features to meet current environmental standards.

State-of-the-art technologies are currently available in the market, with minimal developmental barriers, although its uptake is still limited to a few industries. Considered more efficient and more environment-friendly than traditional technologies, these types of technologies have mainly been taken into account in this study, especially in deriving the structural power capacity in Thai agro-industries.

Emerging technologies are long-term technologies requiring further research before commercialisation can be considered. There is very little information about the uptake of such technologies in Thailand even on a pilot or demonstration scale.

4.2.3 Economic framework for renewable energy

4.2.3.1 Macroeconomic considerations

Economic growth

Because of the economic recovery now more power plants are needed than recently expected. Therefore the use of biowaste in power plants add no extra capacity costs to the economy. From a macroeconomic point of view it is also important to consider the marginal cost of transmission. This means it is necessary to look at geographical differences. There may exist areas with a shortage of power generating capacity. A new build power plant reduces the cost for transmission lines.

The big differences in generating costs between low and high peak hours suggest try to generate electricity if technical possible mainly at peak hours.

4.2.3.2 The electricity sector

Production costs will slowly increase from a rather low level because of economic recovery

There are some information about production cost in Thailand from *PricewaterhouseCoopers 2000*. They calculate marginal cost for energy production with 2.36 US-cent /kWh. To this add marginal capacity cost of 0.52 US-cent/kWh based on the assumption of excess capacity. Usually marginal capacity cost calculated on capital, fixed operation and maintenance costs of an open cycle gas turbine will accrue to more than 1 US-cent/kWh. So this calculation is true only as long no big investment in the power sector is necessary. This situation changes slowly. Furthermore their calculation base on low fuel prices which will never be seen again. Based on their analysis of marginal cost PricewaterhouseCoopers recommend in year 2000 a bulk power tariff for medium voltage of 0.95 Baht/kWh and 2.66 Baht/kWh in peak hours. Regarding the fact of the economic recovery and the need for more power generation plants the price should be higher to reflect the higher long run marginal costs through additional capacity costs.

With this rather low cost it seems that it will be difficult for RE plants to compete with other power plants.

Tariff
There exist a escalating tariff for residential use as well as for small general service. For productive use exist some different tariff options starting with about 1.2 Baht/kWh up to 2.8 Baht/kWh (for details see *www.aseanenergy.org*)

4.2.3.3 Financing and investment

National Energy Policy Office
NEPO assist some programmes which are financed through the Energy Conservation Promotion Fund. ENCON Promotion Fund was founded 1992. The main objectives of the ENCON Program include: (*Angsuwan S. 2000*)

- providing financial assistance and incentives for energy conservation, energy efficiency and renewable energy projects;
- supporting demonstration of energy conservation and renewable energy technologies;
- supporting the promotion and dissemination of proven energy conservation and renewable energy technologies;
- increasing research and development and training in energy conservation technology; and
- organising public awareness campaigns to promote energy conservation.

Use of CDMs
There are some CDM pilot projects. For bigger plants (esp. biogas) this could be a additional source of income.

4.2.4 Socio-cultural and socio-economic framework for RE

Knowledge and acceptance
Some but not sufficient knowledge available
There is already some use of biogas technology. It was first promoted about 30 years ago. There was a biogas promotion programme during the oil crisis end of 70s. But success was limited because of bad construction techniques, lack of experience and awareness on part of the farmers and of the officials of the Department of Agriculture Extension. Since 1988 the German "Gesellschaft für Technische Zusammenarbeit" (GTZ) supported for seven years the Biogas Advisory Unit at Chiang Mai University. This collaboration was a success for the development of biogas technology in Thailand and Biogas Advisory Unit has now some design and construction experience (*Intarangsi and Kiatpakdee 2000*). Technology was mainly developed for manure from animal farming.

This means there are firms which have some technological knowledge. But technology is still under development and not known everywhere. It is strongly recommended to contact operators of existing biogas plants or organisations or universities with the necessary knowledge. This can help to find quickly a lot of information and contacts to suppliers and other people with the necessary engineering knowledge. According to *Intarangsi and Kiatpakdee 2000* many difficulties arise because farmers deviate from the proper construction to save cost. Similar farmers tend to neglect proper maintenance and thwart their project by this way.

Thermal treatment is easier to handle and often used. But for higher efficiency and environmental reasons it is strongly recommended to contact operators of existing plants.

Problems may arise to find people and firms with the necessary engineering knowledge and experience.

Acceptance problems
Nothing is known about acceptance problem in form of religious, ethnic or social taboos.
Unemployment is very high all over the country. Therefore it is expected that people will accept even dirty jobs.

Effects of electrification
Only few remote areas may be better of through better electrification

Only remote areas of Thailand are without electricity connection. Currently there seems to be no scarcity of electricity but with economic growth this may change. Depending upon the price electricity demand may change. With low consumer prices demand for air condition may increase considerably. Better supply of electricity may stabilise economic growth and improve quality of live.

4.2.5 Legislative, regulatory and policy framework conditions for renewable energy

Energy Conservation Promotion Act & Energy Conservation Promotion Fund

The Energy Conservation Promotion Act has been in force since 3 April 1992 with a view to promoting energy conservation discipline and promoting energy conservation investment in factories and buildings. This Act is an innovative policy instrument as it blends incentives with mandatory regulations to facilitate the implementation of mandated energy efficiency measures. The Energy Conservation Promotion Fund (ENCON Fund) was established, under the Act, to provide financial support to government agencies, state enterprises, non-government organizations, individuals, and businesses that wish to implement measures to increase efficiency in energy utilization. At the same time, a punishment clause is stipulated in the Act for owners of any designated factory or building who fails to comply with the standards, criteria and procedures as provided by related ministerial regulations issued under the Act. The role of the public sector is to establish and utilize government mechanisms to encourage and promote energy conservation implementation by consumers, including development and utilization of renewable energy which is environmentally friendly.

Financial assistance from the ENCON Fund to materialize the above-mentioned objectives is monitored under the framework of the Energy Conservation Program, divided into three main areas:

- Compulsory Program
- Voluntary Program
- Complementary Program.

4.2.5.1 Compulsory Program

The Department of Alternative Energy Development and Efficiency (DEDP) of the Ministry of Energy is responsible for the program implementation. This program relates to mandatory energy conservation implementation as specified by laws and regulations enforced under the Act, involving "designated" factories and buildings, using energy at a level of 1,000 kW or 1,175 kilovolt-amperes (kVA) and greater, or using non-renewable energy or steam in a previous year at an amount equivalent to, or greater than, 20 million megajoules of electric power. The program also supports energy conservation in government buildings, of which electrical capacity demand is 100 kW and greater, that wish to implement energy conservation measures as in the case of designated factories and buildings.

The Compulsory Program currently comprises three main projects, i.e.

1. Government Building Project;
2. Project on Existing Designated Factories and Buildings; and
3. Public Awareness Campaign Project, under the DEDP's Responsibility.

Government Building Project aims to promote energy conservation in government buildings that are not designated by laws so as to spearhead energy conservation and to reduce the government expenditure on energy cost.

Project on Existing Designated Factories and Buildings aims to support owners of existing designated factories and buildings for both the development of a comprehensive energy efficiency improvement plan and the investment to improve energy efficiency according to the plan as presented to and approved by the DEDP.

Public Awareness Campaign Project, under the DEDP's Responsibility is to disseminate information to persons directly involved in the ENCON Program, comprising owners and persons responsible for energy of designated factories and buildings, and manufacturers of equipment, machinery and materials contributing to energy conservation. The campaigns will focus on the information about the ENCON Program and the provision of government financial assistance for the implementation of energy conservation measures under the Compulsory Program.

4.2.5.2 Voluntary Program

This program is monitored by the Energy Policy and Planning Office (EPPO) of the Ministry of Energy to ensure continuous implementation of the program so as to achieve the objectives of the ENCON Fund allocation. Support and cooperation are provided to the government agencies, academic institutions or non-government organizations, aiming at the following:

- Promoting efficient use of energy in the agricultural sector, small industries, existing non-designated factories and buildings, the transportation sector as well as in the reuse and recycling of waste materials;
- Widening the market for products and services contributing to energy conservation in factories/buildings, in the transportation sector, and in the reuse and recycling of waste materials; and
- Encouraging studies, research and development on energy technology and energy conservation, and the application of the study/R&D outcomes to the actual operation of factories, buildings as well as households.

A funded entity is called "Project Owner" responsible for the project management. The project may have several "Project Participants" who will undertake energy conservation-related activities under the project. These "Project Participants" will receive both financial and technical assistance from the "Project Owner." The ENCON Fund assistance will be provided to "Project Participants" through the "Project Owner."

The Voluntary Program consists of five major projects as follows:

1. Promotion of Renewable Energy Utilization Project;
2. Industrial Liaison Project;
3. Research and Development Project;
4. Energy Conservation in Non-Designated Factories and Buildings Project; and
5. Promotion of Small Power Producers Using Renewable Energy Project.

Promotion of Renewable Energy Utilization Project focuses on opportunities to develop fuel substitution and on the introduction and dissemination of renewable energy technology, i.e. technology using renewable energy sources more efficiently, by providing full operational cost for project owners and granting financial support in the form of interest subsidies for project participants.

Some examples of funded projects which have proven to be successful in efficient use of renewable energy are as follows. Biogas projects utilizing manure of livestock (pigs in particular) have proved to be a great success. As of September 2002, a total of 56,000 cubic meters (m^3) of the biogas system was installed in medium and large-sized farms, and 75,760 m^3 in small farms nationwide. The yield of biogas is used as energy source for on-site electricity generation and/or cooking in households instead of traditional fuel and LPG. Since the results of biogas projects have been satisfactory, the ENCON Fund will further support the installation of 130,000 m^3 of the biogas system in large farms and 150,000 m^3 in medium-sized farms in seven years starting June 2002 and 300,000 m^3 in small farms during 2003-2009.
Another interesting project is the industrial plant rooftop PV grid connected pilot project to demonstrate power generation from solar or photovoltaic (PV) cells installed on the rooftops of 10 industrial plants, with a 4.2-kWp system each. The excess PV-generated electricity can be sold back to the distribution utilities' grid systems. This project will stimulate the industrial sector to participate in self-generated electricity for on-site use and to use electricity efficiently.

Industrial Liaison Project enhances the capacity of the industrial sector to produce energy efficient equipment. The project also supports small-scale and full-scale demonstration projects, including information dissemination, of proven technology. Some interesting funded projects are the energy efficiency standards regime study, the establishment of household refrigerator testing laboratory, and the Demand Side Management (DSM) Program.

In 1999, EPPO commissioned a study on energy efficiency with a view to establishing the mandatory Minimum Efficiency Performance Standards (MEPS) of six electrical products, i.e. refrigerators, air-conditioners, motors, ballasts, compact fluorescents, and fluorescent tubes. The proposed efficiency levels are currently under review by the Thai

Industrial Standards Institute (TISI) to be enacted in legislation. MEPS defines an energy efficiency performance threshold that energy-consuming equipment should meet. Hence, inefficient products will gradually be removed from the market. The implementation of this project is expected to reduce total energy consumption by 3,500 GWh within seven years' implementation and reduce capacity demand by 700 MW in the corresponding period. On the consumers' side, there will be substantial savings on their electricity bills due to the use of high-efficiency appliances. On the environmental side, it is expected that CO_2 emission will be reduced by about 2 million tons.

The Demand Side Management (DSM) Program was initiated by EGAT in 1993 to promote energy conservation, targeting three major sectors, i.e. residential, commercial and industrial sectors. Market transformation strategy has been introduced, i.e. local manufacturers and importers are stimulated to produce and import energy-saving and efficient appliances whereas consumers are provided with education and energy conservation awareness through various media. Several campaigns have been launched with emphasis placed on utilization of high-efficiency electric appliances, such as lighting equipment, refrigerators, air-conditioners and motors. Manufacturers are encouraged to apply energy efficiency labelling to their products to stimulate and facilitate consumers to select high-efficiency equipment and appliances. The DSM Program stresses not on enforcement but on voluntary collaboration aimed at improving consumers' behavior in electricity utilization but with less consumption and/or a lower power bill. It is reported that the cumulative energy saving as at the end of 2002 was 735.70 MW of peak demand and 4,163.80 GWh energy.

Research and Development Project aims at developing new or improving existing technology, with support to small-scale demonstration projects as well as information dissemination. As of September 2002, the ENCON Fund has supported more than 104 R&D projects concerning energy-related technology development and energy conservation undertaken by various government agencies and academic institutions. An example of funded projects is the performance test of LPG-fired cookers in Thailand, in terms of both thermal efficiency and poisonous gas emission amount. The study outcome can be used to further improve LPG-fired cooker efficiency, which will help reduce LPG consumption, especially in the commercial and residential sectors which, according to the 2001 records, accounting for 71% of the total domestic LPG consumption. Another interesting project is the study on the potentiality of fly ash utilization as a cement replacement material. Fly ash, or pulverized fuel ash, is a by-product of coal combustion for thermal utilization. Currently, only a small portion of fly ash has been utilized to generate economic value; therefore, the amount of fly ash has been increasing substantially and hence may create environmental problems in the nearby areas. To use fly ash in concrete production by mixing it with cement is an option to create economic value of fly ash. This will reduce not only the amount of fly ash but also energy consumption in cement production. The project outcome will contribute to greater utilization of fly ash in place of cement, i.e. 30% of the total fly ash production volume. Hence, energy consumption in cement production can be reduced, accounting for a value of 100 million baht per year. Carbon dioxide emission resulting from the cement manufacturing process can also be reduced.

Energy Conservation in Non-Designated Factories and Buildings Project has the objective is to solve problems related to energy utilization in small and medium-sized enterprises (SMEs), including improvement of human resources and management. The project implementation can help reduce a substantial amount of energy consumption in SMEs. In addition, the production costs and exploitation of several resources in the production process can be reduced. An approach used in most facilities is energy auditing and energy saving development, using "Value Engineering (VE)" technique together with the Demand Side Management by Humanware Approach Technique (DSM by HAT). Energy experts and the factory personnel will jointly develop the implementation plan to reduce energy consumption in their individual facilities. Another approach is the replacement of inefficient equipment by energy efficient equipment/technology ("Standard Measures"). Energy audit will be made before and after the installation of energy efficient equipment in order to verify energy saving achieved.

4.2.5.3 Complementary Program

This program is also monitored by the Energy Policy and Planning Office (EPPO) to ensure effectiveness of the Energy Conservation Program implementation. The Complementary Program consists of three main projects:

1. Human Resources Development Project;
2. Public Awareness Campaign Project, under EPPO's Responsibility; and
3. Management & Monitoring Project.

Human Resources Development Project aims to increase and develop human resources competence to be able to effectively handle the implementation of the Energy Conservation Program. At present, the number of personnel with energy-related expertise is limited, whereas the demand is increasing due to, among others, the requirements of relevant ministerial regulations which require designated facilities to appoint energy managers to monitor energy saving measures in the facilities. Human resources mobilization and development are, therefore, major tasks under the Complementary Program.

Focus will be on the creation of knowledge on energy conservation and renewable energy utilization. Integration of such knowledge will be made into the curriculum of primary and secondary school levels. At the university level, financial support will be provided for the teaching and establishment of laboratories to enhance energy conservation and renewable energy learning process. In addition, university graduates will be encouraged to attend additional training on energy conservation and renewable energy.

Public Awareness Campaign Project, under EPPO's Responsibility aims at creating the general public's consciousness in energy conservation and encouraging their participation in the Energy Conservation Program. Campaigns have been undertaken on a continual basis, via such media as TV, radio and printed matters, with emphasis on the importance of energy saving and adverse impact of inefficient use of energy on the economics, society and environment. Simple energy saving methods that can be practised in daily activities, with low or even no costs, have been disseminated as they can bring about substantial reduction of expenditures on oil and electricity. The achievement and return on investment in energy conservation and renewable energy utilization will be publicized so as to persuade those who have not commenced saving energy or using renewable energy to seriously consider and practically take actions.

Management & Monitoring Project provides financial support to the executing agencies of the government for the launching and monitoring of the Energy Conservation Program to enhance effective monitoring of implementation of various projects and of total savings achieved under the Energy Conservation Program over time, including efficiency and effectiveness of utilization of the ENCON Fund.

Promotion of Small Power Producers Using Renewable Energy Project is to promote greater use of renewable energy for power generation. The government has approved an allocation of 3,060 million baht (about US$ 70 million) from the ENCON Fund to provide incentives in the form of a pricing subsidy for the capacity generated by renewable energy on top of the power purchasing rate from SPPs stipulated by EGAT. A target of 300 MW of electricity generated by renewable energy is expected during a five-year pilot phase starting in 2002. At present, 31 SPPs using mainly biomass, with a total proposed capacity sale of 511 MW, have been initially selected, pending a hearing process organization among the local communities of each individual project. Of the 21 operators of these 31 SPP projects, except for EGAT, all others are private companies.

By the year 2006, the Voluntary Program envisages the implementation of the following: 3.54-MW rooftop PV systems; 13.15-MW PV systems in remote areas; 9.25-MW PV grid support; installation of 54,200 m^2 of solar collector surface area for 10,000 households, 200 hotels and 142 hospitals; 400,000 m^3 of biogas system utilizing pig manure; energy saving projects; and electricity generating from methane gas (landfill). It is also expected that SPPs using renewable energy and supported by the ENCON Fund can commence supplying power to the grid system by 2006.

4.2.5.4 IPP’s and SPP’s

The electricity supply industry is now being deregulated to allow private sector investment in power generation projects, in the form of both IPP’s and SPP’s, and to sell electricity to EGAT. To date, EGAT is expected to purchase power from seven IPP projects, with a total capacity of 5,944 MW, and from approximately 55 SPP projects, with an estimated total sale of 2,500 MW. Power purchase from IPP’s and SPP’s will result in the reduction of EGAT’s required investment in power generation by approximately 300,000 million baht.

Small Power Producer (SPP)

SPPs are small power projects that are either cogenerators or facilities using renewable energy as fuel, which sell power to EGAT of not more than 90 MW for each project. Since each SPP can sell power directly to consumers located in its vicinity, its generating capacity is therefore very often as large as 120-150 MW. A number of SPPs are really Independent Power Producers (IPPs) disguised as cogenerators. Since 1991, 92 proposals have been received by EGAT but some projects have been rejected while some have withdrawn particularly after the baht flotation in July 1997. At present 51 power purchase agreements (PPA) with EGAT have been signed and another 6 PPAs are under negotiation. If all projects are completed then the total purchase would amount to 2,445 MW.

As of December 1998, thirty-one SPPs were already in operations selling 740 MW of power to EGAT, and a number of other projects at various stages of development. After the baht depreciation in July 1997 the government amended the terms and conditions for the SPPs particularly by indexing a part of the capacity payment to the exchange rate in order to cushion the impact of the economic crisis. The amendment of the PPA has helped a number of SPPs to obtain financial closing on their projects thereby allowing them to proceed and complete the projects. However a number of projects still face financing problems and it is possible that up to 11 projects will not be to completed. Under this worse case scenario EGAT would be buying power from 44 SPPs with total purchase amounting to 1,730 MW (see Table 4.2-5)

Table 4.2-5: SPP Proposals Accepted Classified by Type of Fuel as of December 1998

	Number of Projects	**Generating Capacity (MW)**	**Sale to EGAT (MW)**
Commercial Energy			
Natural Gas	23	2,988	1,678
Fuel Oil	1	0	9
Coal	10	1,210	618
Sub Total	**34**	**4,208**	**2,305**
Renewable Energy			
Bagasse	14	301	67.5
Paddy Husk, Wood chips, Saw dust	6	144.3	57
Municipal Waste	1	3	1
Biogas	1	0.06	0.045
Black Liquor	1	32.9	25
Sub Total	**23**	**481**	**150**
Total	**57**	**4,689**	**2,455**

A number of prominent Thai companies are involved in SPP projects for instance Banpu, Advance Agro, Thai Oil, TPI, Bangkok Industrial Gas, EGCO, Hemaraj, Sahapatanapibul and Bangpakong Industrial Park. Many international companies also play significant roles in the SPP business in Thailand. These include

- Sithe Pacific (USA)
- CMS
- Imatran Voima Oy (Finland)
- Air Products (USA)
- Tractebel (Belgium)
- Marubeni (Japan)

The economic crisis has also greatly affected the Thai shareholders in SPP projects forcing them to seek new partners. A number of international companies have recently decided to participate in SPP projects, for instance CMS (USA) and National Power (UK).

Independent Power Producer (IPP)
The first round of IPP solicitation was issued in December of 1994 whereby EGAT would buy up to 5,800 MW of capacity from IPPs for the period 1996-2003 (see Table 4.2.-6) Power Purchase Agreements (PPAs) has been signed with 7 IPPs with a total of 5,944 MW of electricity sold to EGAT.

Table 4.2-6: Thailands's IPP Awards

Company	Investor	Capacity (MW)	COD	Fuel Used
Phase I (1996-2000)				
1. Independent Power (Thailand) Co., Ltd. (IPT)	Thaioil 56% Unocal 24% Westinghouse 20%	700	Sep 99	Natural gas
2. Eastern Power & Electric Co., Ltd. (Bang Bo) (EPEC)	GMS Power Plc 67% Marubeni 33%	350	31 Jan 2002	Natural gas
3. Tri Energy Co., Ltd. (TECO)	Banpu 37.5% Texaco 37.5% Edison Mission Energy 25%	700	July 2000	Natural gas
Phase II (2001-2003)				
1. Union Power Development Co., Ltd.	Union Energy 10% Tomen 34% Imatran Voima Oy 28% Consolidated Electric Power Asia (CEPA) 28%	1,400	Unit 1 1 Oct 2002 Unit 2 1 Jan 2003	Coal
2. Bowin Power Co., Ltd.	Hemaraj 50% Tractebel 50%	713	1 April 2002	Natural gas
3. BLCP Power Limited	Banpu 47.5% Loxley 5% PowerGen 47.5%	1,346.5	Unit 1 1 Oct 2002 Unit 2 1 Feb 2003	Coal
4. Gulf Power Generation Co., Ltd.	Gulf Electric 60% Mission Energy 40%	734	Unit 1 1 Oct 2002 Unit 2 1 April 2003	Coal
Total		**5,943.5**		

The baht flotation in July 1997 was considered as a “change in law”, PPAs were, therefore, amended which significantly helped IPPs to proceed with their projects. At this stage, 2 IPP projects have been able to obtain financial close while the other five IPPs are in the process of obtaining financing. The economic problems have resulted in re-negotiations for the commercial operation date. These negotiations were carried out between May – June 1998 and the results were approved by Cabinet on 16 February 1999, except for BLCP where the negotiation for a 2-4 year delay has not been concluded.
Certain changes in the shareholding structure have taken place, for instance Black & Veatch withdrew from TECO and has been replaced by Mission Energy, Union Energy has reduced its share holding in Union Power in order to bring in CEPA, and Rio Tinto withdrew from BLCP.
The main concern of the financial institutions in providing financing is related to the ability of EGAT to uphold its commitment under the PPA’s as EGAT’s financial position could deteriorate if:

- the economic slow down causes significant slow down in power demand growth resulting in a very high level of reserve margin of the system;
- the government, due to political reasons, does not allow EGAT to adjust the retail power tariff.

It has been pointed out that EGAT’s power development plan has been adjusted by delaying a number of projects while a number of private power projects are facing delays so the reserve margin would not be excessive. Moreover the adjustment in the tariff is automatic and does not require government approval. Since the baht flotation, the tariff has been adjusted four times to reflect the increase in the fuel cost and the cost of debt.

The tariff increased on three occasions between November 1997 and November 1998. The fourth tariff adjustment in December 1998, saw a decrease by 5.08 satang per kWh.

IPP and SPP Solicitation
Given the current economic slowdown and commitments already made by EGAT and the Thai government to buy power from a number of IPPs, SPPs and power projects in Lao PDR, new generation capacity would not be needed until 2008. The folowing table summarizes the IPP/SPP capacity Requirement until 2011.

Table 4.2-7: New IPP/SPP Capacity Requirement

	Base/Intermediate Load (MW)	South (MW)
2008	600	300
2009	1,800	300
2010	1,600	-
2011	1,600	300

This means that, under the single buyer model, the next IPP/SPP solicitation may not be required until 2003 for new capacity for the year 2008. However, if competition in the power supply industry can be established in accordance to the schedule in the Privatisation Master Plan, then there would be no request for proposal in the future, but new capacity expansion would be left to the market.
New power generating plants to be built by EGAT under EGAT's PDP 99-01, approved by Cabinet on 16 February 1999, are Krabi thermal power plant (600 MW), Surat Thani Combined Cycle (300 MW), Chulabhorn and Kiritran pump storage. The Ratchaburi power plant and Lam Takong pump storage power plant are currently under construction.

4.2.5.5 The Electricity Generating Authority of Thailand (EGAT)

The Cabinet resolution of 5 March 1996, giving consent to the resolution of the National Energy Policy Council (NEPC), has prescribed the corporatisation and privatisation of EGAT as follows:

1. The separation of EGAT's thermal power plants from EGAT and their corporatisation into limited companies, selling their shares to the general public/private sector;
2. The corporatisation of the maintenance, engineering, and mining business units into limited companies;
3. The transmission line business and power generation using hydropower will still be retained by EGAT, which will remain a state enterprise.

Following the Cabinet resolution, several advisors were engaged by EGAT to undertake studies in order to implement the policy. The preliminary conclusions of the studies are that EGAT's thermal power plants should be separated and corporatised into three companies (powergens). To make the three companies attractive to investors, the allocation of EGAT power plants (those which currently exist/under construction and those to be constructed in the future) would be made to the three powergens (see Table 4.2-8).

Table 4.2-8: EGAT's Thermal Generation Facilities

EGCO (Already Privatised)		**MW**
Existing Power Plants	Rayong	1,223
	Khanom	824
	Total	**2,047**
Ratchaburi Holding		**MW**
Existing Power Plants	Ratchaburi CC	2,175
	Ratchaburi TH	1,470
	Total	**3,645**
EGAT		**MW**
Existing Power Plants	Bang Pakong	3,675
	Wang Noi	2,031
	North Bangkok	238
	Nam Phong	710

	Mae Moh	2,625
	South Bangkok	2,288
	Sai Noi	244
	Nong Chok	488
	Lan Krabue	134
	Total	**12,433**
Future Power Plants	Krabi	600
	Surat Thani	300
	Total	**13,333**

4.2.5.6 Energy Sector Regulatory Framework

In 1997, NEPO commissioned the consulting firm London Economics to prepare a set of recommendations for a regulatory framework for the energy sector. The project was initiated as a response to the changing regulatory needs of a sector undergoing significant growth and development in addition to the reform and restructuring process. The project would help design and commence the establishment of an independent regulatory office as well as reviewing the required functions of such an economic regulatory body for the energy sector.

Phase I of the project, which was completed in late 1997, reviewed existing and future regulatory functions arising from the structural changes being implemented and developed recommendations for appropriate regulatory responses for the short to medium term transition phase.

Phase II of the project, which was completed in mid 1998 presented a recommended design for an independent regulatory agency as well as providing a number of the requisite legal instruments to enable the agency. This phase also reviewed NEPO's existing regulatory capacity and advised on the directions required to enable NEPO to regulate effectively during the transitional phase to an independent regulator.

Recommendations arising from the project include:

- the establishment of an independent regulatory office responsible for the power and gas sectors
- the office will be headed by 5 commissioners, serving limited tenure.
- primary legislation will include an enabling act which passes requisite powers to the regulatory office
- regulation to be achieved through the use of secondary legislation i.e. licences and will be light-handed, conduct based where possible
- price regulation to be initially based on a CPI-X based revenue cap

The Regulatory Office will be established through a new Energy Law, which is expected to be enacted within 5 years. During the transition phase, NEPO will establish an institutional capability to both manage the process of implementing an independent regulatory office and undertake those regulatory activities and functions necessary. During this transition phase, these activities and functions will include:

- oversight of licenses
- development of regulatory rules
- network tariff calculation
- oversight of distribution functions
- technical standards/quality of service
- oversight of PPA's
- electricity load research
- preliminary policy work on power pool
- oversight of gas contracts
- monitor margins pre competition in the gas sector

4.2.6 General potential for renewable energy production from biomass

Barrier: lack of knowledge and information

Despite some experience with RE further promotion and information about energy generation from biomass is necessary. The existence of some biogas and thermal treatment plants gives a good information base for further development of this technology. Any potential investor should try to collaborate with some existing operator to gain local knowledge.

Structure of the electricity sector basically good
The structure of the electricity sector and the existence of a regulation for IPPs and SPPs give a reasonable framework to develop RE. There is also some promotion of RE from the government. Much will depend upon the price of fossil fuel and therefore the long run competitiveness of RE.

Waste treatment will be more focused on
Agriculture is now more and more centralised and there exist big farms. Especially the bigger animal farms may use biogas technology more because it is not only income generating through electricity and fertiliser selling, it is also cost reducing through cleaning of wastewater. Environmental legislation demand some wastewater treatment from the farms. So this legislation promotes indirectly the production of RE from biowaste.

Recommendations

Regulatory framework
Thailand has some good regulation for SPPs. Further improvement esp. regarding the use of RE would be useful. For SPPs the existing framework gives a base.
Electricity production

In areas with excess producing capacity it may be more difficult to sell energy to EGAT because they will calculate without marginal costs of capacity. In areas with a shortage of producing capacity a higher price should be gained. In general it is useful to sell electricity mainly during the peak hours. Direct consuming or selling may be an opportunity because retail prices are higher than bulk prices of EGAT.

Biogas and biowaste burning helps to reduce waste problem
Electricity selling may often not be sufficient to operate economically. So it is necessary to understand these technologies also as waste treatment technologies. Both technologies will help to reduce waste problems and should therefore promoted by local governments and communities. They can help to reduce the waste problem in agriculture areas as well in cities to generate biogas from landfills.

Knowledge
More promotion of the use of bioenergy is necessary. There remains a lack of knowledge.

Proper design and maintenance
It is really necessary to use the proper design to ensure a working plant. Construction should not changed to save costs and hereby to thwart the whole project. The same apply to maintenance. Some minor mistakes in maintenance ruin the whole plant. Everybody who support the project (especially financially) and has a strong stake in it should urge that the proper design will be kept and should control maintenance.
To save maintenance costs and to make the system simpler moving parts or mechanical equipment should be avoided or reduced. To ensure good maintenance technology should be kept simple and tolerant. So it can be ensured that it needs not so much attention. This is especially important for small plants who can not employ extra skilled technicians.

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5 The potential for renewable energy production from organic substrates in Vietnam and Thailand

Vietnam and Thailand possesses abundant biomass sources that can be used for energy generation. In the following, the potential for renewable energy production from major biomass will be estimated.

5.1 Definitions and Methodology

In general it can be distinguished between the theoretical, technical and economical potential [Kaltschmitt, 2001].

<u>Theoretical potential</u>
The theoretical potential describes the potential that can theoretically be utilised for biomass-based renewable energy production. It corresponds to the physically exploitable energy potential. Therefore, the theoretical potential represents the upper limit of the available potential for energy production.

<u>Technical potential</u>
The theoretical potential is reduced to the technical exploitable potential by taking into account the prevailing technical, structural, administrative and ecological framework conditions.

<u>Economical potential</u>
The economical potential describes the fraction of the technical potential that can be economically exploited for renewable energy production from biomass.

In the following, only the technical potential of biomass sources in Vietnam and Thailand will be determined. An **availability factor** will be used that incorporates the prevailing technical and structural restrictions to the exploitation of biomass sources. In particular, the following restrictions will be considered:

- **Supply constraints** (physical constraints), such as structure of industry, harvesting methods, distribution of production, etc., that directly affect the actual availability of surplus biomass for power generation

- **Competing applications** and consumers of the biomass sources, such as energy and non-energy uses

It should be noted, that due to the underlying assumptions and uncertainties, the determined technical potential can only be regarded as a first indication of the actual available potential for renewable energy production.

The production of renewable energy from organic substrates is basically determined by the available quantity of biomass sources that are suitable for biogas or biomass combustion processes. In general, no data is available for quantities of biomass, residues or organic waste generated. Thus, specific ratios (e.g. residue-product-ratio RPR) will be applied to calculate the available quantity of biomass sources. In the followed simplified approach, all calculations will be based on a yearly basis.

The technical potential will be calculated as energy content of the respective substrates, and thus represents the **technical energy potential**. The technical energy potential will be expressed in the unit Peta Joule per year (PJ/a). For substrates that are suitable for biomass combustion processes, the calculation will be based on typical calorific values. For substrates that are suitable for biogas processes, the energy potential will be calculated on the basis of the methane generation potential. It should be noted that the determined technical energy potential does not represent the actual usable energy production, since efficiencies of energy conversion systems are not taken into account.

5.2 Potential for renewable energy production by biogas and biomass combustion in Vietnam

5.2.1 Collection of data and data sources

Several data sources have been used to determine the available quantity of biomass sources in Vietnam. Statistical data on production of commodities, demographical setting, etc. have been based on the statistics provided by the General statistical office of Vietnam. Data on the current utilization of residues and biomass wastes as well as other framework conditions are based on information provided by the concerned ministries, industrial association and own data acquisition in Vietnam during site investigation. Relevant literature has been consulted to identify appropriate specific values and ratios.

Vietnam possesses abundant biomass resources that can be used for energy production. Depending on their origin, a classification of the several types of substrates can be made into the following main categories:

- Agro based crop substrates
- Animal husbandry
- Municipal solid waste
- Industrial wastewaters

5.2.2 Agro based crop substrates

Agro-based crop substrates derive from a wide variety of agricultural activities. A sub-classification can be made into annual crop residues and perennial plantation crop residues.

Annual crop production generates large quantities of residues that are available abundantly throughout rural areas of Vietnam. A distinction can be made between field residues, that are left in the field after harvesting and process residues that are generated during crop processing (milling, etc.). Field residues are scattered over a wide area whereas process residues are generally available at a central location.

Vietnam has significant biomass resources such as bagasse, rice husks, coffee husks, coconut shells and wood residues. These potential sources of energy are largely used for cooking and heating water. Thermal use is also made of biomass in the industrial sector, for example rice husks in brick making. Further biomass resources could also be developed in particular for combined heat and power plants, using sugar-cane bagasse and residue as well as rice husks.

Paddy
Paddy is planted in over 50% of agricultural land and more than 60% of annual cultivation areas [MARD, 2004]. The production of paddy amounted to 34,52 million tonnes in 2003. More than 50% of the paddy are produced in the Mekong Delta; other regions with high production are the Red River Delta and the North central cost which have a share of the countrywide production of 19% and 9%, respectively [GSO, 2003]. The cultivation and processing of paddy results in the generation of rice straw and rice husk that can both be used as fuel for power generation.

In Vietnam, rice milling is done by a large number of small rice mills that are scattered throughout the rural areas. Altogether, Vietnam has more than 100,000 rice mills, although only approximately 50 are located in the main growing region of the Mekong Delta with a throughput of more than 5 tonnes per hour [Eschborn, 2004].

[Koopmans, 1998] suggests that rice straw is generally burned in the field with the ash used as organic fertilizer, animal fodder, animal bedding, raw material for paper and board making, or building material. It is assumed that the most common current utilization of rice straw in Vietnam is domestic fuel use. Rice husk is often partly utilized for low efficiency power generation in the rice mills, disposed off by open burning or used as fuel in the brick industry.

No accurate data on number and capacity of mills and competitive uses for rice straw and husks in Vietnam was available. Thus, the technical potential can only be estimated based on general data available for Thailand and other regions. It is assumed that 75% of rice straw remains in the fields and another 10% is allocated to competitive uses (e.g. domestic fuel) [Junginger, 2000]. Therefore, only approximately 22% of the total quantity is available for energy production.

Not all rice husk generated is available as surplus biomass due to the structure of the rice milling sector in Vietnam (small mills). It can be estimated that only 70% of the total quantity can generally be used for energy production. Due to the competitive use of rice husk as boiler fuel in the large rice mills, the surplus availability for energy generation is further reduced. In a first approximation, the available surplus amount for energy generation is estimated at 35% [Junginger, 2000].

Sugar cane

Due to the government support in the framework of the Program "one millions tons of sugarcane", the sugarcane area and output all over the country have improved considerably. In 2003, the annual output is predicted as 16,5 million tons. In Vietnam, there are 3 pivotal sugarcane production areas: Thanh Hoa – Nghe An area (27% of total capacity), Quang Ngai area (7,7% of the total capacity) and Tay Ninh area (14,6% of total capacity) There are now 41 companies with a total design capacity of 70.000 tons sugarcane/day [MARD, 2004] indicating that most of the sugar cane is processed in large sugar mills. Most of the 43 existing sugar mills are situated south of Da Nang.

In comparison to other crops, sugar cane gives a very high dry matter yield per unit of land area. The main residues produced are bagasse and sugar cane tops and leaves. Bagasse is normally used as boiler fuel for steam generation in the sugar mills. It is estimated that only 20% of the total quantity of the produced bagasse are available for surplus energy generation.

Sugar cane tops and leaves are a field based residues and are thus confined collectable. Cane tops and leaves are either used as cattle feed or are burnt in the field [Koopmans, 1998]. It is assumed that the surplus availability for energy generation amounts to approximately 35%.

Maize

The main residues produced are stalks, maize cobs and maize husk. In many cases, the stalks are left in the field or used for other purposes such as fodder, while husks and cobs become available at processing sites [Koopmans, 1998]. Thus, only maize cobs and husk can be considered as source for energy generation. The surplus amount available for energy generation is estimated at 50% of the total quantity.

Cassavas

The planted area of cassava is estimated at 371.900 ha in 2003 resulting in a total annual production of 5,23 million tons. The stalk is partly retained for replanting, discarded or used as domestic fuel. It is estimated that approximately 35% of the total quantity can be utilised for energy production.

Perennial crop plantations such as for coconut and rubber generate considerable amounts of wood residues from pruning and replanting activities. The perennial plantations crops in Vietnam, that produce relevant surplus amounts of residues that can be generally be utilised for energy generation are coconut, rubber and coffee.

Coconut

The estimated planted area of coconut trees in Vietnam is 135.800 hectares in 2003, with an annual production of 920.000 tons [GSO, 2003].

Coconut trees generate residues in the form of woods, fronds, husks and shells. With regard to coconut fronds, a value for the residue-to-cropping area of 2,34 tonnes per hectare and year is given by [Koopmans, 1998].

Coconut husks and shells are not always found concentrated and application as domestic fuel has been identified as competitive utilisation in Vietnam. The surplus amount available for energy generation purposes is estimated at 40% of the total quantity.

In general, coconut trees are spread over large areas and parts of the coconut fronds remain in the fields. Utilisation as domestic boiler fuel is a very common application in Vietnam. Therefore, it is estimated that only 20% of the total quantity produced can be used for energy generation purposes.

Productive life of coconut trees can be as high as 100 years. Part of the wood which becomes available after replanting is used as timber while another part is available as a source of energy [Koopmanns, 1998]. Wood residues from replanting activities are not considered in the following since no information on the amount of wood generated could be obtained.

Coffee

The allocated land for growing coffee in 2003 was about 470.000 hectares [MARD, 2004] which is a decrease of over 50,000 hectares when compared to the area under cultivation in 2002 [GSO, 2003]. The coffee production in Vietnam for the year 2003 was estimated to reach 700,000 tonnes [MARD, 2004]. Coffee husks, generated in the further processing, can be used for energy generation purposes. It is estimated that approximately 50% of the total quantity of coffee husks produced are available for energy generation.

Rubber

Among export agricultural products of Vietnam, rubber occupies the third rank after rice and coffee. The rubber production mainly concentrates in the provinces Binh Duong (92 thousand ha), Binh Phuoc (48 thousand ha), Dong Nai (42,5 thousand ha), Gia Lai (50,7 thousand ha) and Da Lac (27 thousand ha) [MARD, 2004]. The estimated total planted area for rubber production is 436.500 ha in 2003 [GSO, 2003].

The productive life of rubber trees is about 25-35 years. The annual yield of wood residues that becomes available after replanting amounts to 2,59 ton/ha [Koopmanns, 1998]. It is estimated that approximately 50% of the produced quantity can be used for energy generation.

Water Hyacinth

Water hyacinth and the produced residues have an exceptional position as biomass source. In many parts of the world, water hyacinth has become such a major problem because of its colossal rate of reproduction. Between 100 g and 500 g fresh weight is produced per m^2 and day, that is between 400 and 1.700 tons per hectare per year. A dry substance value for fresh water hyacinth (entire plant) of 8% has been reported by [Lindsey, 2000]. Thus, each year on average one can yield about 85 tonnes of dry water hyacinth per hectare. The organic matter of dry water hyacinth amounts to 80%.

Areas with high production of water hyacinth in Vietnam are the provinces Hau Giang, Dong Thap, Vinh Long and An Giang in the Mekong Delta. The covered area has been estimated to be as high as 2.261 ha resulting in an annual production of 0,9 million tonnes fresh water hyacinth (based on lower production yield) [BIWARE, 2004]. When water hyacinth is harvested, stalks/leaves and roots can be used as fertilizer or for other non-energy applications.

By taking into consideration the fraction of water hyacinth that actually can be harvested and other non-energy applications, it is estimated that approximately 20% of the produced total quantity can be utilised for energy production.

When applied as feedstock for biogas production, a specific biogas yield of 0,23 m^3 CH_4/kg oDS has been given by [BIWARE, 2004]. Taking into account the given values for DS and oDS, the specific CH_4-production can be calculated to 14,72 m^3 CH_4/tonne fresh water hyacinth.

Summary

Based on the estimated surplus quantity of agro-based crop substrates and the substrate characteristics, the technical energy potential can be determined as shown in Table 5.2-1. Due to the limited information available, there are significant insecurities with the estimation of the quantities of substrates available for renewable energy production. The results can be used as rough indications.

Table 5.2-1: Overview of technical energy potential from agricultural crops in Vietnam

Type	Available substrate quantity [t/a]	Availability factor [%]	Technical energy potential [PJ/a]
Rice (straw)	60.752.736	15	122
Rice (husk)	7.939.278	35	38
Sugar cane (bagasse)	4.792.221	20	14
Sugar cane (top/leaves)	4.957.470	35	19
Maize (cobs)	278.996	50	1
Maize (husks)	235.440	50	2
Cassava (stalks)	358.263	35	2
Coconut (Husks)	385.480	40	2
Coconut (Shell)	110.400	40	1
Coconut (fronds)	317.772	20	1
Rubber tree (wood)	1.470.000	50	10
Water hyacinth[1]	900.000	20	0,10
		Total	**219**

[1] Used for biogas production, expressed as energy potential of methane (CH_4)

5.2.3 Animal husbandry

Manure can be regarded as suitable substrate for biogas processes. In the following, the quantity that is available for biogas processes is estimated.

In the livestock sector, pig raising is the most important sub sector, in which the live weight output accounted for 80% of total life weight output (1999) [MARD, 2004]. Other relevant livestock covered in the following are cattle, buffalo and poultry (chicken, duck, perching duck, goose).

In 2003, the total livestock population in Vietnam is estimated at around 24,88 million (pigs), 2,83 million (buffalos), 4,4 million (cattle), and 254,3 million (poultry) [GSO, 2003]. However, due to the chicken flue disease the number of poultry has decreased considerably from the year of 2004.

The most common utilization of manure is the application to land as fertiliser. However, this practice does not represent a competitive use to biogas processing. By processing the manure in biogas systems, high quality secondary raw material fertiliser is produced that substitutes the direct application of manure to land.

It is reported by [LEOD], that small pig farms make up about 70% of the national farm population. Therefore it is assumed that only 30% of the quantity produced can be utilised as substrate for biogas processes. The same consideration applies for the poultry sector.

The bigger part of the cattle and buffalos are not raised in centralised farms. This situation has a considerable impact on the collectable fraction of manure. It is assumed that only 10% of the produced manure can be used for biogas processing.

Table 5.2-2 summarises the technical energy potential of animal husbandry.

Table 5.2-2: Overview of technical energy potential from animal husbandry

Type	Available substrate quantity [t/a]	Availability factor [%]	Technical energy potential [PJ/a]
Pigs	12.439.550	30	2,58
Cattle	8.047.059	10	0,56
Buffalo	8.277.908	10	0,57
Poultry	2.543	30	0,002
		Total	**3,71**

5.2.4 Municipal solid waste

In the following, the technical energy potential for municipal solid waste will be determined. The calculation will be based on the combustion of the available quantity of municipal waste. It should be noted, however, that the organic fraction of municipal waste can also be used as substrate for biogas processes (prior separation required).

The total population of Vietnam amounts to 80,9 million (2003), while 14,94 million people live in urban areas [GSO, 2003]. Due to the centralised processes of waste collection and treatment, thermal treatment processes can be regarded as feasible option in urban areas. Taking into consideration other ways of municipal waste treatment and disposal, it is assumed that approximately 30% of the produced waste is available for processing in thermal treatment plants. The combustion of waste produced in rural areas of Vietnam is not regarded as feasible option.

The specific production of household waste ranges between 0,4 and 0,8 kg wet substance per person per day. An average value of 0,6 will be used for calculation purposes. The dry solid (DS) and organic dry solid (oDS) of household waste can be estimated at 50% and 80% respectively [BIWARE, 2004].

In order to determine the potential for energy generation from biomass, only the organic fraction of the municipal solid waste will be considered in the calculation. In Vietnam, the organic fraction can be estimated at approximately 60% [BIWARE].

Table 5.2-3 summarises the technical energy potential for thermal treatment of municipal waste.

Table 5.2-3: Overview of technical energy potential for thermal treatment of municipal waste

Type	Available substrate quantity * [t/a]	Availability factor [%]	Technical energy potential [PJ/a]
Municipal solid waste	1.882.440	30	9

* Only organic fraction of municipal solid waste is considered

5.2.5 Industrial wastewaters

Industrial wastewaters with high organic content are a suitable substrate for biogas processes (anaerobic wastewater treatment). In Vietnam, several industries with high-strength wastewaters could be identified:

- Breweries
- Fruit and vegetable processing (can industries)
- Seafood processing (frozen product)
- Slaughterhouse wastewaters

Breweries
In Vietnam, there are six international and several local breweries. The marked is still dominated by the 350-plus small-scale breweries, which own 80% of the market. The total annual beer production amounts to 1,05 million m^3 in 2003 [GSO, 2003]. Due to the structure of the brewery sector, it is assumed that only 20% of the total amount of wastewater produced can be used for biogas production (large scale breweries).

Fruit and vegetable production
The Vietnam National Vegetable and Fruit Cooperation (Vegetexco) is the largest state-owned company in the fruit and vegetable processing sector. It owns 18 fruit and vegetable processing plants, including 11 canning factories. The total processed quantity of canned fruit is 31.770 tons/a (including Non State and Foreign invested sector) [GSO, 2003]. It is assumed that 80% of the produced quantity of wastewater can be used for biogas production.

Seafood processing
Vietnam has around 287 seafood processing factories (as of 25/08/2004), of which 200 are reserved for processing frozen products, with a combined annual capacity of 200.000 tons (2003). About 70 percent are located in the southern region, 24 percent in the central region and 6 percent in the north [GSO, 2003]. It is assumed, that about 80% of the produced quantity of wastewater can be used for biogas processes.

Slaughterhouse
Vietnam has 24 industrial scale slaughterhouses and processing facilities, all of which are government owned. The meat industry is outputting 1,6 million tons annually; 77% is pork, 18% poultry, and 7% red meat. It is assumed that approximately 20% of the produced wastewaters can be used for biogas processes.

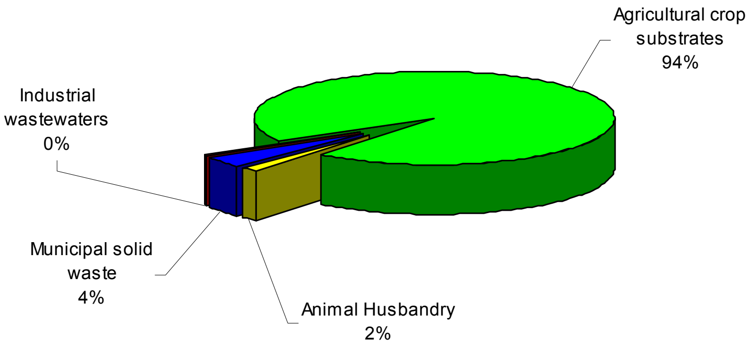
Table 5.2-4 summarises the technical energy potential for industrial wastewater.

Table 5.2-4: Overview of technical energy potential for industrial wastewaters (biogas production)

Type	Available substrate quantity [m3/a]	Availability factor [%]	Technical energy potential [PJ/a]
Brewery	4.199.200	30	0,04
Fruit and vegetable processing (canning)	444.780	80	0,02
Seafood processing	1.600.000	80	0,06
Slaughterhouse/meat processing	32.000.000	20	0,65
		Total	**0,76**

5.2.6 Technical energy potential of biomass sources in Vietnam

Figure 5.2-1 shows a comparison of the technical energy potential of major biomass sources in Vietnam. The determined total technical energy potential from biomass amounts to 233 PJ/a.



Type	Technical energy potential [PJ/a]
Agricultural crop substrates	219
Animal Husbandry	4
Municipal solid waste	9
Industrial wastewaters	1
Total	**233**

Figure 5.2-1: Comparison of technical energy potential of major biomass sources in Vietnam

5.3 Potential for renewable energy production by biogas and biomass combustion in Thailand

5.3.1 Collection of data and data sources

Several data sources have been used to determine the available quantity of biomass sources in Thailand. Published statistical data has been used to determine the production of commodities, number of livestock and wastewater generated. The availability of substrates for energy generation purposes has been estimated based on information provided by relevant institutions and associations.

The following main types of substrates are available in Thailand for energy production by biogas and biomass combustion processes:

- Agro based crop substrates
- Animal husbandry
- Municipal solid waste
- Industrial wastewaters

5.3.2 Agro based crop residues

The technical energy potential has been estimated for the major agro based crop residues in Thailand (Figure 5.3-1).

Table 5.3-1: Overview of technical energy potential for agricultural crops in Thailand

Type	Available substrate quantity [t/a]	Availability factor [%]	Technical energy potential [PJ/a]
Rice Straw (top)	11.647.479	70	83,49
Rice husk	5.993.110	50	42,76
Sorghum (leaves, stems)	165.264	65	2,07
Soybean (stalk, leaves, shell)	692.380	75	10,09
Sugar cane Bagasse	21.609.078	20	62,23
Sugar cane (top and trashier)	22.425.916	98	382,19
Oil Palm (Empty bunches)	1.970.726	60	21,12
Oil palm (Fiber)	676.862	10	1,19
Oil palm (Shell)	225.621	35	1,46
Oil palm (Frond)	11.990.118	100	117,86
Oil palm (male bunches)	1.072.849	100	17,52
Maize (corn cob)	1.154.790	65	13,54
Cotton (stalk)	116.352	100	1,69
Coconut (husk)	513.316	60	5,00
Coconut (shell)	226.880	35	1,42
Coconut (Empty Bunches)	69.482	85	0,91
Coconut Frond	319.050	80	4,08
Cassava (Stalk)	1.484.384	40	10,94
Ground nut (shell)	36.176	100	0,46
		Total	**780,02**

5.3.3 Animal husbandry

Manure can be regarded as suitable substrate for biogas processes. In the following, the technical energy potential from manure is estimated on the basis of the quantity that is available for biogas processes (based on the energy content of methane generated) (Table 5.3-2).

Table 5.3-2: Overview of technical energy potential for animal husbandry in Thailand

Type	Available substrate quantity [t/a]	Availability factor [%]	Technical energy potential [PJ/a]
Cattle	10.797.289	50	3,11
Dairy cow	2.081.611	80	0,96
Buffalo	4.767.502	50	1,37
Female swine	577.448	80	0,38
Male swine	88.259	80	0,06
Piglets	38.993	80	0,03
Swine	1.951.204	80	1,29
Native Swine	142.411	80	0,09
Chicken	27.672.718	80	59,18
Duck	2.606.110	40	2,79
Elephant	41.449	50	0,03
		Total	**69,28**

5.3.4 Municipal solid waste

Energy can be produced by treating municipal solid waste in thermal processes. In the following, the technical energy potential from thermal treatment of municipal solid waste in different regions in Thailand is estimated (Table 5.3-3) . In order to determine the potential for energy generation from biomass, only the organic fraction of the municipal solid waste will be considered in the calculation.

Table 5.3-3: Overview of technical energy potential for thermal treatment of municipal waste in Thailand

Type	Available substrate quantity* [t/a]	Availability factor [%]	Technical energy potential [PJ/a]
Bangkok	1.702.053	80	15,36
Central Plain	1.951.849	50	16,58
North	1.318.529	50	12,37
Northeast	1.966.793	50	15,82
South	912.541	50	7,70
Whole Kingdom	7.851.765		**67,83**

* Only organic fraction of municipal solid waste is considered

5.3.5 Industrial wastewaters

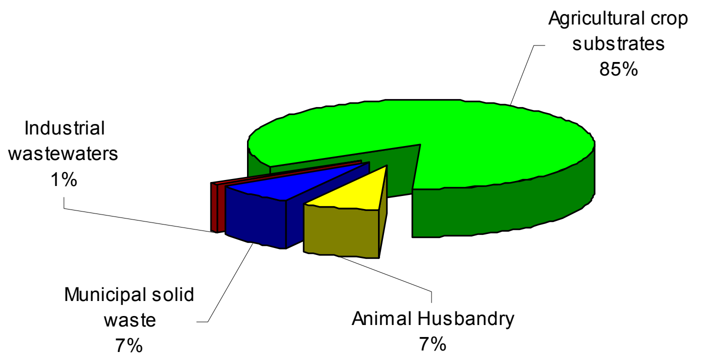
High strength industrial wastewaters can be used as substrate for biogas processes. The technical energy potential derived from anaerobic treatment of major industrial wastewater streams in Thailand are compiled in Table 5.3-4 (based on the energy content of methane generated).

Table 5.3-4: Overview of technical energy potential for industrial wastewaters (biogas production) in Thailand

Type	Available substrate quantity [m3/a]	Availability factor [%]	Technical energy potential [PJ/a]
Slaughter house	16.834.561	100	0,39
Sugar	76.203.540	100	2,27
Alcoholic beverage	256.292	100	0,07
Beer	4.799.800	100	0,12
Raw milk	1.990.049	100	0,03
Canned pineapple	1.948.584	100	0,33
Frozen seafood	15.419.718	100	0,41
Canned seafood	17.385.369	100	1,20
Soda and beverages	12.843.300	100	0,31
Cassava starch	55.005.090	100	4,21
Palm oil	3.256.000	100	1,72
		Total	**11,03**

5.3.6 Technical energy potential of biomass sources in Thailand

Figure 5.3-1 shows a comparison of the technical energy potential of major biomass sources in Vietnam. The determined total technical energy potential from biomass amounts to 928 PJ/a.



Type	Technical energy potential [PJ/a]
Agricultural crop substrates	780
Animal Husbandry	69
Municipal solid waste	68
Industrial wastewaters	11
Total	**928**

Figure 5.3-1: Comparison of technical energy potential of major biomass sources in Thailand

5.4 References for chapter 5

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6 Decision Tree and supporting tools for the applicability of biogas and biomass combustion

6.1 Introduction

6.1.1 Main elements and Nomenclature of the Decision Tree

The Decision Tree flow-chart consists of the following main elements:

Steps

The Decision Tree comprises in total 29 steps. They represent the major aspects which have to be considered in the preparation of a pre-feasibility study. In some instances, a decision (e.g. “Yes”- or “no”- decision) is required which bases on the specific project conditions. In this case the Decision Tree branches out to different routes. Steps are indicated by the signs shown in Figure 6.1-1.

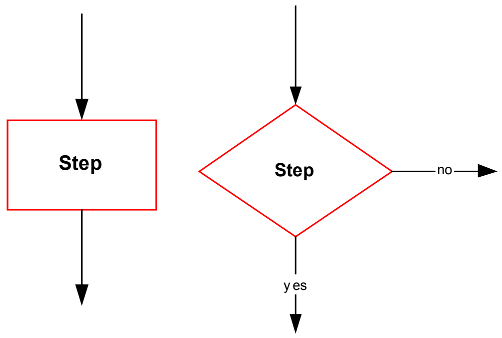

Figure 6.1-1: Steps of the Decision Tree flow-chart

Tools

In total 30 tools are provided at different stages of the Decision Tree, to support the user with expert information or calculation aids. Figure 6.1-2 shows the symbol which indicates that a tool is provided.

Figure 6.1-2: Tools of the Decision Tree

Stop

The “Stop”-sign (Figure 6.1-3) shows that biogas production or biomass combustion is not feasible for the project in question, under the prevailing conditions.

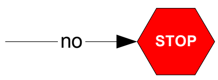

Figure 6.1-3: “Stop-sign” of the Decision Tree

6.1.2 Main Structure of the Decision Tree

To provide a clear structure and a good overview for the user, the Decision Tree has been divided into five main categories (see Figure 6.1-4).

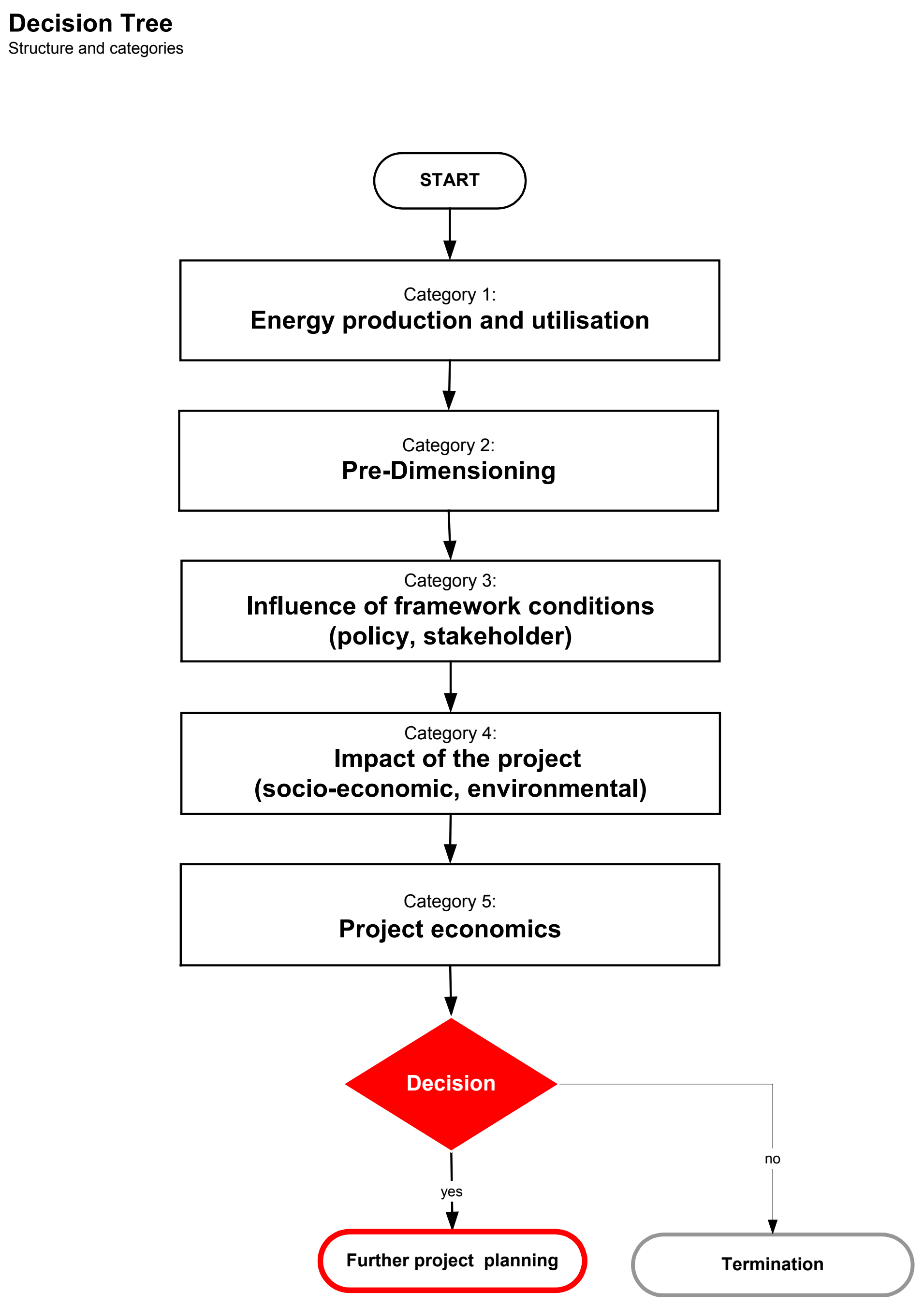

Figure 6.1-4: The Decision Tree is divided into five main categories

6.1.3 Where to start

Generally the user should start from the beginning of the Decision Tree, at the category "Technological Consideration", and work his/her way through each category. However more experienced users only can apply selected elements of the decision tree, for example some tools.

6.2 Decision Tree flow-chart

The Decision Tree flow-chart is presented in Figure 6.2-1 - Figure 6.2-5.

Category 1: Energy production and utilisation

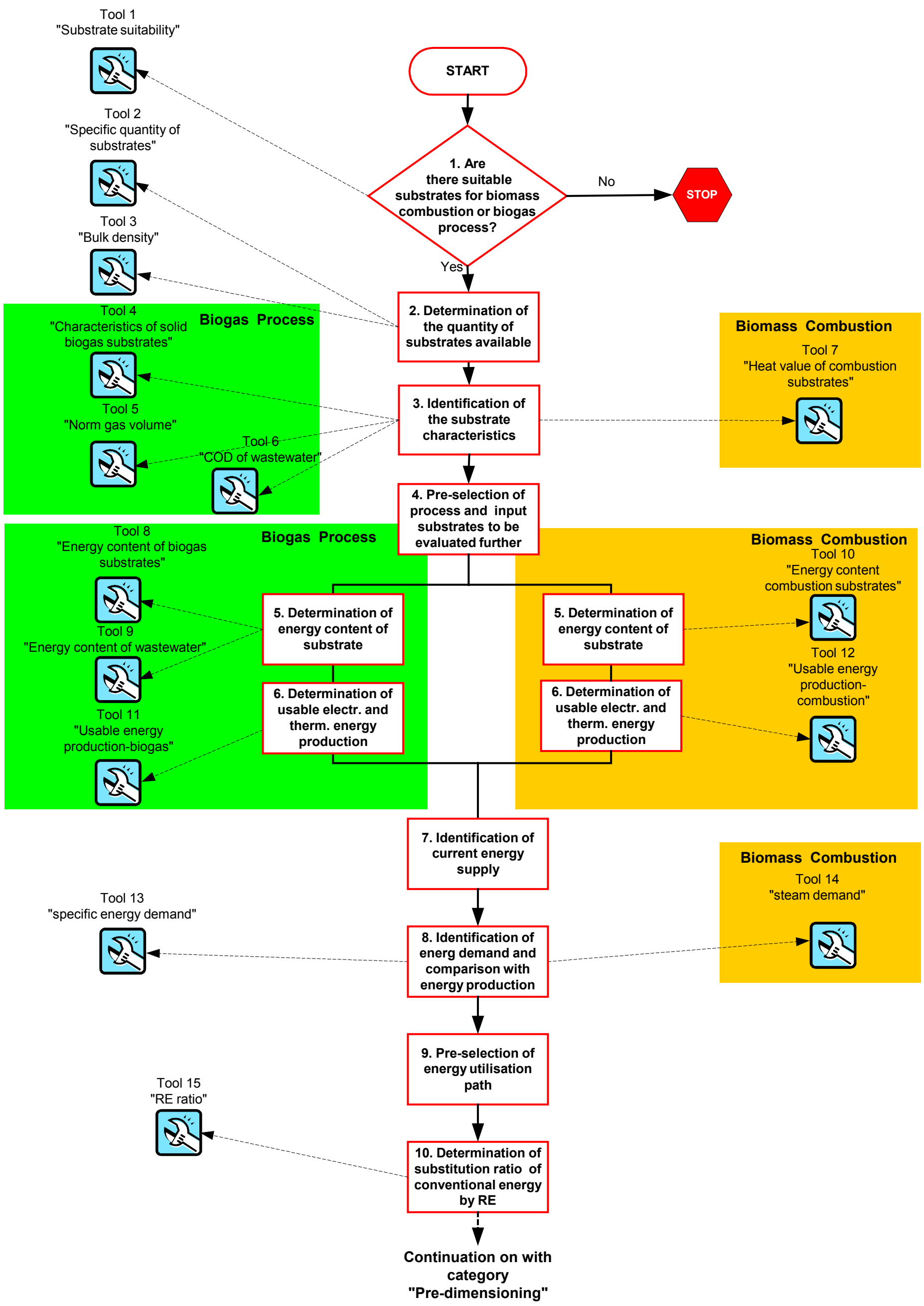

Figure 6.2-1: Decision Tree - Energy production and utilisation (Category 1)

Category 2: Pre-Dimensioning

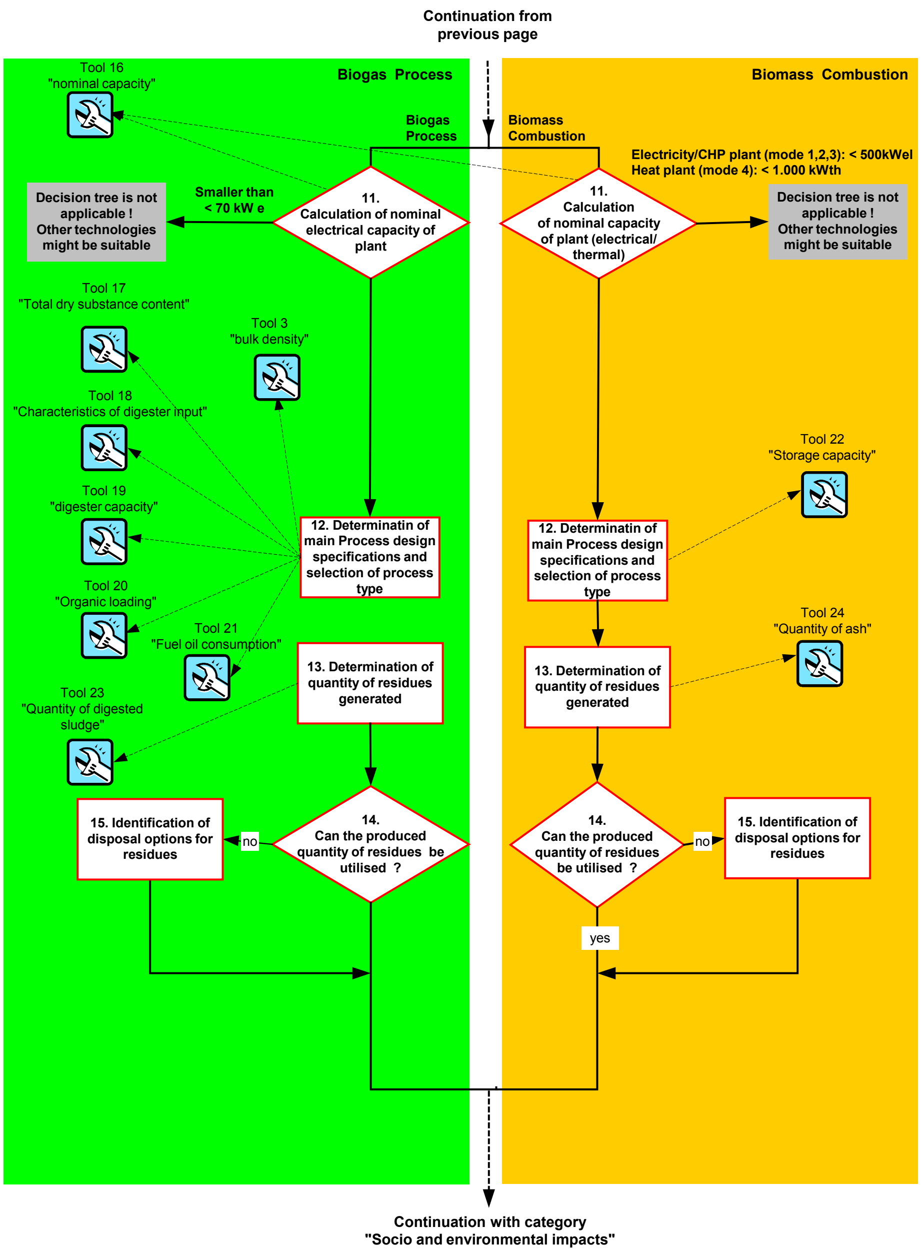

Figure 6.2-2: Decision Tree- Pre-dimensioning (Category 2)

Category 3: Influence of framework conditions

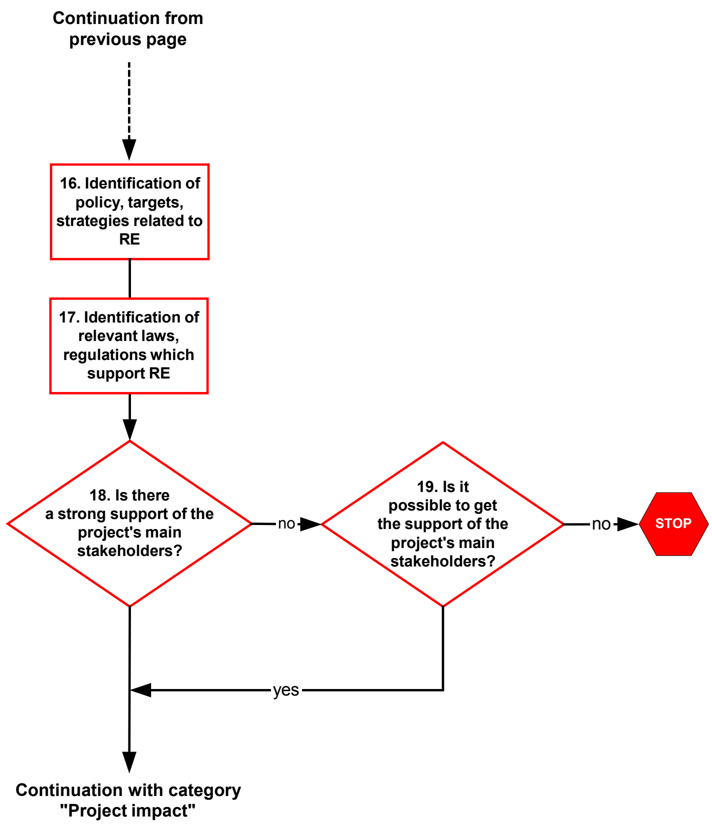

Figure 6.2-3 : Decision Tree – Influence of framework conditions (Category 3)

Category 4: Project impact (socio-economic, environmental)

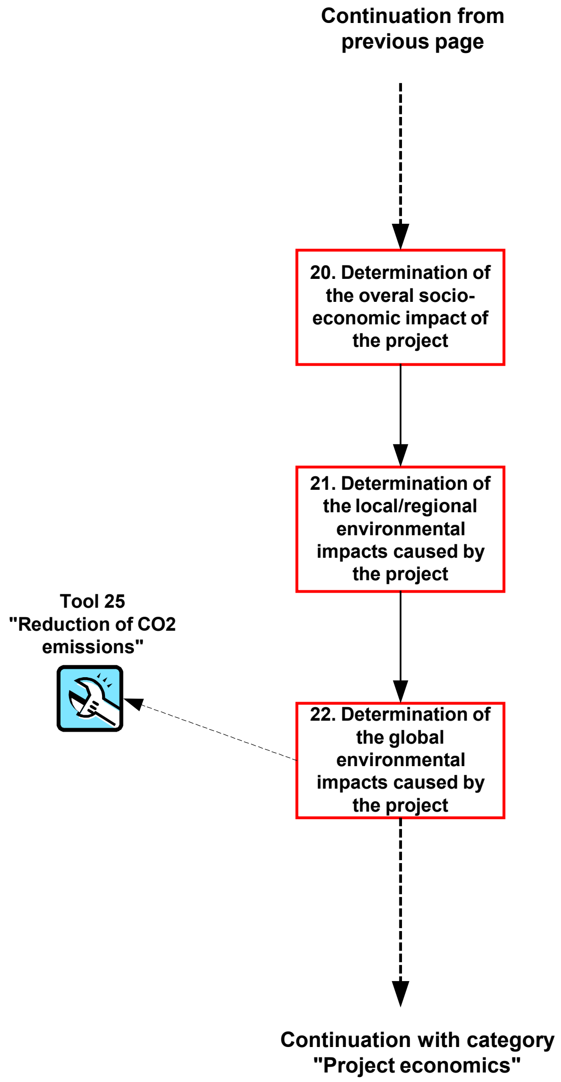

Figure 6.2-4: Decision Tree – Project socio-economic and environmental impact (category 4)

Category 5: Project economics

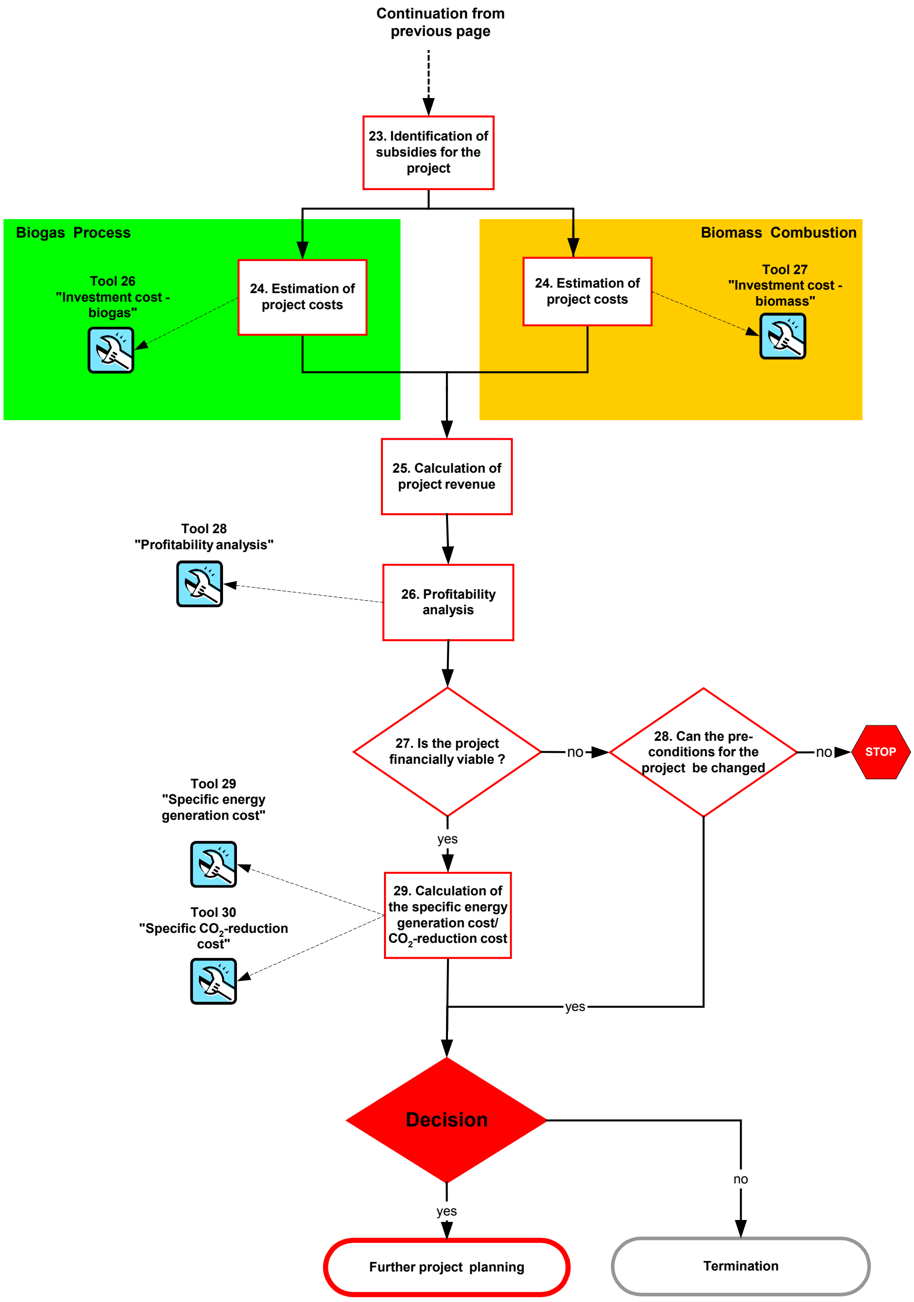

Figure 6.2-5: Decision Tree – Project economics

6.3 Explanation and information to Steps 1-29 of the decision tree

Step 1: Are there suitable substrates for biomass combustion or biogas process?

Explanations of step 1

To be able to identify the potential applicability of a biogas or biomass combustion plant, an inventory has to be carried out to identify the availability of suitable substrates.

There is a wide range of suitable substrates available, which can be utilised for biogas or biomass combustion: energy crops, residues from agriculture and forestry, waste from animal husbandry, residues or waste from industry and commercial activities, household waste, as well as industrial wastewater. Depending on their characteristics, most substrates are either suitable for biogas production (e.g. manure, sewage sludge, food waste) or biomass combustion (e.g. rice husks, bagasse, wood, straw). Certain substrates, like household waste can be suitable for energy generation by both processes. Table 6.3-1 summarises the suitability of substrates. An extensive list with substrates is given in Table 6.3-3 (Tool 1).

Table 6.3-1: Overview of the suitability of substrates for biogas generation or biomass combustion

	Suitability of substrates	
	Biogas process	**Biomass combustion**
Agro based crop substrates - easy degradable (not woody, i.e. high lignin content) e.g. maize silage - high heat value e.g. bagasse, rice husk, straw	✓ -	- ✓
Animal husbandry e.g. manure or dung from pigs, cattle, chicken, etc.	✓	-
Forestry based substrates e.g. wood, saw mill	-	✓
Municipal and industrial waste (solid waste, sludge) - easy degradable e.g. biowaste (organic fraction of household waste), sewage sludge, food waste - high heat value e.g. paper and card board from industry, household waste	✓ -	- ✓
Industrial wastewater e.g. from breweries, canning factories, etc.	✓	-

Substrates suitable for the biogas process

Substrates suitable for biogas production need to be **easily degradable**, containing proteines, carbohydrates, cellulose, hemicellulose and lipids. Solid waste, sludge and wastewater are suitable. However only industrial wastewater contains sufficiently high level of organics (measured in COD Chemical Oxygen Demand) to generate biogas in relevant quantities. Woody substrates contain high levels of lignin or cellulose which is incrusted with lignin (e.g. like in wood or straw) so that they cannot be degraded quickly under anaerobic conditions as required for utilisation in biogas plants.

The inefficient treatment of slaughterhouse waste or improper use of products produced from it respectively leads to the pandemic occurence of animal diseases such as BSE (Bovine Spongiform Encephalopathy) and foot and mouth disease. Therefore **risk substrates** should not be utilised in biogas plants. National regulations have to be considered here, if they exist. For orientation: In Europe a regulation with regard to hygiene of animal by-products have entered into force in 2003 (EG Regulation No. 1774/2002) which regulates the handling of risk-material. High risk material (Category 1) is not allowed to be processed in biogas plants (Table 6.3-2). Manure, digestive tract content, milk or colostrum can be utilised in biogas plants without pre-treatment (until the end of 2004). All other animal by-products need pasteurisation or sterilisation before being utilised as feedstock in “approved” biogas plants which have to obey certain process requirements.

Table 6.3-2: Utilisation of animal by-products in biogas plants, according to the European Union Regulation (EC) No 1774/2002

	Risk Material	**Use in approved Biogas plant**
Category 1 material with highest risk for public health, animals, environment	- Specified risk material (SRM) (According to EU Regulation (EC) 1139/2003: - Bovine animals, aged over 12 months: skull including brain and eyes, excluding mandible vertebral column including dorsal root ganglia and the spinal cord, but excluding vertebrae of the tail, transverse processes of the lumbar and thoracic vertebrae of the tail and the wings of the sacrum - Bovine animals, all ages: tonsils, intestines from duodenum to rectum, mesentery - Ovine and caprine animals, aged over 12 months: Skull including brain and eyes, tonsils and spinal cord - Ovine and carprine, all ages: spleen as well as ileum) - animals suspected of being infected with BSE, ABP, - material with increased concentrations of environmental contaminants, - solid material (> 6 mm) from wastewater treatment in Category 1 processing plants and establishments in which SRM is removed (slaughterhouses and cutting plants), - catering waste from international means of transport (catering from aeroplanes, ships or railways)	**Not allowed for biogas plants** Must be incinerated or landfilled after sterilisation
Category 2	- Manure - digestive tract content (separated from the digestive tract; if there is no risk of dispersal of serious infectious diseases) - milk not fit for human consumption - colostrum	Allowed (without pre-treatment)
	All other materials classified as Category 2, e.g. - perished animals or animals slaughtered, but not intended for human consumption, - solid materials in waste water streams of slaughterhouses and processes plants, particle size > 6 mm (screenings, materials from desanding, grease and oil mixtures, sludge, material removed from drains)	Allowed after sterilisation with steam (133°C, 3 bar, 20 min)
Category 3 material which would be fit for human consumption, but are (for commercial reasons) not intended for human consumption	e.g. - meat-containing wastes from the food stuff industry, - slaughterhouse wastes of animals fit for human consumption - catering waste (e.g. waste food originating in restaurants, catering facilities and kitchens, including central kitchens and household kitchens, as well as used cooking oils) (except from international means of transport)	Allowed after pasteurisation (20 mm, 70°C, 60 min)

<u>Substrates suitable for combustion</u>

Substrates with a **heat value over 6000 kJ/kg** are suitable for energy production by combustion. The heat value of the total substrate mixture must be considered. Generally the heat value depends on the water content of the substrate. Pre-treatment of substrates which effects the water content, e.g. shredding or drying, can increase the heat value of the substrates.

High risk animal by-products (Category 1) which cannot be utilised in biogas plants have to be incinerated or co-incinerated, considering specific hygiene requirements. In Europe, the EG Regulation No. 1774/2002 regarding animal by-produced regulates this issue.

Table 6.3-3: Selection of Suitability of substrates for biogas or biomass combustion processes (Tool 1)

Tool 1

Substrates	Suitability	
	Biogas process	Biomass combustion
Agro based crop substrates		
Algae	+	+
Barley straw	(+)	+
Beet tops	+	+
Beet tops, (sugar beet)	+	+
Beet, sugar beet	+	+
Beet, (fodder)	+	(+)
Blood meal	+	+
Cane trash	+	+
Clover	+	(+)
Coco bean shells	-	+
Elephant grass	(+)	+
Flax	(+)	+
Grass	+	-
Grass silage	+	-
Hay	+	+
Hemp	+	-
Maize silage	+	-
Maize straw	+	+
Oat straw	(+)	+
Peanut husk	-	+
Potato tops	+	+
Rape straw	(+)	+
Rapeseed shred	+	(+)
Reed		+
Residual wood (common)	-	+
Bark	-	+
Rice husk	-	+
Rice straw	(+)	+
Rye straw	(+)	+
Sunflower leaves	+	-
Water hyacinth	+	+
Wheat	+	(+)
Wheat straw	+	+
Animal husbandry		
Cattle manure	+	-
Cattle manure (with straw)	+	-
Chicken manure	+	-
Chicken manure (with straw)	+	-
Horse manure (with straw)	+	-
Pig manure	+	-
Pig manure (with straw)	+	-
Sheep manure (with straw)	+	-
Cattle manure	+	-
Cattle manure (with straw)	+	-
Chicken manure	+	-
Chicken manure (with straw)	+	-
Forestry based residues		
all types of wood and residues (e.g. saw dust)	-	+
Municipal and industrial waste		
Animal cadaver meal	+	+
Bagasse	-	+
Biowaste	+	+
Cereal mash	+	-
Clippings (sedge)	+	
Coco bean shells	-	+
Fat (from fat separators)	+	-
Filtration silica gel (beer)	+	-

Substrates	Suitability	
	Biogas process	Biomass combustion
Float fat	+	-
Flotation sludge	+	(+)
Foliage / leaves	+	(+)
Food waste	+	+
Fruit pulp (fresh)	+	-
Kitchen waste	+	+
Loppings	+	-
Market waste	+	+
Mash of apples	+	-
Mash of fruits	+	-
Molasse	+	-
Molasses mash	+	-
Oil seed residue (pressed)	+	(+)
Peanut husk	-	+
Pomace of apples	+	-
Pomace of fruits	+	-
Pomace of grape	+	-
Potato mash	+	-
Potato peel waste, raw	+	-
Potato pulp	+	-
Potato slop	+	-
Raps extraction residue	+	(+)
Rumen content (pressed)	+	-
Rumen content (untreated)	+	-
Sewage sludge	+	(+)
Slaughterhouse waste	+	(+)
Spent grains from beer	+	(+)
Spent hops (dried)	+	+
Stomache contents (pig)	+	-
Straw	(+)	+
Vegetable waste	+	+
Vinasse	+	-
Whey	+	-
Yard trimming	+	-

\+ suitable
\- not suitable
(+) limited suitability

Remark: The list of substrates represents only a selection of the most relevant substrates. If organic substrates are available, which are not mentioned here, consultation of an expert is required.

Results of step 1

→ Types of substrate available, suitable for biogas processes
→ Types of substrates available, suitable for combustion processes

Decision of step 1

if “yes”→ go to step 2

if “no” → Renewable energy generation from organic substrates is NOT suitable for the chosen application. Other possible locations, where substrates are available, should be identified, or other renewable energy options should be considered, e.g. wind power, hydropower, etc.

Step 2: Determination of the quantity of substrates available

Explanations of step 2

The quantity of substrates realistically available has to be identified. A number of issues have to be considered, which are discussed below.

Reliable substrate supply in the long run

Substrates should always be sufficiently available to be able to provide the required energy supply, to run the plant cost-efficiently and to prevent process breakdown (in case of the biogas process). Usually a prognosis on available supply should be done for 7-10 years. Agreements or contracts with substrate suppliers on qualities and quantity of feedstock can reduce the risk with regard to substrate supply. Overall the evaluation of substrate supply is subject to an individual risk assessment.

Seasonal variations of substrates

Some substrates, like manure, are produced more or less throughout the year. However most substrates are only available in certain seasons or vary in their composition. Therefore, the overall supply of substrates should balance out variations, so that a continuous supply of feedstock can be guaranteed.

Shelf life of substrate

Some substrates, like wood and straw, can be stored for a longer period of time. In contrast to this, most substrates which are suitable for biogas processes cannot be stored due to their degradability. Those substrates have to be used within a couple of days. This makes regular, daily supply important.

Catchment area of substrates

Depending on a variety of factors, e.g. the specific value of the substrates and local transportation costs, there are distance limits, from which the transport of substrates to the biogas or combustion plant is still cost-efficient (and environmentally sound).

Competing applications for feedstock

When estimating the potential supply of available substrates it has to be considered that there are competing forms of utilisation for this material. Not all substrates might be available for energy generation. Table 6.3-4 gives some examples for competing applications of feedstock in Asia.

Table 6.3-4: Examples for competing applications of feedstock in Asia [FOA, 2000]:

Substrates	Utilisation
rice husks:	fuel in brick industry; steel industry; burnt and ash used as fertiliser etc.
bagasse:	Paper and board industry
wood residues:	furniture industry
rice straw:	growing medium for mushrooms
coconut husks	mats, matting, floor coverings, brushes, ropes
field based residues	ploughed directly back into the soil, burned on the field as conditioners and organic fertilisers
straw	animal fodder
food waste	animal fodder

Specific substrate quantities

The information of the total quantity of substrates available is often difficult to obtain. Therefore specific values from literature can be very helpful to obtain a rough orientation (Table 6.3-5, tool 2). The specific quantity of substrates are expressed in different ways, depending on the type of substrate.

- *RPR Residue-Product-Ratio*

The RPR expresses the proportion of a residue (e.g. rice husk) to a product (e.g. rice). The RPR value of, for example 0,2 means, that the residue represents 20% (by weight) of the product. If the quantity of a product is known (e.g. by national statistics), the quantity of residues can be easily be calculated. The RPR can be taken from literature or can be determined by own investigations. The RPR-value depends on weather, crop type grown, water availability, soil fertility and farming practice, thus can vary quite a lot. Also, inaccuracies may result from differences in the water content of the substrates, which is often not specified.

- *Residue-to cropping area*

This specific value is often used for woody residues from perennial corps and is expressed in mass of residues per cropping area (e.g. t/ha). Again, it can be expected that there are wide variations are possible, depending on farming practice and conditions.

- *waste per capita or per animal*

This specific value is generally used for waste and wastewater from humans waste or manure from animal husbandry.

Table 6.3-5: Specific quantities of substrates (Tool 2)

Tool 2

Types of substrate	Specific quantity		Reference
	value	unit	
Agro based crop substrates			
Beet (Fodder beet leaf silage)	450	t DS / ha * a	[CARMEN e.V., 2004]
Beet (fodder beet)	100	t / ha * a	[top agrar, 2002]
Beet (Sugar beet leaf silage)	300	t DS / ha * a	[CARMEN e.V., 2004]
Beet (Sugar beet leaves)	0.7	RPR	[Kaltschmitt, 2001]
Beet (Sugar beet leaves)	40	t / ha * a	[Kaltschmitt, 2001]
Beet leaves	3.9	t / ha * a	[IZES, 2002]
Beets	0.8	RPR	[IE, 2002]
Cassava stalks	0.162	RPR	[Koopmans, 1998]
Cassava stalks	0.088	RPR	[KMUTT, 2004]
Cereal straw	0.9	RPR	[IE, 2002]
Coconut bunches	0.049	RPR	[KMUTT, 2004]
Coconut fronds	0.02	t DS / tree * a	[Koopmans, 1998]
Coconut fronds	0.225	RPR	[KMUTT, 2004]
Coconut husks	0.419	RPR	[Bhattacharya, 1993]
Coconut husks	0.362	RPR	[KMUTT, 2004]
Coconut shells	0.12	RPR	[Bhattacharya, 1993]
Coconut shells	0.16	RPR	[KMUTT, 2004]
Coffee husk	2.1	RPR	[Koopmans, 1998]
Corn silage	45	t / ha * a	[top agrar, 2002]
Cotton stalks	3.232	RPR	[KMUTT, 2004]
Cotton stalks	2.755	RPR	[Koopmans, 1998]
Energy cereals	10	t DS / ha * a	[IE, 2002]
Energy pasture	12	t DS / ha * a	[IE, 2002]
Eucalyptus bark & saw dust	0.25	RPR	[Junginger, 2000]
Eucalyptus waste wood	0.46	RPR	[Junginger, 2000]
Grass (crop grass)	3 - 6	t DS / ha * a	[IZES, 2002]
Grass (Giant Chinese silver grass)	10 - 30	t DS / ha * a	[Kaltschmitt, 2001]
Grass (meadow grass)	90	t DS / ha * a	[CARMEN e.V., 2004]
Grass (Meadow grass, first cut)	80	t / ha * a	[top agrar, 2002]
Grass (reed canarygrass)	11 - 13	t DS / ha * a	[Kaltschmitt, 2001]
Grass (ryegrass)	7.1 - 12.7	t DS / ha * a	[Kaltschmitt, 2001]
Grass (switch grass)	10 - 17	t DS / ha * a	[Kaltschmitt, 2001]
Grass (tall fescue)	11.4 - 13.1	t DS / ha * a	[Kaltschmitt, 2001]
Groundnut shells	0.323	RPR	[KMUTT, 2004]
Groundnut shells	0.477	RPR	[Koopmans, 1998]
Groundnut straw	2.3	RPR	[Koopmans, 1998]

Types of substrate	Specific quantity		Reference
	value	unit	
Hay (meadow hay)	45	t DS / ha * a	[CARMEN e.V., 2004]
Hemp straw	10 - 15	t / ha * harvest	[Kaltschmitt, 2001]
Jute stalks	2.0	RPR	[Koopmans, 1998]
Maize	540	t DS / ha * a	[CARMEN e.V., 2004]
Maize (CCM corn-cob-mix)	15	t / ha * a	[top agrar, 2002]
Maize cobs	0.273	RPR	[Koopmans, 1998]
Maize husk	0.2	RPR	[Koopmans, 1998]
Maize stalks	1.0 - 4.3	RPR	[Koopmans, 1998]
Maize straw	1.5	RPR	[IE, 2002]
Maize straw	1.3	RPR	[Kaltschmitt, 2001]
Maize straw	9	t / ha * a	[Kaltschmitt, 2001]
Oil palm empty bunches	0.428	RPR	[KMUTT, 2004]
Oil palm empty bunches	0.23	RPR	[Koopmans, 1998]
Oil palm fiber	0.147	RPR	[KMUTT, 2004]
Oil palm fronds	2.604	RPR	[KMUTT, 2004]
Oil palm shells	0.049	RPR	[KMUTT, 2004]
Oil seed straw	1.7	RPR	[IE, 2002]
Potatoes	0.4	RPR	[IE, 2002]
Potatoes	45	t / ha * a	[top agrar, 2002]
Potatoes	33 - 50	t / ha * a	[Kaltschmitt, 2001]
Rape (summer rape straw)	4.2 - 5.9	t / ha * a	[Kaltschmitt, 2001]
Rape (winter rape straw)	5.3 - 9.1	t / ha * a	[Kaltschmitt, 2001]
Rapeseed	1.7	RPR	[IE, 2002]
Rapeseed	1.9 - 2.1	RPR	[Kaltschmitt, 2001]
Rice husk	0.27	RPR	[Koopmans, 1998]
Rice husk	0.23	RPR	[KMUTT, 2004]
Rice straw	0.447	RPR	[KMUTT, 2004]
Rice straw (Thailand)	1.76	RPR	[Koopmans, 1998]
Rubber tree (leaves)	1.4	t / ha * a	[Koopmans, 1998]
Rubber tree (wood)	2.59	t / ha * a	[Koopmans, 1998]
Rye (winter rye straw)	5.9 - 8.3	t / ha * a	[Kaltschmitt, 2001]
Rye (winter rye straw)	1.3 - 1.5	RPR	[Kaltschmitt, 2001]
Sorghum straw	1.252	RPR	[KMUTT, 2004]
Soybean stalks, leaves, shells	2.663	RPR	[KMUTT, 2004]
Sugar cane bagasse	0.29	RPR	[Koopmans, 1998]
Sugar cane top/leaves	0.3	RPR	[Koopmans, 1998]
Sunflower straw	8 - 14	t / ha * a	[Kaltschmitt, 2001]
Topinambur	0.8 - 1.4	RPR	[Kaltschmitt, 2001]
Topinambur leaves	8 - 12	t / ha * a	[Kaltschmitt, 2001]
Triticale (winter triticale)	6.0 - 8.4	t DS / ha * a	[Kaltschmitt, 2001]
Triticale (winter triticale)	1.2 - 1.4	RPR	[Kaltschmitt, 2001]
Wheat (summer wheat straw)	5.5 - 8.4	t / ha * a	[Kaltschmitt, 2001]
Wheat (winter wheat straw)	6.6 - 10.5	t / ha * a	[Kaltschmitt, 2001]
Wheat grains	8	t fresh / ha * a	[top agrar, 2002]
Wheat straw	1.1 - 1.4	RPR	[Kaltschmitt, 2001]
Wheat, rye, barley, other cer. (straw)	1.75	RPR	[Koopmans, 1998]
Animal husbandry			
Buffalo manure (Thailand)	2.92	t / animal * a	[KMUTT]
Cattle liquid manure (calf breeding, Germany)	2.9	m³ / animal * a	[Wetter]
Cattle liquid manure (calf feeding, Germany)	1.4	m³ / animal * a	[Wetter]
Cattle manure (dairy cow, Thailand)	5.48	m³ / animal * a	[KMUTT]
Cattle liquid manure (dairy cow, Germany)	19.80	m³ / animal * a	[Wetter]
Cattle liquid manure (young cattle, Germany)	9.0	m³ / animal * a	[Wetter]
Cattle manure with straw	9.1-20.1	t / animal * a	[IZES, 2002]
Cattle liquid manure (cattle feeding, Germany)	8.3	m³ / animal * a	[Wetter]
Cattle liquid manure (350 kg live-weight)	10.6-17.5	m³ / animal * a	[IZES, 2002] + [Wetter]
Cattle manure (Thailand)	1.83	t / animal * a	[KMUTT]
Chicken liquid manure (laying hens, GE)	0.07	m³ / animal * a	[Wetter]
Chicken liquid manure (chicken feeding, 750 g live-weight)	0.025-0.027	m³ / animal * a	[IZES, 2002] + [Wetter]
Chicken liquid manure (chicken feeding, GE)	0.035	m³ / animal * a	[Wetter]
Chicken manure (Thailand)	0.011	t / animal * a	[KMUTT]
Duck manure (Thailand)	0.011	t / animal * a	[KMUTT]
Elephant manure (Thailand)	15	t / animal * a	[KMUTT]
Pig manure (Thailand)	0.44-0.73	t / animal * a	[KMUTT]
Pig liquid manure (young pigs, Germany)	0.7	m³ / animal * a	[Wetter]
Pig liquid manure (pig feeding / breeding, GE)	1.6	m³ / animal * a	[Wetter]
Pig liquid manure (60 kg live-weight)	1.5 - 1.7	m³ / animal * a	[IZES, 2002] + [Wetter]

Types of substrate	Specific quantity		Reference
	value	unit	
Pig liquid manure (Vietnam)	14.6	kg manure / kg live-weight * a	[CTU, 2004]
Turkey liquid manure (turkey feeding, GE)	0.35	m³ / animal * a	[Wetter]
Forestry based residues			
Beech tree growth (Germany, without bark)	2.54-3.81	t / ha * a	[Kaltschmitt, 2001]
Biomass from public park conservation	5	t / ha * a	[IE, 2002]
Biomass from public park conservation	1.8 - 7	t / ha * a	[Kaltschmitt, 2001]
Biomass from roadside maintenance, Germany	3 - 5	t / km * a	[IE, 2002]
Logging (residues in the forest)	1	RPR	[Koopmans, 1998]
Oak tree growth (Germany, without bark)	2.0 - 3.10	t / ha * a	[Kaltschmitt, 2001]
Pine tree growth (Germany, without bark)	1.82-2.91	t / ha * a	[Kaltschmitt, 2001]
Plywood production residues	1	RPR	[Koopmans, 1998]
Saw milling residues (solid woods, fines/dust)	1	RPR	[Koopmans, 1998]
Spruce tree growth (Germany, without bark)	2.53-3.44	t / ha * a	[Kaltschmitt, 2001]
Solid waste			
Garden & park waste/biomass, GE 2002	50	kg / person * a	[Destatis, 2004]
Garden biowaste, Germany	20 - 250	kg / person * a	[IZES, 2002]
Household biowaste, Germany	50 - 150	kg / person * a	[IZES, 2002]
Household biowaste, Germany	100	kg / person * a	[IE, 2002]
Household biowaste, separately collected, GE 2002	44	kg / person * a	[Destatis, 2004]
Household kitchen waste, Germany	30 - 80	kg / person * a	[IZES, 2002]
Household waste, Germany 2002	566	kg / person * a	[Destatis, 2004]
Residential waste (low income country)	91 - 164	kg / person * a	[World Bank, 2004]
Residential waste (middle income country)	128 - 237	kg / person * a	[World Bank, 2004]
Residential waste (high income country)	200 - 365	kg / person * a	[World Bank, 2004]
Industrial wastewater			
Alcoholic beverage production (Thailand)	3.4	m³ / t product	[KMUTT]
Breweries (Germany)	0.4 – 1.2	m³ / hl product	[Pöppinghaus, 1994]
Breweries (Germany)	0.25 – 0.6	m³ / hl product	[ATV, 2000] S. 331
Breweries (Thailand)	0.41	m³ / hl product	[KMUTT]
Canned food production (beans / maize, Germany)	14 - 27	m³ / t process.	[Pöppinghaus, 1994]
Canned food production (capsicum, Germany)	35 - 45	m³ / t process.	[Pöppinghaus, 1994]
Carcass disposal / utilisation (Germany)	0.9 – 1.1	m³ / t carcass	[Pöppinghaus, 1994]
Cassava starch production (Thailand)	24.72	m³ / t product	[KMUTT]
Condensed milk production (Germany)	3 - 5	m³/ t product	[Pöppinghaus, 1994]
Dairy farming (Germany)	0.5 - 3	m³ / t product	[Pöppinghaus, 1994]
Fish processing (Germany)	24	m³ / t fresh fish	[Pöppinghaus, 1994]
Fruit juice processing + bottling (Germany)	0.1 - 0.4	m³ / hl product	[ATV, 2000]
Ice cream production (Germany)	4 - 6	m³ / t product	[Pöppinghaus, 1994]
Lemonade production (Germany)	1.9	m³ / 1000 bottl.	[Pöppinghaus, 1994]
Milk drying facility (Germany)	0.2	m³/ t product	[Pöppinghaus, 1994]
Mineral, spring, table water (Germany)	0.1 - 0.2	m³ / hl product	[ATV, 2000]
Palm oil production (Thailand)	1	m³ / t product	[KMUTT]
Paper factory (Germany)	22 - 144	m³ / t product	[Pöppinghaus, 1994]
Raw milk production (Thailand)	4.05	m³ / t product	[KMUTT]
Seafood processing (canned, Germany)	2	m³ / t product	[ATV, 2000]
Seafood processing (fresh + frozen) (Thai)	31.14	m³ / t product	[KMUTT]
Seafood processing (fresh + frozen, GE)	8	m³ / t product	[ATV, 2000]
Slaughterhouse (beef, Germany)	0.6 – 9.6	m³ / animal	[Pöppinghaus, 1994]
Slaughterhouse (pork, Germany)	0.3 – 0.4	m³ / animal	[Pöppinghaus, 1994]
Slaughterhouse (Thailand)	74.54	m³ / t product	[KMUTT]
Soda and beverage production (Thailand)	9.3	m³ / t product	[KMUTT]
Sugar production (Germany)	0.5 – 1.0	m³ / t beets	[Pöppinghaus, 1994]
Sugar production (Thailand)	11.82	m³ / t product	[KMUTT]

*GE: Germany, Thai: Thailand

Mass of substrates

The quantity of substrates should be expressed as mass (tonnes), so that further calculations can be carried out. In some instances, only data on the volume of substrates might be available. Those data need to be transferred, using the bulk density. The bulk density is defined as the ratio of the mass of a material which is filled in a container, and the volume of the container. Void spaces between the particles are not subtracted. Table 6.3-6 (Tool 3) summarises the bulk densities of solid substrates, which are needed to calculate the respective mass.

For wastewater, the density of 1000 kg/m³ can be assumed.

Table 6.3-6: Bulk densities of solid substrates (Tool 3)

Tool 3

Substrates	Reference	
	Bulk density [kg/m³]	
Forestry based substrates		
Bark		
- hardwood, 85% DS	320	Kaltschmitt, 2001
- softwood, 85% DS	205	Kaltschmitt, 2001
Pellets from wood, 85% DS	600	Kaltschmitt, 2001
Sawdust, 85% DS	170	Kaltschmitt, 2001
Wood		
- Beech, 85% DS	460	Kaltschmitt, 2001
- Fir, 85% DS	310	Kaltschmitt, 2001
Wood chips		
- hardwood, 85% DS	260	Kaltschmitt, 2001
- softwood, 85% DS	195	Kaltschmitt, 2001
Agro based crop substrates		
Chaff		
- Straw, 85% DS	65	Kaltschmitt, 2001
- whole crop, 85% DS	150	Kaltschmitt, 2001
Grains, 85% DS	760	Kaltschmitt, 2001
Hay, 85% DS	100,160	Kaltschmitt, 2001
Maize silage, 85% DS	760	
Straw, 85% DS	85, 140	Kaltschmitt, 2001
Animal husbandry		
Manure from cattle or pig, 7%DS	1000	
Municipal and industrial waste		
Leaves	50-100	Thomé-Kozmiensky, 1995
Pomace	900-950	Thomé-Kozmiensky, 1995
Vegetable waste	450-600	Thomé-Kozmiensky, 1995
Canteen waste	800-1000	Thomé-Kozmiensky, 1995
Loppings	30-200	Thomé-Kozmiensky, 1995
Household waste		
- collected in bag	90-120	Thomé-Kozmiensky, 1995
- pressed in refuse collector	350-550	Thomé-Kozmiensky, 1995
Industrial wastewater		
all wastewater	1000	

Calculation: Volume into mass (tool 3)

$$m_S = \frac{\delta_S * V_S}{1000}$$

where:

m_S = mass of substrate [t/a]

δ_S = bulk density of substrate [kg/m³]

Results of step 2

→ Quantity of substrate [tonnes/a], for wastewater: [m³/a]

Step 3: Identification of the substrate characteristics

Explanations of step 3

Organic substrates can be characterised by a variety of different parameters. A few of those parameters are relevant for identifying the quantity of energy which can be derived from substrates.

Substrates suitable for the biogas process

For solid substrates (manure, biomass, waste) which are utilised for biogas generation, the following parameters are relevant:

- specific methane yield.
- dry substance content (DS)
- organic dry substance content (oDS).

For wastewater utilised in biogas plants, the following parameters are relevant:

- chemical oxygen demand (COD)
- fraction of COD removed.

The **specific methane yield** is a measure of the quantity of methane which is produced from a particular substrate. Depending on its composition the biogas yields can vary widely. As Table 6.3-7 shows, the biogas yield and methane content differs for carbohydrates, proteins and lipids.

Table 6.3-7: Specific biogas yield and methane content for substrate compounds [Weiland, 2001]

	Biogas yield [m³/kg oDS]	Methane content [Vol %]
Digestable proteine	0,6 – 0,7	70-75
Digestable lipids	1 – 1.2	68-73
Digestable carbohydrates	0,7 – 0,8	50-55

For biogas plant planning, not the total methane yield, but the methane yield which refers to typical retention times in biogas plants is of interest, when the degree of degradation typical lies in the range of 40-50% (Loll, 2001). For different types of substrates, typical values can be taken from literature (Table 6.3-8, Tool 4).

Substrates utilised in biogas plants consist of water, organic material and inorganic material, but only the actual *organic substance* of the substrate is degraded to biogas (Figure 6.3-1). Therefore the specific biogas and methane yield of a substance is largely influenced by the water content and the content of organic substances. As a consequence, the specific methane yield should refer to "organic dry substance" and normally is expressed as "*m³ methane / kg organic dry substance".*

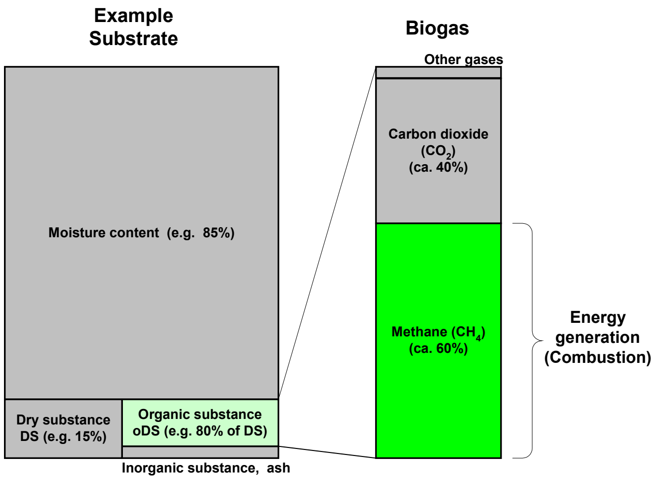

Figure 6.3-1: Composition of substrates and biogas formation

The **content of dry substance (DS)** is the water free fraction of the substrate (Figure 6.3-1). The DS is analysed by drying at 105 °C. Typical values are 6-17 % (for cattle manure) or 40-75 % (Biowaste).

The water free fraction of the substrates (dry substance content) consists of organic and inorganic material (Figure 6.3-1). The **organic dry substance content (oDS)** is a measure for the organic content, which can be degraded or combusted. The oDS is expressed as "% of DS". The oDS is analysed by heating the substrate to 550 °C, so that the organic material is volatilised and the inorganic content (ash) is left.

To be able to calculate the biogas yield for the original wet substrate as supplied to the biogas plant, the water content and organic content need to be considered. If chemical analysis is not possible, typical values from literature can be used (Table 6.3-8). However it must be noted, that great variations might be possible, which might have a big effect on the result.

Most data on biogas or methane yield in literature are expressed in "m³", so it can be assumed that they refer to prevailing conditions of the time of measurement. Therefore it is suggested to convert biogas yields to norm conditions (Tool 5). The volume of gases (i.e. biogas) depends on the ambient conditions, i.e. gas temperature and atmospheric pressure. Therefore gas volumes should be expressed in Nm³ (= "**Norm cubic meter**"), which refers to norm conditions (0°C, 1.013 hPa) to avoid too optimistic or pessimistic prognosis on the energy yield.

Table 6.3-8: Characteristics of solid biogas substrates (Selected values) (Tool 4)

Tool 4

Substrate	**DS [% by weight]**	**oDS [% by weight, of DS]**	**specific methane yield [CH_4/kg oDS]**
Agro based crop substrates			
Beet tops	16-17	75-80	0,3-0,83
Beet, sugar beet	23	90-95	0,42-0,46
Beet, forage beet	16	85	0,48
Beet (Gehaltsrübe)	12-15	75-85	0,33-0,45
Clover	20	80	0,26-0,5
Grass	15	80	0,17-0,33
Grass silage	21-54	76-95	0,3-0,6
Grass sil. (1st. Crop, bloom)	35	89,8	0,3
Maize silage	20-35	85-96	0,22-0,5
Maize straw	86	72	0,6-0,7
Potato tops (Kartoffelkraut)	25	79	0,17-0,6
Rapeseed shred	91		0,4-0,9
Wheat straw	86	92	0,12-0,19
Animal husbandry			
Cattle manure	6-17	72-90	0,1-0,35
Cattle manure (with straw)	12-40	65-85	0,13-0,46
Chicken manure	10-34	70-80	0,19-0,72
Chicken manure (with straw)	20-32	63-80	0,15-0,29
Horse manure (with straw)	28	25-75	0,12-0,4
Pig manure	3-13	52-86	0,18-0,64
Pig manure (with straw)	20-25	75-82	0,16-0,27
Sheep manure (with straw)	25-30	80	0,05-0,5

Substrate	DS [% by weight]	oDS [% by weight, of DS]	specific methane yield [CH4/kg oDS]
Municipal and industrial waste			
Animal cadaver meal	8-25	90	0,5-0,8
Biowaste	40-75	30-70	0,09-0,6
Cereal mash	6-10	83-90	0,26-0,6
Clippings (sedge) (Mähgut)	30-37	91-94	0,48-0,5
Fat (from fat separators)	2-70	75-98	0,36-1,0
Filtration silica gel (beer)	30	6	0,3-0,35
Float fat	5-35	95-98	0,7-0,8
Flotation sludge	5-24	80-98	0,58-0,78
Foliage / leaves	30-85	75-85	0,13-0,4
Food waste	9-40	50-98	0,12-1,0
Fruit pulp (fresh)	13	90	0,39-0,45
Kitchen waste	9-37	75-98	0,5-0,6
Loppings	12-90	25-92	0,29-0,58
Market waste	5-25	76-90	0,25-0,37
Mash of apples	2-3	95	0,33
Mash of fruits	2-7	85-95	0,24-042
Molasse	80-90	85-95	0,26-0,35
Oil seed residue (pressed)	92	97	0,58-0,62
Pomace of apples	25-45	85-90	0,3-0,45
Pomace of fruits	22-50	60-95	0,3-0,48
Pomace of grape	40-50	80-95	0,42-0,45
Potato mash	6-15	81-95	0,24-0,55
Potato pulp	12-16	90-94	0,24-0,55
Potato slop	12-15	90	0,24-0,55
Raps extraction residue	86-93	90-94	0,4-0,6
Rumen content (pressed)	20-45	80-90	0,6-0,7
Rumen content (untreated)	11-19	80-94	0,12-0,4
Sewage sludge (liquid)	3-8	40-70	0,31 (0,19-0,44)
Spent grains from beer	15-25	70-95	0,3-0,7
Spent hops (dried) (Hopfentreber)	97	90	0,5-0,55
Stomache contents (pig)	11-19	75-88	0,16-0,3
Straw	60-90	70-85	0,15-0,2
Vegetable waste	5-25	75-90	0,2-0,66
Whey	80-95	80-95	0,3-0,6
Yard trimming		15-75	

Calculation: "Conversion into norm gas volume" (Tool 5)

Tool 5

$$V_N = \frac{V_G * (P_L - P_R) * 0{,}269}{(273 + T_G)}$$

where:

V_N = norm volume [Nm³]
V_G= Gas volume [m³]
P_L=Atmospheric pressure [hPa], e.g. 960 hPa
P_R= negative pressure in gas flow control system (Gasregelstrecke)
T_G= Gas temperature [°C], e.g. 30 °C

The parameter **chemical oxygen demand (COD)** is used to characterise the energy content of wastewater utilised in biogas plants. COD is expressed as "mg O_2/l" and is defined as the amount of oxygen required for the chemical oxidation of compounds in water, as determined using a strong oxidant (most standard methods use dichromate). Typical COD concentrations can be taken from literature (Table 6.3-9, Tool 6).

Normally, not the total COD is degraded in anaerobic treatment processes. Therefore the degree of **COD removal** is a relevant parameter to consider. The COD removal rate depends on the type of wastewater and the treatment process. It typically ranges between 50 and 90 % and can be assumed to be **80 %** for a course evaluation.

Tool 6

Table 6.3-9: COD of wastewater (Tool 6) [Rüffler, 2001]

Type of industrial wastewater	**COD [mg/l]**
Sugar production	7.500-10.000
Starch production (Potatoes)	5.700
Starch production (Wheat)	21.750-52.500
Starch production (Maize)	8.000-30.000
Cannery (Sauerkraut)	15.000-85.000
Cannery (Fruits)	4.000-5.700
Cannery (Vegetables)	700-9.000
Meat processing	1.000-6.000
Dairy	700-2.900
Fruit juice processing	3.000-6.000
Brewery	1.800-3.000
Yeast factories	5.000-25.000
Canteen	1.800-26.500
Slaughterhouse	1.000-6.000
Fish processing	3.000-4.350
Fish meal processing	1.280-9.400
Mash of molasse .(Melassebrennereien)	15.000-176.000
Sugar production	7.500-10.000
Starch production (Potatoes)	5.700
Starch production (Wheat)	21.750-52.500
Starch production (Maize)	8.000-30.000
Cannery (Sauerkraut)	15.000-85.000

Parameters for substrates suitable for combustion processes

For substrates which are utilised in combustion processes the major parameter to define the energy content is the **lower heat value (h_l)**. Although the heat value depends, among other factors, on the water content of the substrate, specific heat values are listed in literature in "kJ/kg" or "MJ/kg" referring to original substrates with typical dry substance contents (Table 6.3-10, tool 7).

Table 6.3-10: Heat values of substrates suitable for combustion (Tool 7)

Tool 7

Substrate	**Lower heat value h_l [kJ/kg DS] ***	**Water Content [%]**	**DS [%]**
Algae	18.321 - 24.901	83-50	17-50
Animal cadaver meal	20.000	75-92	8-25
Barley straw	17.500	14	8-6
Bark	18.000-19.500	5-15	85-95
Cane trash	17.266	6,5-8	92-93,5
Cattle manure-feces	14.051	12,8-15	85-87.2
cereal straw	14.000 - 17.200	5-15	85-95
Coco bean shells	18.000	4-5	95-96
Corn straw	15.000	5-10	90-95
Fat (from fat separators)	37.229	30-98	2-70
Flax	17.270	3-8	92-93
Food waste (from large kitchens)	12.000-17.000	40-70	30-60
grass mixture	16.300 - 17.100	5-10	90-95
Hay, field, 2st crop beginning bloom	14.100 - 17.600	2-6	94-98
Hemp	16.456 - 17.300	8-12	88-92
Oat straw	17.011	2-6	94-98
Plant seed	14.500 - 24.500	2-10	90-98
Rape straw	15.000 - 15.800	2-5	95-98
Residual wood (common)	11.600 - 12.300	15-40	60-85
Rice husk	14.557	5-15	85-95
Rice straw	14.920	2-6	94-98
Sewage sludge	14.031	30-70	30-70
Wheat grain (Alcohol burnner)	17.039	2-5	95-98
Wood (untreated)	17.500 – 18.500	10-50	50-90

Results of step 3

for biogas, and utilisation of the following substrates: biomass, manure, waste:
→ DS (Dry substance content) [%]
→ oDS (organic dry substance content) [% DS]
→ specific methane energy yield [m³ CH_4/ kg oDS or Nm³ CH_4/ kg oDS]

for biogas, and the utilisation of wastewater:
→ COD [mg/l]
→ COD removal [%]

for biomass combustion:
→ Lower Heat value [MJ/kg]

Step 4: Pre-selection of process and input substrates to be evaluated further

Explanations of step 4

If substrates are available which are suitable for biogas AND biomass combustion, the further evaluation should be done separately, i.e. for biogas only or for biomass combustion only. Also the types and quantity of substrates used as feedstock should be pre-selected here. This pre-selection will be evaluated further.

Results of step 4

→ Pre-selection of input substrates
→ Pre-selection of process, either
- Biogas, using substrates like manure, biomass, waste, or
- Biogas, using wastewater, or
- Biomass combustion

Step 5: Determination of energy content of substrates

This step is different for the biogas process and combustion process. Please only consider the corresponding paragraphs.

Explanations of step 5 (for biogas process)

Biogas

The energy content of the solid substrates (manure, biomass, waste) which are utilised in the biogas plant is calculated by using the formulas below (tool 8). The methane production depends on the specific methane yield of the substrates, the mass of substrates available, the DS (dry substance content) and the oDS (organic dry substance content). The energy content of the produced methane is calculated by considering the heat value of methane (ca. 10 kWh/Nm³ CH_4.).

Tool 8

Calculation: Energy content of biogas substrates (Tool 8)

A. Production of methane (valuable component of biogas)

$$CH_4 = \frac{y_{CH4} * m_S * DS * oDS}{10}$$

where:

CH_4 = Methane production [Nm³]
y_{CH4}= specific methane yield of the substrate [Nm³ CH_4/kg oDS]
m_s = mass of substrate [t/a]
DS= dry substance content of substrate [%]
oDS= organic dry substance [% of DS]

B. Energy content of methane produced

$$E = CH_4 * h_l$$

E= Energy content [kWh/a]
CH_4 = Methane production [Nm³]
h_l= heat value of methane [kWh/Nm³ CH_4] = ca. 10 kWh/Nm³ CH_4

<u>Wastewater</u>
If wastewater represents the input of a biogas plant, the methane production is calculated by considering the COD content of the substrate, the degree of COD removal, the volume of the wastewater and the specific methane yield of wastewater (formula below, tool 9). A typical value for methane production from wastewater is 0,4 m³/kg COD.

Tool 9

Calculation: Energy content of wastewater (tool 9)

A. Production of methane (valuable component of biogas)

$$CH_4 = \frac{y_{CH4} * V_S * COD * r_{COD}}{100 * 1000}$$

where:

CH4 = Methane production [Nm³]
y_{CH4}= specific methane yield per kg COD in wastewater
= presumed: 0,4 [m³ CH_4/ kg COD]
V_S= volume of substrate (wastewater) [m³/a]
COD = COD concentration of the substrate [mg/l]
r_{COD}= COD removal = presumed: 80 [%]
h_l= heat value of methane = ca. 10 [kWh/Nm³ CH_4]

B. Energy content of methane produced

$$E = CH_4 * h_l$$

E= Energy content [kWh/a]
CH_4 = Methane production [Nm³]
h_l= heat value of methane [kWh/Nm³ CH_4] = ca. 10 kWh/Nm³ CH_4

Combustion

Explanations of step 5 (for biogas process)

The total energy content of substrates which are utilised for biomass combustion is directly calculated from the lower heat value h_l multiplied by the mass of input substrate available (see formula below, tool 10).

Tool 10

Calculation: Energy content of combustion substrates (tool 10)

$$E = \frac{h_l * m *}{3{,}6 * 1000}$$

where:

E= Energy content [kWh/a]
h_l= specific lower heat value of the organic dry substrate [MJ/kg]
m = mass of substrate [t/a]

Results of step 5

→ Energy content of substrates [kWh/a]

Step 6: Determination of the usable electrical and thermal energy production

This step is different for the biogas process and combustion process. Please only consider the corresponding paragraphs.

Explanations of step 6 (for biogas process)

Biogas

Biogas normally is electrified in block heat and power plants, which simultaneously generate heat. A block heat and power plant is a combined heat and power plant (CHP) which is completely installed, delivered and run as a "block". Block heat and power plants consist of a combustion engine, normally either Gas-Otto-Motors or pilot injection engines, which are linked to a generator. Other motor types, like Stirling-Motors, fuel cells, micro-gas turbines will not be considered here, as those technologies are still in the development or pilot phase.

The usable energy which is produced in block heat and power units is the quantity of energy generated from the available substrates, which can be provided for external use, e.g. for direct use or feeding into the net.

The **usable electrical energy** is influenced by three factors:

1. addition of auxiliary fuel oil
2. electrical efficiency of the block heat and power plant
3. consumption of auxiliary electrical energy

The **usable thermal energy** is influenced by two factors:

1. thermal efficiency of the block heat and power plant
2. consumption of auxiliary thermal energy.

<u>Auxiliary addition of fuel oil</u>

If block heat and power plants operate with a pilot injection engines, ca. **10% fossil fuel** (fuel oil or diesel) is needed to ignite the biogas. As a consequence, the total quantity of energy produced is considerably higher than with a gas-motors. However the fossil fuel consumption has a negative impact on operating costs and environmental performance of the plant.

It is necessary to pre-select, whether a pilot injection engine or a Gas-Otto-Motor, which does not need auxiliary fuel, is used in the block heat and power plant. There are a number of selection criteria to identify the motor type which is a suitable and the most cost-efficient choice. Table 6.3-11 lists the main characteristics of the Gas-Otto-Motor and pilot injection engine. A pre-selection of the motor type can be done on the basis of the electrical capacity (Figure 6.3-2). Pilot-injection motors have a maximum nominal electrical capacity of ca. 250 kW, whereas Gas-Otto-Motors are available from a capacity range of ca. 100 kW – 1 MW.

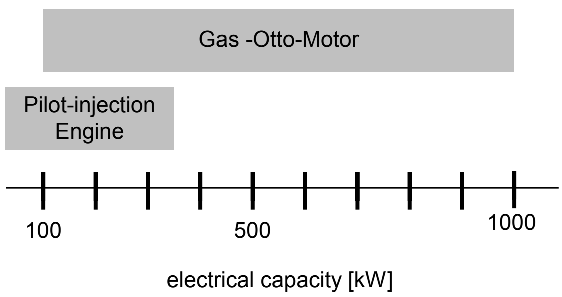

Figure 6.3-2: Applicability of pilot injection engines and Gas-Otto-Motors

Table 6.3-11: Main characteristics of Gas-Otto-Motors and pilot injection engines [extracts from FNR, 2004, changed]

Criteria	Pilot injection engine	Gas-Motors
Overall suitability	Generally suitable for all biogas plants; often more cost-efficient for smaller plants	Generally suitable for all biogas plants; often more cost-efficient for larger plants
Electrical capacity	up to 300 kW	100 kW – up to 1 MW
Additional fuel	auxiliary fossil fuel consumption (e.g. diesel or fuel oil) up to 10%	no additional fuel
Investment costs	slightly lower costs, use of standard motors	slightly higher costs
Operating hours	ca. 35.000 h	ca. 60.000 h
Maintenance	higher maintenance requirements	small maintenance requirements

The nominal electrical capacity is calculated in step 11 (tool 16). Therefore, at this step, a provisional estimation of the nominal electrical capacity has to be carried out, to be able to pre-select the motor type. Table 6.3-12 shows the nominal electrical capacity of a block heat and power unit, depending on the energy content of the substrates available. The values do not consider additional fuel consumption, which increase the energy content utilised.

Table 6.3-12: Rough estimation of the nominal electrical capacity of a required block heat and power plant, in relation to the energy content of substrates available (considers an electrical efficiency of 35%, 8000 operation hours and no additional fuel consumption)

Energy content of the substrate available [kWh/a]	nominal electrical capacity of a block heat and power plant [kW_{el}]
ca. 1.600.000	ca. 70
ca. 2.290.000	ca. 100
ca. 4.570.000	ca. 200
ca. 5.710.000	ca. 250
ca. 11.400.000	ca. 500
ca. 22.900.000	ca. 1.000

<u>Electrical and thermal efficiency of the block heat and power plant</u>

The efficiency of the block heat and power plant is a measure of how effective the supplied energy is utilised. The overall efficiency is the sum of the electrical and thermal efficiency and reflects the efficiency of the motor and the one of the generator. It normally ranges between 60-90% [FNR, 2004].

The electrical efficiency varies with the type of motor. With Gas-Otto-Motors it typically lies in the range of 26 - 38 %. For pilot injection engine it lies in the range of 29-40 % [FNR, 2004]. Figure 6.3-3 gives an overview over the electrical efficiency of pilot injection gas motors and Gas-Otto-Motors, showing that it increases with larger capacities. However it is important to note, that the specification of the manufacturer generally refers to test conditions (continuous run with natural gas under optimised conditions), so that the real values are often lower. Although Figure 6.3-3 shows that the performance of both motor types vary in terms of efficiency, it is sufficient to presume a general **electrical efficiency of 35%.**

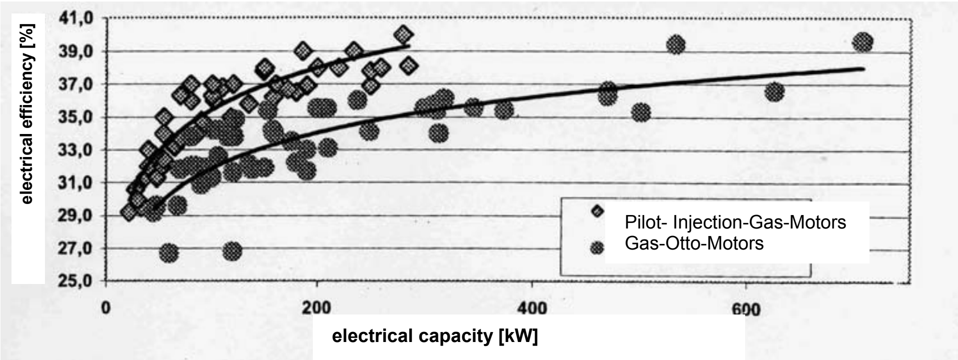

Figure 6.3-3: Electrical efficiency of biogas CHP (combined heat and power) plants, according to manufacturer specification, for pilot injection gas motors and Gas-Otto-Motors [FNR, 2004].

A continuous use of the thermal energy produced from biogas in block heat and power plants is seldom possible. The utilisation of the thermal energy however can represent a vital factor for a cost-efficient biogas plant. Therefore it is essential to know, how much thermal energy actually is available for selling. As a rule of thump, 2/3 of the total efficiency of pilot injection gas motors and Gas-Otto-Motors (i.e. 60-90%) represents the thermal efficiency [FNR, 2004]. Therefore, a **thermal efficiency of 50%** can be applied in a pre-feasibility study (assumed that additional installations like heat exchangers etc. are available).

Auxiliary consumption of electrical and thermal energy

The **electrical energy consumption** of the biogas plant mainly depends on the type of process. Electricity is mainly needed for mixing and pumping the substrates as well as for the measurement and control system in more advanced, automatised biogas plants. The consumption can lie in the range of ≈10 % of the produced electricity. For a course calculation, the electrical process consumption can be presumed to be **10%** referring to the total energy input**.**

A certain fraction of the thermal energy produced can be utilised (via a heat exchanger) as **thermal process energy** in the biogas plant and is not available for external use. However the thermal energy demand depends on the type of process, the climatic conditions of the location and the types of substrates. Thermal energy is required for

- heating the substrate to the process temperature and heating the digester at a constant level
- sanitation requirements.

Most biogas plants are operated under *mesophilic* conditions, i.e. in a temperature range around 37 °C. Therefore, for biogas plants located in tropical regions of Thailand and Vietnam, substrate or digester heating is not required. In temperate climate like Germany, heating is required particularly for the colder months. For substrates with a high water content, e.g. manure, it can be assumed, that thermal energy of approx. 1,16 kWh_{th} (= the specific heat capacity of water) is required for heating of 1 t of substrates by 1 K. In addition, heat requirements to compensate radiation loss of the digester have to be considered, which depend on insulation, surface of the digester and the difference of temperature. Generally, approximately **20-40%** of the total produced thermal energy is used for fermenter **heating** in Germany [FNR, 2004].

Organic substrates can contain bacteria, funghi, viruses and parasites of different types and quantities which can be pathogenous for humans, animals or plants and which can lead to a hygiene risk when digested end products are utilised as fertiliser. Therefore sanitation is required for most organic material. However, energy requirements for sanitation are not considered in this context.

Biogas

Biogas plants without a block heat and power plant

Biogas plants do not necessarily have to include a block heat and power plant, when the energy produced shall be delivered directly as biogas. This can be a suitable and cost-efficient options, when

- local facilities like diesel motors exist, which can be fed with biogas
- biogas is thermally used (burner)
- biogas is used for fuel in vehicles
- biogas is fed into the gas net (potential option for the future- today there are technical and economic problems).

In this case, the production of usable energy mainly depends on the total biogas production. Only the quantity of biogas used for auxiliary consumption of thermal energy (by onsite burner) has to be subtracted. Electrical energy would have to be purchased externally.

Calculation of the usable energy

The usable electrical and thermal energy produced is calculated by using the formulas below (Tool 11)

Tool 11

Calculation: Usable energy - biogas (tool 11)

for electrical energy:

$$E_e = \frac{E * \eta_e}{(100 - f)} * \left(1 - \frac{e_{aux.e}}{100}\right)$$

where:

E_e=	Usable electrical energy [kWh_{el}/a]
E=	Energy content of the substrate [kWh/a]
η_e=	electr. efficiency of block heat and power plant [%]= ca. 35 %
f=	auxiliary fuel [%] = ca. 10%
$e_{aux.e}$=	auxiliary consumption of electrical energy [%]= e.g. 10 %

for thermal energy:

$$E_{th} = \frac{E * \eta_{th}}{100} * \left(1 - \frac{e_{aux.th}}{100}\right)$$

where:

E_{th}=	Usable thermal energy [kWh_{th}/a]
E=	Energy content of the substrate [kWh/a]
η_{th}=	thermal efficiency of block heat and power plant = ca. 50 [%]
$e_{aux.th}$=	auxiliary consumption of thermal energy, for heating of digester [%] = e.g. 50 %

for biogas provision:

$$E_{CH4} = E * \left(1 - \frac{e_{CH_4 aux.th}}{100}\right)$$

where:

E_{CH4}=	Usable energy in form of biogas [kWh /a]
E=	Energy content of the substrate [kWh/a]
$e_{CH4.aux.th}$=	biogas demand for heating of digester [%] = e.g. 25%

Results of step 6 (for biogas process)

→ Selection of motor type for block heat and power plant
→ Thermal efficiency of block heat and power plant [%]
→ Electrical efficiency of block heat and power plant [%]
→ Auxiliary consumption of thermal energy, for digester heating [%]
→ Auxiliary consumption of electrical energy, for pumping, mixing [%]
→ Auxiliary addition of fossil fuel [% of brutto electricity production]
→ Usable electrical energy [kWh e./a], [GWh e./a]
→ Usable thermal energy (hot water) [kWh th./a], [GWh th./a]
→ Biogas [kWh/a], [GWh/a]

Combustion

Explanations of step 6 (for combustion process)

In a biomass combustion plant the biomass is burned to produce hot flue gases, which transfer their heat by a boiler to a circulating transfer medium. Water or steam is used as process medium.

The usable energy production is the quantity of energy generated from the available substrates, which can be provided for external use, e.g. for direct use or feeding into the net.

You have to distinguish between four main operating modes of a combustion plant, depending whether you are aiming at the production of electrical energy, thermal energy or both combined:

1. Electric Power Plant
2. Combined Heat and Power (CHP) - electricity controlled
3. Combined Heat and Power (CHP) - heat controlled
4. Heat Plant

Mode 1: Electric Power Plant

If only **electrical power** is needed, steam is electrified aiming a high electrical efficiency. For this application, most biomass combustion plants utilize the Rankine cycle for electric power generation. It consists of a steam generator (boiler), steam turbine, condenser and pump. In the steam turbine, the steam is expanded to produce mechanical power, which is converted into electricity. The efficiency of the turbine is directly related to the difference between steam inlet and exhaust conditions. Because of this, condensing turbines, which exhaust steam at less than atmospheric pressures, are commonly used in biomass power plant, to obtain high electrical efficiency.

Mode 2 and 3: Combined Heat and Power (CHP)

A CHP-plant generates heat and power simultaneously. Two main types can be distinguished: **back-pressure** plants and condensing plants, which use steam at intermediate pressure, for varying heat demand.

Condensing plants, which use steam for heat production at intermediate pressure, are applied when there is a varying heat demand. This allows an operation of the plant at maximum overall efficiency in winter, with high heat production, and at maximum electric efficiency in summer, with a low heat production. This type of plant is called **electricity controlled CHP**. They are generally used for large-scale applications, because they require expensive technical facilities (e.g. a cooling tower for heat removal). The electrical efficiency is lower compared to a real condensing plant due to the waste heat which is not needed.

Power plants ranging between 0.5 - 5 MW el. normally are operated as back-pressure plants, with heat extraction for thermal use and resulting reduced electric efficiency. The amount of heat produced is fixed, reflecting the heat demand. The electricity and heat generated have a defined proportion. The lower the demand for heat, the lower is the produced amount of steam and the lower is the generated electricity. Hence, these back-pressure steam turbines are called **heat controlled CHP**.

Mode 4: Heat plant

If only heat is required, the flow gases have to be cooled down as much as possible, to secure a high efficiency. This is influenced mainly be the difference of temperatures, of the flue gas and the process medium.

The usable **electrical energy production** is influenced by three factors:

- operational mode (Mode 1-4)
- electrical efficiency of the power or combined heat and power (CHP) plant
- auxiliary consumption of electrical energy production

The usable **thermal energy production** is influenced by two factors:

- operational mode (Mode 1-4)
- thermal efficiency of the heat plant or combined heat and power (CHP) plant

Electrical and thermal efficiencies

Mode 1: Electric power plant
The electrical efficiency of a power plant with a condensing steam turbine varies with the installed electric capacity. Small scale systems (<5 MW el) have to be operated with dry steam which limits their electrical efficiency to about 10-20%. For larger steam turbine plants, water tube boilers and superheaters are employed, thus enabling high steam parameters and the use of multi-stage turbines. This results in electrical efficiencies up to 25% in plants of 5-10 MW el.. To calculate the usable electrical energy we presume an electrical efficiency of 20 %.

Mode 2: CHP (electricity controlled) → condensing plant with use of steam at intermediate pressure:
As mentioned above, this CHP-mode is most suitable for mid or large scale systems (> 5 MW el). The heat/power ratio is about 3:1 to 7:1. The resulting electrical efficiency ranges between ca. 10-20%, and can be presume to be 15%. It is lower compared to a real condensing plant (Mode 1) due to the waste heat which is not needed. The thermal efficiency is about 60%.

Mode 3: CHP (heat controlled) → back-pressure plants
In so called back pressure plants the produced heat and electricity have a defined ratio from about 4:1 to 9:1. The demand of heat determines the plant capacity and influences the electrical efficiency (which varies between 7 and 20 %). By reason of simplification we presume an electrical efficiency of 10 %. The overall efficiency can be as high as 80%, if the heat is fully utilised, resulting of a high thermal efficiency of 60-70 %. To calculate the usable electrical energy, we presume a thermal efficiency of 65 %.

Mode 4: Heat plant: Depending on the process medium utilised, heat of the flue gas is transferred more ore less efficient. Generally, the thermal efficiency of heat plants lies in the range of 85 %.

Table 6.3-13 summarizes the thermal, electrical and overall efficiencies for all plant modes. In addition, Figure 6.3-4 gives an overview over electrical efficiencies of CHP and power plants as a function of the installed electrical capacity.

Table 6.3-13: Thermal, electrical and overall efficiencies of combustion plants

Operational mode	**Electrical eff.** η_{el}	**Thermal eff.** η_{th}	**Overall eff.** $\eta_{overall}$
Power plant (mode 1)	10-30% (20%)	-	25%
CHP plant electricity controlled (mode 2)	10-20% (15%)	55-70% (60%)	75-80%
CHP plant heat controlled (mode 3)	7-20% (10%)	60-70% (65%)	75-80%
Heating plant (mode 4)	-	85%	85%

Combustion

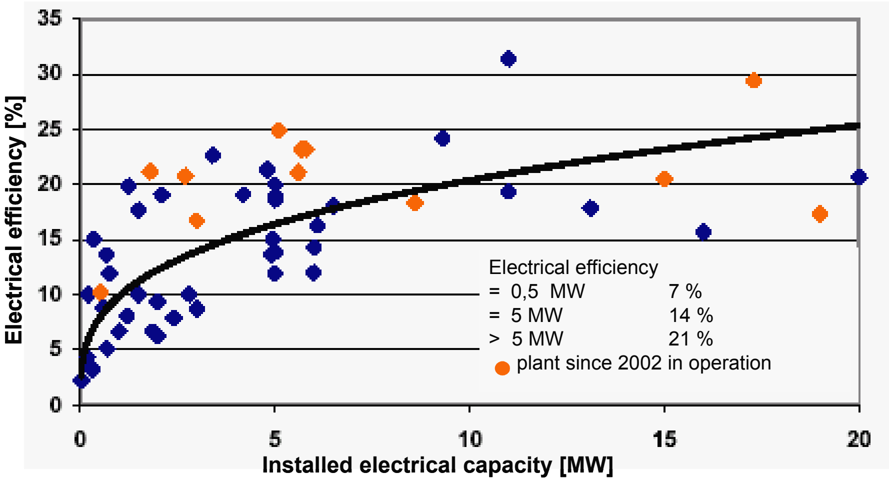

Figure 6.3-4: Electrical efficiency of CHP and power plants, according to operator specifications [Kaltschmitt, 2003]

The nominal electrical capacity of the CHP or Power plant has an influence on the efficiency. It will be calculated in step 11 (tool 16). Therefore a provisional evaluation has to be carried out here, using Table 6.3-14. The table shows the nominal electrical capacity of CHP and power units and the nominal thermal capacity for heat and CHP units, depending on the energy content of the substrate available. The values do not consider additional fuel consumption, which increase the energy content utilised.

Table 6.3-14: Estimation of required nominal electrical and thermal capacities of the following units for the energy content of the substrate available (considers 7500 operating hours).

Energy content of the substrate [MWH/a]	**Nominal electrical capacity of power unit (Mode 1) [MW]**	**Nominal capacity of electricity controlled CHP unit (Mode 2) [MW]**		**Nominal capacity of heat controlled CHP unit (Mode 3) [MW]**		**Nominal thermal capacity of heating unit (Mode 4) [MW]**
		Electrical	Thermal	Electrical	Thermal	
25.000	0,7	0,5	2,0	0,3	2,2	2,7
50.000	1,3	1,0	4,0	0,7	4,3	5,3
100.000	2,7	2,0	8,0	1,3	8,7	10,7
200.000	5,3	4,0	16,0	2,7	17,3	21,3
300.000	8,0	6,0	24,0	4,0	26,0	32,0
400.000	10,7	8,0	32,0	5,3	34,7	42,7
500.000	13,3	10,0	40,0	6,7	43,3	53,3
750.000	20,0	15,0	60,0	10,0	65,0	80,0
1.000.000	26,7	20,0	80,0	13,3	86,7	106,7
2.000.000	53,3	40,0	160,0	26,7	173,3	213,3

Auxiliary consumption of electrical and thermal energy

The electrical energy consumption of biomass combustion plants (CHP or power plants) mainly depends on the combustion technology and the used process for cleaning the flue gas. The consumption can lie in the range of 2-10 % of the produced energy. For a coarse calculation, the electrical process consumption can be presumed to be 8% referring to the total electricity production (for operational mode 1).

Combustion

Tool 12

Calculation of the usable energy production

The usable electrical and thermal energy produced, considering the electrical and thermal efficiencies of the combined heat and power (CHP) plant (power plant, heating plant) and the auxiliary consumption of electrical and thermal energy is calculated by using the formula below (Tool 12)

Calculation: Usable energy production-biomass combustion (tool 12)

for electrical energy:

$$E_e = \frac{E * \eta_e}{100} * \left(1 - \frac{E_{aux.e}}{100}\right)$$

where:

E_e= Usable electrical energy [kWh_{el}/a]
E= Energy content of the substrate [kWh/a]
η_e= electrical efficiency [%] of
- Power plant = 20 %
- CHP plant (electricity-contr.)= 15 %
- CHP plant (heat-controlled) = 10 %

$E_{aux.e}$= auxilliary consumption of electrical energy [%] = e.g. 8 %

for thermal energy:

$$E_{th} = \frac{E * \eta_{th}}{100}$$

where:

E_{th}= Usable thermal energy [kWh_{th}/a]
E= Energy content of the substrate [kWh/a]
η_{th}= thermal efficiency [%] of
- heating plant = 85 %
- CHP plant (heat-controlled) = 65 %
- CHP plant (electricity-contr.)= 60 %

Results of step 6 (for biogas process)

→ Auxiliary consumption of electrical energy (% of total electricity production for operational mode 1)
→ Thermal efficiency [%]
→ Electrical efficiency [%]
→ Usable energy production for 4 different operational modes
Mode 1: electrical power plant:
→ electrical power production [kWh/a]
Mode 2: Electricity controlled CHP plant:
→ electrical power production [kWh/a]
→ thermal power production [kWh/a]
Mode 3: Heat controlled CHP plant:
→ electrical power production [kWh/a]
→ thermal power production [kWh/a]
Mode 4: Heat plant:
→thermal power production [kWh/a]

Step 7: Identification of current energy supply

Explanations of step 7

The current energy supply should be investigated, including the energy generation technology, existing infrastructure and utilisation of fossil fuels. Those factors will have an effect on the choice of future energy production and the suggested infrastructure as well as on the evaluation of the environmental benefit of the renewable energy power plant.

In addition, the technical possibilities to include the biogas or biomass combustion system and the produced energy into the current energy supply system have to be investigated.

Results of step 7

→ Short description of current energy generation technology, infrastructure and quantities

(examples:
- energy production:
  - method, facilities of energy production
  - type and quantity of fuel used
  - amount of electricity produced, in MWh e /a;
  - amount of thermal energy produced, in MWh th/a
  - etc.
- energy supply
  - feeding into net;
  - provision to neighbouring facilities
  - actual supply of electrical and thermal energy
  - etc.)

→ Short description of technical possibility to include the biogas or biomass combustion system and the produced energy into the current energy supply system.

Step 8: Is there a demand for the produced energy ?

Explanations of step 8

At this step the demand for the electrical and thermal energy has to be investigated and compared to the quantity of produced energy.

Biogas and biomass combustion plants can supply energy in the form of electrical and thermal energy (steam or hot water) (Figure 6.3-5). In addition fuel, in form of biogas can be directly supplied. In practice, the utilisation of the thermal energy, in form of hot water or steam, is only seldom possible. But it is worth investigating all options for thermal energy utilisation, as this increases the cost-efficiency of the plant.

Considering the different types of energy and utilisation options for the produced energy, the energy demand has to be specified and quantified. The following issues should taken into account:

- present energy supply to households, businesses, industries, etc.,
- present energy demand (which currently cannot be met by the available supply),
- capacity of electricity nets,
- prognosis of energy demand in the future (e.g. in 5 years).

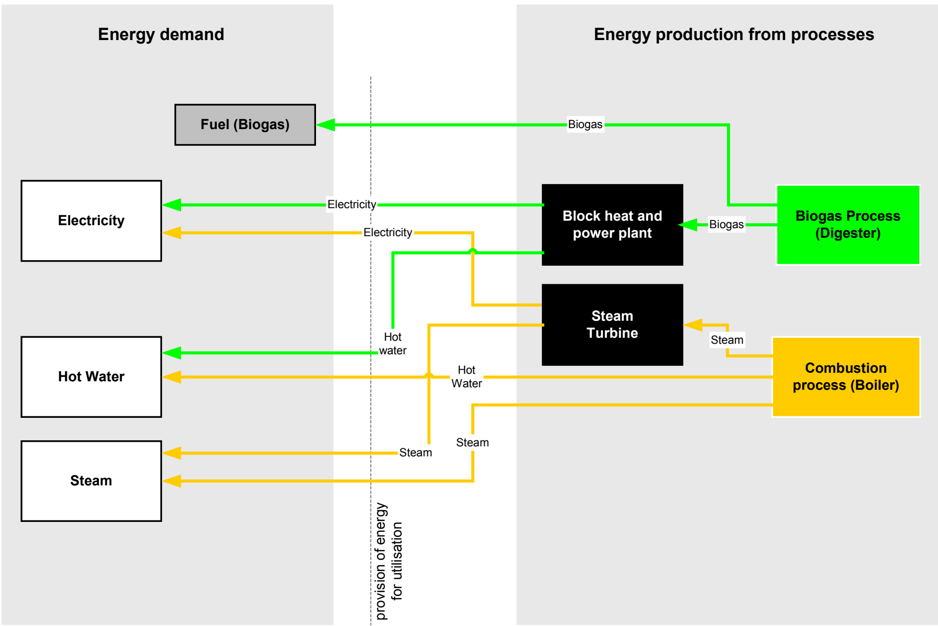

Figure 6.3-5: Types of energy which can be provided by the biogas process and combustion process

<u>Electricity demand</u>

Produced electricity can be supplied to households, neighbouring facilities and industries. It can be difficult to estimate the demand of energy, so that specific energy demand values, e.g. for typical households in Vietnam, can provide an indication about the total energy demand. Table 6.3-15 (tool 13) gives examples for specific energy demands. However those values only represent rough indications and should not substitute the identification of the actual local demand. Local energy supplier should be able to supply information regarding energy demand.

If electricity is supplied for feeding into the regional/national grid network, it is not possible to specify the energy demand.

Table 6.3-15: Specific energy demand (tool 13)

Tool 13

Specification	Value	Unit	References
Domestic electricity consumption (1 person household, Germany)	1.790	KWh/(person*a)	VDEW, 2000
Domestic electricity consumption (2 person household, Germany)	1.515	KWh/(person*a)	VDEW, 2000
Domestic electricity consumption (3 person household, Germany)	1.290	KWh/(person*a)	VDEW, 2000
Domestic electricity consumption (4 person household, Germany)	1.110	KWh/(person*a)	VDEW, 2000
Average domestic electricity consumption (Thailand)	369	KWh/(person*a)	WE, 2002
Average domestic electricity consumption (Vietnam)	197	KWh/(person*a)	WE, 2002

Thermal energy demand

Thermal energy can be provided from biogas or combustion processes as hot water, which can be used from neighbouring facilities for heating (e.g. animal stalls, greenhouses, dairy processing), drying of products (wood, shrimps, etc.), or for long distance community heating. When selling thermal energy it generally must be supplied continuously. The time for interruption of energy production due to maintenance or process stops has to be bridged.

Thermal energy also can be converted into cooling by a sorption process which can be compared to the process in old refrigerators. The operation of “combined-power-heat-and-cooling-units” in biogas plants is currently tested in several agricultural biogas pilot-plants [FNR, 2004]. The potential for utilisation of cooling (e.g. for refrigeration of products or process cooling) is estimated to be significant, particular with tropical countries. However cost-efficient plants or projects still are seldom.

Steam can be provided by biomass combustion plants only. The energy demand in form of steam depends on the temperature and pressure required. Table 6.3-16 (tool 14) can assist to identify the steam demand.

Table 6.3-16: Energy requirement for steam generation (tool 14) [COGEN3, 2004]

Tool 14

Steam parameters		Energy requirement for steam production (saturated steam)
Pressure [bar]	Temperature [°C]	[kWh/kg]
1	99,6	0,714
2	120,2	0,723
3	133,5	0,728
4	143,6	0,731
5	151,8	0,734
6	158,8	0,736
7	165,0	0,738
8	170,4	0,740
9	175,4	0,741
10	179,9	0,742
11	184,1	0,743
12	188,0	0,744
13	191,6	0,745
14	195,0	0,745
15	198,3	0,746
16	201,4	0,746
17	204,3	0,747
18	207,1	0,747
19	209,8	0,748

Biogas demand

In certain cases there is a demand for biogas generated in biogas plants. The biogas can be thermally used, e.g. for cooking, as a fuel for vehicles, or as a substitution for natural gas. The direct use of biogas is mainly done in developing countries, with small scale family-sized biogas plants. Depending on the frame condition, the utilisation of biogas in combustion plants as a co-fuel or in local diesel generators can be a cost-efficient option when investments costs for a block heat and power plant can be saved. In some countries, like Sweden or Switzerland, processed biogas is utilised as fuel for buses and lorries. In Germany some initiatives have been started, however there are no larger scale applications. Generally all gas-fueled vehicles can be utilised with biogas. Due to the considerable processing requirements of the gas and the resulting investment costs it only can be cost-efficient with plants producing more than 2500 m³ biogas per day [FNR, 2004]. Last but not least, the option of feeding biogas into the gas-network should be mentioned. This could represent an option in the future, however before that, existing technical, legal and economic barriers have to be reduced.

Results of step 8

→ demand for electrical energy [kWh/a],
→ demand for thermal energy [kWh/a]
- hot water [kWh/a]
- steam [kWh/a]

→ demand for fuel (biogas) [kWh/a]

Decision of step 8

if "yes"→	go to step 8
if "no" →	The energy produced cannot be utilised. Other options to utilise, recycle or dispose available substrates should be investigated.

Step 9: Balance of energy production and demand and pre-selection of energy utilisation path

Explanations for step 9

The installation of a renewable energy plant is only a viable option if a concrete demand for the produced energy exists or the energy is taken over e.g. into the electricity net.

- **demand > production**
  If the energy demand is higher than the production of energy, the renewable energy from organic substrates only will contribute to cover a part of the energy demand. Other energy sources need to be utilised in parallel. A back-up energy supply is often required anyway to cover the peak demand or as an emergency reserve.

  Special case: steam demand
  If the full steam demand cannot be covered by the steam production, another supply route for steam has to be chosen, which is capable of covering the full steam demand. Two parallel steam production routes are normally not chosen as they are not cost-efficient. In this case, the combustion plant might be operated to produced electricity only.

- **demand < production**
  If more energy is produced than the actual demand, it will be subject of economic and other considerations to decide about the feasibility of a plant. If there is no concrete demand for the produced energy, or there is no option to feed electricity into a net, a RE plant should not be considered. Other options to treat organic substrate will be more cost-efficient, e.g. composting.

Reflecting the energy demand and the expected energy production, the utilisation paths for the energy produced should be pre-selected for

- electrical energy
- thermal energy
- biogas

specifying the type of utilisation and the quantity of energy.

Results of step 9

for biogas process

→ for electrical energy, thermal energy (hot water), biogas:
- demand is bigger (“>”) than the produced energy or
- demand is smaller (“<”) than the produced energy or
- no demand

→ utilisation of energy production [%]
→ Selection and specification of energy utilised in this path [kWh/a]

for combustion process

→ for each type of combustion plant (Mode 1-4), for electrical energy and thermal energy (hot water and steam):
- demand is bigger (“>”) than the produced energy or
- demand is smaller (“<”) than the produced energy or
- no demand

→ utilisation of energy production [%]
→ Selection and specification of energy utilised in this path [kWh/a]

Step 10: Determination of the substitution ratio of conventional energy by renewable energy

Explanations for step 10

The relevance of the potential new energy supply can be determined by its substitution ratio of conventional energy. For this, a reference level has to be determined, for example:

- the current (conventional) energy supply of a region,
- the potential energy demand of a town in 5 years
- etc..

The calculation is carried out using the following formula (tool 15).

Tool 15

Calculation: Substitution ratio by renewable energy (tool 15)

$$r_{RE} = \frac{100 * RE}{CE}$$

where:

r_{RE}= Substitution ratio of conventional energy by RE [%]
CE= Total quantity of conventional energy to be substituted [kWh/a]
RE= Renewable energy produced by the project [kWh/a]

Results of step 10

→ Specification of reference level
→ Conventional quantity of energy to be substituted [KWh/a]
→ Substitution ratio [%]

Step 11: Calculation of the nominal electrical capacity (rated power) and firing thermal capacity of the energy generation system

Explanations for step 11

Nominal electrical capacity (rated power) of biogas plants

The nominal **electrical capacity** of the block heat and power unit of a biogas plant is a major indicator for the plant size. It is calculated, using the formula below, considering the total produced energy (incl. fuel oil) and the total quantity of operating hours per year (see calculation below, tool 16). As a rule of thumb, it can be assumed that a block heat and power unit of a biogas plant operates approx. 8000 h/a (i.e. a 91% availability of the plant).

For biogas plants which operate without a block heat power plant, other specific indicators are applicable, to specify the plant size. In this case, this step does not apply.

→ The nominal electrical capacity calculated in this step has an influence on the selection of the motor type used in the block heat and power unit. The motor type already had to be pre-selected in step 6. As a consequence, the selection in step 6 has to be checked and adjusted if needed !

→ Please note: this Decision Support System only is applicable for biogas plants larger than 70 kW el.

Nominal electrical and thermal capacity of combustion plants

The nominal **electrical capacity** is a major indicator for the plant size of
- *Electricity plants (mode 1)*
- *Combined heat and power plants (mode 2 and 3).*

The nominal **thermal capacity** is a major indicator for the plant size of
- *heat plants (mode 4).*

The nominal capacity is calculated, using the formulas below, considering the total produced energy and the total quantity of operating hours per year (calculation below, tool 16). As a rule of thumb, it can be assumed that a unit of a biomass combustion plant operates approx. 7500 h/a.

→ Please note: this Decision Support System only is applicable for combustion plants larger than
- *5000 kW el.(Electricity plant, mode 1)*
- *500 kW el. (Combined heat and power plant, mode 2 and 3)*
- *1000 kW th. (Heat plant, mode 4).*

Tool 16

Calculation: Nominal capacity (tool 16)

for biogas plants:

$$P_e = \frac{E * \eta_e}{(100 - f) * h_o}$$

where:

P_e= nominal capacity [kW_{el}]
E= Energy content of the substrate [kWh/a]
η_e= electrical efficiency of block heat and power plant [%]= ca. 35%
f= auxiliary fuel [%] = ca. 10%
h_o = operating hours per year, maximum load conditions [h]
= e.g. 8000 h/a

for biomass combustion plants:
(Power plants, or CHP plants (electricity-controlled and heat-controlled) (Modes 1-3):

$$P_e = \frac{E * \eta_e}{100 * h_o}$$

where:

P_e= nominal capacity [MW_{el}]
E= Energy content of the substrate [MWh/a]
η_e= electrical efficiency [%] of
- Electricity plant = 20 %
- CHP plant (electricity-controlled) = 15 %
- CHP plant (heat-controlled) = 10 %

h_o = operating hours per year, maximum load conditions [h]
= e.g. 7500 h/a

(for heating plants, Mode 4):

$$P_{th} = \frac{E * \eta_{th}}{100 * h_o}$$

where:

P_{th}= thermal capacity [MW_{th}]
E= Energy content of the substrate [MWh/a]
η_{th}= thermal efficiency [%] = 85 %
h_o = operating hours per year, maximum load conditions [h]
= e.g. 7500 h/a

Results of step 11

→ annual operating hours
(Biogas plants: approx. 8000 hours,
Biomass combustion plants: approx. 7500 hours)
→ availability of system [%]
→ nominal electrical capacity [kW_{el}] or nominal thermal capacity [kW_{th}]

Decision of step 11

If nominal electrical capacity larger than 70 kW (Biogas plant) → go to step 12
If nominal electrical capacity 5000 kW el.(Electricity plant, mode 1)
If nominal electrical capacity 500 kW el. (Combined heat and power plant, mode 2 and 3)
If nominal thermal capacity 1000 kW th. (Heat plant, mode 4).

If the nominal electrical or thermal capacity is lower → this Decision Tree is not applicable

Step 12: Determination of main process design specifications and selection of process type

This step is different for the biogas process and combustion process. Please only consider the corresponding paragraphs.

Explanations of step 12 (for biogas process)

Biogas

Selection of main process type

There is a wide range of different biogas process types and plant configurations on the market, which can vary with regard to many criteria (see Table 6.3-17). The process types are optimised in certain respects and thus have different advantages (e.g. low investment costs, high flexibility, high energy yield or small footprint, etc.) and respective disadvantages. Nevertheless most plants types can be applied for many applications so that it is not possible to select a specific plant configuration within the framework of a pre-feasibility study. This can only be done by a planning expert, who will consider all influencing factors as well as benefits and costs, on the basis of concrete offers.

Table 6.3-17: Overview over main process

Criteria	Characteristics
Process temperature	phychrophil operation (up to 20 °C) mesophilic (25-43 °C) thermophilic operation (from 55 °C)
dry substance content of the substrates	wet fermentation dry fermentation wastewater treatment
substrate feeding interval	batch semi continuous
process stages	single stage (all microbial processes in one digester) two stage (with extra hydrolyses stage) multi stage (with extra hydrolyses and acid formation stage)
Mixing principle	mechanical hydraulical pneumatical none
Gas collection	Fixed dome principle Floating dome principle Balloon
Digester designs	standing cylinders, or lying digesters underground or over ground digesters container, boxes, tunnels
Technical configurations	high tech (e.g. with steel digesters, online measurement and control devices, etc.) simpler technology (e.g. with concrete digester)

The only pre-selection which can be done at this stage bases on the water content of the substrates. Depending on the dry substance content of the substrates mixture, dry or wet fermentation can be applied (Table 6.3-18). Pumpable substrates (with a dry substance content of less than 12%) are suitable for wet fermentation. Substrates which are stapable (i.e. with a dry substance content of 20% are higher) are more suitable for dry fermentation.

The original water content of the substrate mixture can be adjusted to achieve the desired concentration for wet fermentation. This is only an option, when the main substrate is liquid, e.g. manure, or process water can be used. Only in exceptional cases fresh water should be used. When only solid biomass or waste are available, wet fermentation is only possible with a high technical effort, high energy costs, high water consumption and resulting cost. For those applications, dry fermentation should be considered. However, in contrast to wet fermentation, the experiences with large scale applications are limited.

For wastewater specific wastewater treatment processes are applied. A further differentiation with regard to treatment principles and technologies will not be done here.

Biogas

Tool 17

The calculation of the average dry substance content of the substrate mixture is shown in the calculation below (Tool 17).

Calculation: Average dry substance content of substrate mixture (tool 17)

$$DS_{substrate.ave} = \frac{(m_{substrateA} * DS_{substrateA}) + (m_{substrateB} * DS_{substrateB}) + ...}{(m_{substrateA} + m_{substrateB} + ...)}$$

where:

$DS_{substrate.ave}$	= Average dry substance content of substrate mixture [%]
$m_{substrate\ A,\ B}$	= Mass of substrate A, substrate B [t/a]
$DS_{substrate\ A,\ B}$	= dry substance DS of substrate A, substrate B [%]

Table 6.3-18: Pre-Selection criteria on biogas process types

Major process types	Dry fermentation	wet fermentation	anaerobic waste water treatment technologies
Substrates characteristics (digester input)	ca. 15 – 65 % DS (substrates are stackable) e.g. organic household waste, maize silage, grass	ca. < 15 % DS (substrates can be pumped) e.g. Co-fermentation of manure with other (drier) substrates	Industrial wastewater
Risk	only few plants in operation → higher risk	widely proven technology	widely proven technology

Digester input characteristics

Often more than one substrate is utilised in biogas plants. As a result, the characteristics of the substrate mixtures, i.e. the average dry substance content of digester input, and the average organic dry substance content, have to be considered when designing the process.

In wet fermentation processes, where the average dry substance content of the substrate mixture is higher than 10%, the dry substance content will be adjusted by addition of water (or recycled process water). As a result, the total mass and volume of the substrate input increases.

The calculation of the following parameters regarding digester input are shown below (tool 18):

- total mass (or volume) of the substrate feed into the digester
  i.e. substrate mixture, or where applicable: substrate mixture inclusive water addition
- average organic dry substance content.

Calculation: Characteristics of digester input (tool 18)

For dry fermentation:

1) Total mass of digester input (=substrate mixture)

$$m_{substrates.total} = m_{substrateA} + m_{substrateB} + m_{substrateC} + ...$$

where:

$m_{substrates.total}$= total mass of substrates= total digester input [t/a]
$m_{substrate\ A,\ B}$= mass of substrates A, substrate B [t/a]

2) Average dry substance content of substrate mixture ($DS_{substrate.ave}$):
(see tool 17)

3) Average organic dry substance (oDS) content of substrate mixture:

$$oDS_{substrate.ave} = \frac{[(m_{substrateA} * oDS_{substrateA}) + (m_{substrateB} * oDS_{substrateB}) + ...]}{(m_{substrateA} + m_{substrateB} + ...)}$$

where:

$oDS_{substrate.ave}$= average oDS of substrate mixture [%, of DS]
$m_{substrate\ A,\ B}$= mass of substrates A, substrate B [t/a]
$oDS_{substrate\ A,\ B}$ = oDS of substrate A, substrate B [%]

For wet fermentation:

1) Total mass of substrate mixture

$$m_{substrates.total} = m_{substrateA} + m_{substrateB} + m_{substrateC} + ...$$

where:

$m_{substrate.total}$= total mass of substrates[t/a]
$m_{substrate\ A,\ B}$= mass of substrates A, substrate B [t/a]

2) Quantity of water (fresh or process water) to be added to adjust DS (e.g. to 10%):

$$m_{water.addition} = \left(\frac{m_{substrates.total} * DS_{substrate.ave}}{DS_{wf}} \right) - m_{substrates.total}$$

where:

$m_{water.addition}$ = water addition to digester [t/a]
$m_{susbtrates\ total}$ = total mass of substrates utilised [t/a]
$DS_{substrate.ave}$ = average DS of substrate mixture [%]
DS_{wf}= Desired DS of wet fermentation process [%]
= recommended: 10 %

3) Total mass of digester input (=substrate mixture plus water):

$$m_{digester} = m_{water.addition} + m_{substrates.total}$$

$m_{digester}$= total input into digester [t/a]
$m_{water.addition}$= water addition to digester [t/a]
$m_{susbtrates\ total}$ = Total mass of substrates utilised [t/a]

4) Average dry substance (DS) content of substrate mixture:
(see above (2):
→ DS_{wf} = Desired DS of wet fermentation process [%]
= recommended: 10 %)

5) Total organic dry substance (oDS) content of substrate mixture:

$$oDS_{substrate.ave} = \frac{[(m_{substrateA} * oDS_{substrateA}) + (m_{substrateB} * oDS_{substrateB}) + ...]}{(m_{substrateA} + m_{substrateB} + ...)}$$

where:

$oDS_{substrate.ave}$ = average oDS of substrate mixture [%, of DS]
$m_{substrate\ A,\ B}$= mass of substrates A, substrate B [t/a]
o $DS_{substrate\ A,\ B}$ = oDS of substrate A, substrate B [%]

Biogas

Tool 18

Characteristics of digester input (tool 18) *(continued)*

For wastewater treatment:

1) Total volume of substrate mixture

$$V_{substrates.total} = V_{substrateA} + V_{substrateB} + V_{substrateC} + \dots$$

where:

$V_{substrate.total}$= total volume of substrates[m³/a]
$V_{substrate\ A,\ B}$= volume of substrates A, substrate B [m³/a]

2) Average COD concentration of substrate mixture:

$$COD_{substrate.ave} = \frac{[(V_{substrateA} * COD_{substrateA}) + (V_{substrateB} * COD_{substrateB}) + \dots]}{(V_{substrateA} + V_{substrateB} + \dots)}$$

where:

$COD_{substrate.ave}$= average COD of substrate mixture [mg/l]
$V_{substrate\ A,\ B}$= volume of substrates A, substrate B [l]
$COD_{substrate\ A,\ B}$ = COD of substrate A, substrate B [mg/l]

(Hydraulic) retention time

The retention time (for wet fermentation and wastewater treatment: hydraulic retention time hrt) is a major process design parameter for biogas plants. It represents the average time the substrate stays in the digester. The retention time depends on various factors, like degradability of the substrate, process temperature and the aimed degree of degradation. The retention time should not be chosen to short, otherwise relevant quantities of methane will be lost, leading to reduced energy generation and greenhouse gas emissions. Also, retention times must be long enough, so that bacteria are not washed out more quickly than they can be reproduced in the digester. Due to the slow growth of the involved bacteria, retention times between 15 - 60 days are required for plants operating in the mesophilic temperature range of 30-45 °C. The retention time can only be reduced by the immobilisation or recirculation of bacteria, which is applied with certain types of processes. It must be kept in mind, that long retention times lead to large reactor volumes and higher investment costs. Table 6.3-19 suggests average retention times which can be used for a first rough calculation for the biogas reactor capacity.

Table 6.3-19: Retention times for biogas plants

	typical (hydraulic) retention times	**Literature**
wet fermentation:		
- 30-35°C (mesophile process)	30-50 days	[Schulz, 2001]
- chicken manure	30 days	[Schulz, 2001]
- pig and cattle manure	40 days	[Schulz, 2001]
- dung (manure with straw)	50 days	[Schulz, 2001]
- 45-55°C (thermophile process)	15-25 days	[Schulz, 2001]
dry fermentation:	15-50 days (manufacturers data)	[Kraft, 2002]
anaerobic wastewater treatment		
- Completely mixed	20 days	
- UASB, high rate	4-12 hours	[Metcalf; 2001]

Biogas

Calculation of the digester capacity

The digester capacity gives an indication of the size of the plant (see formula below, tool 19). The effective digester capacity depends on the hydraulic retention time and the daily input of substrates into the digester. The total digester capacity is calculated by adding a certain freeboard allowance, e.g. 10%.

For substrates like biomass, waste and manure (which quantities are expressed as mass, in “t”) the bulk density of the substrate has to be considered for calculating the digester capacity. Please note: the bulk density of the *substrate mixture* has to be considered.

Tool 19

Calculation: Capacity of digester (tool 19)

1) Calculation of the effective digester capacity

for wet fermentation:

$$V_{d.effective} = \frac{m_{digester} * rt * 1000}{\delta * 365[\frac{d}{a}]}$$

where:

$V_{d\ effective}$= effective capacity of the digester [m³]
$m_{digester}$= total input into digester [t/a] = **see tool 18**
rt= hydraulic retention time of substrates in the digester [d]
δ = bulk density of substrate mixture [kg/m³] = **see tool 3**

for dry fermentation:

$$V_{d.effective} = \frac{m_{substrates.total} * rt * 1000}{\delta * 365[\frac{d}{a}]}$$

where:

$V_{d\ effective}$= effective capacity of the digester [m³]
$m_{substrates.total}$ = Total mass of substrates mixture [t/a] **see tool 18**
rt= retention time of substrates in the digester [d] = **see above**
δ = bulk density [kg/m³] = **see tool 3**

for wastewater:

$$V_{d.effective} = \frac{V * rt}{365[\frac{d}{a}]}$$

where:

$V_{d\ effective}$= effective capacity of the digester [m³]
V= volume of wastewater per year [m³/a]
rt= retention time of substrates in the digester [d]

2) Calculation of the total digester capacity, incl. freeboard

$$V_{d.total} = \frac{V_{d.effective} * 100}{100 - V_f}$$

where:

$V_{d\ total}$= total capacity of the digester [m³]
$V_{d\ effective}$= effective capacity of the digester [m³]
V_f= free volume in the digester [%] = e.g. 10%

Biogas

Organic Loading Rate OLR

The organic loading is another very important design parameter. It represents, how much organic material (kg organic dry substance) can be fed into the digester per day. The OLR mainly depends on the process temperature, the organic dry substance content and the hydraulic retention time (The longer the retention time, the lower the organic loading rates). There is a limit for organic loading rates of biogas plants because excessive input of organic material cannot be degraded by the methane producing bacteria and will cause process problems. Typical values for OLR for wet and dry fermentation are summarised in Table 6.3-20. The organic loading rate can be calculated by using the formula below. After having selected a hydraulic retention time and calculated the reactor volume, it is useful to check the resulting OLR.

Table 6.3-20: Typical organic loading rates (tool 20)

Process type	Unit	Organic loading rate
Wet fermentation		
simple plants	kg oDS/m³*d	0,5-1,5
plants with optimised process conditions	kg oDS/m³*d	2-4
Maximum	kg oDS/m³*d	5
Dry fermentation	kg oDS/m³*d	9-12
Wastewater processes	kg COD/m³*d	1-5

Tool 20

Calculation: Organic loading rate OLR (tool 20)

For wet and dry fermentation:

$$OLR = \frac{m_{substrates.total} * oDS_{substrate.ave} * DS_{substrate.ave}}{365 * V_{d.effective} * 100 * 100}$$

where:

OLR = organic loading rate [t/(m³*d)]
$m_{susbtrates\ total}$ = Total mass of substrates utilised [t/a] = **see tool 18**
[% of DS] = **see tool 18**
$DS_{substrates.ave}$ = average DS of substrate mixture [%]= **see tool 18**
$oDS_{substrates.ave}$= average oDS of substrate mixture [% of DS]
= **see tool 18**
$V_{d.effective}$= effective digester capacity [m³]

For wastewater:

$$OLR = \frac{V_{substrates.total} * COD_{substrate.ave}}{365 * V_{d.effective} * 1000}$$

where:

OLR = organic loading rate [kg/(m³*d)
$V_{substrate.total}$ = total volume of substrates [m³/a]
$V_{d.effective}$= effective digester capacity [m³]
$COD_{substrate.ave}$= average COD of substrate mixture [mg/l]

Biogas

Tool 21

Auxiliary fuel oil consumption

When utilising a pilot injection gas motor in the block heat and power unit of the biogas plant, approximately 10% of the total energy input should represent fuel oil (diesel), (see step 6). The volume of fuel oil needed is calculated by using the formula below (tool 21).

Calculation: Fuel oil consumption (tool 21)

$$V_f = \frac{E * \eta_e * 100 * 3600[\frac{kJ}{kWh}]}{(100 - f) * H_{l\,f} * \delta_f}$$

where:

V_f= Volume of fuel oil [l/a]
E= Energy content of the substrate [kWh/a]
η_e= electrical efficiency of block heat and power plant [%]= ca. 35%
f= auxiliary fuel [%] = ca. 10%
H_l=lower heat value of fuel oil (e.g. diesel) [kJ/kg]
= 42.800 kJ/kg
δ_f = bulk density of diesel [kg/l] = 0,84 kg/l

Land requirements

The minimum of required space for small biogas plants is 2.000 m^2. The required space might be much larger, depending on the type of the plant, the needed storage capacity of the substrate and the fermented material. For a 500 kW biogas plant the average needed area can amount to 5.000-10.000 m^2.

Sanitation requirements of substrates

Organic substrates can contain bacteria, funghi, viruses and parasites of different types and quantities which can be pathogen for humans, animals or plants. To reduce hygiene risks with the utilisation of the digested end product (as fertiliser) the material has to be sanitised. National regulations have to be considered here.

It can be assumed that also at a mesophilic operation a considerably reduction of pathogenic germs and shooting sprouts can be achieved. In case of substrates which are contaminated by e.g. salmonellae (e.g. poultry manure), it can be assumed that a sufficient sanitation cannot be obtained. Not only the presence of pathogenic germs, but also their concentration is decisive in the risk assessment. Therefore the decision concerning necessary sanitation measures should be made in coorporation with a veterinary.

For orientation: In Germany approximately 2000 biogas plants are in operation. Recently the Hochschule Bremen made a survey of all district veterinaries (“Kreisveterinäre”; responsible authority in Germany), which has shown that there has not been one single event of phyto- and hygienic damage of fermented substrate from biogas plants in the participating districts (approx. 50 %).

In Germany, the Biowaste Regulation *(Bioabfallverordnung, 1998)* regulates the sanitation requirements for all organic substrates. The substrates must be digested either at a temperature level of 55 °C (at present a minimum temperature of 50°C is discussed) for a minimum of 20 days (thermophilic operation) or sanitised at 70°C for 1 hour before or after digestion. However the regulation does not apply for the substrates manure and dung, and for the own utilisation of the digested products (e.g. on own farmland).

Biogas

Results of step 12 (for biogas process)

Pre-selection of process type

→ Average dry substance content of the substrate mixture ($DS_{substrate.ave}$) [%]
→ Pre-selection of process type:
"dry fermentation process", or
"wet fermentation process", or
"anaerobic wastewater treatment"

Characteristics of digester input

→ total mass of substrates ($m_{substrate.total}$) [t/a]
→ average organic dry substance content of substrate mixture ($oDS_{substrate.ave}$) [% of DS]
→ Quantity of water added to adjust DS ($m_{water.addition}$) [t/a]
(if applicable, for wet fermentation)
→ total mass of digester input ($m_{digester}$) [t/a]
(if applicable, for wet fermentation)

for wastewater treatment:
→ total volume of substrate mixture ($V_{substrate.total}$) [m³/a]
→ COD of the substrate (wastewater) mixture ($COD_{substrate.ave}$) [mg/l]

(Hydraulic) retention time

→ (hydraulic) retention time of substrates in the digester [d]

Digester capacity

→ δ= bulk density of the substrate mixture [kg/m³] (if applicable)
→ effective capacity of the digester ($V_{d\ effective}$) [m³]
→ total capacity of the digester ($V_{d\ total}$) [m³]

Organic loading rate
→ Organic loading rate (OLR) [kg/(m³*d)]

Volume of fuel oil
→ Volume of diesel/light fuel oil [l/a]

Land requirements
→ land required [m²]

Sanitation requirements for substrates
→ "Yes" or "no"

Combustion

Explanations for step 12 (for combustion process)

1. Estimation of the storage capacity

A temporary storage of biomass for energetic utilisation is necessary where a continuous supply of biomass fuels cannot be guaranteed. The type of storage depends on the moisture content of the substrates, the fuel requirements and the transportation distances.

Flat bunker and silos are most commonly used for temporary storage of dry biomass fuels. The storage of solid fuels with moisture content above 15-20 % (i.e. 80-85 % DS) is problematic:

- Self-heating of the stored matter with a risk of self ignition
- Degradation of the carbon
- Danger of mildew formation and ill-smelling emissions.

The calculation of the storage capacity bases on the determination of the operational capacity of the plant (= quantity of the substrate fed to the plant per hour) and the necessary storage time of the fuel (See calculation below, tool 22). The storage time of the fuel has to be long enough to ensure a continuous run of the plant, reflecting the frequency of guaranteed fuel deliveries.

In addition to the storage capacity, the storage area should be determined. The storage height has to reflect the type of substrate and the storage conditions.
For example: Wood chips can be stored up to 7m. However without aeration, coarse fresh wood chips should not be stored to more than 2 m.

Tool 22

Calculation: Storage capacity and area (tool 22)

1) Storage capacity:

$$V_{storage} = \frac{\dot{m} * 24 * st * 1000}{\delta}$$

where:

$V_{storage}$ = capacity of the storage [m³]
m = operational substrate capacity per hour [Mg/h]
st= storage time of substrates [d]
δ = bulk density of substrate mixture [kg/m^3] = **see tool 3**

2) Storage area:

$$A_{storage} = \frac{V_{storage}}{h}$$

where:

$A_{storage}$ = storage area [m^2]
$V_{storage}$ = capacity of the storage [m³]
h = storage height [m]

Selection of process type (combustion technology)

There are different biomass combustion systems available for mid- and large-scale plants. Each system needs to be properly designed for a specific fuel type in order to guarantee adequate combustion quality and low emissions. The design of a combustion plant mainly is determined by factors like characteristics of the fuel (moisture, grain size, ash content etc.), plant capacity, environmental legislation, etc.. Plant design only can be done by a planning expert who will consider all influencing factors as well as benefits and costs. In this context it is only possible to (pre-select) the combustion types.

Three main combustion principles with automatic fuel-feeding systems can be distinguished:

a) fixed-bed combustion (underfeed stoker or grate furnace)
b) fluidised-bed combustion (bubbling or circulating)
c) dust combustion.

Combustion

The basic principles of these technologies are shown in Figure 6.3-6. There are many variations of these technologies, but they will not be further described here. The following table (Table 6.3-21) summarises the main features of those systems, which allows a pre-selection according the quantity and quality of the substrates available.

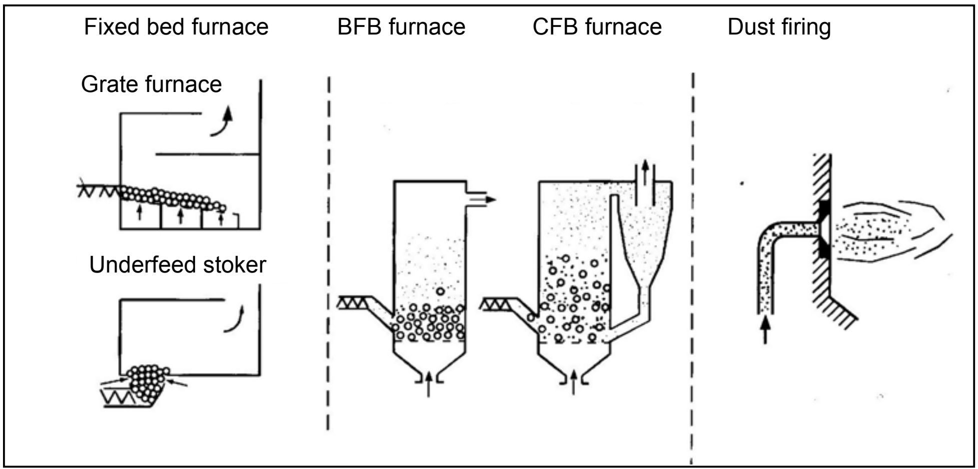

Figure 6.3-6: Principle combustion technologies for biomass

Table 6.3-21: Selection criteria for the main combustion technologies [IE, 2003]

Type	Capacity range	Fuel characteristics	Moisture content [%]
a) Fixed-bed combustion			
Underfeed stoker	10 kW – 2,5 MW	Wood chips (ash content ≤ 1%), wood pellets	5 – 50
Grate furnace	150 kW – 15 MW	All woody fuels (ash content ≤ 50%)	5 – 60
b) Fluidised bed			
Bubbling fluidised bed	5 MW – 15 MW	Fuel size ≤ 10 mm in diameter	5 – 60
Circulating fluidised bed	15 MW – 100 MW	Fuel size ≤ 10 mm in diameter	5 – 60
c) Dust furnace	2 MW – 10 MW	Fuel size ≤ 5 mm in diameter	Mainly < 20

Combustion

Results for step 12 (Combustion process)

Estimation of the storage capacity
→ Storage time of substrates [d]
→ Storage capacity [m^3]

Estimation of the storage area
→ h = storage height [m]
→ δ = bulk density of substrate mixture [kg/m3] = see tool 3
→ Storage area [m^2]

Selection of the combustion technology
→ Selection of combustion technology
- fixed-bed combustion (underfeed stoker or grate furnace)
- fluidised-bed combustion (bubbling or circulating)
- dust combustion

Step 13: Determination of the quantity of residues generated

This step is different for the biogas process and combustion process. Please only consider the corresponding paragraphs.

Explanations for step 13 (for biogas process)

Biogas

The quantity of residues generated has to be estimated, to get an indication about the need for utilisation or disposal capacities as well as the respective revenues or costs.

The solid residue of a biogas process is called “slurry” or “digested sludge” and can be used as fertiliser. The digested sludge has been subject to anaerobic degradation in the biogas reactor. The initial input substrate is reduced by 24-80 % of the organic dry substance content, because the majority of the carbon compounds is degraded to methane and carbon dioxide [FNR, 2004]. The reduction of material depends on the degree of degradation, which again depends on the composition of the initial substrate and the process characteristics, like temperature, retention time and the organic loading in the reactor. For a course evaluation of the quantity of substrates, a **reduction of 50% of the organic dry substance** content can be assumed. The calculation of the quantity of digested sludge is shown below (tool 23).

The output of the digester is often used directly for fertilising. If the fertiliser cannot be sold or distributed but must be stored, drying (e, g. solar, thermal, filter press, centrifuge) might be the only viable option, although this means addition cost and effort. Also agricultural or logistical requirements might cause the need for dried fertiliser. However these cases are not considered here.

Tool 23

Calculation: Quantity of digested sludge (tool 23)

for wet fermentation

Quantity of residues from biogas process

$$m_{residue} = m_{substrates.total} + m_{water.addition} - \left(\frac{m_{substrates.total} * oDS_{substrate.ave} * d}{100} \right)$$

where:

$m_{residue}$=mass of residues from biogas process [t/a]
$m_{substrates.total}$ = Total mass of substrates utilised [t/a] **(see tool 18)**
$m_{water.addition}$ = Water added to substrate for wet fermentation [t/a] **(see tool 18)**
$oDS_{substrate.ave}$ = organic dry substance content of substrate mixture [%] **(see tool 18)**
d= degradation rate [%] = assumed: 50%

for dry fermentation

Quantity of residues from biogas process

$$m_{residue} = m_{substrates.total} - \left(\frac{m_{substrates.total} * oDS_{susbtrate.ave} * d}{100} \right)$$

where:

$m_{residue}$=mass of residues from biogas process [t/a]
$m_{susbtrates\ total}$ = Total mass of substrates utilised [t/a] **(see tool 18)**
$oDS_{substrate.ave}$ = organic dry substance content of substrate mixture [%] **(see tool 18)**
d= degradation rate [%] = assumed: 50%

Results of step 13 (for biogas process)

→ Quantity of digested sludge generated [t/a]

Combustion

Explanations of step 13 (for biomass combustion)

The solid end product of the combustion process is ash. The ash quantity has to be estimated, to get an indication about the need for utilisation or disposal capacities as well as the respective revenues or costs. The ash content of biomass fuels mainly varies between 0.5 % – 12 % (Table 6.3-22).

Table 6.3-22: Ash content of major biomass fuels [Sjaak, 2003]

Combustion substrates	Ash content [% of DS]	DS [%]
Bark	5.0-8.0	10
Wood chips with bark	1.0-2.5	15
Wood chips without bark	0.8-1.4	15
Waste wood	3.0-12.0	20
Sawdust	0.5-1.1	5
Straw and cereals	4.0-12.0	3-5
Mischantus	1.7-7.0	3-5
Household waste	25	25-45

In biomass combustion plants three ash types can be distinguished (see Figure 6.3-7):

- **Bottom ash**
  Bottom ash is produced on the grate, often mixed with impurities contained in the biomass fuel, like sand, stone and earth. These impurities can cause the formation of slag and sintered ash particles.

- **Cyclone fly ash**:
  Cyclone fly ash consists of fine, mainly inorganic ash particles. It is carried with the flue gas and precipitates in the secondary combustion zone, in the multi-cyclones, which is situated behind the combustion unit.

- **Filter fly ash:**
  Filter fly ash is a secondary, finer fly ash which precipitates in electrostatic filters or fibrous filters, or as condensation sludge in flue gas condensation units. In plants without this efficient dust precipitation technology, this fraction is emitted with the flue gas.

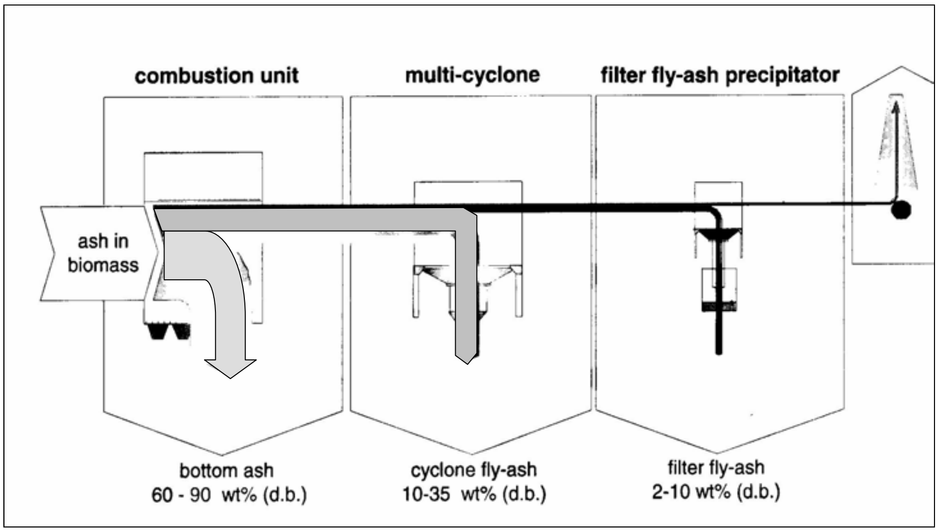

Figure 6.3-7: Various ash fractions produced in a biomass combustion plant (data are valid for fixed bed combustion units)

In **fixed bed combustion units** the total ash consists of 60-90 % of bottom ash, 10-35 % of cyclone fly-ash and 2-10% of filter fly-ash (Figure 6.3-7). In fluidised bed combustion units fly-ash is quantitatively dominant. Although the quantity of total ash and of the different ash types depends on the type of combustion process, it is suggested to use the above mentioned values for calculation, for simplification.

Combustion

Tool 24

Calculation: Quantity of ash generated (tool 24)

1) Calculation of quantity of total ash:

$$m_{ash} = \frac{m_{substrates.total} * f_{ash}}{100}$$

where:

m_{ash} = mass of total ash generated [t/a]
$m_{substrates.total}$= total mass of substrates [t/a]
f_{ash}= fraction of ash [% of DS]

2) Calculation of quantity of ash types (bottom ash, cyclone fly-ash, filter fly-ash)

$$m_{bottom.ash} = \frac{m_{ash} * f_{bottom.ash}}{100}$$

where:

$m_{bottom.ash}$ = mass of ash type (e.g. bottom ash) generated [t/a]
m_{ash} = total mass of ash [t/a]
$f_{bottom.ash}$ =fraction of ash type (e.g. bottom ash) [% of total ash content]

Results of step 13 (for biomass combustion)

→ ash content of substrate [%]
→ total mass of ash generated [t/a]
→ fraction of ash types
- bottom ash [%, of total ash]
- cyclone fly-ash [%, of total ash]
- filter fly-ash [%, of total ash]

→ mass of ash types
- bottom ash [t/a]
- cyclone fly-ash [t/a]
- filter fly-ash [t/a]

Step14: Can the produced quantity of residues be utilised?

This step is different for the biogas process and combustion process. Please only consider the corresponding paragraphs.

Explanations for step 14 (for biogas process)

Biogas

In a pre-feasibility study it is useful to identify the potential utilisation paths for residues of the renewable energy plant. Ideally, the digested sludge can be utilised as valuable organic fertiliser in agriculture, gardening, etc.. If the fertiliser can be sold, an additional revenue is generated for the biogas plant. If this is not possible, the digested sludge has to be disposed, which can generate additional costs. Figure 6.3-8 summarises the possible utilisation and disposal paths.

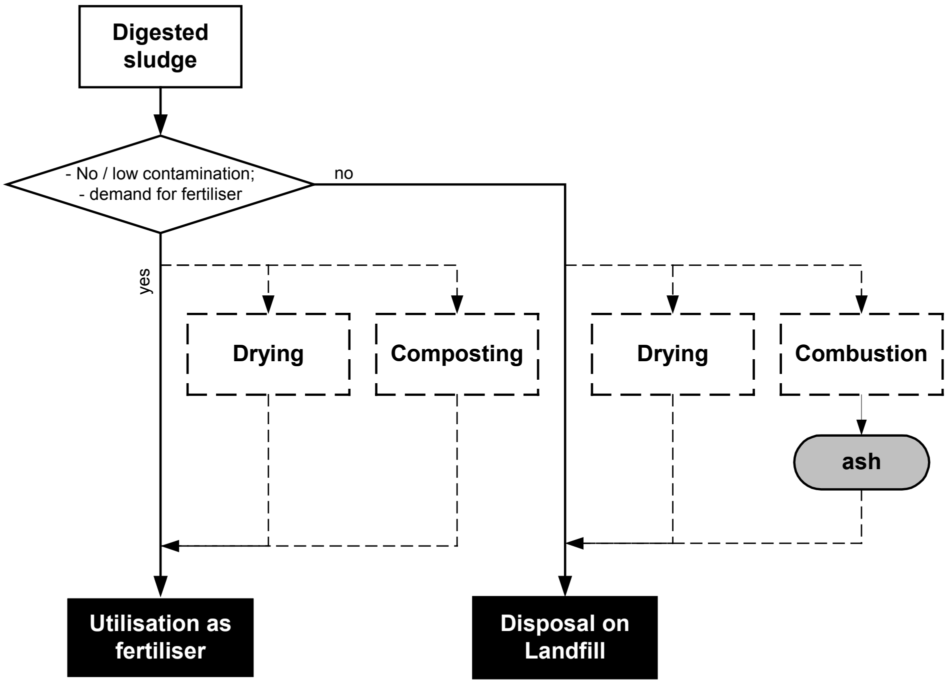

Figure 6.3-8: The possible utilisation and disposal paths of digested sludge

There are a wide range of benefits to use digested sludge as fertiliser. In contrast to mineral fertiliser, the secondary raw material fertiliser produced in biogas plants can be cheaper and do not has to be imported. Due to the previous anaerobic decomposition and breakdown of parts of its organic content, digested sludge provides fast-acting nutrients that easily enter into the soil solution, thus becoming immediately available to plants and soil organism. The sludge has soil improving characteristics, it increases the soils permeability and prevents nitrogen wash-out and erosion. Overall the utilisation of sludge represents an environmentally sound option, substituting mineral fertiliser and recycling nutrients into the soil. In contrast to raw substrates, e.g. manure, digested sludge causes less smell, has less aggressive organic acids and contains nutrients which are better available for plants.

If digested sludge is applied in agriculture, it should not contain relevant concentrations of contaminations, e.g. heavy metals. The quantity of contaminations depends on the input substrates. Due to degradation processes of organic material, contaminants which do not degrade accumulate in the end-product. The evaluation of the relevance of existing contaminations must be done with regard to existing national threshold values, if they exist. For orientation, the German threshold values from the National Association of Quality Assurance Compost (*Bundesgütegemeinschaft Kompost e.V.)*, are presented in Table 6.3-23, which define quality requirements for secondary raw material fertiliser. Also the fertiliser should be free of other disturbing matter, e.g. plastic foil, metal, etc.. Most substrates are not likely to contain relevant concentrations of harmful substances. But fertiliser derived from the

- organic fraction of household waste (not separated at source),
- certain types of industrial wastes or
- industrial wastewater

can contain heavy metals or other contaminants. It has to be clarified in the further project planning (e.g. by chemical analysis) whether the digested sludge is suitable to be applied as fertiliser.

Biogas

Table 6.3-23: German threshold values for digested sludge from wet fermentation (*Bundesgüte-gemeinschaft Kompost e.V.)*

Heavy metals	threshold values [mg/kg DS]
lead	150
chromium	100
nickel	50
zinc	400
cadmium	1,5
copper	100
mercury	1,0

The output of the digester is often used directly for fertilising. This is the most cost-efficient strategy. If the fertiliser cannot be sold or distributed but must be stored, drying (e.g. solar, thermal, centrifuge) might be the only viable option, although this means addition cost. Also agricultural or logistical requirements might cause the need for dried fertiliser. Sometimes, digested sludge is further treated by a composting process, to further degrade the digested sludge. Drying or composting of the digested sludge is not further considered here.

It is an important task, to investigate the actual local/ regional market for the produced fertiliser:

- is the quality of the digested sludge suitable for fertiliser application?
- is there a market for the digested sludge? What quantity can be sold/ distributed?
- how much revenue can be gained ?

Results for step 14 (for biogas process)

→ utilisation of fertiliser “possible” (or “disposal required”)
→ Specification of utilisation path
→ Quantity of residues that can be utilised [t/a]

Explanations for step 14 (for combustion process)

Ashes from biomass combustion can be utilised or disposed:

- Utilisation
  - as fertiliser in agriculture and forestry
  - as secondary raw material for concrete and chemicals, in industrial processes)
  - as secondary raw material for road construction (slagged bottom ash is suitable)
- Disposal
  - on landfills.

Mostly, ashes are utilised as fertiliser, or are disposed on landfills. The industrial utilisation of ash for concrete or chemical production is only applicable with large scale combustion plants.

The possible utilisation or disposal path for ash is mainly influenced by its composition with regard to nutrients and contaminants. Figure 6.3-9 and Figure 6.3-10 show the nutrients and heavy metal concentration in bottom ash, cyclone fly-ash and filter fly-ash.

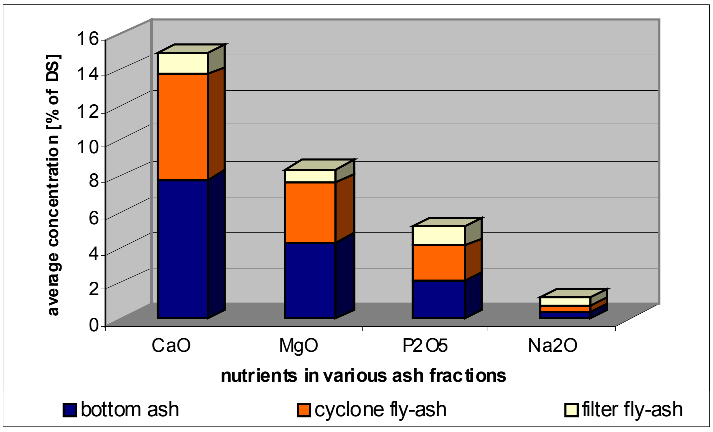

Figure 6.3-9: Average concentrations of nutrients in various ash fractions of straw incinerators [IE, 2003]

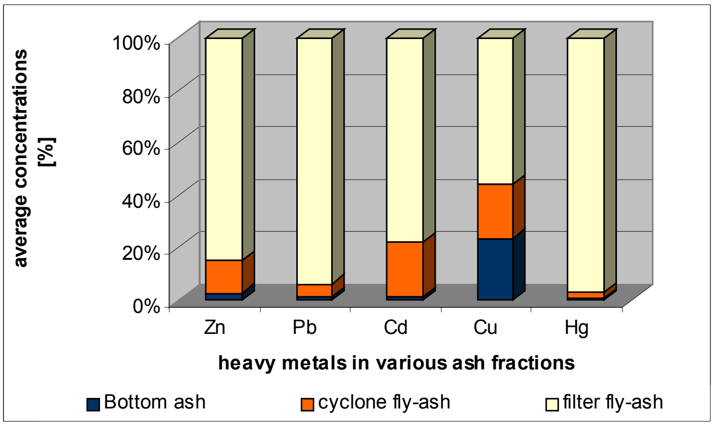

Figure 6.3-10: Average concentrations of heavy metals in various ash fractions of bark, wood chips and sawdust incinerators [Sjaak, 2003]

For the utilization or disposal of biomass ashes the following principles and conclusions should be considered:

- approximately 80-95 % of the nutrients from the biomass are accumulated in the bottom and cyclone ash, thus those fractions are suitable for fertiliser application
- The filter fly ash should be disposed, due to the high concentration of heavy metals.
- Generally the concentration of heavy metal is increasing with a decreasing particle size of the ash fraction.

Combustion

- High cadmium (Cd) and zinc (Zn) concentrations cause most problems in ashes of biomass combustion plants.
- Ashes from waste wood and household waste should be disposed on landfills due to high level of contaminations.

Results for step 14 (for biogas process)

→ utilisation of fertiliser “possible” (or “disposal required”)
→ Specification of utilisation path
→ Quantity of residues that can be utilised [t/a]

Step 15: Identification of the disposal options for residues

This step is different for the biogas process and combustion process. Please only consider the corresponding paragraphs.

Biogas

Explanations for step 15 (for biogas process)

Digested sludge should only be disposed on landfills, if utilisation as fertiliser in agriculture is not possible, e.g. due to high contaminations or lack of a market. Even with high environmental safety standards, like impermeable barriers and methane collection, landfills represent a long-term environmental hazard with regard to ground water contamination, and uncontrolled release of greenhouse gas methane when waste is disposed, which is degradable and wet.

Digested sludge can be disposed directly on landfills or after pre-treatment (drying of combustion). However national regulation must be considered. For example: In Germany it is not allowed to dispose material with an organic content more than 3% (5%) on sanitary landfills, so that combustion is required beforehand.

Disposal will imply costs i.e. transport costs and gate fee. Pre-treatment will imply additional costs.

Results for step 15 (for biogas process)

→ quantity of ash for disposal [t/a]
→ Specification of disposal option

Combustion

Explanations for step 15 (for combustion process)

Ash from biomass combustion should only be disposed on landfills, if a utilisation is not possible due to high contaminations or lack of a market. Filter fly ash and ashes from waste wood and household waste should always be disposed, due to the high concentration of heavy metals. Disposal will imply costs i.e. transport costs and gate fee. Pre-treatment will imply additional costs.

Results for step 15 (for combustion process)

→ quantity of ash for disposal [t/a]
→ Specification of disposal option

Step 16: Identification of policy, targets and strategies related to renewable energy

Explanations for step 16

Why is it useful to identify general policy and strategies?

Renewable energy production is slightly different from other kinds of projects:

- It is part of the infrastructure development, so that a highly regulated sector is involved.
- Often, new and not very well known technologies are applied, so that the communication of objectives, benefits and technical options of the project, to other business partners, administration, other involved groups and professionals can be difficult.
- Renewable energy projects often need favourable framework conditions in order to be economically viable, e.g. subsidised feed in tariffs, investment grants, etc..

For those reasons, it is worth looking for support, for smoothing the planning process, finding financial support and easing communication. It is vital to identify every possible option relevant for the specific project and country, considering regional, national or international support.

<u>Identification of governmental plans and targets related to renewable energy implementation</u>

Official plans and targets related to renewable energy help to convince local administration and give good arguments to effected parties and the public. They can provide the basis for being able to acquire financial support from national and international sources and to clarify the legal framework. The following points could be of particular interest:

- General plans about development of the energy sector
- Special plans about development of renewable energy
- Legal framework for renewable energy and plans to develop it
- Position of the country to goals of the international community, e.g.
- Kyoto-protocol (Framework Convention on Climate Change UNFCCC, with the aim to reduce greenhouse gas emissions
- Agenda 21 (A comprehensive plan of action to be taken globally, nationally and locally by organizations of the United Nations System, Governments, and Major Groups in every area in which human impacts on the environment).

<u>Identification of fiscal policy and support mechanism</u>

Some countries already have existing programs which provide financial support on some form to renewable energy projects.

Results for step 16

→ Plans, targets and national policy related to renewable energy
→ Fiscal policy and other support mechanisms which are applicable to the project

Step 17: Identification of relevant laws, regulation which support RE

Explanations for step 17

Based on step 16 all relevant laws and regulations which support the implementation of Renewable Energy projects and the operation of respective plants should be identified. They will have impact on, e.g.

- technical design
- project economics
- form of contracts
- involvement of public institutions, etc.

Results for step 17

→ List of relevant laws and regulation, which support renewable energy projects

Step 18: Is there a strong support of the project's main stakeholders?

Explanations for step 18

Stakeholders are persons, groups or institutions with an interest (or "stake") into the project, i.e. anyone who is directly or indirectly involved. The following list will gives an overview over possible main stakeholders:

- *Biomass suppliers*
  If biomass is utilised from external sources, biomass suppliers e.g. farmers, industrial companies, are crucial for the success of a renewable energy plant. If possible agreements regarding the quality and quantity of substrates should be done, to guarantee the long-term supply of feedstock for the plant.

- *Public power companies*
  They will be involved if the electricity generated will be fed into the grid network.

- *Private power consumer*
  If applicable, the energy can be supplied to private companies.

- *Local government and administration*
  The project needs permits and licences from local authorities.

- *Residents in surrounding*
  Residents are indirectly affected by the building and operation of plants utilising biomass, incl. increased traffic through biomass transport. Issues of concern may be local environmental pollution (emissions, noise, bad smell) as well as adverse health effects.

- *Employees*
  Future employers will directly benefit of the renewable energy facility. The availability of sufficiently skilled worker is vital for the operation of the plant. Employment and working conditions will influence the support and motivation of employees.

- *End consumer*

End consumer have an interest in cheap and reliable energy supply. Also environmental friendly energy production might be of interest.

In addition to those mentioned above, there a many more stakeholders which play a more or less important role. Their careful integration and involvement will be useful and beneficiary:

- Financial Institutions
- Insurance companies
- Construction and engineering companies
- Central government and state level government, including, e.g.
- the Ministry responsible for rural development,
- the Ministry responsible for agriculture,
- the Ministry responsible for environment and forests,
- the Ministry responsible for energy or electricity,
- the Ministry responsible for revenue and financing,
- the Ministry responsible for international affairs
  (if the project involves international financing or technical cooperation);
- Nongovernmental organisations and bilateral and multilateral organisations for example:
- NGOs dealing with environment and development, and
- Nongovernmental labour organisations, farmers organisations, and trade organisations
- United Nations, World Bank, national aid agencies
- etc..

It is necessary to identify any persons, groups or institutions which will be affected by the project, either positively or negatively. Also indirect impacts and long term effects have to be considered. The stakeholders attitude towards the project and their potential influence has to be investigated.

Results for step 18

→ List of stakeholders
→ Attitude, support and influence of these stakeholders on the project

Decision

if "yes" (all relevant stakeholders support the project)	→ go to step 20
if "no" (there are relevant stakeholders who do not support the project	→ Look at step 19 if it is possible to get the support of these stakeholders

Step 19: Is it possible to get the support of the critical stakeholders?

Explanations for step 19

For stakeholders which have a high influence on the project but are likely to offer low or now support it is necessary to find strategies to ensure their support. The following paragraphs give some examples:

Provision of Information
Most problems arise because people are not informed properly about projects, its background and effects. The lack of information may result in project rejection and unspecific fears.

Early involvement
It is important to involve stakeholders from at an early in the planning stage, to use the opportunity to influence the formation of their opinion towards the project.

Consideration of adjustments of the project
If there are no possibilities to overcome problems with stakeholders, the project probably has to be adjusted, e.g. with regard to locations, technologies, etc.

Financial compensation
Financial compensation can represent an option to get support from stakeholders which are affected negatively by the project.

Proper contract design
Contracts with business partners must be beneficial for all to ensure long term fulfilment.

Support from accepted authorities
Stakeholders might be positively influenced if support is granted from accepted persons or institutions, like:

- religious leaders
- elders of the community, leaders of influential groups
- teachers or schools
- health authorities like hospitals or medicos
- etc..

Involvement of shareholders
If applicable, the company form of a renewable energy producing company should be carefully selected. It can be very useful, if major stakeholders, e.g. biomass suppliers, are co-owners, to ensure the long-term support.

Results for step 19

→ List of critical stakeholders
→ Measures to get support from this stakeholders
→ Estimation if it is possible that the measures will reach their goals

Decision

if "yes" (support can be achieved)	→ go to step 20
if "no" (support can't be achieved)	→ It can be expected that the project will not have success because influential groups will thwart it. Probably some redesign in basic business structure (e.g. ownership, business partners, involvement of public institutions) can help.

Step 20: Determination of the overall socio-economic impact of the project

Explanations for step 20

Every economic activity causes a variety of different direct and indirect impacts. Among others, they have an effect on social aspects, e.g. increase or decrease of income. The determination of the social impact of a project provides "non or indirect financial" arguments which are important to convince stakeholders like residents and the local community and administration about the project's benefit. Furthermore, positive socio-economic effects are a vital factor considered by foreign organisations or local organisations/government for granting funding.

Examples for direct local effects on employment, health conditions and poverty alleviation:

- Job creation:
  Number of direct created jobs
  Number of indirect created jobs, e.g. through economic effects like structural changes in agriculture, new business opportunities
- Income generation: Amount of direct and indirect created income
- Electricity supply: Effects of improved electricity supply
- Health: Effects of better sanitation through better water and fertiliser quality
- Effects in agriculture: Use of better fertiliser
- etc..

An useful tool (Table 6.3-24) to estimate determine the overall influence of a project on the regional socio-economic development has been developed by Kartha and Larson (2000):

Table 6.3-24: Overall influence on the regional socio-economic development (Kartha, Larson, 2000)

Category	Impact	Quantitative indicators, based on assessment of:
Basic needs	Improved access to basic services.	Number of families with access to energy services (cooking fuel, pumped water, electric lighting, milling, etc.), quality, reliability, accessibility, cost.
Income generating opportunities	Creation or displacement of jobs, livelihoods.	Volume of industry and small-scale enterprise promoted, jobs per $ invested, jobs per ha used, salaries, seasonality, accessibility to local workers, local expenditure of revenue, development of markets for local products.
Gender	Impacts on labour, power, access to resources.	Relative access to outputs of bioenergy project. Decision-making responsibility both within and outside of bioenergy project. Changes to former division of labour. Access to resources relating to bioenergy activities.
Land use competition and land tenure	Changing patterns of land ownership. Altered access to common land resources. Emerging local and macroeconomic competition with other land uses.	Recent ownership patterns and trends (e.g., consolidation or distribution of landholdings, privatization, common enclosures, transferral of land rights/tree rights). Price effects on alternate products. Simultaneous land uses (e.g. multipurpose co-production of other outputs such as traditional biofuel, fodder, food, artisanal products, etc.)

Results for step 20

→ Estimate the local economic and social impact in different categories by use of several indicators

Step 21: Determination of the local/regional environmental impacts caused by the project

Explanations for step 21

In general, environmental impacts can be subdivided in terms of their geographic extend into:

- Global impacts
- Regional impacts
- Local impacts.

At first, local and regional environmental impacts caused by project implementation will be investigated; global environmental impacts will be covered in Step 22.

Local and regional environmental impacts caused by project implementation can either be positive (resulting in an improvement of local/regional environmental conditions) or negative (resulting in a deterioration of the local/regional environmental conditions). The project's impact will be assessed by identifying and rating environmental impacts in several categories. Impact categories that will be considered in the assessment, as well as examples for potential impacts caused by the project, are compiled in Table 6.3-25.

Table 6.3-25: Impact categories for local and regional environmental impacts and examples for potential impacts

Impact category	Potential positive impacts caused by project implementation	Potential negative impacts caused by project implementation
Direct local impacts		
Air	- replacement of fossil fuel leading to a reduction of local air pollution - reduction of indoor air pollution by replacement of traditional kerosene lamps for lighting, biomass for heating, drying, etc.	- increase of local traffic resulting in local air pollution (transport to/from biogas/biomass combustion facility)
Soil	- reduction of soil pollution caused by uncontrolled disposal/handling of municipal waste (e.g. open dumping sites) - improvement of soil conditions by application of bio-fertiliser	
Water	- reduction of water pollution (groundwater, rivers, lakes) caused by uncontrolled disposal/handling of municipal waste (e.g. open dumping sites)	
Noise	- reduction in noise exposure by replacement of outdated energy generation systems (e.g. diesel generators)	- increase in noise exposure for direct neighbours of biogas/biomass combustion faciltiy - increase of local traffic (transport to/from biogas/biomass combustion facility)
Smell	- reduction in smell from inappropriate waste handling/disposal (e.g. open dumping)	- exposure to smell for direct neighbours of biogas/biomass combustion plant
Regional impacts		
Deforestation	- reduction of deforestation due to provision of electricity/heat	
Acid rain	- replacement of fossil fuel combustion leading to a reduction in emission of oxides of nitrogen and sulphur	

The potential impact of the project in each of the impact categories specified in Table 6.3-25 will be assessed by applying the following ranting scale:

- considerable negative impact
- negative impact
- no impact
- positive impact
- considerable positive impact.

Results for step 21

→ Identification and evaluation of local/regional environmental impacts

Step 22: Determination of the global environmental impacts caused by the project

Explanations for step 22

Besides local and regional environmental impacts, there are a number of impacts caused by the project which take effect on a global scale, including:

- Consumption of non-renewable resources
- Emissions to air, which contribute to global warming, e.g. carbon dioxide (CO_2), methane (CH_4)
- Emissions to air, which contribute to stratospheric ozone depletion, e.g. CFCs.

Assessing all potential global environmental impacts caused by the project is beyond the scope of this pre-feasibility study. The performance of the project will rather be measured on the basis of one selected global environmental indicator that is of high relevance for energy projects: **The project's impact on global warming**

In general, **climate-relevant impacts** comprise all emissions of so-called greenhouse gases that contribute to global warming. However, in the followed simplified approach, only emissions of carbon dioxide (CO_2) and methane (CH_4) will be considered in the analysis. The climate-relevant impacts are expressed as "CO_2-equivalents", a commonly used reference indicator for impacts on global warming. In order to express the contribution of methane emissions to global warming as "CO_2-equivalents", an equivalency factor of 21 is applied, meaning that the global warming potential of methane is 21 times higher in relation to CO_2 [IPCC, 1996].

In general, renewable energy projects have a positive impact on global warming because a reduction in climate-relevant emissions can be achieved by project implementation. For biogas and biomass combustion projects this reduction results from:

- Replacement of fossil fuel-based energy provision
- Avoidance of climate-relevant impacts caused by organic substrate disposal

In order to determine the reduction in climate-relevant impacts, the project is compared to a reference **or baseline scenario**. The baseline is a likely scenario in absence of the project, i.e. the anticipated situation without project implementation. Consequently, a baseline has to be defined for production of energy and organic substrates disposal. For those baselines, the climate-relevant impacts in absence of the project have to be determined.

The impacts caused by the baselines will be (partly) compensated by project implementation. Thus, by taking into consideration the climate-relevant impacts caused by the project itself, the overall reduction in impact on global warming is calculated as shown in the following formula (tool 25a).

Tool 25a

Calculation: Project's overall reduction in impact on global warming (tool 25a)

$$R_{CO2} = (BE_{CO2} + BS_{CO2}) - P_{CO2}$$

where:

R_{CO2} = Project's overall reduction in climate-relevant impacts [t CO_2-equiv./a]
BE_{CO2} = Impacts caused by the baselines for energy production [t CO_2-equiv./a]
BS_{CO2} = Impacts caused by the baseline for substrates disposal [t CO_2-equiv./a]
P_{CO2} = Impacts caused by the project [t CO_2-equiv./a]

A negative result for R_{CO2} would mean, that no reduction in impact on global warming can be achieved by the project, i.e. the baseline is the option having less impact on global warming. The calculation of impacts caused by the baselines and the project is explained in the following. Generally, it should be noted, that estimation of impacts can only be regarded as a first rough estimate due to the assumptions and simplifications used in the underlying calculations.

Climate-relevant impacts caused by the baseline for energy production

The fossil fuel-derived production of energy results in climate-relevant impacts. Typical specific CO_2-emissions of several baselines for energy production and the use of fossil fuels for energy generation are compiled in tool 25b (Table 6.3-26). Besides CO_2-emissions, no other climate-relevant impacts caused by the baseline for energy production will be considered.

Tool 25b

Table 6.3-26: Typical specific CO_2 emissions of different baselines for energy generating systems and the use of fossil fuels for energy generation (tool 25b)

Baseline for energy production	Specific CO_2 - emissions [g CO_2/kWh]	Reference
Production of electrical energy		
Average grid Vietnam	340	COGEN 3, 2004
Average grid Thailand	691	COGEN 3, 2004
Average grid Germany	650	GEMIS, 2003
Diesel generator; 30% electrical efficiency	928	COGEN 3, 2004
Diesel generator; 35% electrical efficiency	669	COGEN 3, 2004
Diesel generator; 40% electrical efficiency	505	COGEN 3, 2004
Diesel generator; 25% electrical efficiency	1.056	COGEN 3, 2004
Diesel generator; 20% electrical efficiency	1.320	COGEN 3, 2004
Natural gas (combined cycle)	500	COGEN 3, 2004
Coal steam turbine	1180	COGEN 3, 2004
Production of thermal energy		
Heating plant (light fuel oil); 90% thermal efficiency	296	Based on GEMIS, 2003
Heating plant (natural gas); 90% thermal efficiency	223	Based on GEMIS, 2003
Steam boiler (light fuel oil); 85% thermal efficiency	313	Based on GEMIS, 2003
Steam boiler (natural gas); 85% thermal efficiency	236	Based on GEMIS, 2003
Use of fossil fuels for energy generation (to be replaced or substituted by biogas)		
Diesel/light fuel oil	266	Öko-Institut (GEMIS)
Natural gas	201	Öko-Institut (GEMIS)

The climate-relevant impacts caused by the baseline for energy production is determined on the basis of the specific CO_2-emissions for the selected baseline and the project's usable energy production, as shown in the following formula (tool 25c):

Tool 25c

Calculation: Climate-relevant impacts caused by the baseline for energy production (tool 25c)

$$BE_{CO_2} = \frac{C_{specific} * E}{1.000.000}$$

where:

BE_{CO2} = Climate-relevant impacts caused by the baselines for energy production [t CO_2-equiv./a]

$C_{specific}$ = Specific CO_2-emissions for baseline for energy production [gCO_2/kWh]

E = Project's usable energy production (Thermal, electrical or biogas production) [kWh/a]

Climate-relevant impacts caused by the baseline for organic substrate disposal

If organic substrates are disposed on **landfills**, methane is generated, which is very climate-relevant due to its high global warming potential (equivalency factor of 21). This impact would be (partly) compensated by processing the substrate in biogas or biomass combustion systems. Therefore, if landfilling is the baseline for substrate disposal, the climate-relevant impacts caused by this disposal practice have to be determined.

Different methodologies can be applied to estimate the methane emissions from solid waste disposal sites. In the following, the default methodology proposed in the *revised 1996 IPCC guidelines for National Greenhouse gas inventories* will be used.

In the first step, the degradable fraction organic carbon (DOC) content of solid waste, i.e. the organic carbon that is accessible to biochemical decomposition has to be estimated. If no specific DOC value is available for the substrates used, typical DOC values for major waste streams given in tool 25d (Table 6.3-27) can be used as a first approximation:

Table 6.3-27: Typical DOC values for major waste streams (values for wet/fresh waste)(tool 25d) [IPCC, 1996]

Tool 25d

Waste stream	Per cent DOC (by weight)
Paper and textiles	40
Garden and park waste, and other (non-food) organic putrescibles	17
Food-waste	15
Wood and straw waste (excluding lignin C)	30

Subsequently, the type of disposal site has to be identified in order to determine the appropriate methane correction factor, i.e. a factor that reflects the methane generation potential of different types of disposal sites. Typical values for the methane correction factor are given in tool 25e (Table 6.3-28).

Table 6.3-28: Methane correction factor for different types of disposal sites (tool 25e) [IPCC, 1996]

Tool 25e

Type of site	Methane correction factor
Managed	1
Unmanaged – deep (>5m waste)	0,8
Unmanaged – shallow (< 5m waste)	0,4
Default value – uncategorised disposal site	0,6

In managed disposal sites, the produced landfill gas is often captured and then flared off or utilised for energy production in block heat and power plants. In this case, the fraction of landfill gas that is recovered has to be estimated. In general, a **recovery rate of 75%** can be used as first approximation.

In a final step, the climate-relevant impact caused by the baseline for organic substrate disposal, are calculated as shown in tool 25f.

Tool 25f

Calculation: Climate-relevant impacts caused by the baseline for organic substrate disposal (tool 25f)

$$BS_{CO_2} = \frac{m_S * MCF * DOC * DOC_F * F * 16 * (100 - R)}{12} * (100 - OX) * 21$$

where:

BS_{CO2} = Impacts caused by the baselines for substrate disposal [t CO2/a]
m_S = Total mass of substrates [t/a]
MCF = Methane correction factor [-]
DOC = Degradable organic carbon [%]
DOC_F = Fraction dissimilated DOC (portion of DOC that is converted to landfill gas) (default value: 0.77) [-]
F = Fraction of CH_4 in landfill gas (default value: 0,5) [-]
R = Methane recovered [%]
OX = Oxidation of CH_4 in upper layers/cover material (default value: 0) [%]

The default values included in the formula (tool 25f) can be adjusted if more specific data is available.

<u>Climate-relevant impacts caused by the project</u>

a) biogas projects

The use of **biogas for energy production** is CO_2 –neutral because only CO_2 is emitted that was previously absorbed (short term carbon cycle). Hence, no climate-relevant emissions derive from biogas-based energy generation (negligence of methane slip in the block heat and power plant).

Organic matter is only partly degraded in the biogas process. If residues generated are disposed in **landfills**, the resulting impact on global warming needs to be considered. The calculation of climate-relevant impacts from the disposal of residues can be carried out utilising tool 25 d-f by considering the following adjustments:

- $\mathbf{m_S}$ is defined as the quantity of residues that has to be disposed off (Step 14)
- **DOC** content is reduced by 50% (prior degradation of organic substance in biogas process)
- $\mathbf{DOC_F}$ is reduced to 0,5 (The remaining DOC is less accessible to the biological process, i.e. conversion into landfill gas)

The use of **fuel oil** results in climate-relevant impacts that are determined on the basis of the fuel oil consumption (tool 21) and the specific CO_2-emission factors for Diesel/fuel oil (tool 25b).

The total climate-relevant impact caused by the biogas project ($\mathbf{P_{CO2}}$) are calculated as sum of the impacts caused by residue disposal and fuel oil consumption.

b) biomass combustion projects

For the **combustion of substrates**, two cases have to be distinguished:

<u>Case 1: Substrates are only composed of biogenous matter</u>

If the substrates are only composed of biogenous matter (e.g. wood, agricultural residues) CO_2-emissions derived from the combustion process are not climate-relevant. CO_2 emitted was previously absorbed by the plants and, therefore, does not have adverse impacts on global warming (short term carbon cycle).

Case 2: Substrates contain non-biogenous matter

If substrates are used that contain non-biogenous matter, such as solid waste (plastic), the CO_2 emissions derived from the fossil carbon content of the substrate are climate-relevant and need to be considered. For household wastes with a typical fossil carbon content of 33%, the climate-relevant emissions can be estimated based on a specific CO_2-emission factor of **356 g CO_2/t** [Öko-Institut, 2002].

The **residues** (ashes) produced in biomass combustion processes do not result in any direct climate-relevant impacts.

As a result, the total climate-relevant impact caused by the biomass combustion project (**P_{CO2})** corresponds to the CO_2-emissions caused by the combustion of non-biogenous matter (case 2).

Results for Step 22

→ Baseline for energy production
→ Baseline for disposal of organic substrates
→ Climate-relevant impacts caused by the baseline for energy production [t CO_2 -equiv./a]
→ Climate relevant impacts caused by the baseline for disposal of substrates [t CO_2-equiv./a]
→ Climate relevant impacts caused by the project [t CO_2-equiv./a]
→ Project's total reduction of impact on global warming [t CO_2-equiv./a]

Step 23: Identification of subsidies for the project

Explanations

In this step, subsidies available for the project should be specified.

Investment grant

Identify any kind of subsidy which directly reduces investment costs, i.e. **non-recurring subsidies**. Investment grants reduce equity and thereby improve profitability and ease project implementation.

Other type of subsidies (recurring subsidies)

Identify any kind of subsidy which **increase revenue**. These type of subsidies increase profitability and thereby secure long run success of the project and economic viability.

Renewable energy projects might be eligible for the following types of subsidies:

- Investment grant
- Tax rebate
- Power purchasing programs with preferential prices/other preferential conditions/with bonus for small and very small power producers
- Special loans or guarantees for commercial loans, i.e. lower interest rate, longer interest fixing, longer duration of loan, need of less collateral, longer grace period.
- Preferential treatment or simpler procedures in construction law or other bureaucratic procedures.
- Other support of the community/local government
- Funding opportunities by bi- or multilateral programs e.g.:
    - European Community http://europa.eu.int/comm/europeaid/cgi/frame12.pl
    - Gesellschaft für Technische Zusammenarbeit (GTZ) http://www.gtz.de/en/
    - United Nations Environment Programme (UNEP), Capacity development for the CDM (Clean Development Mechanism): http://www.cd4cdm.org/
    - Worldbank, e.g. Community development carbon fund http://carbonfinance.org/cdcf/home.cfm
    - Prototype carbon fund http://prototypecarbonfund.org/splash.html,
    - etc..

Results for step 23

→ Non-recurring investment grants
→ recurring subsidies

Step 24: Estimation of project costs

This step is different for the biogas process and combustion process. Please only consider the corresponding paragraphs.

A financial evaluation of the project to be developed is given in Step 24 - 27 and Tool 26 - 28. Estimations of planning, approval, investment, operation, repairs and maintenance are made. This can only be done very generally in a universal Handbook which is intended to apply to the most differing cases in various different countries. In profit and loss calculations it is of course important to consider if only plant operation or also storage of large quantities of substrates and fermentation goods and possibly also their transport over long distances are to be included into the calculation. Furthermore it will make a difference, if a plant in the planning can be linked with an already existing operation already having infrastructure (social rooms, workshop, book-keeping, company management etc) or if the plant is to stand on its own.

As the question of cost must be asked early on in the planning stages of plants for the generation of renewable energy, it is necessary despite significant uncertainties to consider the financial feasibility of the plant. It must be pointed out to the user, that the tool results and work stages given here require careful interpretation. It must be understood that these stages are intended as the initial steps to be taken as part of the project development as a whole. The calculation of costs in particular requires a great deal of experience and it is strongly recommended to bring in experts at the early stages of the process.

The project costs have to be estimated as a basis for the profitability analysis. Four cost groups must be taken into account when determining the project costs:

- Investment costs
- consumption-related costs
- operation related costs
- other costs (e.g. insurance, taxes)

Explanations for step 24 (biogas process)

Biogas

Investment costs

In a first step, the investments in operational system parts and the associated components are to be determined. If no cost estimates are available for the considered **biogas system** (e.g. from economic calculations or tender documents), typical specific investment costs for biogas plants can be used as a first approximation. In order to obtain meaningful results on the project profitability, these first rough estimates should be revised with more accurate cost estimates in a subsequent more detailed feasibility study.

The specific investment costs for biogas plants can be related to the nominal electrical capacity (rated power). Typical investment costs for biogas plants with nominal electrical capacities from 15 to 800 kW_{el} are compiled in tool 26 (Figure 6.3-11). This compilation of typical specific investment costs is based on more than 500 existing plants and thus represents a cross section of a wide variety of different plant concepts. As a result, the values in tool 26 differ considerably and can only be used for a first rough estimation of the total plant costs.

In general, investment costs for biogas plants, which operate with solid organic waste are higher compared to agricultural biogas plants (using manure or biomass). This is due to higher feedstock pre-treatment and sanitation requirements.

Biogas

Tool 26

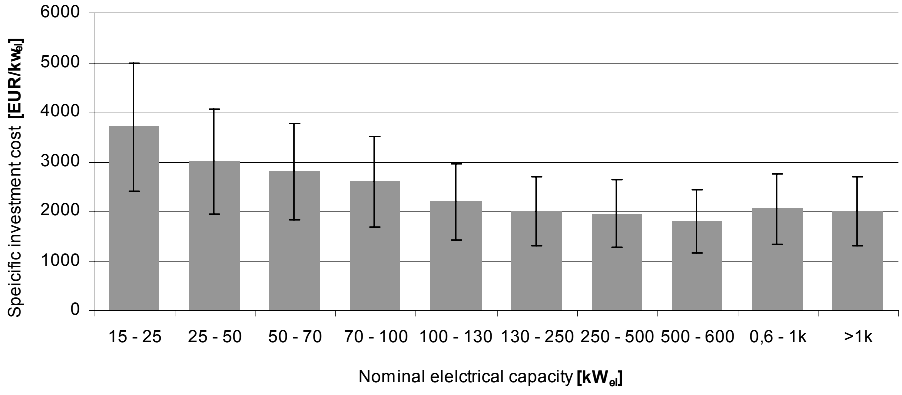

Figure 6.3-11: Typical specific investment for biogas plants (tool 26) [Institut für Energetik und Umwelt GmbH, quoted in BMU, 2003]

The service life of the technical components of a biogas system varies considerably. Thus, the determined total investment cost has to be subdivided by system part in order to be able to determine the annual depreciation and maintenance and repair costs for each component (see below). A typical breakdown of investment costs for biogas plants with nominal electrical capacities of 70 and 500 kW$_{el}$ is shown in the Figure 6.3-12 and Figure 6.3-13.

Nominal Capacity: 70kW $_{el}$.

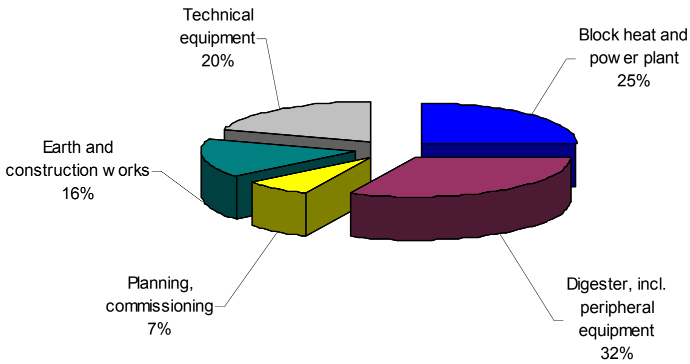

Figure 6.3-12: Typical breakdown of investment costs for biogas plants with nominal electrical capacities of 70 kW$_{el}$ [Institut für Energetik und Umwelt GmbH, quoted in BMU, 2003]

Nominal Capacity: 500 kW $_{el}$.

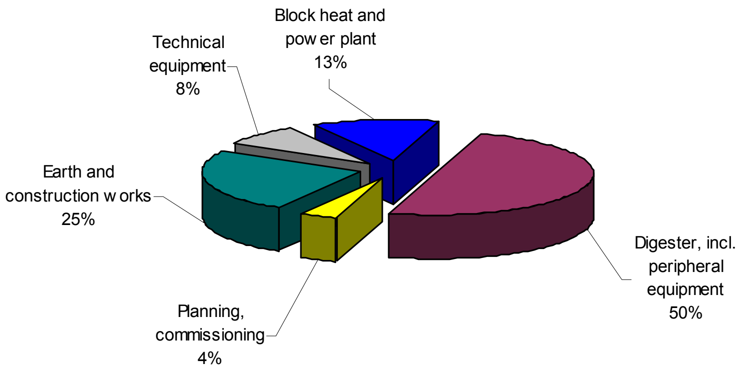

Figure 6.3-13: Typical breakdown of investment costs for biogas plants with nominal electrical capacities of 500 kW$_{el}$ [Institut für Energetik und Umwelt GmbH, quoted in BMU, 2003]

The system parts defined in Figure 6.3-13 include the following technical components:

Technical equipment: Pumps, piping, electrical installation, gas piping, measurement and control technology

Block heat and power plant: Grid connection, piping for utilisation of thermal energy (hot water)

Digester: incl. heating system, insulation, mixing devices.

The typical specific investment costs compiled in tool 26 are based on existing plants in industrialised countries. A reduction of investment cost may apply if biogas plants are built in developing or transforming nations. The different economic setting in less developed countries (e.g. lower wages, material costs, etc.) can result in a considerable reduction of total investment costs for the biogas system. However, some system components such as the block heat and power plant and control and measurement devices are not always available locally and must be imported. Taking into account the typical breakdown of investment cost presented in Figure 6.3-12 and Figure 6.3-13, the applicable reduction of investment cost for the different assemblies can be estimated.

The investment cost for the biogas plant should include a contingency sum of approximately 5% in order to account for unforeseen expenses.

Besides the cost for the biogas system, the following **additional investment costs** are to be determined:

- cost for land (based on land requirements estimated in Step 12)
- other additional investment costs (e.g. infrastructure, preparation of land for building)

Consumption-related costs

The following consumption-related costs have to be determined:

Cost for substrates: The cost for substrates is dependent on the type of substrate, the required collection processes and the transportation distance. Costs emerging from employment of labour for substrate provision (e.g. harvest, transport) are to be included in the cost for substrates. Waste management companies, local authorities or other relevant institutions may be consulted to estimate the specific cost for the considered substrates (total cost for provision to biogas facility).

Cost for residue utilisation/disposal: The specific cost is to be estimated on the basis of the selected utilisation path or residue disposal option (e.g. cost of further treatment, cost for disposal on landfill). Costs emerging from employment of labour for utilisation/disposal of substrates are to be included in the cost for residue utilisation/disposal.

Energy costs: If the auxiliary consumption of electrical energy cannot be covered by the biogas system, i.e. in the case of direct utilisation of biogas, the required electricity has to be purchased. The determination of the resulting energy costs should be based on the applicable local electricity tariffs.

If a pilot injection engine is used in the block heat and power plant, costs occur for the required fuel oil consumption. The resulting energy cost is to be determined on the basis of the fuel requirements (Step 12) and the applicable fuel prices (light fuel oil/diesel).

Operation-related costs

The operation-related costs include the costs of repairs and maintenance and the costs of using the plant (labour costs).

The annual costs of **repairs and maintenance** for structural system parts (e.g. technical equipment, digester) can be estimated as fixed percentage of the total investment costs for the respective system parts. Typical efforts on repairs and maintenance are shown in Table 6.3-29:

Table 6.3-29: Typical efforts on repair and maintenance for assemblies of biogas plants [according to VDI 2067]

System part	Effort on repairs and maintenance [% of investment]
Technical equipment (pumps, piping, etc.)	3
Digester (incl. peripheral equipment)	2
Earth and construction works	0,5
Property	0,5

Service contracts with a wide variety of scopes are offered for the required maintenance and repair measures of the **Block heat and power plant unit**. A complete repair and maintenance contract covers all measures that are necessary to guarantee a smooth operation within the typical contract period of 10 years, including replacement of parts, operating supplies and a general overhaul. Figure 6.3-14 shows a compilation of guiding prices for complete servicing contracts of block heat and power plants against the nominal electrical capacity (rated power) that can be used for a first approximation.

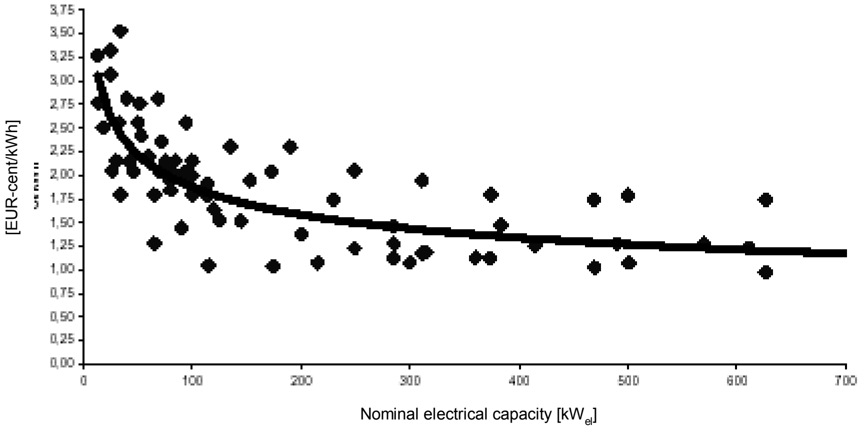

Figure 6.3-14: Guiding prices for complete servicing contracts of biogas operated CHP plants [FNR, 2004]

The **labour requirements** for operation and maintenance of the biogas plants differ considerably, as they are plant specific to a high degree. In general, the labour requirement decreases with the plant capacity due to higher levels of automation. Biogas plants operating with solid organic waste etc. have higher labour requirements compared to agricultural plants utilising manure as main substrate. For a first rough estimation, typical labour requirements for biogas plants compiled in Figure 6.3-15 (against the nominal electrical capacity) can be used. The calculation of the total labour costs shall be based on typical wages of the region (skilled workers).

All costs emerging form the required employment of labour for provision of substrates (e.g. harvest, transport) as well as utilisation/disposal of residues shall be included in the cost for substrate and cost for residue utilisation/disposal (consumption related costs)

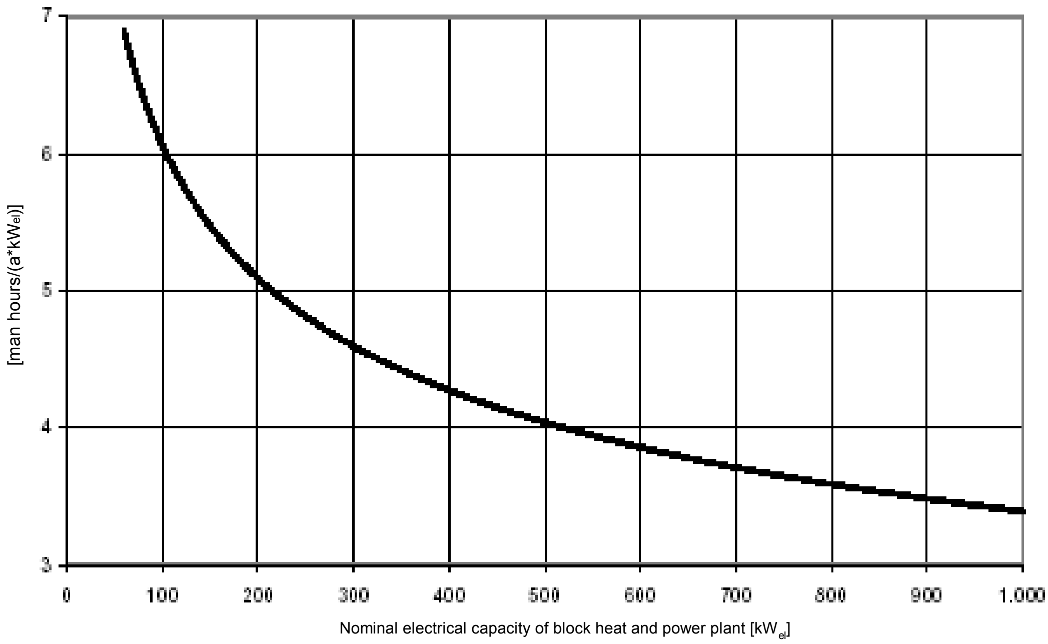

Figure 6.3-15: Specific labour requirements for operation of biogas plants [FNR, 2004]

Other costs

These include costs of insurance, general output and shared administration costs. A percentage of 0,5% of the total investment cost can be applied for insurance purposes.

Results for step 24

→ total investment cost [EUR]
→ total consumption related costs [EUR/a]
→ total operational related costs [EUR/a]
→ total other costs [EUR/a]

Explanations for step 24 (biomass combustion process)

Combustion

Investment costs

In a first step, the investments in operational system parts and the associated components are to be determined. If no cost estimates are available for the considered biomass combustion system (e.g. from economic calculations or tender documents), typical specific investment costs for biomass combustion plants can be used as a first approximation. In order to obtain meaningful results on the project profitability, these first rough estimates should be revised with more accurate cost estimates in a subsequent more detailed feasibility study

Depending on the operational mode, specific investment costs for biomass combustion plants are related to the nominal electrical capacity (mode 1-3) or the nominal thermal capacity (mode 4).

Mode 1-3:

Typical specific investment costs for electric power plants and electricity- or heat-controlled CHP-plants with nominal electrical capacities from 0.5 to 20 MW_{el} are compiled in tool 27 (Figure 6.3-16).

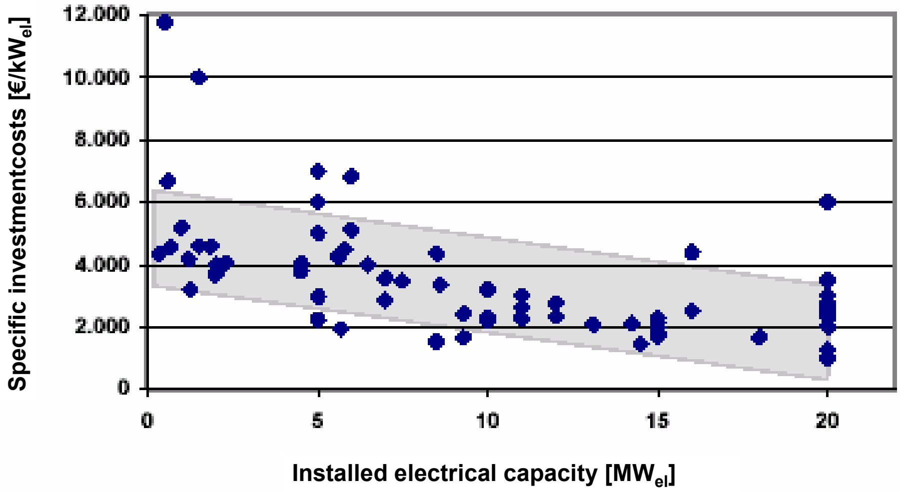

Figure 6.3-16: Average specific investment costs of biomass combustion plants for heat and/or power generation (planned and operating plants) [IE, 2003]

The compilation of typical specific investment costs is based on a wide variety of different existing plants. Therefore, the costs differ considerably and can only be used for a first rough estimation of the total plant costs. In general, specific investment costs are higher for plants, which are operated with fuel pre-treatment and for plants with a high degree if automation.

Mode 4

Typical specific investment costs for heat plants are compiled in Table 6.3-30

Table 6.3-30: Typical specific investment costs of biomass heating plants [BMU, 2003]

Nominal thermal capacity of heat plant	Specific investment costs [EUR/kW_{th}]
0,5-1 MW_{th}	100-200
1-5 MW_{th}	100-250
>5 MW_{th}	250-350

The determined total investment cost has to be subdivided by system part in order to be able to determine the different annual depreciation and maintenance and repair costs for each component (see below). A typical breakdown of investment costs for a CHP-plant (2 MW_{el}) and a heat plant (1 MW_{th}) is shown in Figure 6.3-17.

The system parts defined in Figure 6.3-17 include the following technical components:

Technical equipment: the whole machinery inclusive the machinery of the fuel storage and fuel feeding systems, boiler with fuel-feeding system, ash removal and storage, flue gas cleaning, process water treatment
For CHP plants: steam turbine, generator

Electrical equipment: Electrical compounds of the machinery, measurement and control technology (costs vary very much with plant size and the degree of automation)

Other costs: planning and commissioning, etc.

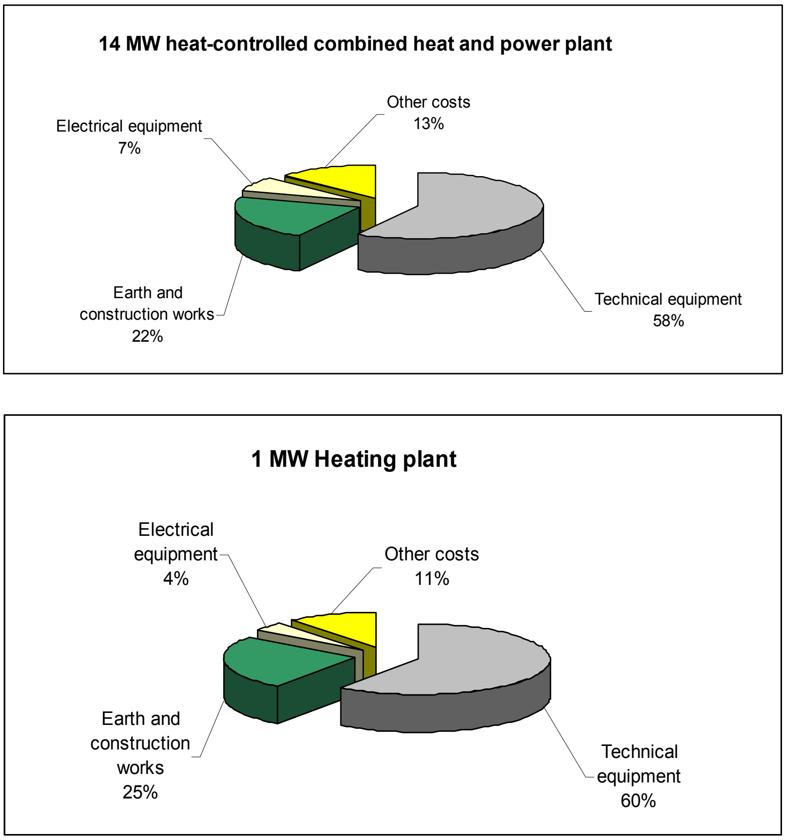

Figure 6.3-17: Typical breakdown of investment costs for a combined heat and power plant (14MW$_{el}$) and a heating plant (1MW$_{th}$) [FNR, 2001]

The typical specific investment costs compiled in tool 27 are based on existing plants in industrialised countries. A reduction in investment cost may apply if biomass combustion plants are built in developing or transforming nations. The different economic setting in less developed countries (e.g. lower wages, material costs, etc.) can result in a considerable reduction of total investment costs for the biomass combustion system. However, certain system components such as control and measurement devices, etc. are not always available locally and must be imported. Taking into account the typical breakdown of investment cost presented in Figure 6.3-17, the applicable reduction of investment cost in the different assemblies can be estimated.

Besides the costs for the biomass combustion plant, the following **additional investment costs** have to be determined:

- cost for land (based on land requirements estimated in Step 12)
- other additional investment costs (e.g. infrastructure, preparation of land for building)

Consumption-related costs

The following consumption-related costs are to be determined:

Cost for substrates: The cost for substrates is dependent on the type of substrate, the required collection processes and the transportation distance. Costs emerging from employment of labour for substrate provision (e.g. harvest, transport) are to be included in the cost for substrates. Waste management companies, local authorities or other relevant institutions may be consulted to estimate the specific cost for the considered substrates (total cost for provision to biogas facility).

Cost for residue utilisation/disposal: The specific cost is to be estimated on the basis of the selected utilisation path or residue disposal option (e.g. cost of further treatment, cost for disposal on landfill). Costs emerging from employment of labour for utilisation/disposal of substrates are to be included in the cost for residue utilisation/disposal.

Energy costs: If the auxiliary consumption of electrical energy (combustion unit, flue gas cleaning system, etc.) cannot be covered by the combustion plant, i.e. in case only thermal energy is produced (mode 4 – heat plant), the required electricity has to be purchased. The determination of the resulting energy costs should be based on the applicable local electricity tariffs and the determined auxiliary consumption (step 6).

Operation related costs

The annual costs of **repairs and maintenance** for structural system parts (e.g. technical equipment, electrical equipment, etc.) can be estimated as fixed percentage of the total investment costs for the respective system parts. Typical efforts on repairs and maintenance are shown in Table 6.3-31:

Table 6.3-31: Typical efforts on repair and maintenance for assemblies of biomass combustion plants

System part	Effort on repairs and maintenance [% of investment]
Technical equipment (pumps, piping, boiler, turbine etc.)	2,0
Electrical equipment	1,5
Earth and construction works	1,0

The **labour requirements** for operation and maintenance of biomass combustion plants differ considerably, as they are plant specific to a high degree. In general, the labour requirement decreases with the plant capacity due to higher levels of automation. For a first rough estimation, the typical labour requirements for biomass combustion plants showed in Table 6.3-32 can be used. The calculation of the total labour costs shall be based on typical wages of the region (skilled workers).

All costs emerging form the required employment of labour for provision of substrates (e.g. harvest, transport) as well as utilisation/disposal of residues should be included as consumption related costs.

Table 6.3-32: Approximate values of labour requirements for biomass combustion plants [FNR, 2001]

Biomass plant	Annual labour requirement for operation and management [man-hours/a]
Combined heat and power plant; >5 MW_{th} (mode 1-3)	1.920 – 3.360
Heating plant; 1-5 MW_{th} (mode 4)	480 – 1.440
Heating plant; > 5 MW_{th} (mode 4)	1.440 – 2.400

Other costs (e.g. insurance, taxes)

These include costs of insurance, general output and shared administration costs. A percentage of 0,5% of the total investment cost can be applied for insurance purposes.

Results for step 24

→ total investment cost [EUR]
→ total consumption related costs [EUR/a]
→ total operation related costs [EUR/a]
→ total other costs [EUR/a]

Step 25: Calculation of project revenue

Explanations for step 25

At this step the revenues for the project are to be calculated. In general, revenues for biogas and biomass combustion projects derive from:

- energy production
- processing of substrates (e.g. organic waste)
- utilisation of residues as secondary raw material fertiliser (or other utilisation paths)
- reduction of climate-relevant emissions (potential additional revenue for CDM or JI projects eligible under the Kyoto Protocol)

Revenue for energy production

The calculation of revenues from energy production is based on the determined annual production of usable energy (Step 6). For each type of energy, the appropriate specific revenue is to be determined.

If the **electricity** produced is fed into the national grid network, the applicable feed-in tariff for independent power producer (IPPs) has to be requested from the respective power supply companies. It should also be investigated if subsidised electricity feed-in tariffs exist for renewable energy based power production (see Step 23). For all other utilisation paths, the achievable revenue for electricity production has to be investigated in particular cases. If no specific information can be obtained, the current electricity tariff can be applied as a first approximation.

In order to calculate the revenue for the supply of **thermal energy** (steam, hot water) the achievable specific price for supply of thermal energy has to be investigated in particular cases. If the achievable price cannot be determined, the revenue can be estimated based on the current price for provision of thermal energy.

The produced **biogas** can be directly utilised in a wide variety of applications to replace or substitute conventional liquid fuels or fuel gases (diesel, natural gas, etc.). If no specific information is available on the achievable revenue, the price of the conventional fuel (expressed on the basis of the thermal value, i.e. EUR/kWh) that is to be replaced/complemented by biogas can be taken as a basis.

Revenue for processing of substrates (e.g. organic waste)

Depending on the type of substrates, additional revenue may be obtained for **the processing of substrates**. This applies particularly for substrates such as municipal and industrial organic wastes.

Revenue for utilisation of residues as secondary raw material fertiliser (or other utilisation paths)

Residues produced in biomass combustion and biogas processes can be utilised as bio-fertiliser if utilisation is not restricted due to contaminations of the input substrates (see Step 14). The calculation of total revenue from utilisation of residues is based on the determined quantity of residues that can be utilised (Step 13).

Revenue for reduction of climate-relevant emissions

Besides the revenues for energy production, utilisation of residues and processing of substrates, the **reduction of climate relevant emissions** through project implementation provides a potential source for additional revenues. However, this revenue can only be considered if the project has been accredited under one of the flexible emission trading mechanism of the Kyoto Protocol, i.e. Clean Development Mechanism (CDM) or Joint Implementation (JI).

Sales of emission certificates from JI- and CDM-Projects can be handled through a number of distributive channels: bilateral trade between the project executing organization (seller) and buyer, funds for the purchase of emission credits (i.e. Proto type carbon fund of the Worldbank, KfW-Klimaschutzfonds, etc.) or emission trading exchange (i.e. ECX/London, Nord Pool/Norway). In order to estimate the potential additional revenue through sales of emission certificates, the current market price for emission reductions can be taken as basis for the calculation (e.g. published on: www.nordpool.com). This price has to be multiplied with the project's reduction in climate-relevant impacts (step 22) to calculate the total revenue.

Results for step 25

→ Total revenue for energy production [EUR/a]
→ Total revenue for processing of substrates [EUR/a]
→ Total revenue for utilisation of residues [EUR/a]
→ Potential additional revenue for reduction of climate-relevant impacts [EUR/a]

Step 26: Project profitability

Explanations

Based on the determined project costs and revenues, a profitability analysis is carried out in order to determine whether the project or investment is financially desirable. In general it should be noted, that the analysis is based on many assumptions and projections. Thus, the results only represent a rough indication of the project's profitability and must be interpreted with care.

A simplified static approach is applied in carrying out the profitability analysis. Compared to a more sophisticated dynamic analysis the following simplifications apply:

- the analysis is based on a representative period
- the analysis is based on approximate calculations (rules of thumb)
- time value of money is not considered (a Euro now is worth more than a Euro in future).

Despite these simplifications, the significance of the profitability analysis is regarded sufficient for a first approximation at a pre-feasibility level.

<u>Calculation of capital-related costs</u>

In a first step, the capital-related costs are to be calculated on the basis of the determined investment costs. If the initial investment is reduced by an **investment grant** (non-recurring subsidy), the calculation of capital-related costs is based on the reduced investment cost.

The annual capital-related cost is calculated as shown in the following formula (tool 28a):

Tool 28a

Calculation: Capital-related costs (tool 28a)

$$C_T = D + Z$$

where:

C_T = Annual capital related costs [EUR/a]
D = Depreciation [EUR/a]
Z = Annual imputed interest [EUR/a]

Applying straight-line linear depreciation, the annual cost-accounting **depreciation** for each system part is calculated using the formula below:

Calculation: Annual cost-accounting depreciation

$$D = \sum \frac{I_i - S_i}{n_i}$$

where:

D= Depreciation [EUR/a]
I_i= Investment cost for system part i [EUR]
n_i= Calculative service life of system part i [a]
S_i= Salvage value of system part i [EUR]
(S_i is assumed to be 0 in a first approximation)

Typical calculative service life (useful life) for system parts of biogas and biomass combustion plants are shown in Table 6.3-33:

Table 6.3-33: Calculative service life for system parts of a biogas and biomass combustion plant

System part	Calculative service life n [a]
Biogas plants [BMU, 2003]	
Technical equipment (pumps, piping, etc.)	10
Digester (incl. peripheral equipment)	15
Earth and construction works	15
Block heat and power plant	10[25]
Planning and commissioning, contingency	15 (based on the max. service life of the investment)
Biomass combustion plants [according to VDI 2067]	
Technical equipment	20
Electrical equipment	15
Earth and construction works	20
Other (planning, commissioning), contingency *	20

* based on the max. service life of the investment

For investments in property, no depreciation is calculated (no obsolescence).

The **interest calculation** is based on the applicable imputed interest rate and the average fixed capital as shown in the following formula:

Calculation: Annual interest

$$Z = \left(C_D + C_0\right) * i$$

where:

Z = Annual interest [EUR/a]
C_D = Average fixed capital (assets with depreciation) [EUR]
C_0 = Average fixed capital (assets without depreciation) [EUR]
i = imputed interest rate

[25] Only applies if a useful life of 10 years is guaranteed by a complete service and maintenance contract (see Step 24). Without such service contracts, the service life has to be adjusted and resulting costs for replacement and overhaul have to be considered in Step 24. Typical useful life for pilot injection engines is 4,5 years (complete replacement required), whereas gas engines have a typical useful life of 5,5 years (general overhaul).

The calculation of the average fixed capital for assets with depreciation (e.g. plant components) and assets without depreciation (e.g. property) is shown in the formula below:

Calculation: Average fixed capital (tool 28a)

a) Fixed assets with depreciation (plant components, etc.)

$$C_D = \frac{I_D - S_D}{2}$$

where:

C_D = Average fixed capital (assets with depreciation) [EUR]
I_D = Investment cost (assets with depreciation) [EUR]
S_D = Salvage value (assets with depreciation([EUR]
(S_D is assumed to be 0 in a first approximation)

b) Fixed assets without depreciation (property)

$$C_0 = I_0$$

where:

C_0 = Average fixed capital (assets without depreciation) [EUR]
I_0 = Investment cost (assets without depreciation) [EUR]

<u>Comparison of annual project costs and revenues</u>

The total **annual project cost** is calculated by summing up the determined annual costs of the following categories:

- capital related costs [EUR/a]
- consumption-related costs [EUR/a]
- operation-related costs [EUR/a]
- other costs [EUR/a].

The total **annual project revenue** is calculated by summing up all project revenues of the following categories:

- revenue for energy revenue for energy production [EUR/a]
- revenue for utilisation of residues [EUR/a]
- revenue for processing of substrates [EUR/a]
- revenue for reduction of climate-relevant emissions (can only be regarded as potential additional revenue)[EUR/a]

<u>Calculation of project annuity (annual profit/loss)</u>

The difference of the annual project revenue and the annual project cost gives the total annuity of the project, as shown in the following formula (tool 28b)

Tool 28b

Calculation: Total annuity of the project (annual profit/loss) (tool 28b)

$$A = PR - PC$$

where:

A = Total annuity of project (annual profit/loss) [EUR/a]
PR = Total annual project revenue [EUR/a]
PC = Total annual project cost [EUR/a]

The annuity must be positive in order for the project to be financially viable. If the determined annuity is positive (A > 0), the annuity can be interpreted as the **annual profit** of the project. If the determined annuity is negative (A<0)), the project does not make any profit (annual deficit/loss). It should be noted, that the impact of tax is not considered in the analysis.

Calculation of return on assets

The significance of the determined indicator “annual profit” is limited, since it does not reflect the correlation between investment and profit. In order to provide additional information about the profitability of the investment, the **return on asset** is calculated (tool 28c):

Tool 28c

Calculation: Return on asset (tool 28c)

$$R = \frac{A + Z}{C_D + C_0} * 100$$

where:

R= Return on asset [%]
A = Total annuity of project [EUR/a]
Z= Imputed annual interest [EUR/a]
C_D= Average fixed capital (assets with depreciation) [EUR]
C_0= Average fixed capital (assets without depreciation) [EUR]

The return on asset can be interpreted as the expected rate of interest on investment. The project can be regarded as financially viable, if it provides the expected minimum attractive rate of return. It should be noted, that the calculation is based on the reduced total investment if an investment grant (non-recurring subsidy) is considered. Thus, the expected return on asset does not reflect the overall performance of the project. It rather indicates the profitability for the investor.

Calculation of project cash flow

As additional financial indicator, the project cash flow can be calculated as shown in the following formula (tool 28d):

Tool 28d

Calculation: Project cash flow (tool 28d)

$$CF = A + D$$

where:

CF= Project cash flow [EUR/a]
A = Total annuity of project [EUR/a]
D = Total annual depreciation [EUR/a]

Payback time

The payback time of the initial investment, or amortization is a frequently used financial indicator to estimate the risk of investments. Using the payback time as decision criterion, the period of time until the initial investment is recovered by the project (full amortisation) should match the expectations of the investor (risk assessment). The calculation of payback time is shown in the following formula (tool 28e):

Tool 28e

Determination of the project’s payback time (tool 28e)

$$P = \frac{I_T}{CF}$$

where:

P = Payback time [a]
CF= Project cash flow [EUR/a]
I_T = Total investment (reduced by grant) [EUR]

Consideration of potential CDM-revenue in profitability analysis

In general, the revenue for sale of emission certificates should not be considered in the analysis, as it only represents a potential additional revenue (in case the project has proved eligibility in accordance with the requirements of the project based flexible mechanism of the Kyoto Protocol). However, by considering a potential revenue for sale of emission certificates, the influence of this additional revenue on the project's profitability can be determined. As a result, the project's external environmental effects would be included in the financial analysis.

Results for step 26

→ Total annual profit/deficit [EUR/a]
→ Return on asset [%]
→ Project cash flow [EUR/a]
→ Payback time (amortization) [a]

Step 27: Is the project financially viable?

Explanations for step 27

As a result of the profitability analysis (Step 26), several indicators have been calculated that can be used to assess the financial viability of the project. These indicators highlight different aspects of the profitability of the project and can be used independently or combined as basis for decision-making. However, one should bear in mind that the underlying cost estimates as well as the determined revenues only represent rough estimates. Thus, the determined financial indicators can only be regarded as first indication of the projects financial performance.

Decision for step 27

If "yes" → go to step 29
If "no" → go to step 28

Step 28: Can the pre-conditions for the project be changed?

Explanations

The profitability analysis might indicate, that the project does not appear to be financially viable. This result however can only be regarded as a first indication since the evaluation is based on a great number of assumptions. In this step it should be investigated if the pre-conditions for the project can be changed. Both, factors directly influencing the project profitability (revenues, investment costs), as well as general pre-conditions (quantity of substrates, characteristics of substrates) should be considered. Subsequently, the project analysis (application of decision tree) is to be carried out based on the changed pre-conditions in order to determine the project profitability on the basis of the new setting.

Important factors with high influence on the project profitability are:

- Project financing (availability of subsidies, etc.)
- Achievable revenue for energy production (feed-in tariff for electricity, etc.)
- Initial investment cost
- Quantity of substrates (availability of additional substrates, availability of co-substrates that provide additional revenue)
- Characteristics of substrates (especially specific methane yield, etc.).

Decision for step 28

If "yes" → go to step 29
If "no" → on the basis of the underlying pre-conditions, the project does not appear to be financially viable. If the general influential framework conditions such as feed-in tariffs, availability of subsidies are not likely to change, another project should be identified.

Step 29: Calculation of the specific energy generation cost and specific CO_2-reduction cost

Explanations

The project profitability analysis carried out in the previous step reveals if the project can be regarded as financially viable, i.e. if the investment in the project provides attractive returns for the investor. In order to broaden up the scope of the analysis, additional indicators will be calculated that go beyond the single consideration of the project's financial viability.

Specific energy generation cost

The specific energy generation cost is an indicator that enables the comparison of the biogas or biomass combustion project with other means of energy generation. Hence, the competitiveness of the project in relation to other energy systems can be determined.

The specific energy generation cost will be calculated in relation to the main type of energy produced by the system. Revenues derived from so-called by-products (e.g. revenue for production of thermal energy, revenue for utilisation of residues, etc.) will be considered in an additional calculation. Non-recurring subsidies (initial investment grants) will not be considered in order to determine the "real" energy generation cost.

The specific energy generation cost is calculated using the formula below (tool 29):

Tool 29

Calculation of the specific energy generation cost (tool 29)

a) Specific energy generation cost (no consideration of revenue for by-products, such as revenue for production of thermal energy, etc.)

$$E_S = \frac{PC}{E} * 100$$

where:

E_S = Specific energy generation cost [EUR-cent/kWh]
PC = Total annual project cost [EUR/a]
E = Usable energy production (main type of energy produced) [kWh/a]

b) Specific energy generation cost (consideration of revenue for by-products, such as production of thermal energy, etc.)

$$E_S = \frac{PC - R}{E} * 100$$

where:

E_S = Specific energy generation cost [EUR-cent/kWh]
PC = Total annual project cost [EUR/a]
E = Usable energy production (main type of energy produced) [kWh/a]
R = Additional annual project revenue for by-products (e.g. revenue for production of thermal energy, etc.) [EUR/a]

For **biogas processes**, the specific energy generation cost will be related to the production of electrical energy and thus be expressed as specific electricity generation cost. If the produced biogas is used directly, no specific generation cost will be calculated.

Depending on the selected operational mode, the specific energy generation cost for **biomass combustion** processes will be either related to the production of electrical or thermal energy. For electrical power plants (operational mode 1) and CHP-plants (operational mode 2+3), the specific energy generation cost will be related to the production of electrical energy. For heat plants (operational mode 4), the specific energy generation cost will be related to the production of thermal energy.

Specific CO_2-reduction costs

This indicator is used to compare different technical measures (e.g. energy projects) with regard to their cost-effectiveness in reducing climate-relevant emissions. The reduction in climate relevant emissions (expressed as CO_2-equivalents) is set in relation to the required expenditure for the emission reduction. Specific CO_2-reduction costs for different energy systems are compiled in Figure 6.3-18:

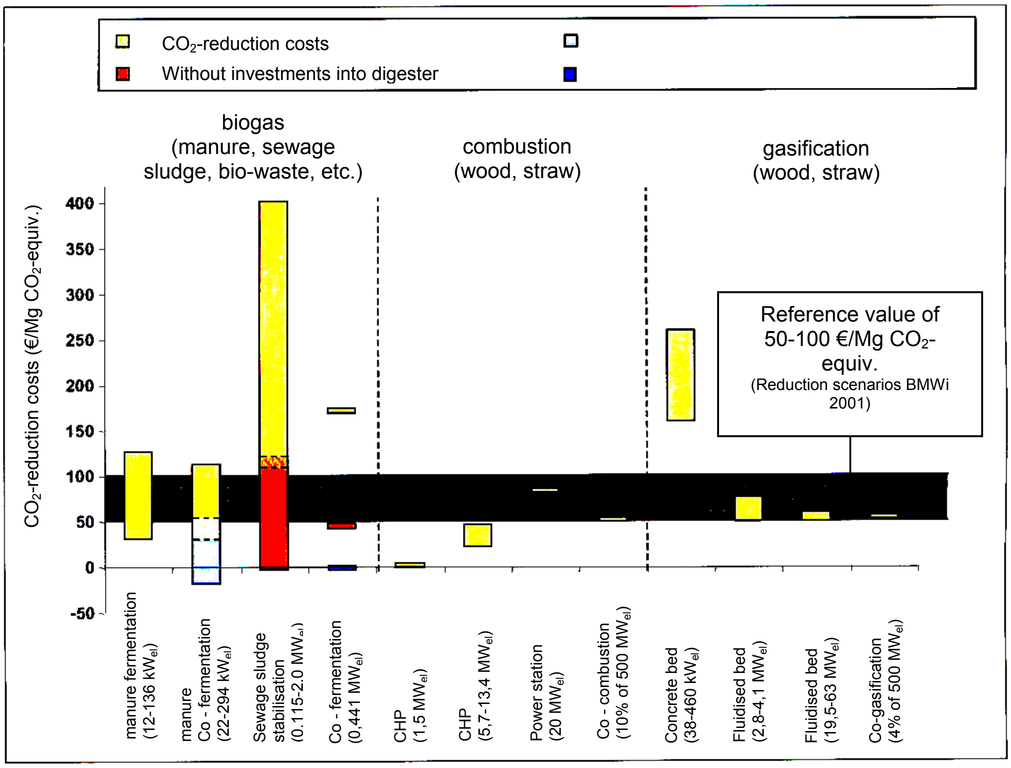

Figure 6.3-18: Comparison of specific CO_2-reduction costs for different technologies [ITAS, 2003]

In general the measure with the lowest CO_2-reduction cost should be implemented in order to follow an economically reasonable CO_2-abatement strategy. However, one should bear in mind that the specific CO_2-reduction cost is only one among many criteria to be taken into consideration in selecting the most favourable option.

The specific CO_2-reduction costs are calculated by comparing the specific energy generation cost and climate relevant emissions of the project with a **baseline scenario,** i.e. a likely scenario for energy generation in absence of the project. This comparison reveals the additional expenditure required to produce energy at cost of the baseline (current energy generating cost) and the achievable reduction in climate relevant emissions through project implementation. The resulting costs per ton of CO_2-equivalents saved can be calculated as shown in the following formula (tool 30):

Calculation: Specific CO_2 reduction cost (tool 30)

$$C_{CO_2} = \frac{E_S - E_B}{R_{CO_2} * 100} * E$$

where:

C_{CO2} = Specific CO_2 reduction cost [EUR/t CO_2]
E_S = Specific energy generation cost of project [EUR-cent/kWh]
E_B = Specific energy generation cost of baseline [EUR-cent/kWh]
R_{CO2} = Reduction in climate relevant emissions through project implementation [t CO_2-equiv./a]
E = Usable energy production [kWh/a]

The specific CO_2-reduction cost can be calculated including or excluding revenues derived from by-products, i.e. revenues for production of thermal energy, etc.

If the calculation of the specific CO_2 reduction cost yields a **negative value**, no compensation for the reduction of climate-relevant emissions would be required to make the project profitable (no-regret measure).

Results for step 27
→ Specific energy generation cost of biogas/biomass combustion plant [EUR-cent/kWh]
→ Specific CO_2-reduction cost [EUR/t CO_2-equiv.]

6.4 Excel application aid

An excel-based application aid is available that guides the user systematically through all decision steps and facilitates the application of the decision tree described in chapter 6.3. All tools, calculations and databases are integrated in the excel version. The application aid can be found attached to this handbook on CD-ROM or can be downloaded from www.biware.hs-bremen.de. Figure 6.4-1 and Figure 6.4-2 represent screenshots of the application aid.

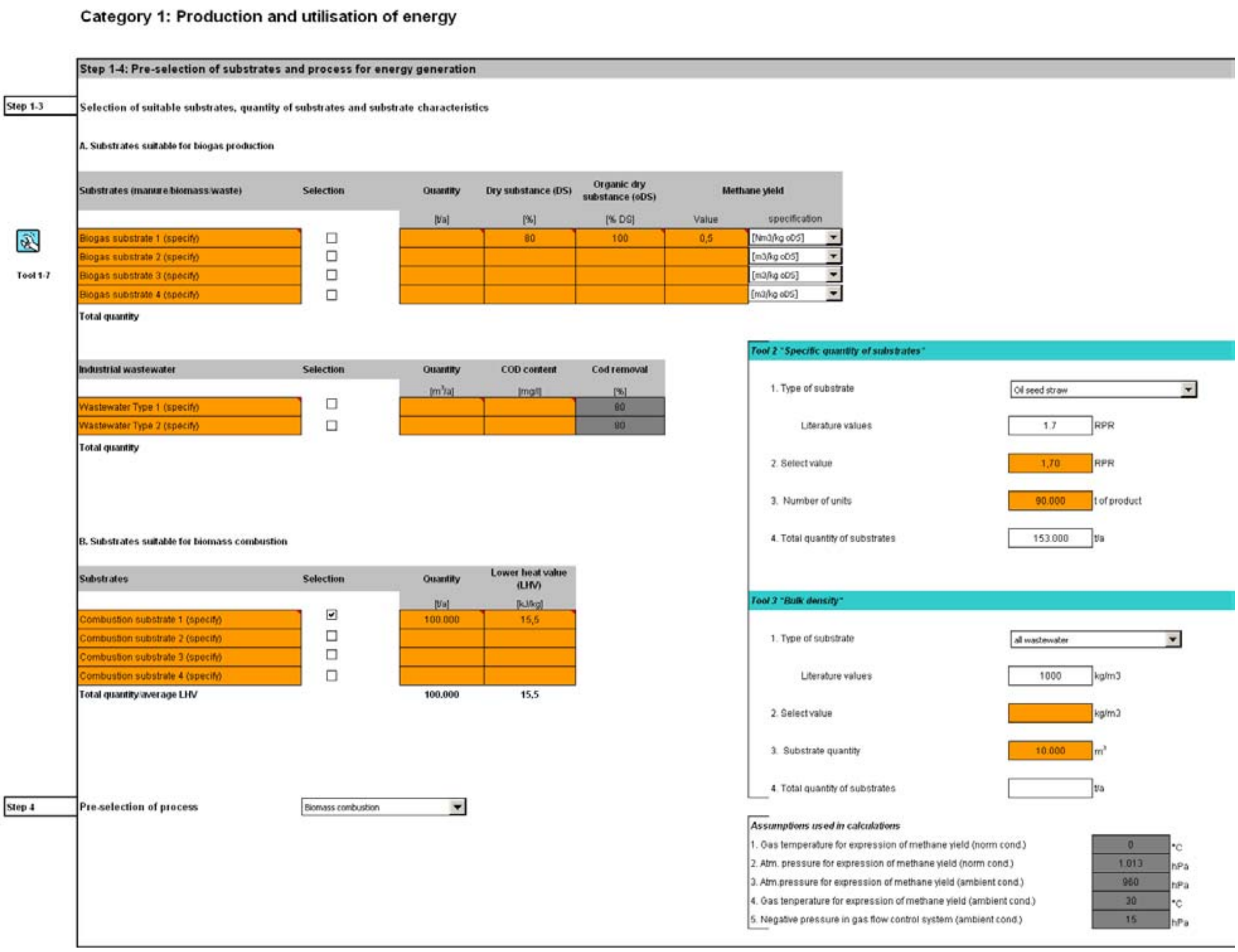

Figure 6.4-1: Excel-based application aid of the decision tree, exctract from Category 1: Production and utilisation of energy

Category 3: Socio-economic and environmental impact of the project

Step 16 and 17: Identification of relevant framework conditions related to renewable energy

Step 16 — **Identification of national policies, targets, strategies related to renewable energy**

A. Identification of government plans and targets related to renewable energy implementation

(please specify)

B. Identification of fiscal policy and support mechanism

(please specify)

Step 17 — **Identification of relevant laws and regulations in relation to renewable energy**

(please specify)

Step 18 and 19: Identification of stakeholders impact on the project

Step 18 — **Is there a strong support of the projects main stakeholders?**

A. Identification of major stakeholder groups

B. Estimate attitude and influence of identified stakeholders

List relevant stakeholders	Attitude/ support	Influence
(please list stakeholders)		
(please list stakeholders)		
(please list stakeholders)		
(please list stakeholders)		
(please list stakeholders)		
(please list stakeholders)		

Attitude:

++	strongly in favour
+	in favour
0	indifferent or undecided
-	weakly opposed
--	strongly opposed

Influence:

H	High (this person or group has power of veto)
M	Medium (Goals could probably be achieved against this person/group)
L	Low (This person/group can do little to influence the outcome of the intended actions)

Figure 6.4-2:Excel-based application aid of the decision tree- Extract from category 3: Socio-economic and environmental impact of the project.

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7 Case studies

7.1 Application of biogas process - Renewable energy for Phu Quoc island, Vietnam

7.1.1 Framework conditions for renewable energy production from organic substrates on Phu Quoc island

General

The island of *Phu Quoc*, *Kien Giang* province, South Vietnam, is the biggest island of Vietnam with a total area of 568 km² and 76.585 inhabitants. The two major cities on the island are the capital *Duong Dong*, located in the island's centre and the fisheries port *An Thoi* at the southern tip of the island. Recently great efforts are undertaken to promote eco-tourism (Decision 97/TTCP from the Prime Minister 2000). Thus the political aim is to **promote a sustainable development** and to "keep the island green".

The provincial government plans to develop *Phu Quoc* into one of the countries most exclusive tourist destinations. The anticipated steady rise in number of tourists and the resulting demographic increase will lead to considerable infrastructural developments. The annual growth of population is estimated at 15% over the next decade. Consequently, appropriate measures will be required to avoid adverse impacts on the environment.

Current energy supply system

The island is located approx. 30 km from the mainland. The option to connect the island's electricity system to the mainland electricity grid was abandoned, because it was found to be not economically feasible. It was rather decided to expand the existing diesel-based decentralised power generation facility. In 2004, a new power station was built and took up operation to complement the unreliable electricity production of the old generation system. The new power station, located approx. 8 km north of the island's capital, is equipped with two diesel-fuelled generators (genset) of 2,5 MW nominal electrical capacity each. In order to cover the increasing electricity demand, the commissioning of two additional generators is planned in 2005, resulting in a total installed electrical capacity of 10 MW. Currently, the demand for electricity is much higher than the supply, resulting in frequent power cuts. Therefore, the old generation site will be kept in operation until the demand can be covered by the new generators (Figure 7.1-1).

Figure 7.1-1: Power generation on Phu Quoc island: New power plant near the capital Duong Dong a-Diesel generators at the old generation site

In 2004, the total electricity production amounted to approximately 23 Mio kWh. Due to the anticipated demographic growth and development of the tourist and industrial sectors, it is foreseen that the electricity demand will increase with a constant pace in the future. In addition, the island's north will be linked up to the main grid network within the next couple of years resulting in a further increase in electricity demand.

The average tariff for end consumers connected to the island's grid network amounts to the equivalent of 7.2 EUR-cents/kWh. Taking into account the relatively high specific generation cost of diesel generators it is assumed that the long-term marginal costs are not covered by the current tariff. Consumer tariffs in remote areas without access to the island's grid network can be as high as 1 €/kWh. In those areas, electricity is produced by small-scale diesel generators or supplied by ice-making works. Supply of electricity is highly unreliable and only available at particular times of the day. An extension of the island's grid network to remote areas will lead to a considerable improvement of living standard rural residents (Figure 7.1-2).

Figure 7.1-2: Electricity transmission on Phu Quoc: The end of the grid network – Rural electrification in remote areas. A substantial part of the inhabitants only have access to expensive energy from small-scale diesel generators

Solid waste management

The household waste from the cities *Duong Dong* and *An Thoi* constitutes the major part of the island's total waste production. The daily waste generation in semi-urban areas can be estimated at 0,53 kg per capita. Taking into account the anticipated demographic growth, the annual quantity of household waste produced can be calculated to 15,5 million kg in 2005. In addition, approx. 1,5 million kg of food leftover and kitchen waste are produced annually in the major hotels and restaurants at the island's west coast.

At present, the waste collected is disposed off without prior treatment in an unmanaged disposal site located in the north of the island's capital (Figure 7.1-3). The current waste handling practice is leading to local environmental hazards such as rodents, smell and ground water pollutions. Furthermore, resulting uncontrolled emissions of methane (CH_4) have adverse environmental impacts on global climate change. The provincial government initiated plans to build a managed landfill in the island's north near to the locality of *Xa Bai Thom* within the next years. The introduction of environmental sound waste handling practices is ranked high on the agenda of local as well as regional politicians, who want to promote eco tourism. Initiatives in the field of waste management will be boosted by the perceived urgent need to improve the island's environmental conditions.

Figure 7.1-3: Current practice of uncontrolled waste dumping – Planned area for new managed waste disposal site in the island's north

Demand for fertilizer

Agriculture plays a vital role in Phu Quoc's economy. The area under cultivation amounts to 860 ha for pepper plantations, 1.000 ha for fruit trees, 200 ha for vegetables, 570 ha for cashew nuts and 270 ha for coconut trees (Figure 7.1-4). The extensive agricultural activity of the island is leading to a high demand for fertiliser. Besides livestock manure, a great amount of conventional mineral fertiliser is used to cover the demand.

Figure 7.1-4: Pepper plantations on Phu Quoc

Attitude of market actors and stakeholders

Interviews in a participatory workshop held in December 2004 revealed that both, the provincial government of *Kien Giang* as well as the local government of *Phu Quoc* highly support the introduction of renewable energy and waste treatment technologies on the island. The establishment of environmental sound practices in the field of energy production and waste management is regarded crucial to ensure a future sustainable development.

The responsibility for production, distribution and sale of electricity on Phu Quoc lies with the Power Company 2 *in Kien Giang* Province, a regional subsidiary of the national state-owned utility Electricity of Vietnam (EVN). The initiative to complement the island's electricity system with renewable energy technologies was received well by the Power Company 2.

Project concept

The framework conditions on the island of *Phu Quoc* were found to be very favourable for the application of renewable energy by biogas processes. The prevailing relatively high electricity tariff (compared to 5,1 EUR-cents/kWh on the mainland) is expected to provide attractive returns for the project. The production of bio-fertiliser will result in additional revenue that further improves the project profitability. As side benefit, the problems related to the current waste handling practices will be addressed leading to a considerable improvement of local environmental conditions. This combined and integrated approach is in line with the development goals set by the local and regional governments, and the project will thus receive support from all relevant project stakeholders.

Comprehensive on-site investigations were carried out in order to identify the most suitable location for the biogas project. By considering both, energy and waste-related factors, the location near the new *Phu Quoc* power station was selected as the most promising site for the project (Figure 7.1-5).

Figure 7.1-5:Selected site for the biogas plant next to the new power station near to the capital Duong Dong (extract of map of Phu Quoc)

The household waste collected in the cities *An Thoi* and *Duong Dong* was selected as main feedstock for the biogas system. The solid waste is characterised by a relatively high organic content that makes it a suitable substrate for biogas processes.

Based on the average dry substance content of the substrate that amounts to approx. 50%, a dry fermentation process was selected as main process type. In general, dry fermentation systems enable the processing of substrates such as household waste without prior treatment or separation. During processing in the biogas system, the organic substance of the substrate is degraded into biogas.

Different utilisation paths for the biogas produced were evaluated in relation to their effectiveness and practicability. The generation of electricity in a biogas engine and feeding the produced electricity into the island's grid network has been evaluated as most promising option.

The residues obtained after processing the waste in the biogas system are stabilised and problems inherent in untreated waste such as smell, spreading of pathogens etc. have been minimised to a large extend. Residues can be refined further in a down-stream composting process in order to produce a high quality raw material fertiliser that can be applied to agriculture. Separation of interfering matter can implemented in a screening process. Interfering matter is to be disposed of in the landfill.

A flow chart for a possible plant concept is shown in Figure 7.1-6.

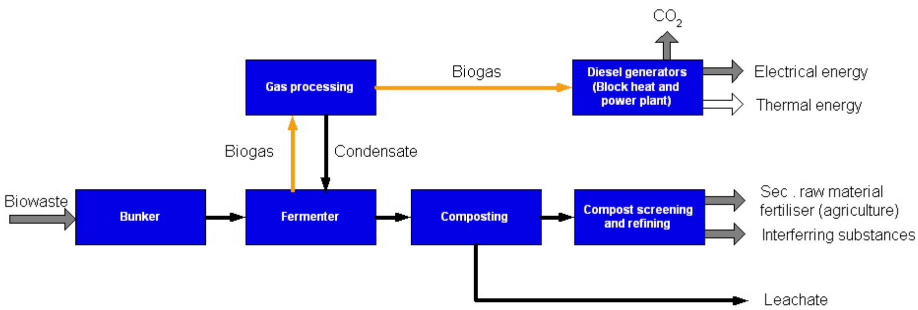


Figure 7.1-6: Flow chart of the plant concept for the biogas plant (dry fermentation process)

7.1.2 Results from application of the decision tree to selected case study in Vietnam

The decision tree has been applied to the case study on Phu Quoc island in order to verify the biogas component of the developed system. The result-sheet of the excel-based application aid for the selected case study is presented in the following figures (see Figure 7.1-7 to Figure 7.1-12).

7.1.2.1 Category 1 - Energy production and utilisation

'BiWaRE- Biomass and Waste for Renewable Energy'

Result Summary sheet

- Decision-Making for a biogas or biomass combustion project -

Project idea	Renewable energy production and waste management by biogas processes on Phu Quoc island, Vietnam
Author	BIWARE-team (BUAS)
Date	June 2005

Category 1: Energy production and utilisation

Step 1-4: Pre-selection of substrates and process for energy generation

Step 1-3 **Selected substrates, substrate quantity and characteristics**

Type of substrate	Quantity [t/a]	Dry substance [%]	Organic dry substance [% of DS]	Specific methane yield	
Household waste, Phu Quoc (Vietnam)	15.500	35	80	0,25	[Nm3 CH4/kg oDS]
Total quantity	**15.500**				

Step 4 **Pre-selection of process** **Biogas process (solid substrates)**

Step 5: Energy content of substrates

Step 5

Type of substrate	Energy content [kWh/a]
Household waste, Phu Quoc (Vietnam)	9.119.523
Total energy content	**9.119.523** kWh/a

Step 6: Determination of usable energy production

Step 6 **A. Production of electrical energy**

Electrical energy **3.032.241** kWh/a

B. Production of thermal energy

Thermal energy (hot water) **4.559.761** kWh/a

C. Production of biogas **9.119.523** kWh/a

Figure 7.1-7: Result sheet of the excel-based application aid for the selected case study on Phu Quoc island, Vietnam – Category 1: Decision step 1 - 6

Step 7-9: Current energy supply system, energy demand and utilisation of the produced energy

Step 7

A. Characteristics of current energy supply system

Decentralised diesel fueled power generation. Two units (2,5 MW each) are operated in the new Phu Quoc power plant near the capital Duong Dong; the old power station is still in operation. Electricity is transmitted at 15kV level via overhead grid network.

B. Integration of renewable energy system into current energy supply system

The electricity produced can be fed into the island's grid network. Another option is to directly utilised the biogas produced in the existing diesel engines. This co-firing of biogas can be considered a technical feasible option.

Step 8-9

A. Specified energy demand

Type of energy	kWh/a	
Electrical energy	not specifiable	--> Surplus electricity will be supplied to the electrical grid-network
Thermal energy (steam)		
Thermal energy (hot water)		
Fuel (biogas)		

B. Comparison of energy demand with energy production, pre-selected energy utilisation path

Type of energy	Comparison of production and demand	Utilisation [% of production]	Utilisation path
Electrical energy	grid network	full utilisation	Feed-into grid, Phu Quoc
Thermal energy	-	- no utilisation -	-
Biogas	-	- no utilisation -	-

Step 10: Determination of substitution ratio of conventional energy by renewable energy

Step 10

Type of energy	Substitution ratio [%]	Reference level
Electrical	13%	Electricity generation Phu Quoc (2005)
Thermal (hot water)	-	-
Thermal (steam)	-	-
Biogas	-	-

Figure 7.1-8: Result sheet of the excel-based application aid for the selected case study on Phu Quoc island, Vietnam – Category 1: Decision step 7 - 10

7.1.2.2 Category 2 – Pre-dimensioning

Step 11: Determination of nominal electrical capacity (rated power) or firing thermal capacity of energy generation system

Step			
Step 11	**A. Availability of energy system**		
	Annual operating hours	8.000	h/a
	Capacity factor	91	%
	B. Nominal capacity of energy generation system (rated power/firing thermal capacity)		
	Nominal electrical capacity (rated power)	399	kW el

Step 12: Determination of main process design specifications

Step			
Step 12	Pre-selection of process type	**Dry fermentation process**	
	Calculation of digester capacity (incl. freeboard)	5.662	m3
	Organic loading of digester	2,33	kg/oDS/(m3*d)
	Fuel oil consumption	no demand	l/a
	Estimated land requirements	5.000	m2
	Motor type in CHP plant	**Gas engine**	
	Feedstock sanitation	**No requirement for feedstock sanitation**	

Step 13 -15: Utilisation/Disposal of residues generated

Step			
Step 13	**Generation of residues**		
	Residues generated	13.330	t/a
Step 14	**Residue utilisation**		
	General suitability for utilisation	**Disposal of residues required**	
Step 15	**Disposal of residues**		
	Quantity of residues for disposal	13.330	t/a
	Disposal option	**Unmanaged disposal site -deep (>5m waste)**	

Figure 7.1-9: Result sheet of the excel-based application aid for the selected case study on Phu Quoc island, Vietnam – Category 2: Decision step 11 - 15

7.1.2.3 Category 3- Influence of framework conditions

Figure 7.1-10: Result sheet of the excel-based application aid for the selected case study on Phu Quoc island, Vietnam – Category 3: Decision step 16 – 19

Category 3: Influence of framework conditions

Step 16 and 17: Identification of relevant framework conditions related to renewable energy

Step 16 **A. Identification of government plans and targets related to renewable energy implementation**

Several government policies support the application of renewable energy technologies in Vietnam. The Renewable energy action Plan (REAP), and other policies directly encourage the implementation of renewable energy technologies.

B. Identification of fiscal policy and support mechanism

Reduced import taxes apply for all kinds of renewable energy technologies.

Step 17 **Identification of laws and regulations**

A new power sector law is currently drafted in Vietnam which has the particular purpose of defining the conditions for competition in production and trade of electricity. With Decision No. 22 in 1999, the Vietnames government established the first policy framework for using renewable energies for power generation and rural electrification. A government ordinance (Decree No. 95/2001/QD-Ttg) in June 2001 gave foreign investors the opportunity to acquire financial interests in the power generation sector.

Step 18 and 19: Identification of stakeholders impact on the project

Step 18 **Attitude and influence of project stakeholders**

Identified stakeholders	Attitude	Influence
Local government of Phu Quoc Island	strongly in favour	High influence
Government of province of Kein Giang	in favour	High influence
Subsidiary of EVN, Phu Quoc Island	in favour	Medium influence
Power Company 2 in HCMC, regional subsidiary of EVN	indifferent or undecided	Low influence
EVN headquarter, Hanoi	indifferent or undecided	High influence
Island's residents, direct neighbours to planned facility	strongly in favour	Low influence

Step 19 **Getting the support of critical stakeholders**

Identified critical/crucial stakeholder	Means to the get the support of critical stakeholders	Possibility to get support
EVN, Hanoi	Discuss possible problems related to application of RE	medium probability
Government of province of Kein Giang	Clarify benefits of project/with regard to sustainable devel.	medium probability
(please list critical stakeholders)	(please specify)	(please specify)

7.1.2.4 Category 4 – Project impact

Figure 7.1-11: Result sheet of the excel-based application aid for the selected case study on Phu Quoc island, Vietnam – Category 4: Decision step 20 – 22

Category 4: Project impact

Step 20: Determination of the overall socio-economic impact of the project

Step 20 **A. Direct local effects on employment, health conditions and poverty alleviation**

The current waste management practices are directly impacting the health condition of the island residents. Thus, the introduction of waste managemant system will result in considerable improvement of living conditions on the island. Furthermore, the ever growing demand for electricity will be partly covered by environmentally sound renewable engery production. Electricity that is utilised fpr producitve uses will directly foster the socio-economic development of the island.

B. Overall influence on the regional socio-economic development

Category	Impact assessment
Basic needs	The renewable energy project will facilitate access to a reliable energy service for many of the island's inhabitents (particularly in the island's north)
Income generation opportunities	The renewable energy/waste management project will directly generate jobs for operation and maintenance of the facilities. Furthermore, the gneral socio-economic development of the island's north will be fostered.
Gender	The main responsibility for collection and handling of waste lies with the women. The negative impacts caused by the current inappropriate waste handling practices wil be reduced considerably by project implementation --> improvment of women's situation.
Land use competition and land tenure	There won't be any impact by the project on this category

Step 21 and 22: Determination of environmental impacts caused by the project

Step 21 **A. Determination of the local/regional environmental impacts caused by the project**

Impact categories	Rating	Comments
Direct local environmental impacts		
Air	considerable positive impact	Reduction of air pollution from combustion of fossil fuels
Soil	considerable positive impact	Soil contamination (landfill) / improvement of soil quality (fertiliser)
Water	positive impact	Reduction of leachate form unmanged treatment of waste (landfill)
Noise	no impact	Noise reduction in power generation but increase in transportation
Smell	positive impact	Reduction in smell from unappropriate waste handling
Regional environmental impacts		
Deforestation	no impact	The project will not cause any impact of deforestation
Acid rain	positive impact	Fossil fiels will be replaced by biogas --> reduction in acid rain

Step 22 **B. Determination of the global environmental impacts caused by the project**

Climate relevant impacts caused by the baseline for energy production	3.202	t CO_2-equiv./a
Climate relevant impacts caused by the baseline for substrate disposal	20.051	t CO_2-equiv./a
Climate relevant impacts caused by the project	6.510	t CO_2-equiv./a
Project's overall reduction in climate relevant impacts	**16.743**	t CO_2-equiv./a

Category 5 – Project economics

Step 23: Financing/Identification of subsidies for the project

Step 23

A. Investment grant (reduces investment)

30% of the total investment costs will be covered by a grant

B. Other types of subsidies (e.g. subsidiesed feed-in tariff, etc.)

There will be no specific feed-in tariff for renewable energy-based electricity production, that is fed into the island's grid network. The average price for independent power producer (IPP) is 4 EUR-cent/kWh. The project can generally be accredited as CDM project and thus receive additional revenue for the reduction of CO2-emissions. In order to incorporate the potential revenue, an average price for emissions reductions of 5EUR/t CO2 is applied.

Step 24-25 : Project costs and revenues

Step 24

Project costs

Total investment cost for the project	2.597.354	EUR
Total consumption-related coss	-	EUR/a
Total operation-related costs	93.022	EUR/a
Other costs (insurance, etc.)	12.987	EUR/a

Step 25

Project revenues

Total revenue from energy production	303.224	EUR/a
Total revenue from utilisation of residues	-	EUR/a
Potential CDM revenue (reduction of CO2-emissions	83.714	EUR/a
Other revenues	-	EUR/a

Key input parameters

Feed-in tariff for electrical energy	10	EUR-cent/kWh
Revenue for steam	-	EUR-cent/kWh
Revenue for supply of hot water	-	EUR-cent/kWh
Revenue for supply of biogas	-	EUR-cent/kWh
Revenue for fertiliser	-	EUR/t
Revenue for aceptance of substrate	2	EUR/t

Step 26 -27: Profitability analysis

A. Main assumptions

Investment grant	30	% of investment
Total investment grant	779.206	EUR
Total investment (reduced by grant)	1.818.148	EUR
Imputed interest rate	4	%

B. Fixed costs (capital related costs)

Annual depreciation	106.059	EUR/a
Annual interest charges	36.363	EUR/a

C. Project profitability

Total annual profit/deficit (before tax)	**138.508**	EUR/a
Return on assets	**9,6**	EUR/a
Project cash flow	**244.567**	EUR/a
Payback time (simple)	**7,43**	a

D. Impact of CDM

--> Potential impact of CDM is considered in profitability analysis

Considered price for CERs	5	EUR/t CO2

Step 29: Calculation of specific energy generation costs and specific investment costs for reduction of CO_2-emissions

A. Specific energy genration cost

Specific energy generation cost	**9,70**	EUR-cent/kWh

B. Specific investment cost for reduction of CO2-emissions

Specific investment cost for CO2-reduction	**5**	EUR/t CO2

Figure 7.1-12: Result sheet of the excel-based application aid for the selected case study on Phu Quoc island, Vietnam – Category 5: Decision step 23 - 28

7.2 Application of biomass combustion process – Biomass-based power generation in the Palm oil industry

7.2.1 Framework conditions for renewable energy production in the palm oil industry in southern Thailand

In Thailand, palm oil is produced in large quatities (200,000 t per annum) in 30 palm oil mills (16 large mills), which have an average milling capacity of over 10 tons of fresh fruit bunches (FFB) per hour [Pressea]. Most of the palm oil mills are located in the southern provinces of Thailand (see Figure 7.2-2).

Figure 7.2-1: Generation of empty fruit bunches (EFB) in the palm oil industry

Residues generated during the milling process are fibres, shells and empty fruit bunches (EFB). Fibres and shells are partly utilised to co-generate heat and power for internal consumption in the palm oil mills. EFB are currently used as mulch in the palm oil plantations or disposed of by open burning. The use of EFB for renewable energy production is limited to very sporadic applications so far.

7.2.2 Project concept

The southern Thai province of Surat Thani has been selected as location for biomass based renewable energy production in the palm oil milling industry. Empty fruit bunches produced in a mill with an average milling capacity with 10 tons of FFB per hour has been selected as substrate for the biomass combustion plant. Figure 7.2-2 shows the location of the palm oil mill that has been selected as case study.

Figure 7.2-2:Location of the biomass combustion facility in southern Thailand

The biomass plant is operated in co-generation mode. Heat generated is partly used internally for the process requirements of the mills whereas surplus electrical energy is fed into the national grid. Thereby, this renewable energy project will make a considerable contribution to satisfy the ever-growing electricity demand in the surrounding area.

Currently, approx. 30% of the EFB is used as mulch in the palm oil plantations and the use as fuel amounts to less than 5% [BIWARE, 2004]. The ash generated in the combustion process can be applied as secondary raw material fertiliser to e.g. agriculture.

A conventional but specifically designed water tube boiler is used to co-generate electricity in a steam turbine generator. The boiler is operated at a medium pressure of 40 bar. Condensing steam turbines with extraction of process steam are used. The estimated economic life of the plant is about 20 years.

Utilizing EFB in the boiler can create combustion problems because of the moisture content of the fuel (60 – 65 %), its fibrous nature and amount of soluble alkalis within it. In order to achieve a self-sustained combustion process, the moisture content need to be reduced to 20% in a prior drying process (waste heat from the flue air is used for the drying process). A shredder is used to chop the bunches and adjust the required fuel characteristics. The flue gases are cleaned up in a multi cyclone system [BIWARE, 2004].

The main fuel characteristics of empty fruit bunches (EFB) generated in the palm oil industry are summarized in the following table:

Table 7.2-1: Fuel characteristics of EFB in the palm oil industry

Parameter	Unit	Value
Moisture (wet basis)	%	65
Ash content	%	6 - 8
Heat value (wet basis)	KJ/kg	7.000 –9.000

Table 7.2-1gives an overview about a possible machinery formation for the biomass co-generation project in the palm oil industry.

Machinery	Description
Storage buildings	The prepared material can be stored in a silo or underground store room in order to achieve a high weather protection
Shredder	Chopping of EFB in order to adjust the required fuel characteristics
Ventilate drying with heated air	Utilisation of waste hear for the drying process (By active processes mostly belt-, rotary- or flash dryers)
Discharge screw or similar hoisting and conveying engineering's	Feeding of materials into the combustion system
Fixed-bed combustion process (Underfeed stoker) and water tube boiler system	Biomass is fed into the combustion system by a discharge screw (automatic feeding process). Steam is generated in the boiler system
Condensation steam turbine	Generation of electrical energy and extraction of process steam
(Multi-) cyclone	Cleaning of flue gases - bottom and cyclone fly-ash is generated
Other exhaust cleaning systems can be applied if deemed necessary	e.g. filter fly ash precipitator

Table 7.2-2: Machinery formation of the biomass combustion plant in the palm oil industry

The surplus electricity generated is fed into the national grid network. The feed-in tariff for renewable energy production in Thailand is 1,72 EUR-cent/kWh [BIWARE, 2004]

7.2.3 Results from application of the decision tree to selected case study in Vietnam

The decision tree has been applied to the selected case study in Thailand in order to verify the biomass combustion component of the developed decision support system.

The result-sheet of the excel-based application aid for the case study is presented in the following figures (see Figure 7.2-3 to Figure 7.2-8).

7.2.3.1 Category 1 - Energy production and utilisation

'BiWaRE- Biomass and Waste for Renewable Energy'

Result Summary sheet

- Decision-Making for a biogas or biomass combustion project -

Project idea	Biomass-based co-generation in the Thai palm oil industry (Surat Thani Province)
Author	BIWARE-team (TUD/BUAS)
Date	June 2005

Category 1: Energy production and utilisation

Step 1-4: Pre-selection of substrates and process for energy generation

Step 1-3 **Selected substrates, substrate quantity and characteristics**

Type of substrate	Quantity [t/a]	Lower heat value [MJ/kg]
Empty fruit bunches (Palm oil industry)	32.000	8
Total quantity	**32.000**	

Step 4 **Pre-selection of process** **Biomass combustion**

Step 5: Energy content of substrates

Step 5

Type of substrate	Energy content [kWh/a]
Empty fruit bunches (Palm oil industry)	71.111.111
Total energy content	**71.111.111** kWh/a

Step 6: Determination of usable energy production

Step 6 **A. Production of electrical energy**

Electric power plant (mode 1)	**13.084.444**	kWh/a
Electricity controlled CHP-plant (mode 2)	**9.528.889**	kWh/a
Heat controlled CHP-plant (mode 3)	**5.973.333**	kWh/a

B. Production of thermal energy

Electricity controlled CHP-plant (mode 2)	**42.666.667**	kWh/a
Heat controlled CHP-plant (mode 3)	**46.222.222**	kWh/a
Heat plant (mode 4)	**60.444.444**	kWh/a

Figure 7.2-3: Result sheet of the excel-based application aid for the selected case study in the palm oil industry, southern Thailand – Category 1: Decision step 1 - 6

Step 7-9: Current energy supply system, energy demand and utilisation of the produced energy

Step 7

A. Characteristics of current energy supply system

Grid connection is the most common form of electricity supply in the region. Electricity demanded for process requirements in the palm oil mill is produced by a biomass fired generator system (use of shells and fibres). The palm oil mill is connected to the national grid network.

B. Integration of renewable energy system into current energy supply system

The electricity produced in the biomass-based renewable energy project is partly utilised in the palm oil mill for internal process requirements. Surplus energy produced is fed into the national grid network. Since the palm oil mill is already connected the the grid network, the integration of the biomass project is considered feasible.

Step 8-9

A. Specified energy demand

Type of energy	kWh/a	
Electrical energy	not specifiable	--> Surplus electricity will be supplied to the electrical grid-network
Thermal energy (steam)	11.984.000	
Thermal energy (hot water)		
Fuel (biogas)		

B. Comparison of energy demand with energy production, pre-selected energy utilisation path

Type of energy	Comparison of production and demand	Utilisation [% of production]	Utilisation path
Electrical energy	grid network	full utilisation	Feed into national grid network+own use
Thermal energy	production > demand	28	Feed into national grid network+own use
	-		

Selected operational mode **Electricity controlled CHP-plant (mode 2)**

Step 10: Determination of substitution ratio of conventional energy by renewable energy

Step 10

Type of energy	Substitution ratio [%]	Reference level
Electrical	2%	Electricity demand in the province
Thermal (hot water)	-	-
Thermal (steam)	30%	Total demand of the palm oil mill
Biogas	-	-

Figure 7.2-4: Result sheet of the excel-based application aid for the selected case study in the palm oil industry, southern Thailand – Category 1: Decision step 7 - 10

7.2.3.2 Category 2 – Pre-dimensioning

	Step 11: Determination of nominal electrical capacity (rated power) or firing thermal capacity of energy generation system		
Step 11	**A. Availability of energy system**		
	Annual operating hours	7.500	h/a
	Capacity factor	86	%
	B. Nominal capacity of energy generation system (rated power/firing thermal capacity)		
	Nominal thermal capacity	1.422	kW

	Step 12: Determination of main process design specifications		
Step 12	Pre-selection of combustion system	**Grate furnace**	
	Estimated land requirements	2.000	m2

	Step 13 -15: Utilisation/Disposal of residues generated		
Step 13	**Generation of residues**		
	Quantity of bottom ash generated	1.152	t/a
	Quantity of fly ash generated	768	t/a
Step 14	**Residue utilisation**		
	General suitability for utilisation	**Utilisation of bottom/cyclone ash possible**	
	Specify utilisation path	**Utilisation of fertiliser --> palm oil plant.**	
	Utilisation ratio	52	%
Step 15	**Disposal of residues**		
	Quantity of residues for disposal	1.320	t/a
	Specify disposal route	**Landfilling --> managed landfill**	

Figure 7.2-5: Result sheet of the excel-based application aid for the selected case study in the palm oil industry, southern Thailand – Category 2: Decision step 11 - 15

7.2.3.3 Category 3- Influence of framework conditions

Category 3: Influence of framework conditions

Step 16 and 17: Identification of relevant framework conditions related to renewable energy

Step 16 **A. Identification of government plans and targets related to renewable energy implementation**

Eighth NESDP (1997 - 2001) - promotion of biomass utilization in Small Power Producers (SPP); The Ninth NESDP (2002-2006) - promote on research & development of renewable energy, Thai govenment set target to increase the share of renewable energy from the present level of 0,5% to 8% by the year 2011

B. Identification of fiscal policy and support mechanism

A reduced import tax applies for renewable energy technologies

Step 17 **Identification of laws and regulations**

In Thailand, net metering applies for renewable energy-based power production.

Step 18 and 19: Identification of stakeholders impact on the project

Step 18 **Attitude and influence of project stakeholders**

Identified stakeholders	Attitude	Influence
Owner of the palm oil company	weakly opposed	High influence
Electricity Generation Authority of Thailand (EGAT)	indifferent or undecided	High influence
Local government	in favour	Medium influence
Provincial government of Surat Thani	in favour	Low influence
Residents sorounding the palm oil mill	strongly in favour	Low influence
(please specify)		

Step 19 **Getting the support of critical stakeholders**

Identified critical/crucial stakeholder	Means to the get the support of critical stakeholders	Possibility to get support
Owner of the palm oil mill	Clarify benefits of the project in relation to the core business	medium probability
Electricity generation authority	Clarify role of RE, possibilities of integration into grid network	high probability
(Please specify)	(Please specify)	(Please specify)

Figure 7.2-6: Result sheet of the excel-based application aid for the selected case study in the palm oil industry, southern Thailand – Category 3: Decision step 16 - 19

7.2.3.4 Category 4 – Project impact

Step 20: Determination of the overall socio-economic impact of the project

Step 20

A. Direct local effects on employment, health conditions and poverty alleviation

The current practice of open burning of produced empty fruit bunches (EFB) results in negative health impacts of the sorounding residents. Thus, the biomass co-generation project will lead to a considerable improvement of the local health condition. Furthermore, several jobs will be generated by the project (medium and high skilled workers)

B. Overall influence on the regional socio-economic development

Category	Impact assessment
Basic needs	The project exemplarily demonstrates, how electricity can be provided in an environmentally sound and sustainable way (--> concept of waste to energy). It can be expected that new projects are initiated by this demonstration plant
Income generation opportunities	The biomass combustion project can be regarded as show-case for a new business opportunity in the palm oil industry. The regional socio-economic development will benefit from this approach.
Gender	The project won't have a direct impact on gender issues
Land use competition and land tenure	The project won't have a direct impact on land use competition and land tenure

Step 21 and 22: Determination of environmental impacts caused by the project

Step 21

A. Determination of the local/regional environmental impacts caused by the project

Impact categories	Rating	Comments
Direct local environmental impacts		
Air	considerable positive impact	Reduction of air pollution from open burning of EFB
Soil	positive impact	Ash will be utilised as fertiliser, improved fertiliser application
Water	no impact	No impact on water could be identified
Noise	no impact	The project does not result in any direct impacts
Smell	no impact	The project does not results in any direct impacts
Regional environmental impacts		
Deforestation	no impact	The project will not cause any impact on deforestation
Acid rain	considerable positive impact	The biomass-based power production will substitute fossil fuels

Step 22

B. Determination of the global environmental impacts caused by the project

Climate relevant impacts caused by the baseline for energy production	6.584	t CO_2-equiv./a
Climate relevant impacts caused by the baseline for substrate disposal		t CO_2-equiv./a
Climate relevant impacts caused by the project		t CO_2-equiv./a
Project's overall reduction in climate relevant impacts	**6.584**	t CO_2-equiv./a

Figure 7.2-7 Result sheet of the excel-based application aid for the selected case study in the palm oil industry, southern Thailand – Category 4: Decision step 20 - 22

7.2.3.5 Category 5 – Project economics

Step 23: Financing/Identification of subsidies for the project

Step 23 | **A. Investment grant (reduces investment)**

15% of the total investment costs will be covered by a grant

B. Other types of subsidies (e.g. subsidiesed feed-in tariff, etc.)

The feed- in tariff for renewable energy-based electricity generation amounts to 1,72 EUR-cent/kWh (national grid network in Thailand). The project can generatlly be considered eligible as project under the Clean Development Mechanism (CDM) of the Kyoto Protocoll. The current market price of 5 EUR/t CO2 reduced can be applied to estimate the potential additional revenue obtained through the reduction of climate-relevant emissions.

Step 24-25 : Project costs and revenues

Step 24 | **Project costs**

Total investment cost for the project	5.251.667	EUR
Total consumption-related coss	-	EUR/a
Total operation-related costs	98.045	EUR/a
Other costs (insurance, etc.)	26.258	EUR/a

Step 25 | **Project revenues**

Total revenue from energy production	283.737	EUR/a
Total revenue from utilisation of residues	1.200	EUR/a
Potential CDM revenue (reduction of CO2-emissions	32.922	EUR/a
Other revenues	-	EUR/a

Key input parameters

Feed-in tariff for electrical energy	1,72	EUR-cent/kWh
Revenue for steam	0,01	EUR-cent/kWh
Revenue for supply of hot water	-	EUR-cent/kWh
Revenue for supply of biogas	-	EUR-cent/kWh
Revenue for fertiliser	2	EUR/t
Revenue for aceptance of substrate	-	EUR/t

Step 26 -27: Profitability analysis

A. Main assumptions

Investment grant	30	% of investment
Total investment grant	1.575.500	EUR
Total investment (reduced by grant)	3.676.167	EUR
Imputed interest rate	4	%

B. Fixed costs (capital related costs)

Annual depreciation	186.999	EUR/a
Annual interest charges	73.873	EUR/a

C. Project profitability

Total annual profit/deficit (before tax)	**-67.316**	EUR/a
Return on assets	-	EUR/a
Project cash flow	-	EUR/a
Payback time (simple)	-	a

D. Impact of CDM

--> Potential impact of CDM is considered in profitability analysis

Considered price for CERs	5	EUR/t CO2

Step 29: Calculation of specific energy generation costs and specific investment costs for reduction of CO_2-emissions

A. Specific energy genration cost

Specific energy generation cost	**4,66**	EUR-cent/kWh

B. Specific investment cost for reduction of CO2-emissions

Specific investment cost for CO2-reduction	**38**	EUR/t CO2

Figure 7.2-8: Result sheet of the excel-based application aid for the selected case study in the palm oil industry, southern Thailand – Category 5: Decision step 23 - 28

8 Examples of plants for renewable energy production from organic substrates

8.1 State of the art of biogas plants

8.1.1 Biogas plants in Thailand

Table 8.1-1: Overview over selected biogas plants in Thailand

Industry	No	Name of Company	Location, Region	Process	Operation since
Tapioca starch	1	Sa-nguan Wong Co., Ltd.	Nakorn Ratchsima Province, Northeast	Anerobic buffle Reactor, Mesophilic	2003
	2	National Starch and Chemical, Co. Ltd.	Kalasin Province, Northeast	UASB, Mesophilic	1996
	1	Thai Prasit Starch, Co. Ltd.		UASB, Mesophilic	2004
	1	Thai wa, Co. Ltd.	Rayong Province, East	Anerobic buffle Reactor, Mesophilic	1999
	1	General starch, Co. Ltd.		UASB, Mesophilic	2004
	1	Sumpalung Pattana, Co. Ltd.	Rayong Province, East	Plug flow 6000 m3	
	1	Chokechai Starch, Co. Ltd.	Uthai thani Province, Central Region	UASB	2004
	1	Chao Khun Kaset Pudpon, Co. Ltd.	Saraburi Province, Central Region	Anerobic buffle Reactor, Mesophilic	
Rice Starch	1	Chau Heng, Co. Ltd.	Nakorn Pratom Province, Central Region	UASB,Mesophilic	2000
	1	Bangkok InterFood, Co. Ltd.	Nakorn Pratom Province, Central Region	Anaerobic Fixed Film Reactor, Mesophilic, size 5200 m3	2000
Brewery	1	Boonrod Brewery, Co. Ltd.	Khonkaen Province, Northeast	UASB, Mesophilic	1994
Alcoholic Beverages	12	Surathip Group, Co. Ltd.		UASB, Mesophilic	1984
		Beer Thai, Co. Ltd.		UASB	1998
Frozen Seafood/ Canned food	5	Tropical Canning Group; Thai Union frozen food		UASB, Mesophilic	
	1	Siam Food, Co. Ltd.	Chonburi, East	UASB, Mesophilic	
	1	See-Ong-Hong	Ratchburi Province, Central Region	Anaerobic Fixed Film Reactor, Mesophilic	2004
Oil Palm	1	Asian Plam oil, Co. Ltd.	Krabi province, South	CSTR, Mesophilic	2000
Swine Farm	20	Large and Medium scale	Central Plain and East	Plug flow + UASB	1996
	1	Farm CP		Cover Lagoon	2002
Petro chemical	1	TunTex	East	UASB,Mesophilic treating PET WW	1999
Slaughter House	1	Pitsanulok Province	Pitsanulok Province, North	Plug flow + UASB	2001
Soda and beverages	1	Greenspot, Surat Thani	Patumthani Province, Central Region	Anaerobic Fixed Film Reactor, Mesophillic, size 11,840 and 5,040 m3	
	2	Sermsuk		UASB	

8.1.2 Biogas plants in Vietnam

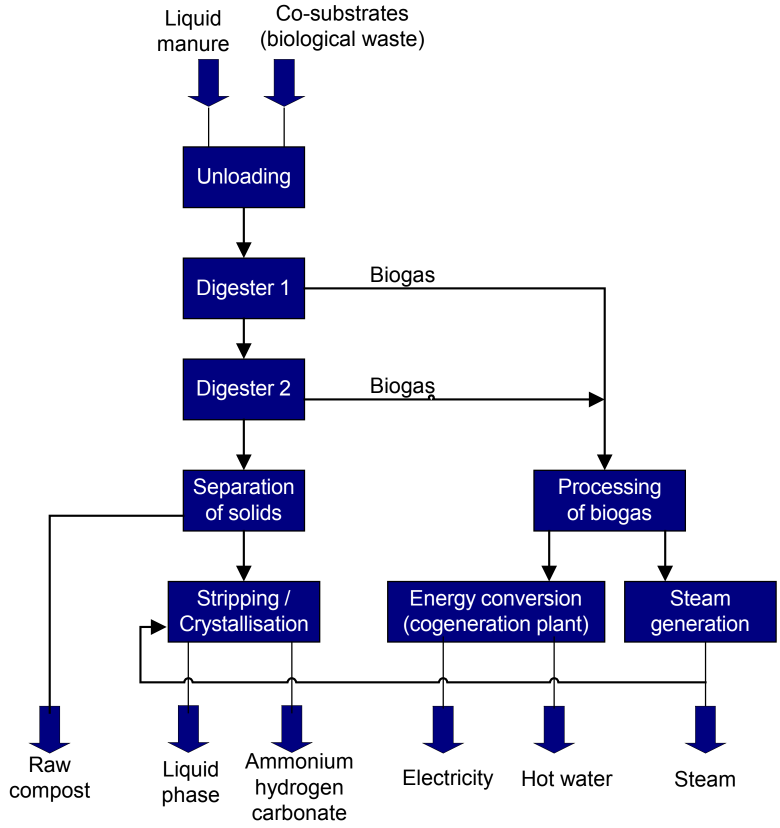
Application of biogas in Vietnam has been limited to small-scale household systems so far. There are only very sporadic applications of larger biogas plants, e.g. treatment of effluent in the sugar industry/distilleries.

8.1.3 Biogas plants in Germany

8.1.3.1 Biogas plant Finsterwalde, Germany (Schwarting-Uhde process)

Region, city	State of Brandenburg, Finsterwalde
Address	Drößinger Straße 23, 03238 Finsterwalde, Germany
Manufacturer	Schwarting Umwelt GmbH Lise-Meitner-Str. 2 D-24941 Flensburg Tel. +49 (0) 461-9992-121 Fax +49 (0) 461-9992-101 http://www.schwarting-umwelt.de Company ist currently re-organised
Operated by	Biokraft Finsterwalde GmbH & Co. KG (formerly: Bioreststoff Recycling Produktions- und Handels GmbH Finsterwalde) Drößiger Str. 23 03238 Finsterwalde Tel. 03531-600-690 Fax 03531-600-691
In operation since	1996
Process type/process characteristics	This plant uses the two-step SCHWARTING-UHDE-process running in an upright installed plug-flow fermenter with moderate agitation/mixing intervalls. Both the initial hydrolysis and the subsequent methanisation step occur at 55°C, though the plant concept also allows mesophilic hydrolysis. The post-treatment of substrates comprises dewatering, composting and separation of ammonia (crystallisation as ammonium hydrogencarbonate, used as fertiliser).
Tape of substrate utilised	Up to 68% liquid manure, remainder slaughterhouse waste, food leftovers and other biogenic substrates
Maximum capacity/actual throughput of substrates	87.600 Mg/a / 45.000 Mg , plant is currently not operating due to lack of substrates
Equipment and machines	The generated biogas is incinerated in a cogeneration unit delivering 6.800 MWh/a electrical energy and 11.000 MWh/a thermal energy. Digested substrates are processed in a filtration und dewatering unit made by Huber company, delivering a fermentation residue of about 30% d.w. and crystalline ammonium hydrogencarbonate. http://data.huber.de/erfahrungsberichte/kinfo2.htm
Investment costs	Information not available
Building time frame	Information not available
References	Wiemer/Kern, "Kompost-Atlas 1998/99", Witzenhausen-Institut (Online: http://www.forumz.de/kompostatlas/) http://www.schwarting-umwelt.de/00_eng.htm http://www.schwarting-umwelt.de/03e_ref.htm http://data.huber.de/erfahrungsberichte/kinfo2.htm

Process flowsheet



Picture of the plant

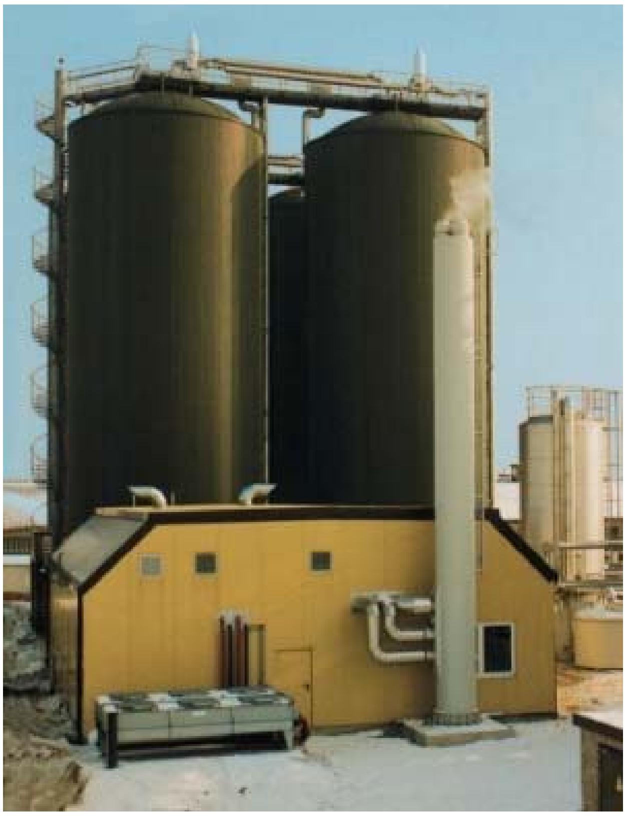


Figure 8.1-1: Fermentation plant Finsterwalde

(http://www.schwarting-umwelt.de/03e_ref.htm)

8.1.3.2 Description of selected plants of the BTA process (complete plants or containing essential components of the BTA process)

Biogas plant Wadern-Lockweiler (Saarland)

Address: BioSaar GmbH, Buttnicher Weg, 66687 Wadern-Lockweiler.

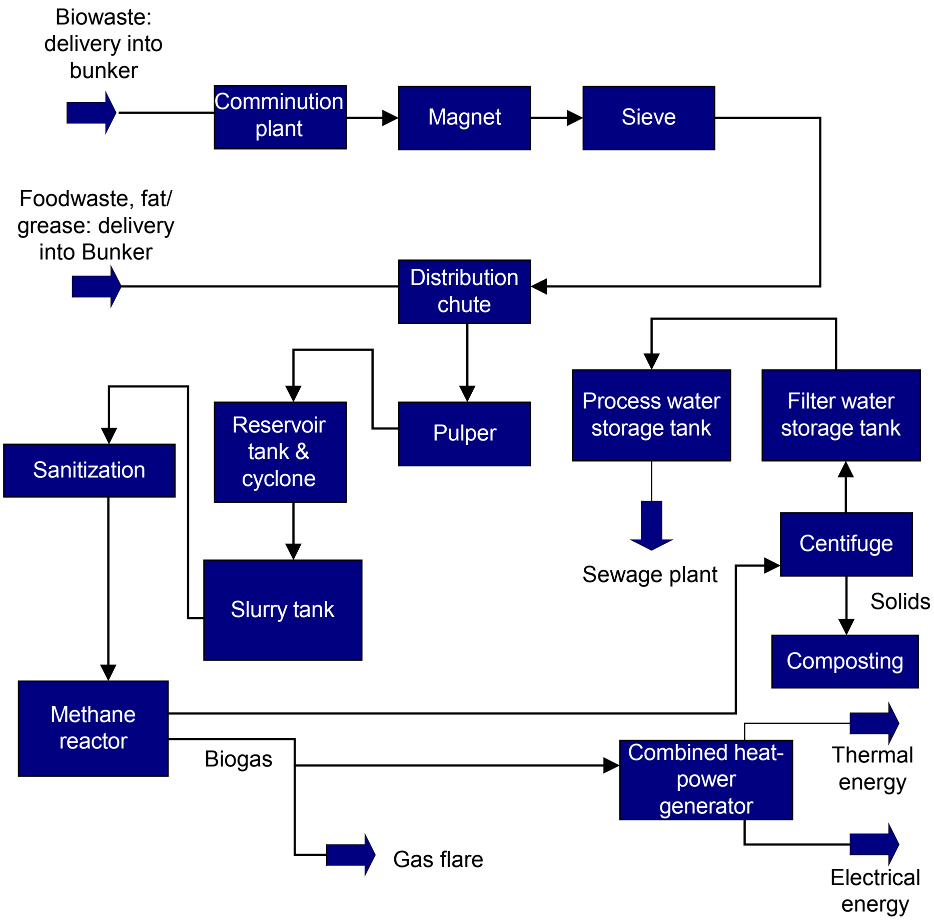


Figure 8.1-2: Process flow diagram of the BTA plant, Wadern-Lockweiler
(source: http://www.biosaar.de/index_2.html)

The plant was constructed in 1998, making use of suitable equipment already on the site of what had been a rendering plant. Investment costs amounted to 12 million euro (Internet presence of BioSaar GmbH, http://www.biosaar.de/index_2.html; specific investment costs 460 €/mta). The plant's original capacity of 20,000 Mg/a has since been increased to 26,000 Mg/a, the substrates processed being biowaste and commercial waste. The plant design comprises a "quasi 2-stage" fermentation, in which methane production is preceded by concentration of the slurry with partial fermentation (intermediate storage in a slurry tank with preliminary acidification/hydrolysis). Before being transferred to the methane reactor, the slurry is sanitized by heating to over 70 °C for at least one hour. Retention in the mesophilic fermentation stage is for 20 days. The fermentation residue is composted and marketed as compost.

Biogas plant Erkheim (District of Unterallgäu)

Address: Bio-Energie Schwaben GmbH, Eidlerholzweg 101, D-87746 Erkheim.

The plant, with an initial capacity of 11,500 Mg/a, but which has since been increased to 18,000 Mg/a, went into operation, processing biowaste and commercial waste, in 1997. Preparation of the substrate is completely automated, with an agricultural fermentation stage. Following the removal of interfering substances, preparation of the slurry and grit separation there are 20 days of single stage methane production. The remaining fermentation residue is turned into compost.

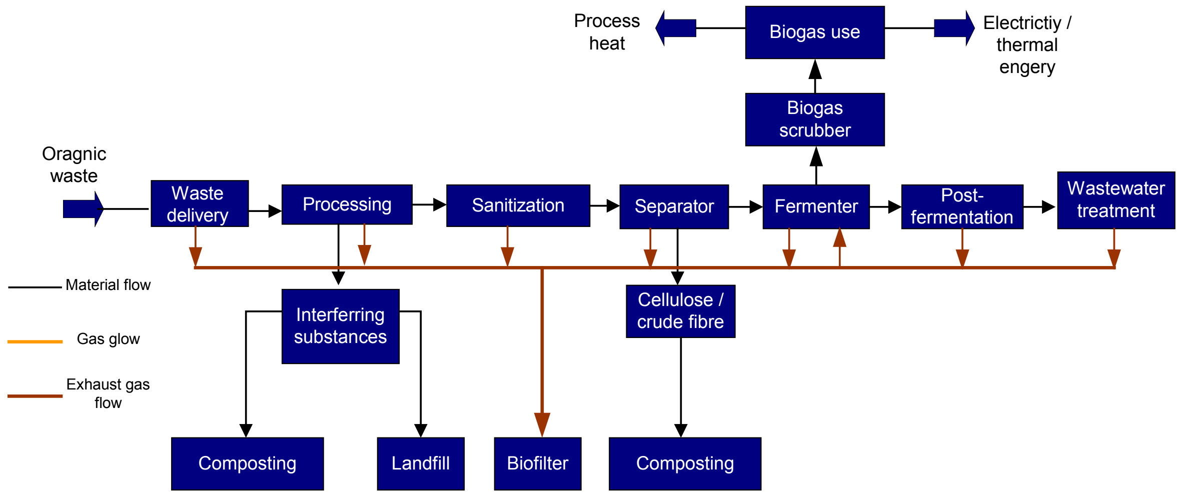


Figure 8.1-3: Process flow diagram of the BTA plant, Erkheim

Biogas plant Kirchstockach/Brunnthal (District of Munich)

Address: Vergärungsanlage Kirchstockach, Taufkirchner Str. 1, 85649 Brunnthal.

The plant started operating in 1997, following an investment of 16 million euro (Online-Article http://www.solarenergie.com/solarzeitung/biomasse/biogas-07-02.html; specific investment costs: 640 €/mta). The plant's initial capacity of 20,000 Mg/a biowaste has since been expanded to 25,000 Mg/a. It operates a 2-stage fermentation, whereby the prepared slurry is subjected to preliminary sanitzation and hydrolysis, the resulting dissolved organic substrate being fed successively into the methane producing stage. The residue from hydrolysis is used as peat substitute, in gardening, thus removing the need to compost it.

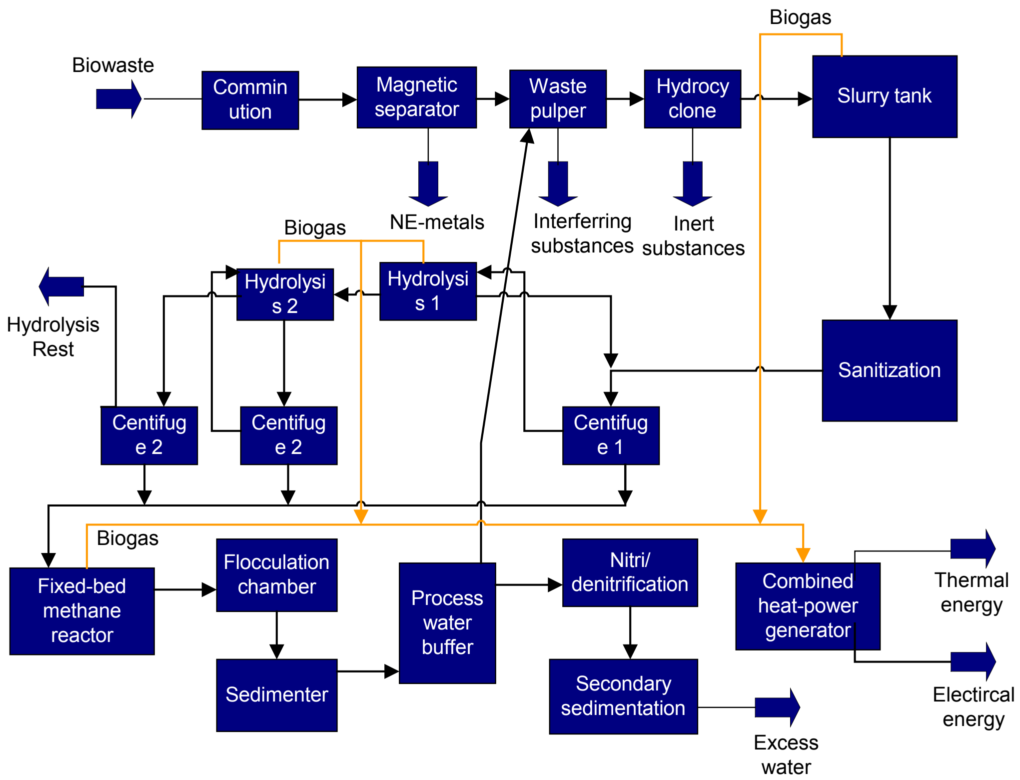


Figure 8.1-4: Process flow diagram of the BTA plant, Kirchstockach

Biogas plant Karlsruhe

The plant, which went into operation in 1996, was constructed at a landfill site in order to make use both of biogas and of landfill gas. It is capable of processing 8,000 Mg/a of biowaste. It comprises a single-stage process, which involves agitating the fermentation slurry with process gas, and a typical retention time of 16 days. The fermentation residue is subsequently mixed with structural material prior to composting. Total investment costs amounted to 15.5 million DM (just under 8 million euro; online information provided by MAT at http://www.bionet.net/mat/karlsruh.htm; specific investment costs 990 €/mta).

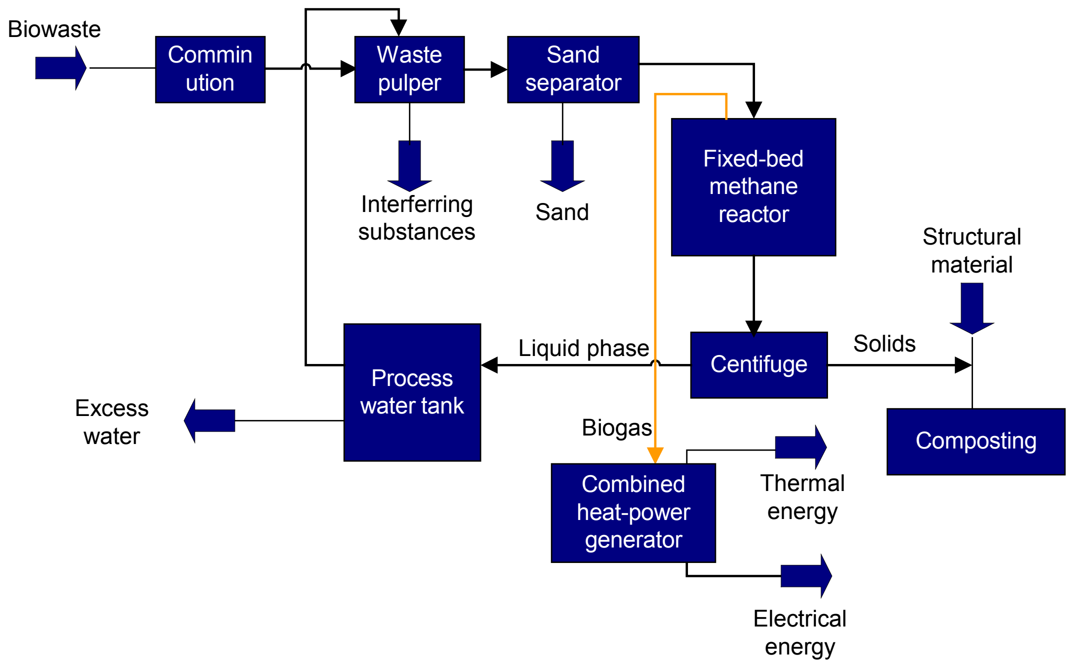


Figure 8.1-5: Process flow diagram of BTA plant, Karlsruhe

(source: http://www.bta-technologie.de/files/karlsruhe-fliess.JPG)

Biogas plant Dietrichsdorf (Landkreis (District of) Kelheim)

This plant, which went into operation in 1995, comprises a single-stage fermentation with a capacity of 17,000 Mg/a (biowaste and commercial waste); since 1997 it has the additional capacity to prepare waste food for fermentation, including sanitization. There are two lines for different input materials: following the removal of interfering substances and the addition of process water, biowaste and solid organic commercial waste are fed, without sanitization, into a 20 m^3 capacity pulper, while waste food is first pasteurised for at least 30 minutes before being fed into a pulper of 8 m^3 capacity. Both slurries, with a shared solids content of 7-8%, are mixed together in a feed storage tank; any remaining inert, granular interfering substances are removed, prior to transfer to the reactor for methane production. Mixing is achieved through forced aeration with biogas. Solids from the fermentation slurry are subsequently composted, which the liquid phase is passed through a biofilter.

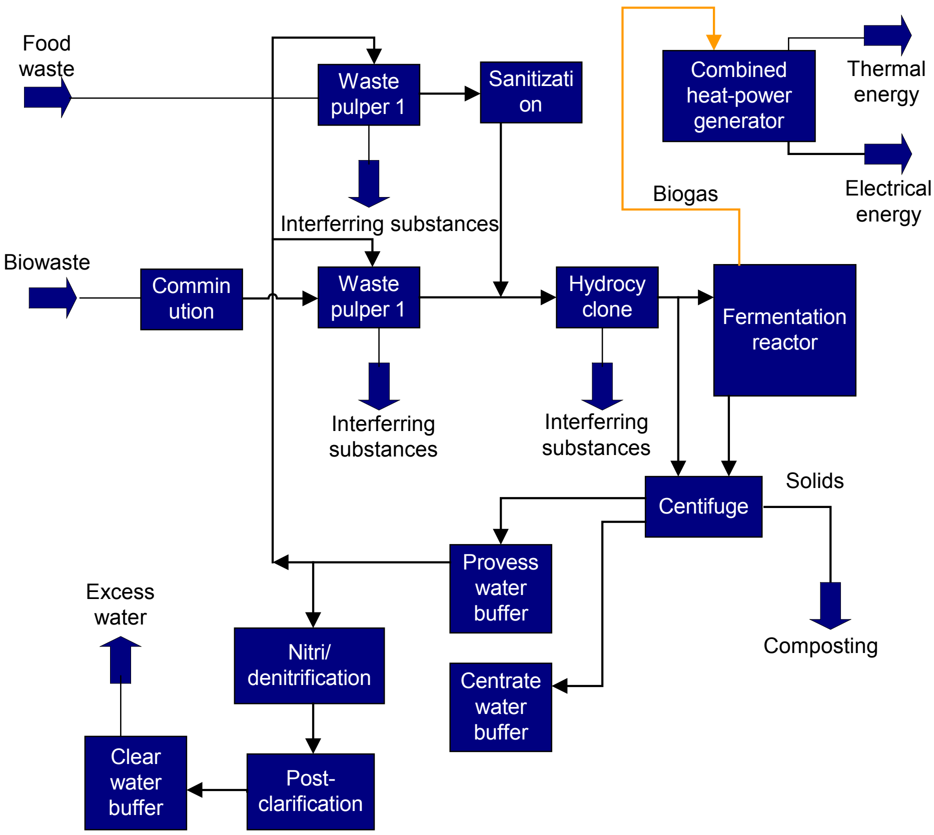


Figure 8.1-6: Process flow diagram of the BTA plant, Dietrichsdorf (LK Kelheim)

(source: http://www.bta-technologie.de/files/hoegl-fliess.JPG)

Biogas plant Baden-Baden

The plant, designed to handle 5,000 Mg/a biowaste, was integrated into an existing sewage works, which, through the use of existing plant, meant that investment costs were just 5 million DM (2.56 million euro; online information provided by MAT at http://www.bionet.net/mat/badtxt.htm; specific investment costs were about 500 €/mta; operating costs about 115 €/Mg biowaste). The plant went into operation in 1993. The overall design is of a single-stage BTA plant, since the aqueous phase of the prepared slurry is fed into sewage work's anaerobic digesters without passing through a hydrolysis stage (single-stage co-fermentation). Solids from dewatering the slurry (per centrifuge) following fermentation, are composted externally with garden waste.

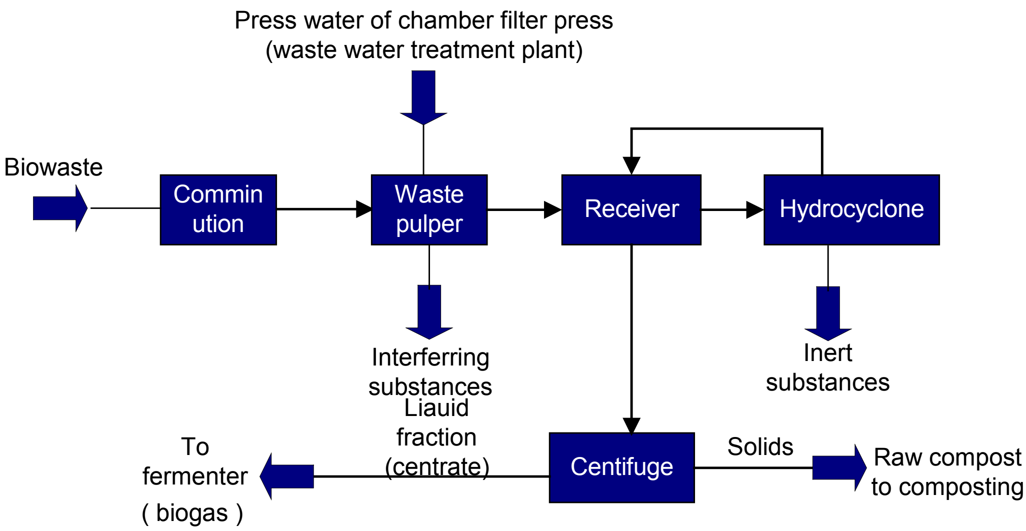


Figure 8.1-7: Process flow diagram of the BTA plant, Baden-Baden

(source: http://www.bta-technologie.de/files/baden-fliess.JPG)

Biogas Plant Karlshof (Munich city)

This is an agricultural plant which processes, through co-fermentation, liquid cattle manure (5,500 Mg/a) and maize (2,500 Mg/a). The plant, which carries out mesophilic fermentation at 35 °C, went into operation in May 2000. Liquid cattle manure is fed directly into the first biogas reactor, while maize silage is prepared by first mixing it with liquid cattle manure. From the first biogas reactor the fermentation slurry passes into a second biogas reactor. The fermentation residues are collected in storage tanks and used as liquid fertiliser.

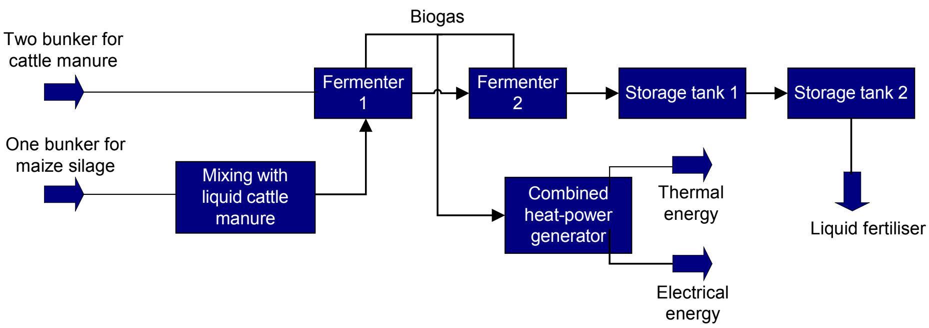


Figure 8.1-8: Process flow diagram of the BTA plant, Karlshof (Munich)

8.1.3.3 Description of selected plants of the Bigadan Process / Krüger Biogas

Biogas plant Dithmarschen

Address: Vergärungsanlage Dithmarschen, Moorstrich 1, 25693 St. Michaelisdonn.

The plant, which has been in operation since 1996, required an investment volume of 8.5 million DM (almost 4.5 million euro; information provided by BEA Dithmarschen GmbH; specific investment costs, just under 110 €/mta). The plant has a capacity of 40,000 Mg/a, which is used to about 75% for animal excrement and to about 25% for biowaste of various kinds. The slurry is sanitized for at least one hour at 70°C before single-stage fermentation at of 38-39°C with a retention period 21 days. The fermentation residue is returned to the agricultural sector for use as fertiliser. The plant was retrofitted with a biofilter and with an ionizer for exhaust air purification.

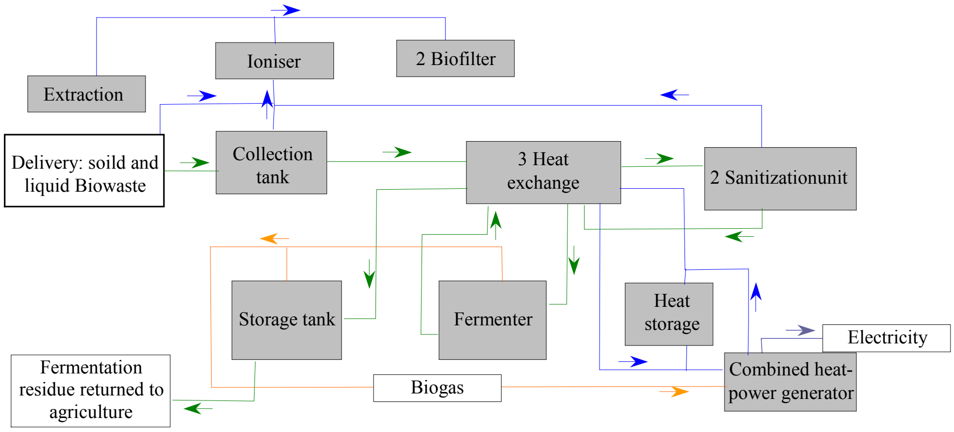


Figure 8.1-9: Process flow diagram of the Bigadan/Krüger biogas plant, Dithmarschen

Biogas plant Wittmund

Address: Vergärungsanlage Wittmund, Isums 45A, 26409 Wittmund,

http://www.biogasanlage-wittmund.de, in operation since 1996. With a total plant capacity of 128,000 Mg/a, currently 80,000 Mg/a of liquid manure and 35,000 Mg/a of biowaste are fermented. The fermentation residue is not composted, but used as fertilizer, just as raw liquid manure would be. The energy yield of the plant is 11,300 and 9,050 MWh/a, thermal and electrical, respectively. Total investment costs for the plant amounted to 11.2 million euro (Internet presence of the biogas plant, Wittmund at http://www.biogasanlage-wittmund.de/d/wirueberuns.html; specific investment costs are just under 88 €/mta).

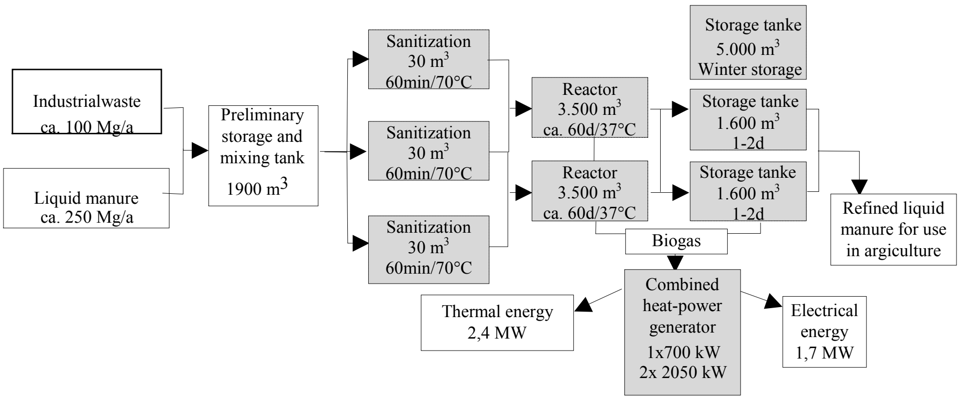


Figure 8.1-10: Process flow diagram of the Bigadan/Krüger biogas plant, Wittmund

8.1.3.4 Examples of the Linde Liquid Fermentation process

Biogas plant Radeberg (Linde-KCA)

The plant can handle up to 40,000 Mg of clarification sludge (5-6 % solids) and between 15,000 and 20,000 Mg of biowaste per annum. Clarification sludge from the Radeberg sewage works, as well as liquid, semi-solid and solid biowaste are delivered separately and stored in separate (some heated) storage tanks. Solid biowaste is placed in a shallow bunker, where it is subjected to a rough initial inspection and unsuitable charges removed for disposal.

The remaining solid biowaste is broken up (comminution) and ferrous metals removed, before it is made into a slurry by a pulper. Light and heavy components are separated from the slurry before it is sanitized at 70°C. It is then mixed with clarification sludge for co-fermentation (mesophilic fermentation with a retention period of 15-20 days). The fermentation residue is dewatered using centrifuges. The liquid phase clarified in Radeberg's municipal sewage works, while the solids are composted before use. A diagram of the plant is shown below:

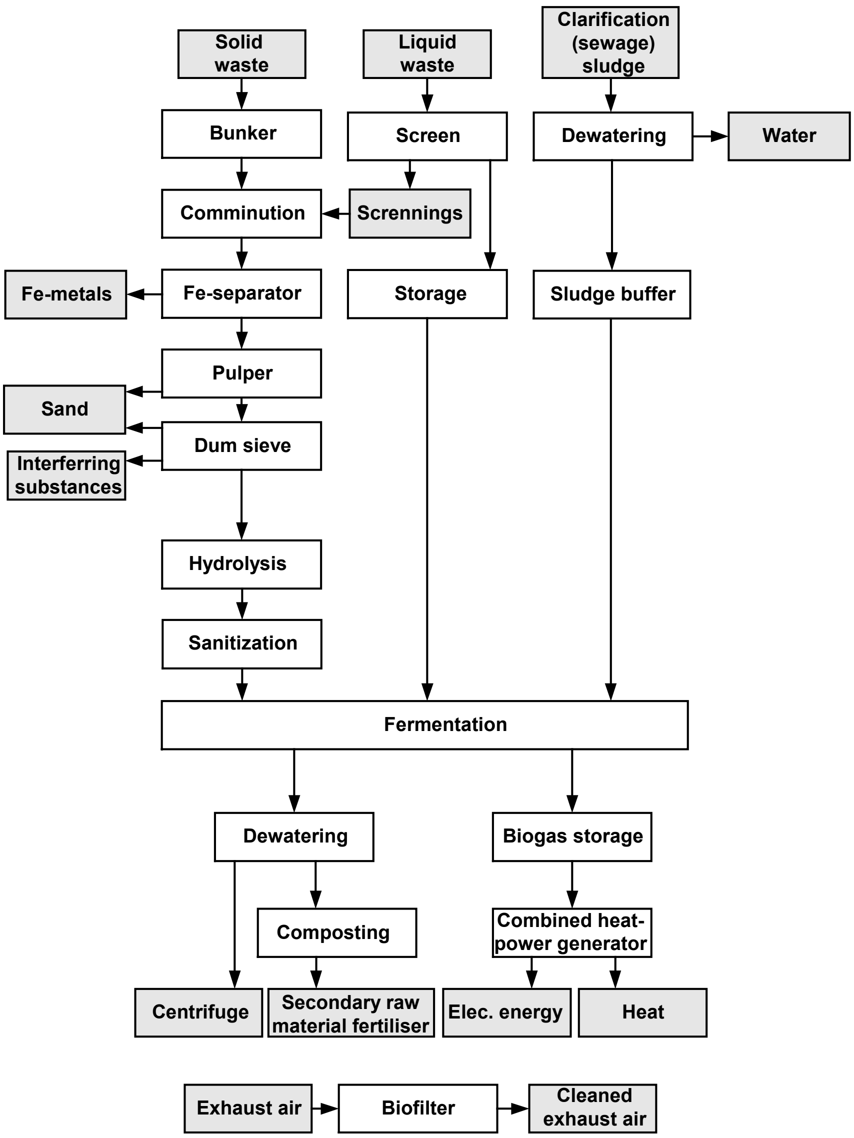


Figure 8.1-11: Process flow diagram of the biogas plant, Radeberg

The types of waste processed in Radeberg
Clarification sludge together with a wide range of biowaste.

Size of the Radeberg plant
55,000 Mg/a.

Specific investment costs of the Radeberg plant (per Mg/a)
Investment costs for the plant, which went into operation in 1999, amounted to 10 million euro (with a licensed capacity of 55,000 Mg/a, this gives specific investment costs of 182€/mta).

Figure 8.1-12: Biogas plant Radeberg, showing two digesters (each 2000 m³ Volumen) and a biogas storage

Figure 8.1-13: Machinery for mechanical processing of solid biowaste, market waste, etc. (Comminution, pulper, sieve for removal of disturbing particles).

Figure 8.1-14: Pulper, for water addition to solid substrates (15 m³, 230 $kW_{el.}$)

Figure 8.1-15: Bunker, with wheel loader and biowaste from communal waste collection.

Figure 8.1-16: Biofilter (left) including humidifier (right)

Figure 8.1-17: Comminution of biowaste

Figure 8.1-18: Emergency torch with hidden flame

Biogas plant Sagard/Rügen (Linde-BRV)

Address: Vergärungsanlage Sagard, Vorwerk, 18551 Sagard / Rügen
The plant, which was designed to have a capacity of 48,000 Mg/a, has been in operation since 1996. Currently it processes about 35,000 Mg/a of liquid manure from a nearby dairy farm and about 8,000 Mg/a of food waste with a solids content of approximately 20 percent. The waste food is delivered to a separately located processing plant, because for reasons I of hygiene it cannot be processed in the direct vicinity of the dairy plant. Here it is broken up, homogenised and freed of interfering substances, before being transported to the biogas plant and sanitization at 70°C.

The homogenised waste food and liquid manure are mixed in the above stated proportions, before being fed into the reactors, where it is retained for 15-25 days during mesophilic fermentation. There are 3 horizontal fermenters, designed as plug-flow reactors, for a solids content of max. 15 percent. In fact, they are operated with a solids content of between about 7 and 10 percent. A diagram of the plant is shown below:

<u>The types of waste processed in Sagard</u>
Liquid manure and waste food

<u>Size of the Sagard plant</u>
48,000 Mg/a.

<u>Specific investment costs of the Sagard plant (per Mg/a)</u>

Investment costs for the plant, which went into operation in 1996, amounted to 3.5 million euro (the plant's current capacity of 43,000 Mg/a gives specific investment costs of 81 €/mta).

Figure 8.1-19: Substrate reception area, with sanitation units (behind)

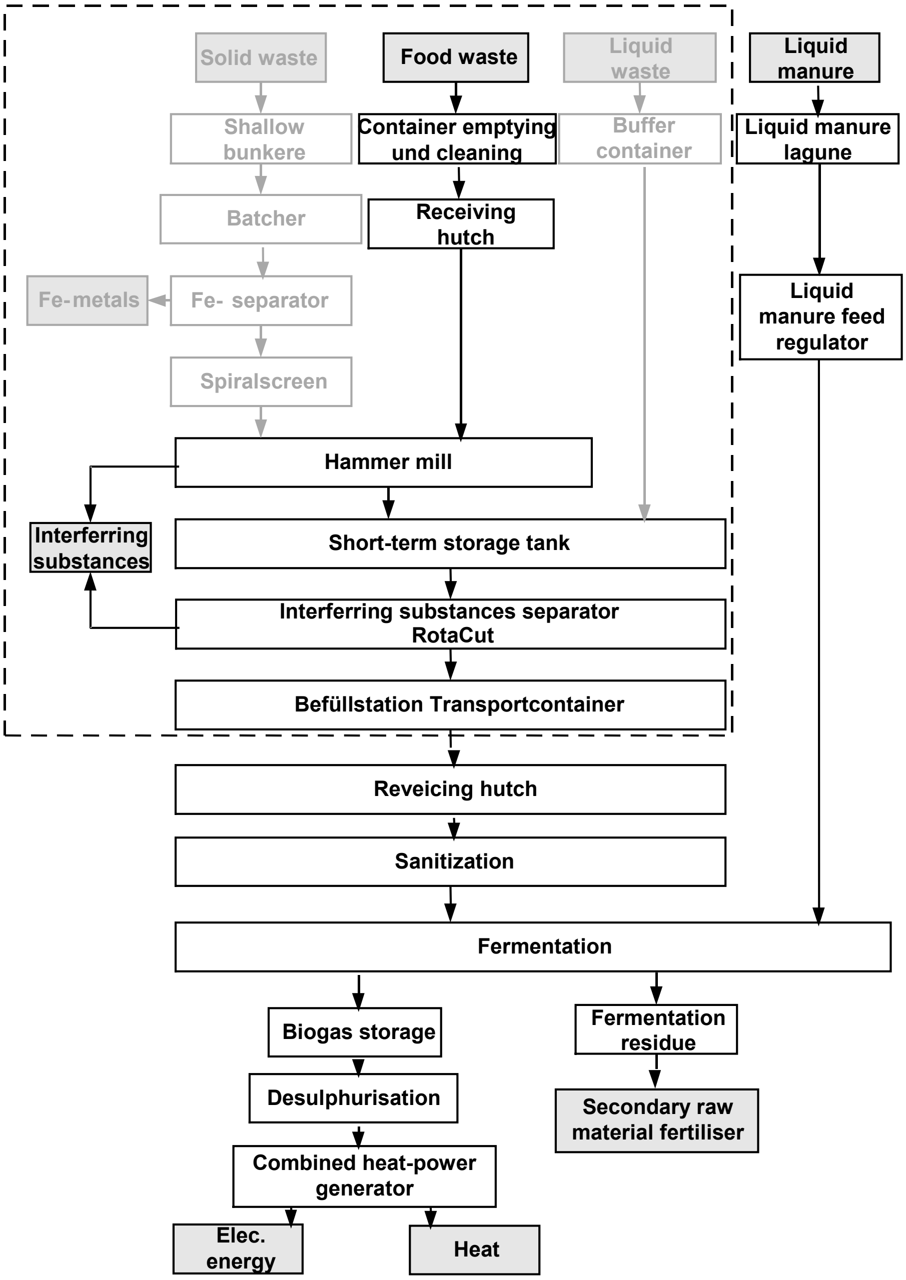


Figure 8.1-20: Process flow diagram for the biogas plant Sagard)

8.1.3.5 Description of selected plants in Gemany (complete plants or including essential components of the Kompogas process)

Biogas plant Braunschweig

Capacity: 24,000 Mg/a,
In operation: since 1997.
According to the operator of the biogas plant (Braunschweiger Kompost GmbH, Frankfurter Straße 251, 38122 Braunschweig) the plant currently processes 17,500 Mg/a source separated biowaste, collected from households. The plant design corresponds essentially with the Kompogas-Standard. There is an aerobic pre- and post-treatment of the substrate for 3 and 10 days, respectively, while fermentation itself lasts about 20 days. A diagram of the process and mass balance are shown below (Figure 8.1-21).

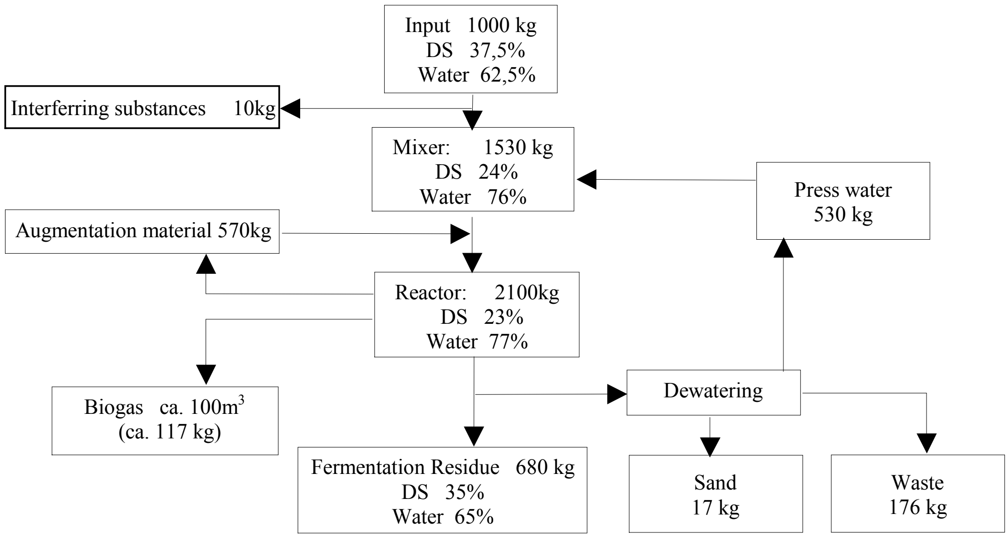


Figure 8.1-21: Process diagram and mass balance for the Kompogas fermentation plant, Braunschweig-Watenbüttel

Biogas plant Wüschheim/Hunsrück

Address: Fermentation plant Wüschheim, Im Faas 1, 55471 Wüschheim
In operation: since 1997
Operator: Frey Entsorgungs-GmbH (a daughter company of RWE Umwelt).
Capacity: 13,000 Mg/a;
Main Substrate: source separated biowaste from households.

Further information:
http://www.muf.rlp.de/inhalt/107/download/Kompostatlas_2001.pdf
http://www.wifo.at/Stefan.Schleicher/teach/course/se_enpol/part2/2-12_EurElHeat.pdf

Biogas plant Alzey-Worms

Address: 55234 Framersheim
In operation: since 1999
Operator: LK Alzey-Worms
Costs: the construction costs amounted to 20 million DM (10.2 million €; information of MPE Engineering; specific investment costs, 426 €/mta).
Capacity: 24,000 Mg/a
Main substrate: 90% biowaste and 10% garden and parkland waste.

Further information:
http://www.muf.rlp.de/inhalt/107/download/Kompostatlas_2001.pdf

Biogas plant Burgberg (Vergärungsanlage Oberallgäu Süd)

Capacity: 10,000 Mg/a
In operation: since 1995
Investment costs: amounted to 10 million euro (information provided by plant manufacturer, SOTEC, Herr Dietz; specific investment costs, 1000 €/mta).
Substrate: biowaste, 15 percent grass cuttings.
Installation and operation: SOTEC GmbH, Hafenstrasse 25, 66111 Saarbrücken,
Proprietor: Association of municipal waste management authorities (Zweckverband für Abfallwirtschaft) Kempten.

8.1.3.6 Description of selected plants of the STEINMÜLLER-VALORGA PROCESS in Germany

Biogas plant Engelskirchen/Leppe

The plant, which went into operation in 1998, has a capacity of 35,000 Mg/a. It processes kitchen and garden waste in two bioreactors with a capacity of 3,000 m^3, in a thermophilic temperature range. It includes a dewatering facility and a facility for composting the fermentation residue.

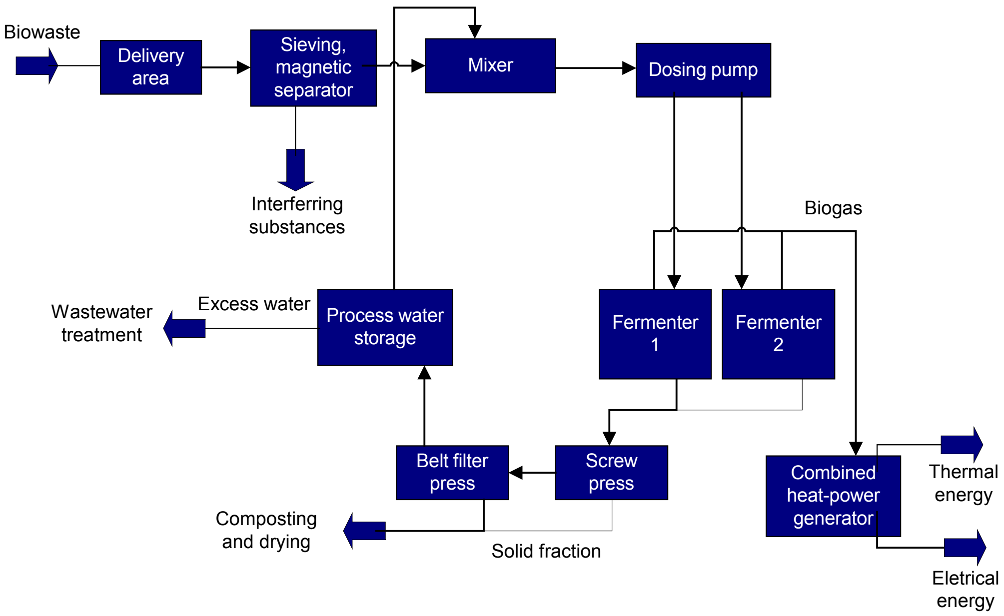


Figure 8.1-22: Diagram of the biogas plant, Engelskirchen, according to company information

Further information: http://www.unitechnik.de/specialistareas/environment_ref1.html)

8.1.3.7 Description of selected plants of the Dranco Process

Biogas plant Bassum

The plant, which was built by SOTEC GmbH and completed in 1997, is owned by the Abfallwirtschaftsgesellschaft mbH (Waste Management Company GmbH) Bassum. It is integrated into a fermentation and composting concept for 65,000 Mg of domestic waste per year, with a fermentation capacity of 13,500 Mg/a (capacity of the fermenter, 1,280 m³). The substrate is taken from the < 40mm fraction of domestic waste, which is mixed with aerobically stabilised clarification sludge. It can have a solids content of up to 40 percent. The anaerobic phase is thermophilic, with a retention time generally of 20 days. The fermentation residue is composted together with other material from the domestic waste treatment plant.

Further information: http://www.sotec.de/leistungen/mechanisch/raba_bassum_tech.html

8.1.3.8 Description of selected plants of the Dry Process Linde-BRV

Biogas plant Heppenheim

Address: Composting and fermentation plant, Heppenheim, Ratsäckerweg 12, D- 64646 Heppenheim.

The plant, which has been in operation since 1999, has a capacity of 36,000 Mg/a. It was constructed though modification and extension of an already existing composting plant. Three fermenters, operated thermophilically at 55-57 °C, ferment the substrate, consisting of biowaste, vegetable waste and organic commercial waste made into a slurry with a solids content of 20-40 percent, over a period of 22 days. Prior to fermentation, the substrate is composted for 2-4 days; following fermentation the residue is composted for about another 21 days.
(See also: http://www.ingut.de/Deutsch/aktInfo.htm)

Biogas plant Lemgo

Operator: Abfallbeseitigungs-GmbH Lippe
Address: Zur Maibolte 200, D-32657 Lemgo

The plant has a capacity of 38,000 Mg/a, of which 30,000 Mg/a are biowaste, 6,000 Mg/a are garden and parkland waste, plus an optional 2,000 Mg/a of commercial waste. The plant was converted and modernised in the period 1998-2000 at a cost of 30 million euro (specific investment costs, 790 €/mta). The whole process includes pre-treatment of the substrate through 3-5 days of intensive composting at 40-50 °C, 21 days fermentation at 55 C, and 3-4 weeks of subsequent composting of the residue which has been dewatered to 40 percent.

Further information: http://www.abg-lippe.de/set.htm.

8.1.3.9 BEKON ENERGY TECHNOLOGIES GmbH & Co KG

Biogas plant of the BEKON Process in Munich

So far there is one pilot plant with a capacity of 8,000 Mg/a for processing biowaste. The following Figure 8.1-23 provides a process diagram:

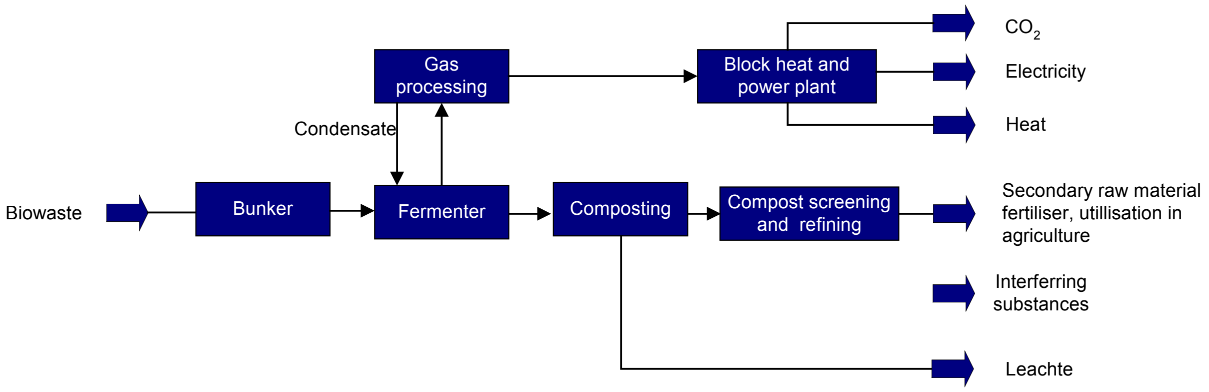


Figure 8.1-23: Process diagram of the BEKON pilot plant in Munich

Company Address
BEKON ENERGY TECHNOLOGIES GmbH & Co KG
Nikolastraße 18, 84034 Landshut
http://www.bekon.org/Bekon-EnergyTec/Trockenfermentation-Titel.htm

This new, single-stage process operates at mesophilic temperatures between 34-37°C. A number of fermenters are charged successively at specific time intervals and closed with gates fitted with air-tight flanges. Air is prevented from entering the fermenters through the inside pressure (explosion protection). The water content necessary for the process biology and inoculation is provided by circulating percolate, whereby pH can also be adjusted to its optimal value. Fresh and already fermented substrate amounts are mixed in equal (inoculation), thus ensuring continual and rapid optimisation of conditions for the microorganisms. The retention time of substrate in a fermenter is 3-4 weeks.

The single-stage design, lack of mechanical mixing, and automatic input and output systems reduce susceptibility to disturbances and also operating costs. The plant's modular design facilitates expansion and contraction of its operating capacity.

Types of waste processed
Biowaste, grass cuttings, agricultural biomass, solid animal manue.

The size of plants actually built
The pilot plant already in existence has a capacity of 8,000 Mg/a

Specific investment costs (per Mg/a)
According to the manufacturer, the specific investment costs for a plant with a capacity of 18,000 Mg/a is about 220 €/mta.

Figure 8.1-24: Biogas plant from BEKON, Munich

Figure 8.1-25: Closed tunner reactors for dry fermentation

Figure 8.1-26: Wheel loader in the process of loading the digester/ reactors

Figure 8.1-27: Post-composting of the digested sludge, in open windrows

Figure 8.1-28: Sieving of the compost to a particle size of < 12 mm

8.2 State of the art of biomass combustion plants

8.2.1 Biomass combustion plants in Thailand

The following **Fehler! Verweisquelle konnte nicht gefunden werden.** summarises the major biomass combustion plants in Thailand.

Table 8.2-1: Overview over selected biomass combustion plants in Thailand

Industry	Owner/developer	Location	Equipment	Cost (US $)
Rice (husk)	A.T. Biopower Co, Ltd	Central Thailand	4x22 MW Power plant boiler: 86 tph, 65 bar, 480 degree celcius turbine type: fully condensing	
Rice	Patum Rice Mill and Granary Public. Co. Ltd.	Pathumtani, Thailand	TBD	
Sugar	Mitr Phol Sugar Corp., Ltd.	Supahanburi, Thailand	TBD	
Wood	Electricity Generating Public Co., Ltd.	Yala Province, South	21 MW Cogen Plant Boiler: 86.6 tph, 61 bar, 450 deg C Turbine: 22 MW extraction/condensing	
Wood (Wood Frame Factory)	Laem Chabang Industry Co., Ltd.*	Chonburi Province, East	Wood residues collecting system Dust collector, silo Hot water boiler : 400,000 kcal/hr Kiln dryers	
Wood (Parquet Flooring)	Areechai Woodtech Co. Ltd.*	Srakaew Province, East	Wood residues collection and combustion Dust collector, silo Boiler : 1,250,000 kcal/hr Kiln dryers	180,000
Paper	High Tech Paper Co. Ltd.*	Panom Sarakham, Chachoengsao, Thailand	Turbine: 600 kW back pressure (20 bar - 6 bar)	
Rice	Chia Meng Co. Ltd.*	Nakorn Ratchasima, Northeast	2.5 MW Cogeneration plant Boiler : 17 tph, 35 bar, 420 degree celcius Turbine : 2.5 MW condensing	3,865,000
Rubber Wood	TRT Parawood Co. Ltd.*	Surat Thani, South	2.5 MW Cogeneration plant Boiler : 21 tph, 24 bar, 320 degree celcius Turbine : 2.5 MW extraction/condensing	2,187,000
Palm Oil	The Southern Palm (1978) Co., Ltd.	Surathani, South	44 MW Cogen Plant Steam boiler: 179.4 tph, 62 bar, 482 degree celcius Turbine: 48,600 kW extraction/condensing Biomass handling: 55 tph waste	Postponed

8.2.2 Biomass combustion plants in Vietnam

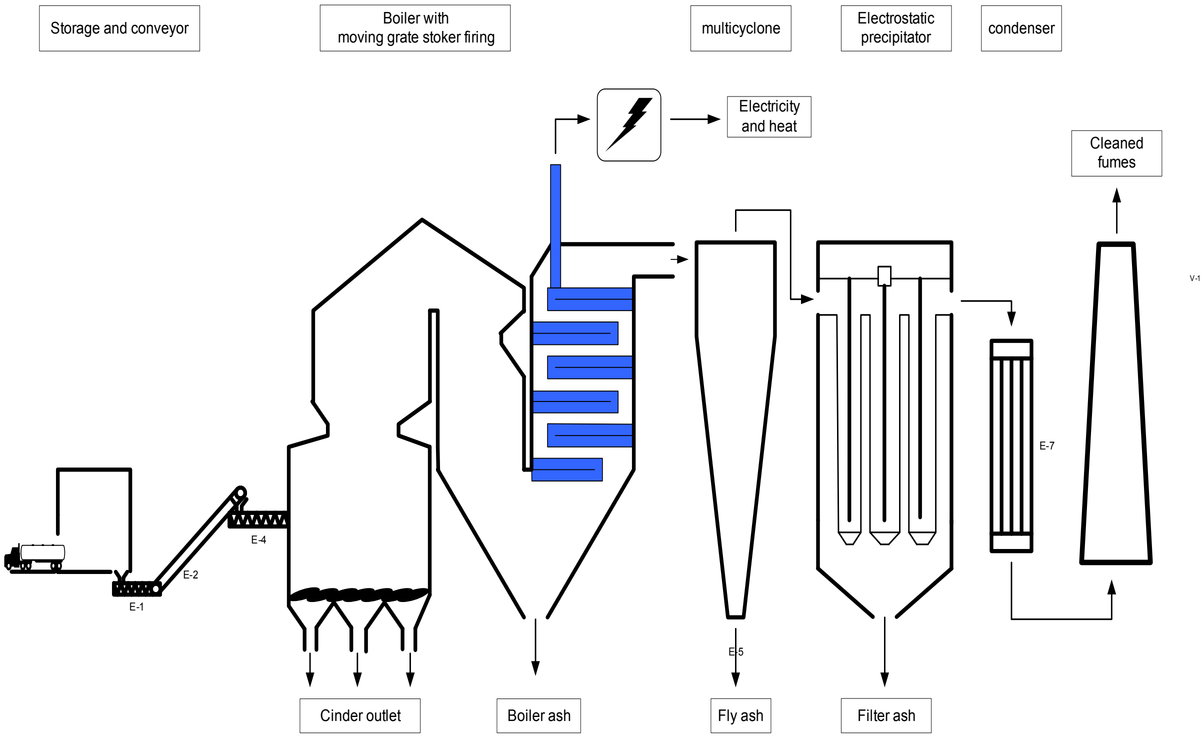
There have only been very sporadic applications of biomass combustion plants in Vietnam so far.

8.2.3 Biomass combustion plants in Germany

8.2.3.1 Biomass heat plant Dresden, Holz-Heizkraftwerk

Region, city	State of Saxonia
Address	Schönfeld 13, 96142 Hollfeld, Germany
Manufacturer	Ingenieurbüro Michael Gammel GmbH An den Sandwellen 114 D-93326 Abensberg Tel.: ++49 (0) 9443 929 0 Fax.: ++49 (0) 9443 929 292 E-mail: gammel@gammel.de
Operated by	BHO Biomassehaizanlage Obernsees GmbH Schönfeld 13 96142 Hollfeld
In operation since	1998
Process type/process characteristics	The boiler consists of a firing grate system with a combustion chamber beyond and a horizontal boiler behind. The fuel is reaching the firing grate over a funnel. The added air is separated in several zones.
Tape of substrate utilised	The plant is operated with untreated fresh wood chips and remaining wood from saw mills
Maximum capacity/actual throughput of substrates	- Heat capacity obtained by biomass: 450 kW, by petroleum: 430 kW. - Combusted wood chips: 1.500 t/a, petroleum: 30.000 l/a
Equipment and machines	The combustion plant consists of a biomass boiler (450 kW) and a feeding grate stoker furnace. In case peak loads, the demand can be provided by a buffer store system with a water volume of 13.000l. The fumes are cleaned from dust and ashes by a multicyclone and condenser boiler.
Investment costs	1,4 million EUR
Building time frame	1997 – 2003
References	http://www.gammel.de http://www.carmen-ev.de http://www.therme-obernsees.de/

Process flowsheet



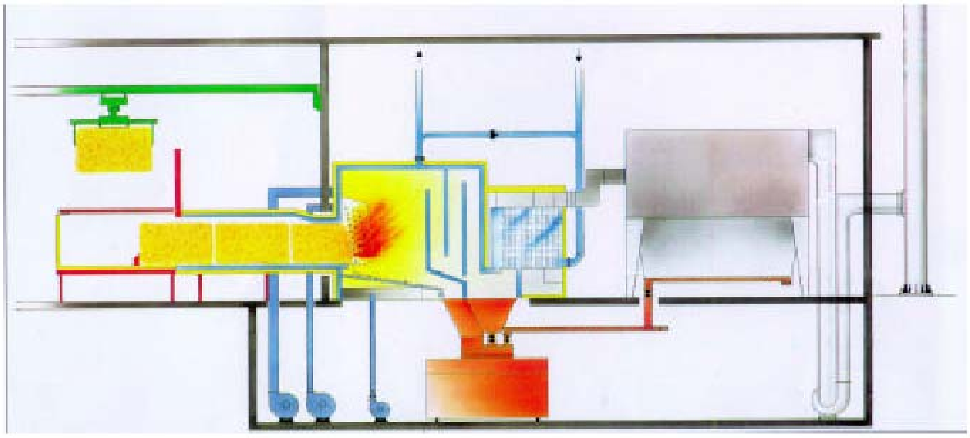
Picture of the plant

Figure 8.2-1: Biomass combustion plant in Dresden

8.2.3.2 BKS Bio-Kraftwerk Schkölen

Region, city	State of Thuringia, Schkölen
Address	Zschorgulaer Strasse 24 07619 Schkölen
Manufacturer	Babcock & Wilcox Vølund ApS Falkevej 2 6705 Esbjerg Ø fon +45 76 14 34 00 fax +45 76 14 36 00 E-mail: bwv@volund.dk
Operated by	BKS Biokraftwerk Schkölen Zschorgulaer Strasse 24 07619 Schkölen fon/fax +49 366 94 224 30
In operation since	1993
Process type/process characteristics	The so-called cigar burner is a grate firing system. The oblong straw bales are craned onto the inducting port and are burnt at the front side. The bales are pushed slowly into the combustion chamber. Unburnt parts of the bales are falling down into a inclined grate, where they are combusted completely.
Tape of substrate utilised	In this plant the sole fuel is gramineous biomass. The straw is pressed into oblong bales
Maximum capacity/actual throughput of substrates	Not available/3.000 Mg
Equipment and machines	The plant has a maximal heating temperature of 120°C and a rated load of 3,13 MW. For the fuel gas cleaning a cyclone dust collector and a flue gas filter are installed.
Investment costs	Information not available
Building time frame	Information not available
References	http://www.thueringen.de/de/publikationen/pic/pubdownload396.pdf http://www.volund.dk

Process flowsheet



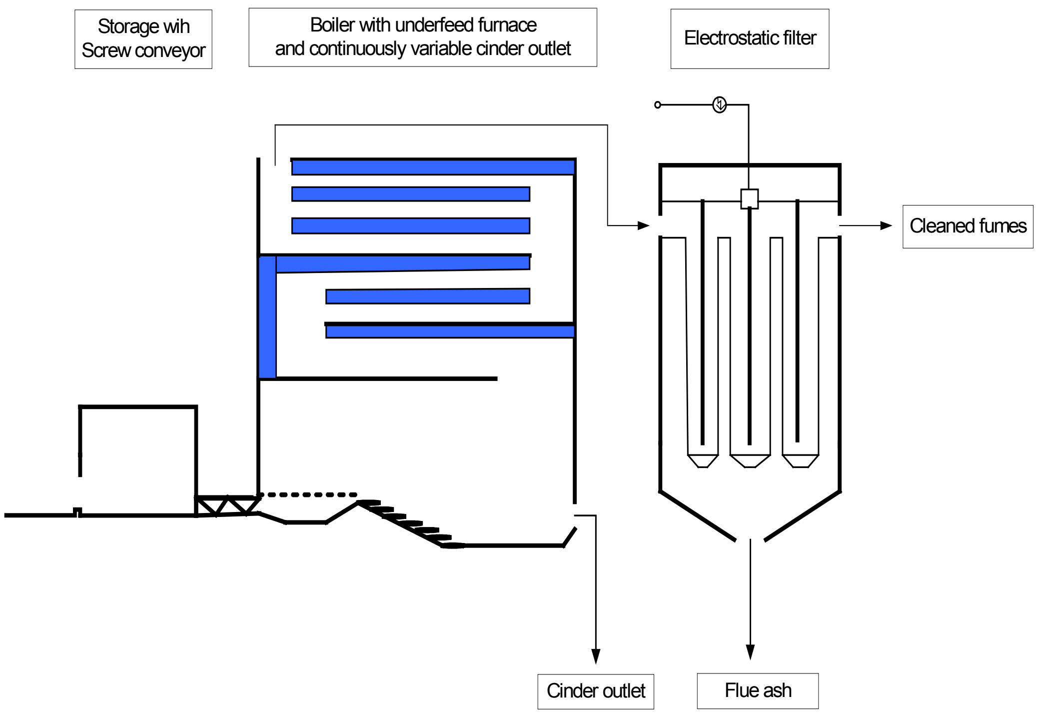
Picture of the plant

Figure 8.2-2: Straw combustion plant Schkoelen

8.2.3.3 Biomasseheizwerk Gemünden

Region, city	State of Bavaria, Gmünden
Address	Gemeindezentrum Münsingen Weipertshausener Strasse 5 82541 Münsing
Manufacturer	WVT Bioflamm
Operated by	Stadtwerke Gemünden Mühltorstraße 44 97737 Gemünden am Main Tel.: (0 93 51) 97 34-0
In operation since	2001
Process type/process characteristics	The plant was constructed to replace a heating system for a spa with public swim-hall and the public school. As the town of Gmünden is situated in a well wooded area, it was decided to construct a wood chips combustion plant
Tape of substrate utilised	In this plant, wood chips are used as fuel sole (650 kW) as well as natural gas (1.750 kW) for peak period demand.
Maximum capacity/actual throughput of substrates	Nominal capacity biomass boiler: 650 kW, annual power output 2.550 MWh/a, annual consumption wood chips: 3.550 Srm/a Nominal capacity natural gas boiler: 1.750 kW, annual power output 150 MWh/a, annual consumption 17.500 m³
Equipment and machines	The plant consists of two boilers: one biomass boiler with a nominal heat capacity of 650 kW and a natural gas boiler with a nominal heat capacity of 1.750 kW. The base consumption is covered by the biomass boiler, 94 % of the delivered heat is produced by biomass furnace. The facility is equipped with an electrical filter system
Investment costs	1.013.300 €
Building time frame	1997-2001
References	Biowärme Nettersheim GmbH (BiNe): Ökologische Nahwärme für die Gemeinde Nettersheim, http://www.bine-nettersheim.de, 2002. Biomasse Info-Zentrum (BIZ): Nettersheim – Kleine Gemeinde mit Vorbildcharakter, Newsletter, 2001.

Process flowsheet



Picture of the plant

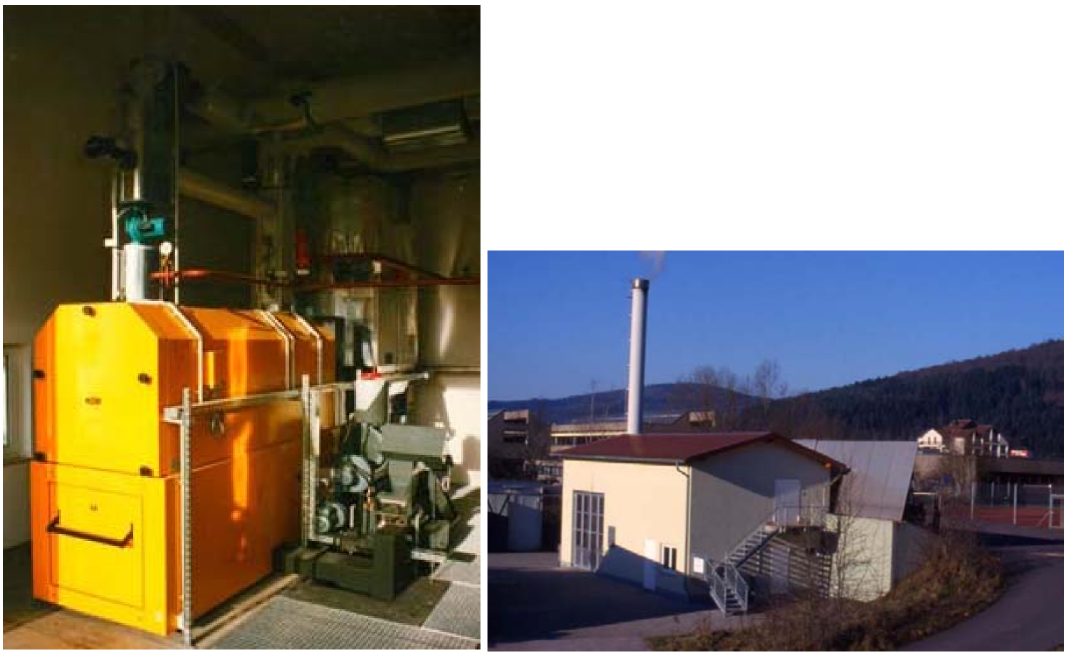
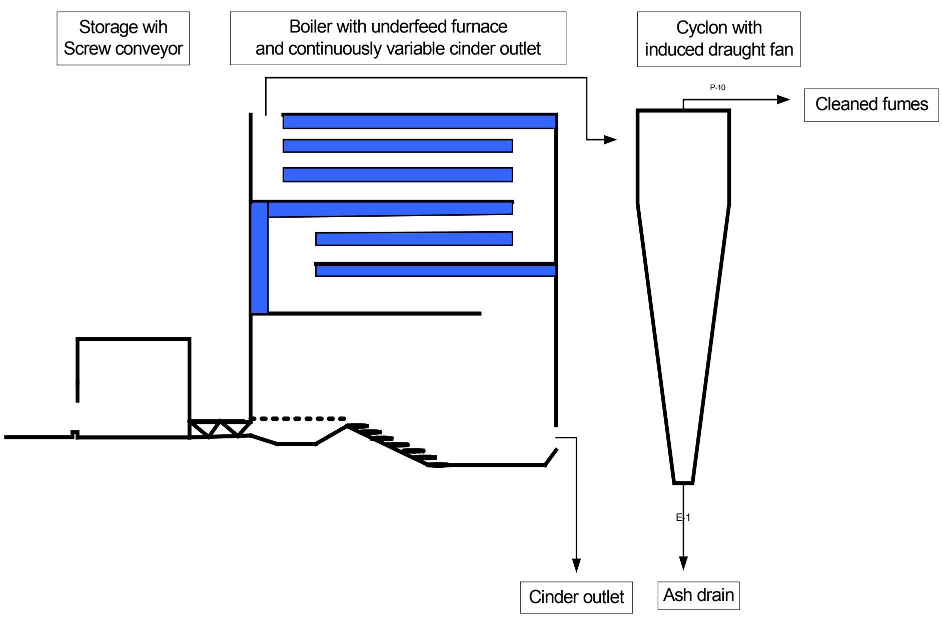


Figure 8.2-3: Biomass boiler (KÖB) with exhaust gas cleaning system;
Photos by: Städtische Forstverwaltung Gemünden

8.2.3.4 Biomass combustion plant, Melle Buer (Waldholzhackschnitzelanlage Melle-Buer)

Region, city	State of Lower Saxony, Melle Buer
Address	Gemeindezentrum Münsingen Weipertshausener Strasse 5 82541 Münsing
Manufacturer	WVT Bioflamm
Operated by	OVE Energie GmbH & Co. KG
In operation since	2001
Process type/process characteristics	The heating installation of the public school in the small town of Melle had to be replaced a it was decided to use weak wood from the environmental forests. The combustion plant is situated in an out-building of the public school. The boiler consists of two biomass boilers (450 kW) designed by KÖB. The wood chips are transferred automatically from the depot to the boiler by conveyor belts and screw conveyor. The dosage of the fuel is adapted to the required demand and is infinitely variable. Incurring ashes are exhausted by a specialised pump and collected in containers. As stand-by plant a diesel-powered boiler was installed (constructed by Weisshaupt).
Tape of substrate utilised	Wood chips are used as fuel sole (450 kW), the stand-by diesel powered boiler hasn't been used until these days
Maximum capacity/actual throughput of substrates	800 MWh/a/ 1.400 Srm (Schüttraummeter)
Equipment and machines	Two biomass boiler (450 kW), automatically fuel dosage, by conveyor screw and conveyor belt, exhaust ashes pump.
Investment costs	383.000 €
Building time frame	1995-1996
References	Interessengemeinschaft für nachwachsende Rohstoffe und erneuerbare Energien in Melle-Buer e.V.: Waldhackschnitzelanlage Melle-Buer; Informationsblatt, 2002. OVE Energie GmbH & Co. KG: Schulzentrum in Niedersachsen (Modernisierung); Informationsblatt, Rothenfelde, o.J. Brinkschulte, H.: Die Holzhackschnitzelanlage des Schulzentrums Melle-Buer, sechs Jahre Betriebserfahrung; Vortrag im Rahmen des Seminars „Klimaschutz durch Holzenergie – Realisierungsmöglichkeiten für niedersächsische Kommunen“, Melle-Buer, 19.03.2002. Deutsche Bundesstiftung Umwelt: Holz zur Wärmeversorgung eines Schulzentrums, http://www.dbu.de, 2002. Meller Kreisblatt: CO2-Ausstoß in die Atmosphäre um 280 Tonnen verringert; 12.12.1997.

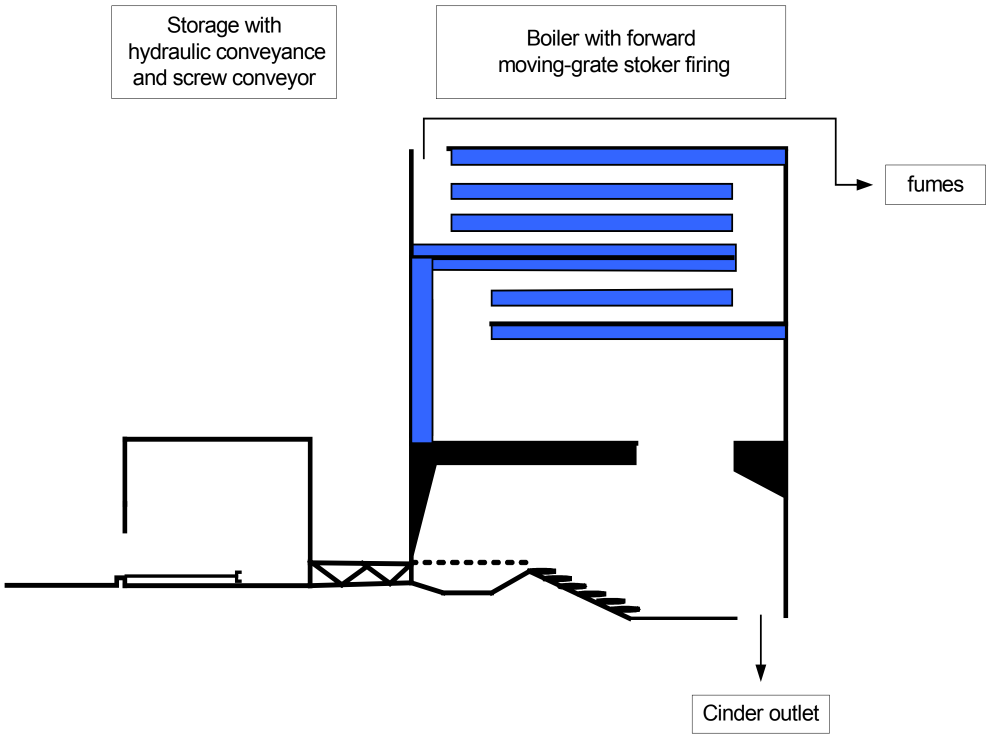
Process flowsheet



8.2.3.5 Biomass combustion plant, Münsingen

Region, city	State of Bavaria, Münsingen
Address	Gemeindezentrum Münsingen Weipertshausener Strasse 5 82541 Münsing
Manufacturer	Kess GmbH Hochgernstraße 14 83209 Prien am Chiemsee Telefon +49 (0) 8051 6865-0 Telefax +49 (0) 8051 6865-22 E-Mail : info@kess-gmbh.com
Operated by	Maschinenring Wolfratshausen AG
In operation since	2001
Process type/process characteristics	The combustion plant is designed as thermal heat plant for the public buildings in Münsingen (school, parish house, swim hall). The boiler is suited for woodchips, obtained from regional wood mills.
Tape of substrate utilised	In this plant, wood chips are used as fuel sole (300 kW) as well as petroleum (300 kW) for peak period demand
Maximum capacity/actual throughput of substrates	900 m^3 wood chips, 1.500 l/a
Equipment and machines	The biomass combustion plant is situated in the a former boiling room of the fire brigade and is heating the surrounding public buildings. From a silo nearby the wood chips are transported by conveyor belts to the biomass boiler. The boiler is equipped with a feed rate furnace. The fuel is dried and gasified on a moving grate. At the end of the grate the coal is burnt
Investment costs	440.000 €
Building time frame	10/2000-10/2001
References	http://www.carmen-ev.de http://www.kess-gmbh.com

Process flowsheet



Picture of the plant

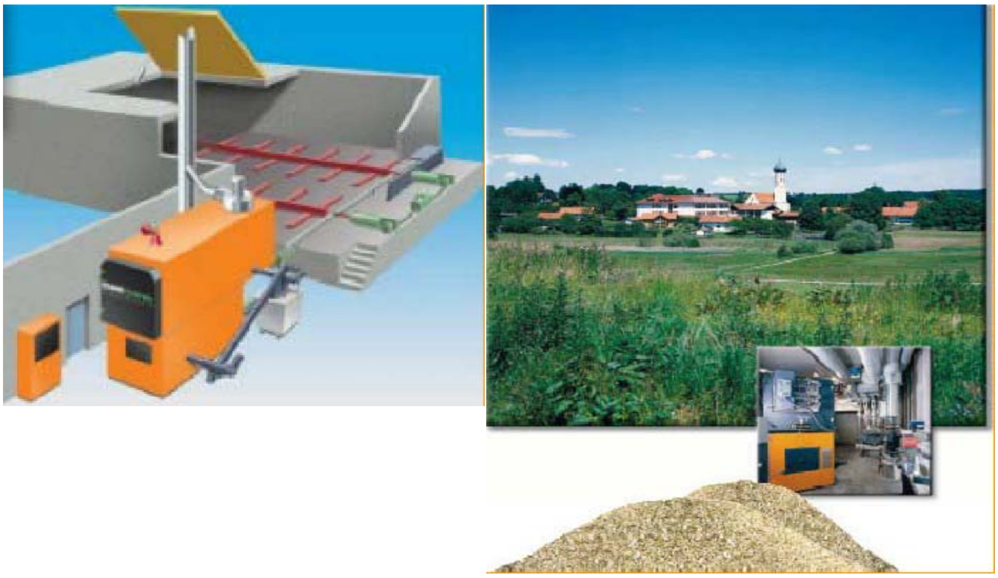


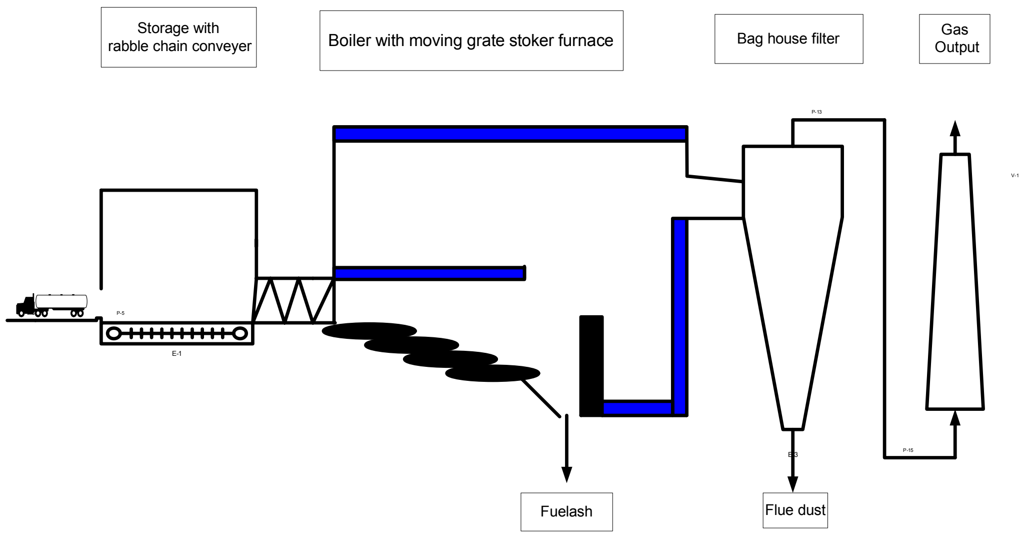
Figure 8.2-4: Model of the biomass boiler incl. fuel deposit (Kess GmbH)

Photo: www.Carmen-ev.de

8.2.3.6 Biomass combustion plant, Nettersheim (Biomasse-Nahwärmeversorgung)

Region, city	State of North Rhine Westphalia, Nettersheim
Address	Gemeinde Nettersheim Römerplatz 8-10 53947 Nettersheim Wilfried Pracht Tel. (0 24 86) 78 50 Fax. (0 24 86) 78 78 E-Mail: nettersheim@eifel-online.de Internet: http://www.holzkompetenzzentrum.de
Manufacturer	WVT Bioflamm
Operated by	Biowärme Nettersheim GmbH Oberlüghause 27 51503 Rösrath Hans-Helmut Forsbach Tel .: (0 22 05) 8 44 17 Fax.: (0 22 05) 26 28 E-Mail: HH.Forsbach@ETAEnergiegmbh.de
In operation since	2001
Process type/process characteristics	The combustion plant is designed as thermal heat plant for several public and private buildings in the town of Nettersheim with 7.500 inhabitants (school, guesthouse, swim hall). The network was built with a total length of 1.500m. As the region is well wooded, the wood chips from natural wood are obtained from local enterprises
Tape of substrate utilised	In this plant, wood chips are used as fuel sole (600 kW) as well as natural gas (2*400 kW) for peak period demand
Maximum capacity/actual throughput of substrates	800t wood
Equipment and machines	The furnace equipment consists of biomass boiler (600 kW) with an integrale burner and a feeding grate designed by Bioflamm WVT. The biomass boiler covers the basic consumption. For peak consumption two natural gas boiler were added (400 kW each)
Investment costs	**1.500.000 €**
Building time frame	1998-2001
References	Biowärme Nettersheim GmbH (BiNe): Ökologische Nahwärme für die Gemeinde Nettersheim, http://www.bine-nettersheim.de, 2002. Biomasse Info-Zentrum (BIZ): Nettersheim – Kleine Gemeinde mit Vorbildcharakter, Newsletter, 2001

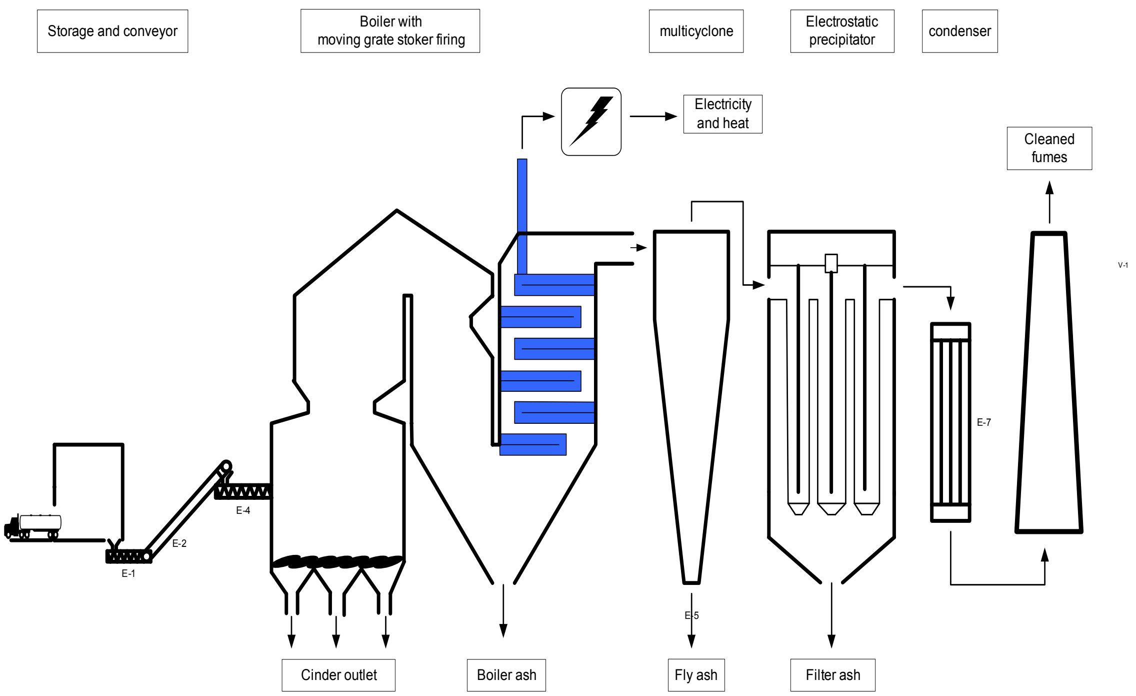
Process flowsheet



8.2.3.7 Biomass heat and power plant, Pfaffenhofen

Region, city	State of Bavaria
Address	Posthofstrasse 2 85276 Pfaffenhofen
Manufacturer	Babcock & Wilcox Vølund ApS Falkevej 2 6705 Esbjerg Ø fon +45 76 14 34 00 fax +45 76 14 36 00 E-mail: bwv@volund.dk
Operated by	Biomasse Heizkraftwerk GmbH Posthofstrasse 2 85276 Pfaffenhofen
In operation since	1991
Process type/process characteristics	The combined heat and power plant (CHP) is equipped with one biomass boiler and two spare boilers The biomass boiler is a steam boiler with natural circulation. It generates 23,3 MW firing heat capacity, up to 6 MW electricity and additional heat, which is inducted into the community heating. The combustion of the wood is a combination of fluidised bed combustion and grate firing. The fuel is added into the flame turbulences, heavier peaces of wood are falling on the grate, every 30 minutes the grate is shaken and the ashes are kept in the bottom discharge
Tape of substrate utilised	The plant is operated with untreated fresh wood chips and remaining wood from saw mills. The water content can be up to 60%. 1/3 of the fuel can be obtained from the region near Pfaffenhofen
Maximum capacity/actual throughput of substrates	200.000 MWh heat/ 42.000 MWh electricity. 88.000 t/a fuel
Equipment and machines	The biomass boiler generates 23,5 MW firing heat capacity and up to 6 MW electricity and additional heat, which is inducted into the community heating. The Turbine output is ~ 7 VA
Investment costs	45,6 mio. €
Building time frame	Begin of construction: January 2000, begin of first operation: January 2001, full operation: June 2001
References	http://www.bmhkw.de/start.html http://www.eta-energieberatung.de/aktuell/info/bbhkw_info.pdf

Process flowsheet



Picture of the plant

Figure 8.2-5: Biomass combustion plant Pfaffenhofen

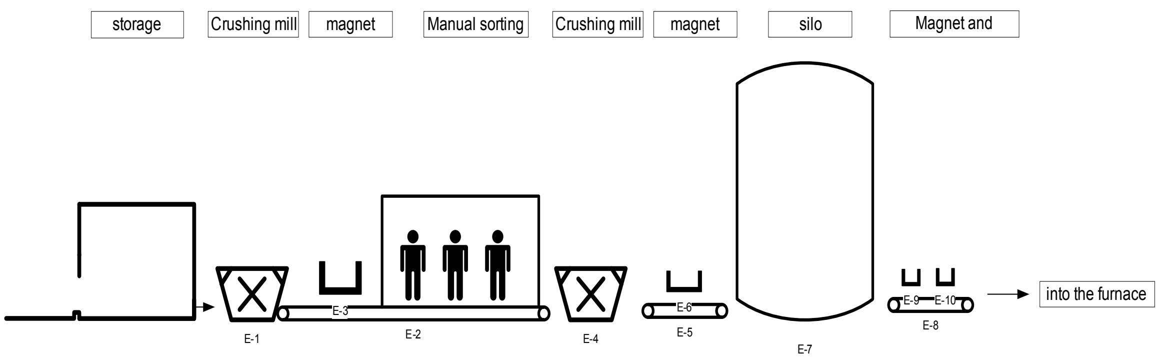
8.2.3.8 Straw combustion plant Jena

Region, city	State of Thuringia, Jena
Address	
Manufacturer	LIN-KA Maskinfabrik A/S (LIN-KA ENERGY) Nylandsvej 38 DK-6940 LEM ST. Denmark Phone +45 97341655 Fax +45 97342017 E-mail: linka@linka.dk
Operated by	Landesanstalt Jena
In operation since	1995
Process type/process characteristics	The straw combustion plant is designed as thermal heat plant. The boiler is suited for straw, as well as for combustion of hole plants, and hay from landscape conservation. The size of the bales is variable, so that the fuel can be obtained from different bale presses. The incoming material is cut into slices before it is loaded into the boiler. The combustion is based on a water-cooled grate firing system with pre-gasification. The flue gas is cleaned by a cyclone and a bag filter
Tape of substrate utilised	In this plant the sole fuel is gramineous biomass, but also for hole plants and hay. The straw bales can have different sizes
Maximum capacity/actual throughput of substrates	1,7 MW
Equipment and machines	The plant consists of a straw boiler with 1.7 MW heat output. Exhaust gases are cleaned by cyclone and bag filter. Before fed into the boiler, the fuel is cut into pieces of 30 cm in length by a slice cutter
Investment costs	Information not available
Building time frame	Information not available
References	http://www.thueringen.de/de/publikationen/pic/pubdownload396.pdf ttp://www.linka.dk

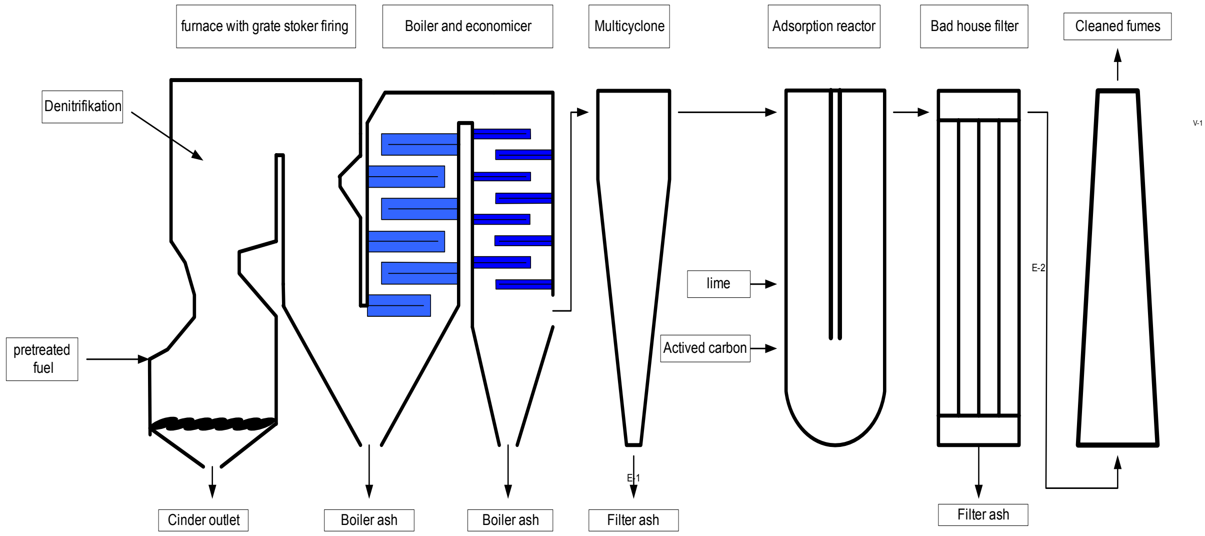
8.2.3.9 Biomass power plant Mannheim (MVV)

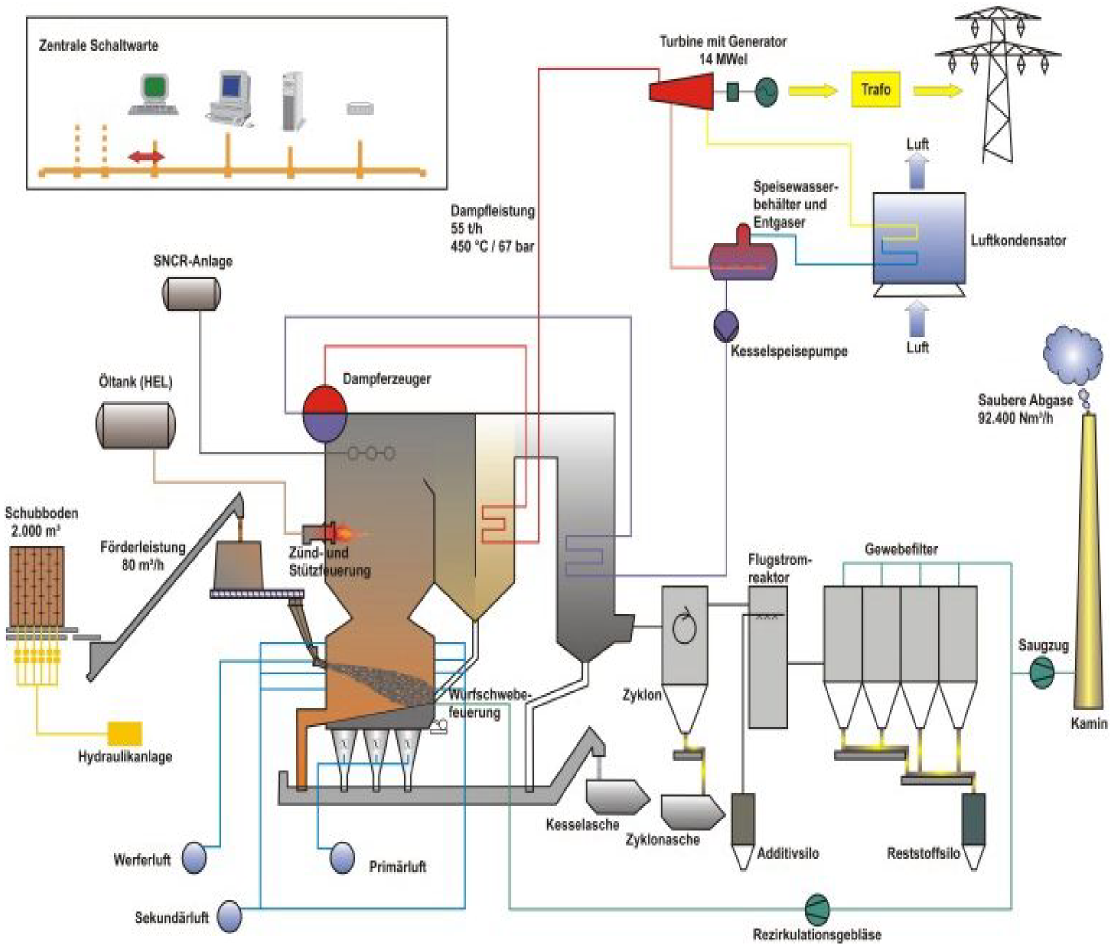
Region, city	State of Baden-Württemberg
Address	Otto-Hahn-Strasse 1 68169 Mannheim fon: + 49 (0) 621 / 290-4601 fax: + 49 (0) 621 / 290-4606 E-Mail: bmkw-ma@mvv.de
Manufacturer	MVV RHE AG (MVV Energie AG; Luisenring 49; 68159 Mannheim)
Operated by	MVV Biomassekraftwerk (BMKW) Mannheim GmbH management of the power plant by: MVV O&M (operation and maintenance) GmbH management of the wood treatment by: BHG Biomasse Handelsgesellschaft mbH
In operation since	Oct. 2003
Process type/process characteristics	The wood chips are fed in top of the burning area. One part of the substrate burns in the air and the other part burns on the grate. The boiler produces 80 Mg steam. The steam goes to the condensation turbine and in the following the generator produce electrical power. The fumes are introduced into the step of cleaning
Type of substrate utilised	The plant is operated with mechanical treated wood chips and waste wood, which are contaminated by colour, varnish and so on
Maximum capacity/actual throughput of substrates	Power capacity: 160.000 MWh per year, enough to 50.000 households, steam capacity: 80 Mg per hour with 65 bar and 450°C thoughput of woodchips: 124.000 Mg per year, 15,5 Mg per hour
Equipment and machines	The combustion plant consists of a biomass and the furnace is equipped with a combination of a fluidised bed and a grate firing. The electricity is produced by a condensation turbine and a generator (20 MW). The fumes are cleaned from nitrogenoxides, dust, heavy metal, acid parts, PCDD and PCDF by selected non catalytic reduction technique, by cyclones, by reaction with Ca OH_2 and active coal and by a textile filter
Investment costs	
Building time frame	July 2002 to October 2003
References	www.mvv-busniss.de

Process flowsheet - Pretreatment



Process flowsheet - Combustion





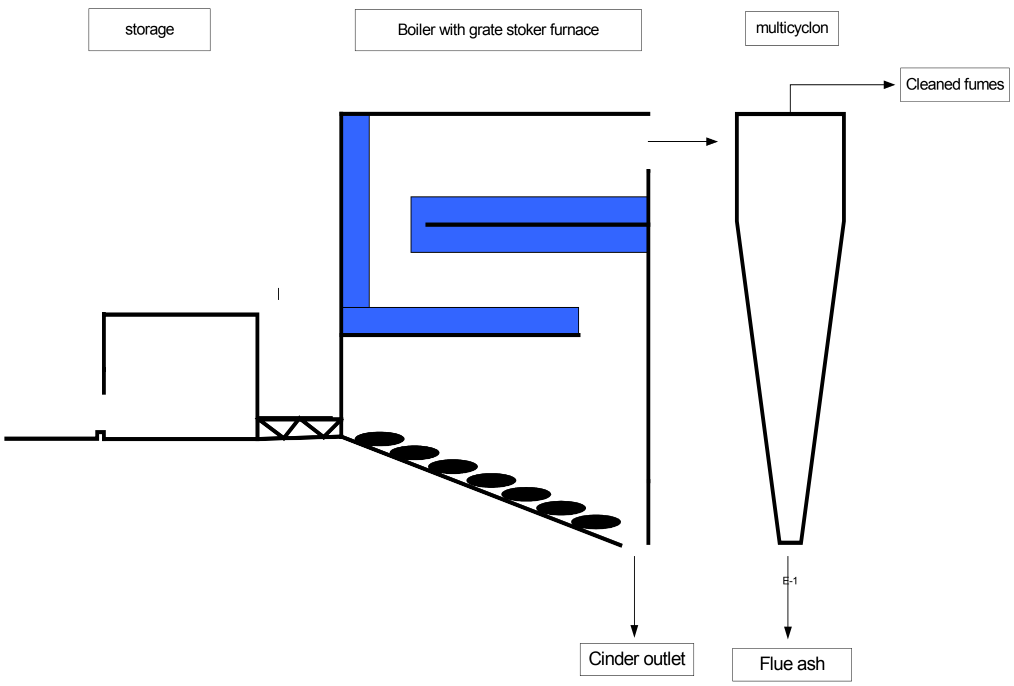
Picture of the plant

Figure 8.2-6: Biomass combustion plant Mannheim

8.2.3.10 Biomass heat plant, Obernsees

Region, city	State of Bavaria
Address	Schönfeld 13 96142 Hollfeld
Manufacturer	Ingenieurbüro Michael Gammel GmbH An den Sandwellen 114 D-93326 Abensberg fon: +49 (0) 9443 929 - 0 fax:: +49 (0) 9443 929 - 292 E-Mail: gammel@gammel.de
Operated by	BHO Biomasseheizanlage Obernsees GmbH Schönfeld 13 96142 Hollfeld
In operation since	1998
Process type/process characteristics	The biomass combustion plant was built as heating maintenance for hot springs. The heat plant is equipped with one biomass boiler.
Type of substrate utilised	The plant is operated with untreated fresh wood chips and remaining wood from saw mills
Maximum capacity/actual throughput of substrates	Heat capacity obtained by biomass: 450 kW, by petroleum: 430 kW. Combusted wood chips: 1.500 t/a, petroleum: 30.000 l/a
Equipment and machines	The combustion plant consists of a biomass boiler (450 kW) and a feeding grate stoker furnace. In case peak loads, the demand can be provided by a buffer store system with a water volume of 13.000l. The fumes are cleaned from dust and ashes by a multicyclone and condenser boiler
Investment costs	1,4 mio. €
Building time frame	1997-2003
References	http://www.gammel.de http://www.carmen-ev.de http://www.therme-obernsees.de

Process flowsheet



Picture of the plant

Figure 8.2-7: Biomass combustion plant Obernsee

8.2.4 Biogas plants in the United Kingdom

8.2.4.1 Biomass combustion plant Glanford

Region, city	North Lincolnshire, Scunthorpe
Address	Flixborough Industrial Estate, Scunthorpe, North Lincolnshire
Manufacturer	Owners' Engineers: Foster Wheeler Energy Ltd Boiler supplier: Aalborg Boilers A/S. Turbine provider: NEI-Allen (W.H. Allen of Bedford)
Operated by	EPR Project company: Fibrogen Ltd
In operation since	Commission: November 1993 Re-commission: May 2000
Process type/process characteristics	Conventional moving grate boiler and steam cycle
Type of substrate utilised	Poultry litter Meat and bonemeal (MBM)
Maximum capacity/actual throughput of substrates	13, 5 MW 89.000 Mg/a
Equipment and machines	
Investment costs	£ 24 million
Building time frame	
References	http://www.eprl.co.uk/assets/glanford/overview.html

Picture of the plant

Figure 8.2-8: Biomass combustion plant Glanford

8.2.4.2 Biomass combustion plant Eye

Region, city	Suffork, Eye
Address	Oaksmere Business Park, Eye, Suffork
Manufacturer	Aalborg Boilers A/S. Turbine provider: NE-Allen (W.H. Allen of Bedford) Owner Engineers: Foster Wheeler Energy Ltd
Operated by	EPR Project company: Fibropower Ltd
In operation since	Date of commission July 1992
Process type/process characteristics	Conventional moving grate boiler and steam cycle
Type of substrate utilised	Poultry litter, Horse bedding, Feathers
Maximum capacity/actual throughput of substrates	12, 7 MW; 160 000 Mg/a
Equipment and machines	
Investment costs	£ 22 million
Building time frame	
References	http://www.eprl.co.uk/assets/eye/overview.html

Picture of the plant

Figure 8.2-9: Biomass combustion plant Eye

8.2.4.3 Biomass combustion-plant in Westfield, Scotland

Region, city	Scotland, Westfield
Address	Business Park in Westfield
Manufacturer	
Operated by	Originally with Mitsui Babcock EPR Scotland Ltd took over O&M in August 2003
In operation since	January 2001
Process type/process characteristics	
Type of substrate utilised	(Poultry litter) Chicken litter (Feathers)
Maximum capacity/actual throughput of substrates	9,8 MW / 110.000 Mg/a
Equipment and machines	
Investment costs	Investment costs (overall/ specific) in Euro: Project costs ₤ 22 million
Building time frame	
References	http://www.eprl.co.uk/assets/westfield/overview.html

8.2.4.4 Biomass combustion plant Ely Power Station

Region, city	Ely in the north from Cambridge
Address	
Manufacturer	Constructor was FLS Miljo
Operated by	EPR Ely Ltd in partnership with Cinergy Global Power
In operation since	December 2000
Process type/process characteristics	Vibrating gate with conventional steam cycle
Type of substrate utilised	Oil seed rape and miscantuhus Cereal straw Up to 10 % natural grass
Maximum capacity/actual throughput of substrates	39 MW; 270 GWh/a (parameter of steam: 540°C, 92 bar) 200.000 Mg straw/a
Equipment and machines	
Investment costs	₤ 60 million
Building time frame	
References	http://www.eprl.co.uk/assets/ely/overview.html

8.2.4.5 Biomass combustion plant Thetford

Region, city	Norfolk, Thetford
Address	Munford Road, Thetford, Norfolk
Manufacturer	Taylor Woodrow Management and Engineering (TAYMEL) Turbine supplier: Ansaldo Energia SpA Boiler supplier: Foster Wheeler Ltd of Canada Grate system supplier: Destroit Stoker Inc. Fuel handling system supplier: Birtly Engineering plc
Operated by	Fibrothetford Ltd
In operation since	Date of commission June 1999
Process type/process characteristics	Conventional moving grate boiler and steam cycle
Type of substrate utilised	Poultry litter, chicken litter; Feather and other agricultural residues
Maximum capacity/actual throughput of substrates	420.000 Mg litter / a
Equipment and machines	Chain grate, spreader stoker combustion system
Investment costs	₤ 56 million
Building time frame	
References	http://www.eprl.co.uk/assets/thetford/overview.html