EC-ASEAN ENERGY FACILITY

Guidelines for the Preparation of Feasibility Studies for the Generation of Renewable Energy from Organic Waste and Biomass for Vietnam and other ASEAN Countries

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These guidelines were produced by the following consortium of six institutions from Europe and Vietnam, within the framework of the project::

"Development of practice oriented guidelines for the preparation of feasibility studies on the production of renewable energy from organic waste and biomass by biogas plants and biomass combustion plants, with an applied example for Phu Quoc/S.R.Vietnam" (Acronym: RENEW)

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for the Generation of Renewable Energy from Organic Waste and Biomass for Vietnam and other ASEAN Countries

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1. Introduction

The guidelines for the preparation of feasibility studies for generation of renewable energy from organic waste in ASEAN countries contain information on several levels relevant to the project development. In the following we would like to give a reader a brief overview of what to expect for the following sections, this is also meant as a guide as to which sections are most useful depending on the readers background.

The introduction severs to inform the reader about the project as a whole, objectives, target group, funding sources and a bit about how this project developed are presented. This section contains information that is of very general interest.

In the second section we will discuss the relevance of renewable and present an overview as well as details about two methods for energy generation from organic waste, the biogas pant and biomass combustion pant. This is mainly of interest for the reader who comes from a less technical background and is not familiar with these technologies. It will give local decision makers an idea of the relevance and benefits of renewable energies in the second part of the section (Section 2.2). The reader, not familiar with the process details but interested, will find information about requirements and technological processes in Section 2.3.

If you are familiar with energy generation for renewable sources such as organic waste, but new to the topic of feasibility studies then Section 3 might be a good place to start with. In this section we will discuss why a feasibility study might be useful and how it is embedded within the project development process. Following this we will go through all the aspects of a feasibility study step by step in Section 4. This section provides check lists and short easy to use information, as an example and for more details a feasibility study is attached in the appendix. Literature and additional references are given for even more information.

1.1. Objective of the Guidelines

Objectives of the guidelines are to aid with the production of integrated feasibility studies for the renewable energy sector, considering technical, environmental, economic, social/ cultural, legal and institutional aspects which are particular applicable for ASEAN countries.

The following document are comprehensive guidelines for the preparation of feasibility studies in the renewable energy sector. This involves a definition of the scope, which reflects the aims and objectives of the target groups (supplier, operator etc. of renewable energy supply). At the heart of the document are the methodologies and tools which should guide the reader through such questions as: why is it useful to do a Feasibility Study for renewable energies; what needs to be done; who can help; what needs to be take care off; and, how much detail is needed. All relevant aspects will be covered: data collection, selection of sites and options, and how to assess the feasibility of options, including technical, environmental, economic, social, cultural, legal and institutional aspects. Furthermore, methods and tools for risk assessment and decision-making (multi-criteria analysis) will be developed or compiled. In addition, to support European companies, guidance on cultural aspects of project development will be developed. A practical plan of procedures will be developed which guides the user through a feasibility study.

1.2. Target Group

The main target group and direct beneficiaries of the guidelines are European companies (particularly small and medium sized) in the energy /renewable energy sector (plant and equipment construction, suppliers of energy facilities and equipment, operators, planners). Small and medium sized European companies are very important for the European economy, however international business and innovative tasks are particularly difficult for them due to lack of resources. The following guidelines on the production of feasibility studies in ASEAN countries will help these companies to advance into a market which would be difficult to reach without this form support. Feasibility studies and life cycle assessments are generally conducted by specialised experts or bigger players only. This project will strengthen the capacity, mainly of small and medium sized companies by the development and provision of guidelines. The guidelines are in the also relevant to Vietnamese/ ASEAN companies in the energy /renewable energy sector. Together with the feasibility study for renewable energy in Phu Quoc, the guidelines give these companies information about renewable energy from organic waste with a direct outlook toward implementation.

Another target group are local or regional decision-makers, representatives of administration and stakeholders involved in energy supply and sustainable development as well as other decision-makers, representatives of administration, stakeholders involved in energy supply and sustainable development in the ASEAN region. Local or regional decision-makers, representatives of administration and stakeholders decide upon the system of energy supply in any region or country. Generally the main obstacles when implementing new sustainable strategies like renewable energy by biogas or biomass combustion is the lack of information on feasible options. Information in the form of guidelines and example feasibility studies (like the one for Phu Quoc) can help to overcome these obstacles and aid with the planning of renewable energy projects. The guidelines help to spread knowledge about renewable energy and can help to develop of the know-how for best technical, economical and environmental sound option for ASEAN countries.

Furthermore, the feasibility study will provide information on European products to ASEAN decision-makers. This will rise interest in European services and products (e.g. pumps for biogas plants, generators, plant concepts like the dry fermentation process, etc.). If implemented, the suggested renewable energy plant fo-r Phu Quoc will represent the first demonstration plant in Vietna) EAEF ASI/B7/m, showing European Technology. For companies from the ASEAN region, the project will offer international know-how of a unique quality. They will by supported in developing new market sectors (renewable energy options; feasibility studies). Increasing the awareness regarding renewable energy supply options derived by organic substrates can help in achieving political goals such as reducing the pollution, promoting eco-tourism and providing cost-effective, decentralised energy supply for the inhabitants; it can form the ground for policy developments and further activities regarding CDM (Clean Development Mechanisms)-projects on the basis of the Kyoto-Protocol.

1.3. Funding of the Project

The production of the *Guidelines for the Preparation of Feasibility Studies for the Generation of Renewable Energy from Organic Waste and Biomass for Vietnam and other ASEAN Countries* and the *Feasibility Study for the Generation of Renewable Energy from Organic Waste and Biomass on Phu Quoc Island, S.R. Vietnam* has been co-funded by the European Union, within the framework of the EC-ASEAN Energy Facility Programme (EAEF)
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The EAEC programme was launched in March 2002 with duration of five years until February 2007. It aimed at the cooperation between the European Community (EC) and the Association of Southeast Asian Nations (ASEAN) to facilitate partnerships between ASEAN and European organisations in developing specific joint projects in the energy sector.

For further information regarding EAEF and the European Union, please see the following web pages:

- EAEF
  www.aseanenergy.org/eaef
- European Commission
  www.europa.eu.int
- European Commission External Relations
  www.europa.eu.int/comm/external_relations
- European Commission External Relations
  www.europa.eu.int/comm/external_relations
- European Commissions DG Development
  www.europa.eu.int/comm/development
- European Union in the World
  www.europa.eu.int/comm/world

2. Relevance of Renewable Energy/IB

In this section we will discuss renewable energies and their relevance as well as some technological aspects. The focus here is on renewable energy generation for organic waste, in particular biogas plants and biomass combustion plants. If you are familiar with these technologies and processes you can skip section 2 and start with section 3 where the methodology of feasibility studies in the context of project development is introduced.

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 gives an overview over renewable energy sources in form of thermal, chemical and electrical energy.

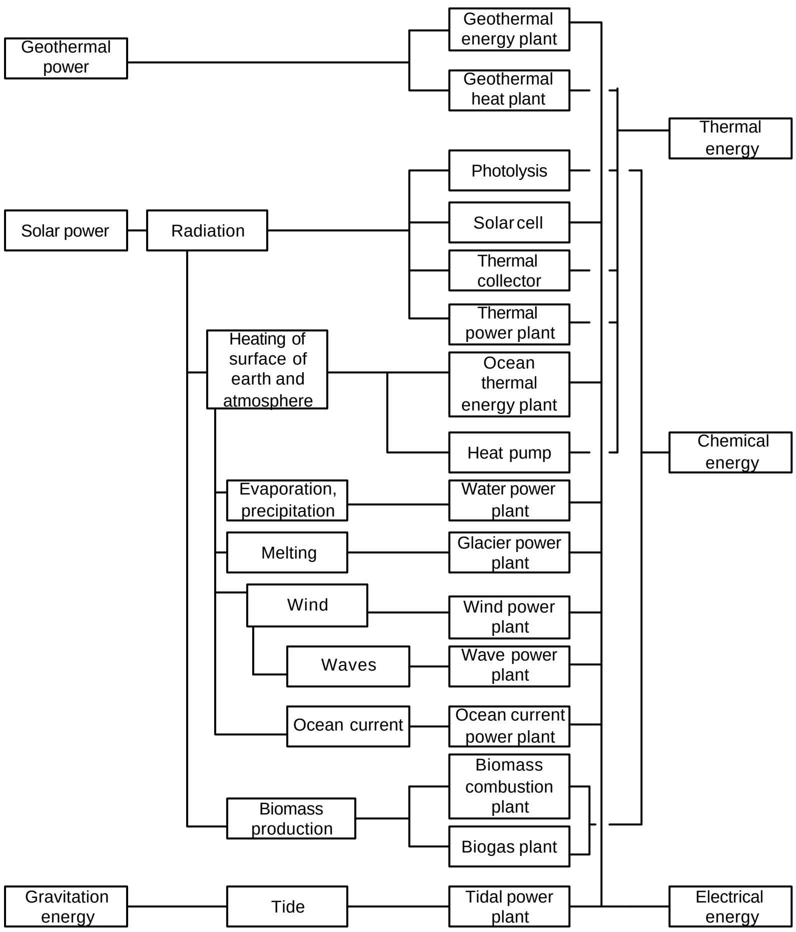


Figure 2.1: Options of renewable energy [Kaltschmitt, M., Hartmann, 2001]

Biomass

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 2.2):

- 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.).

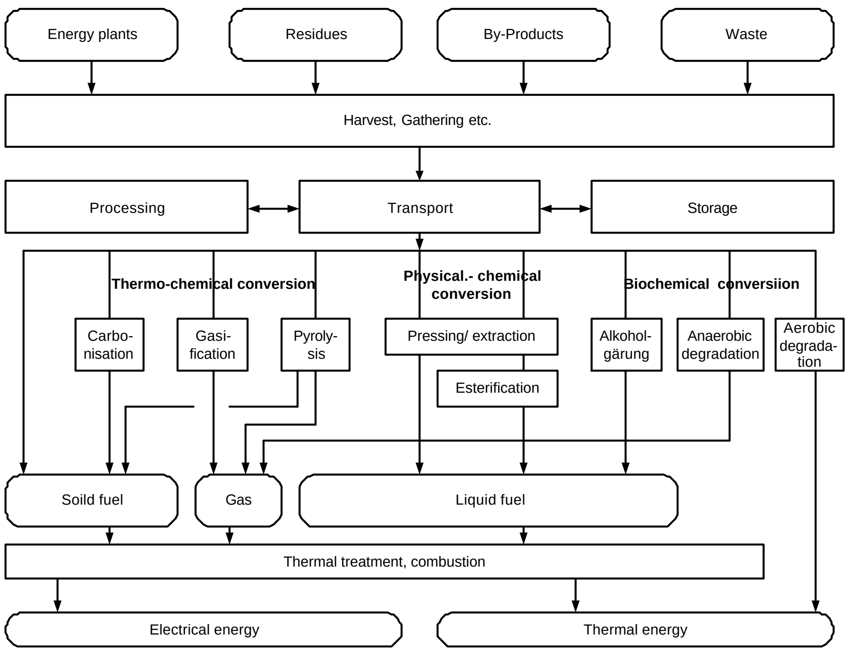


Figure 2.2: Overview of renewable energy production from organic substrates [Kaltschmitt, M., Hartmann, 2001, changed]

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

In this subsection we will consider economic or financial effects and issues related to the increased use of RE and especially from RE generated from biomass. This will give a general picture and should help to understand the economic background and implications of the use of RE from biomass. We give some generally 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 the dependency world market price of fossil energy</u>
Increasing energy production from renewable sources has not only local social and economic effects. It also brings several economical changes and benefits to the whole country. Most countries depend on the 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 which increases short and long term economic stability, especially given the fact that energy prices will increase in future because of production constraints and demand increases (especially from Asian countries). Energy price fluctuations in highly energy dependent countries have lead 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 the energy prices are prices for chemical fertiliser (because their production is very energy intensive). Biogas technology especially helps to save countries expenses of 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 other more 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 there will be no shortage of oil and gas 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 longer. 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.

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 and 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 the 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. It appears to be 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 as 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 the 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 but 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 does 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 on costs the external effects have to be considered. Energy production from fossil sources causes external costs which are usually much higher than external costs from RE these include local and global effects e.g. through GHG emission and the long run dangers caused by it. Coal has additional environmental damage through mining (destruction of landscape, intervention in the water household, health problems of miners and residents etc). All these external costs paid by the people surrounding a mine or power plant as well as 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 and reducing those 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

The costs arising in the 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 (100%).

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 a 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.

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.

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.

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. 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. Besides these 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.

In the future it may be possible to generate additional income with RE by Clean Development Mechanism. Some estimations expect prices of 3-6 $/tCO2equivalent (*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.

2.2.2.3. 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.

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

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 SO2 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

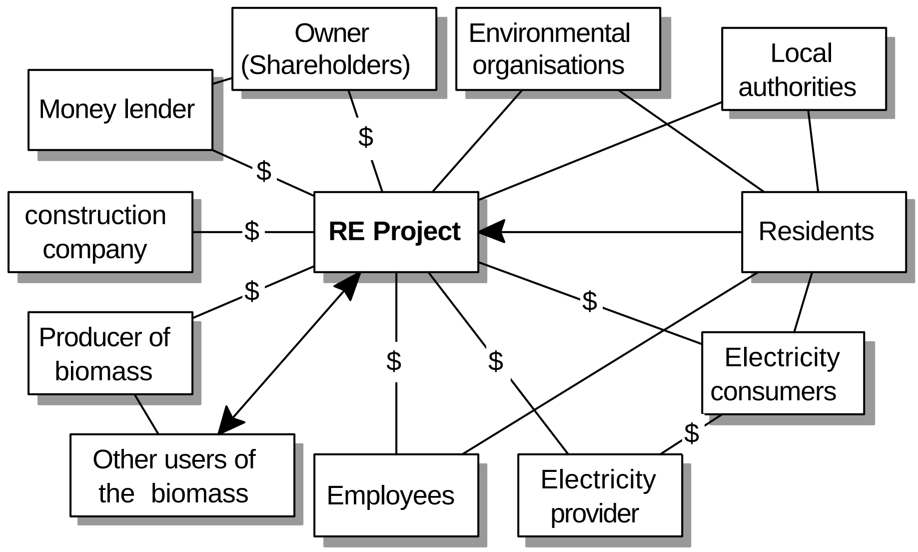
This subsection gives information which goes beyond economical issues. It looks at different economical, social and cultural issues people may be confronted with when a biomass using power generation activity is started. This subsection deals more with small scale, local issues and problems which are 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

Many groups are directly and indirectly involved in a project
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.



Network of Stakeholders

Figure 2.3: Network of project's stakeholders

Ownership one of the key issues

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 be more involved. 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. 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. Each members responsibility within a big group may diminish because everybody think someone else will 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 ones (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 as it depends too much upon local conditions, it is clear however that sometimes small changes in ownership lead to more involvement of important stakeholders, 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 highly 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 himself 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.
Technology may have to be adapted to a level which can be handled with locally available knowledge. Some technology which looks more primitive and is less efficient from a purely technical point of view may be better suitable for the project and more sustainable because it can be better maintained. Finding a maintenance engineer or spare parts for more complex technology may involve high costs and delay 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 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.
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 the 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 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 with the project. This leads very quickly 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, like certain groups have some privileges when it comes to work. These 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.

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 may have some influence to change the attitude of the people.

Start the information process as early as 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 solutions together. 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 at first.

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. 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

In the following paragraphs we 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.

1. 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*).

It is also estimated that the investment requirement per job is much lower in biomass energy industries than in other branches, i.e. with the same amount of money more employment is generated.

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.

RE from biomass generates income locally

Energy production from biomass in rural areas brings additional advantages, it can generate some income (for the owner and for the employees) and make these 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, which is not the case for big power plants where the money flows only into the areas with power plants (or even abroad to pay for the fuel).

Biomass use in rural areas diversifies the economic structure. This gives a region 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.

2. Improvement of energy supply

Better energy supply is advantageous but not automatically beneficially for all

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 though it is not enough to alleviate poverty. 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.

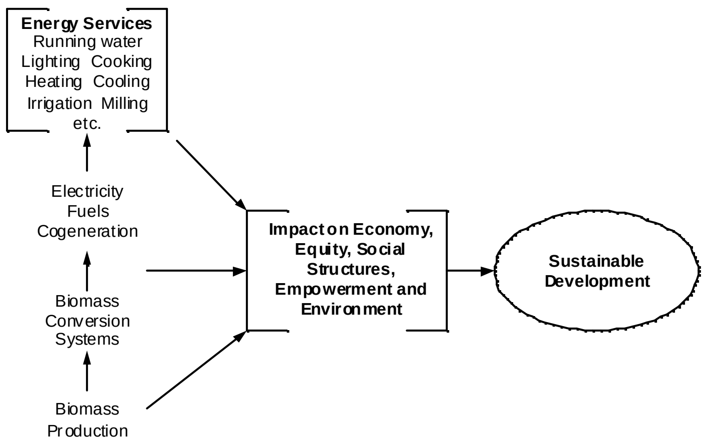


Figure 2.4: Concept of biomass energy systems and linkages to sustainable human development [Kartha and Larson, 2000]

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 which helps 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, job and income creation. 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 there was nothing before. In this case the effects are difficult to estimate as 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 as it will mainly be through saving of energy costs and more reliability.

<u>Improvement of energy supply will enhance quality of life</u>

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).

3. Demand and supply effects on different markets

<u>Other business will be affected indirectly</u>

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. In the following we describe markets in which the influence of a biomass power plant is large. Influence in other markets on prices 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.

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.

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)*

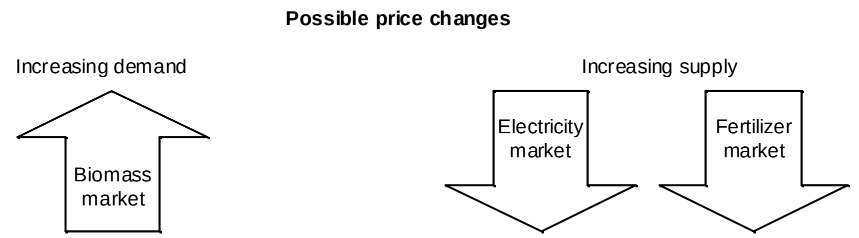


Figure 2.5: Price changes affecting the application of renewable energy

It is very important to look at all relevant markets. The people involved in these markets will be directly or indirectly affected as they usually do not have a contract with the plant operator 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) and sell their biomass. As compensation they would get some income from their biowaste but 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

<u>Bioenergy is quite well accepted - burning technologies more problematic</u>

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.

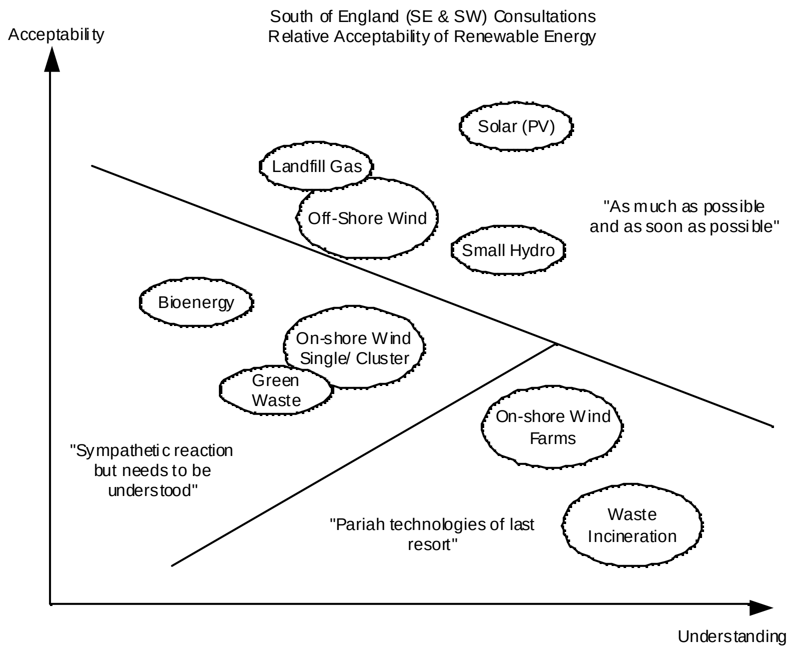


Figure 2.6: Positioning of different kinds of renewable energy [Community Preferences for Bioenergy Development in the South East of England Keith Richards and Annette Deveson in J. Domac and K. Richards (eds.) 2001]

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 much 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.

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.

2.3. Energy Generation from Renewable Energy Sources

There are many different possibilities for generating energy from renewable sources. We will in this section focus on biogas and biomass combustion, as we have seen earlier these methods are not very well understood but well accepted.

2.3.1. Energy from biogas

In the following we will look at energy generation from biogas in more detail. This includes a definition of biogas, the principal of anaerobic metabolism, process parameters, the technical application, how to utilise biogas and a discussion of the benefits.

2.3.1.1. Definition of 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 (CO2), as well as traces of hydrogen sulfide (H2S), Nitrogen (N2) and carbon monoxide (CO) (Table 2.1).

Table 2.1: 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.

2.3.1.2. 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 2.7) shows the different phases of the methanogenesis, involving three different bacterial communities.

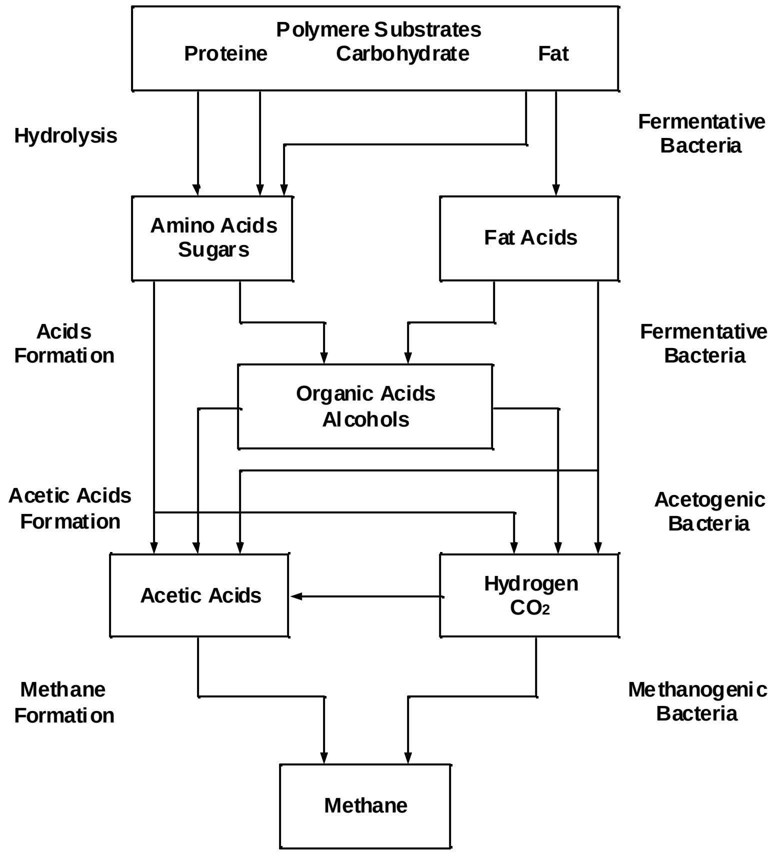


Figure 2.7: The phases of methane production

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 and propionic acid), alcohol, hydrogen and carbon dioxide.

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

Methane and acetogenic bacteria act in a symbiotic way. The latter creates an atmosphere with ideal parameters for methane producing bacteria (anaerobic conditions, compounds with a low molecular weight), the former use 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.

2.3.1.3. 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 2.8).

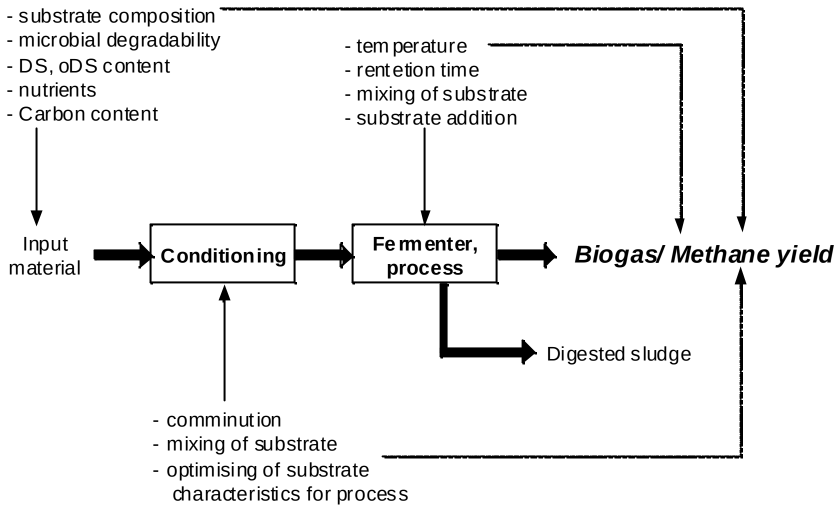


Figure 2.8: Factors which influence the biogas and methane yield [Weiland, 2001]

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 2.2 for examples for typical substrates and possible methane yields, or tool 1 for a comprehensive list of suitable substrates and their characteristics.

Table 2.2: Typical substrates and biogas yield

	Methane yield [CH_4 m³/kg oDS]
Cattle manure	0,10-0,35
Pig manure	0,18-0,64
Maize silage	0,22-0,50
Grass silage	0,30-0,60
Food waste	0,30-0,60
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 2.3 shows the theoretical, specific biogas yield. The different methane concentrations result from the differences of the relative carbon ratio.

Table 2.3: Specific biogas yield and methane concentration

	Biogas yield [l/kg oDS]	**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, easily 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 2.4). The optimisation of the nutrient supply must be carried out on an empirical basis, considering the mechanical, chemical and physical framework conditions.

Table 2.4: Typical Constitution of Biomass (Bidlingmaier, 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

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.

2.3.1.4. 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 (see below). The storage and transport of liquid substrates are done using agricultural equipment and machines.

Table 2.5: 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 (DS from 15 to 65%) Wet fermentation (DS up to 15%) Anaerobic wastewater treatment (for wastewater)
Type and source of substrate	Agricultural mono-fermentation plants (manure fermentation) or Co-fermentation plants (manure plus additional substrates) 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

2.3.1.5. 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 sulphide (S2-). The sulphide will then exist as hydrogen sulphide (H2S) in the biogas. During the oxidation of biogas in a unit power station, heating boiler or other energy conversion plant, H2S is converted into SO42-. In the form of sulphuric acid (e.g. in exhaust gas heat exchanger in a unit power station) it can lead to significant corrosion problems in the condensation zones. The removal of H2S from the biogas can be achieved through biological or chemical purification.

Chemical de-sulphuring is generally carried out by precipitation of H2S 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 (O2). On the surfaces in the fermenter or in external reactors, micro-organisms will grow which can oxidise H2S, S and S2O32- to SO42-. H2S is removed from the gas phase (biogas). A significant decrease in pH values on the H2S oxidising micro-organism growing surfaces will result, and so these should be regenerated from time to time.

If silicon compounds are added (e.g. those used as de-foamers in some lemonade) in the fermentation process, Silan (SiH4) 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 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 efficiency rate 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 application with or without exhaust heat exchanger. When heat is utilised alongside electricity, the process 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 can be run on biogas alone, with gas-diesel engines (Figure 2.9) require an oil-ignition part alongside the biogas (e.g. 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.

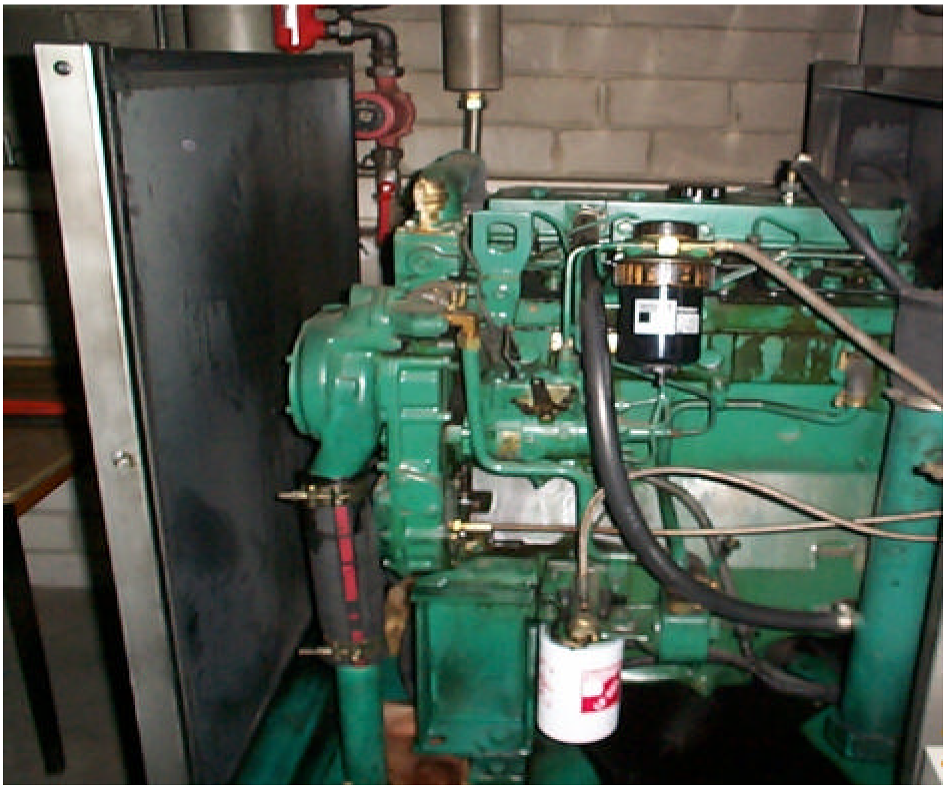


Figure 2.9: Unit power station with gas-diesel motor with an electrical output of 60 kW

2.3.1.6. 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 add new value to life 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 2.6**).
Table 2.6).

Table 2.6: 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

2.3.2. Energy generation from biomass

Another way to generate energy from organic waste is through biomass combustion. We will lo at substrates for the process, the technology, discuss some by-products of the process and the heat and power utilisation of these plants.

2.3.2.1. Substrate and Substrate Treatment

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 (rape cake, fruit pulp) and wood processing industry including forestry itself (wood residues and off cuts, 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 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.

Biofuels are differentiated into three main groups dry solid biofuels, solid biofuels (> 15-20 % moisture content) and fluid biofuels (rape oil)
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).

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.
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. The following methods are used for drying: open air drying, drying by flue gas and by steam.

Depending on the combustion technology used fuel products must fulfil 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.

2.3.2.2. Combustion technology

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.

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.

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.

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].

2.3.2.3. 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 2.10. Variations of these technologies are available but not further described here.

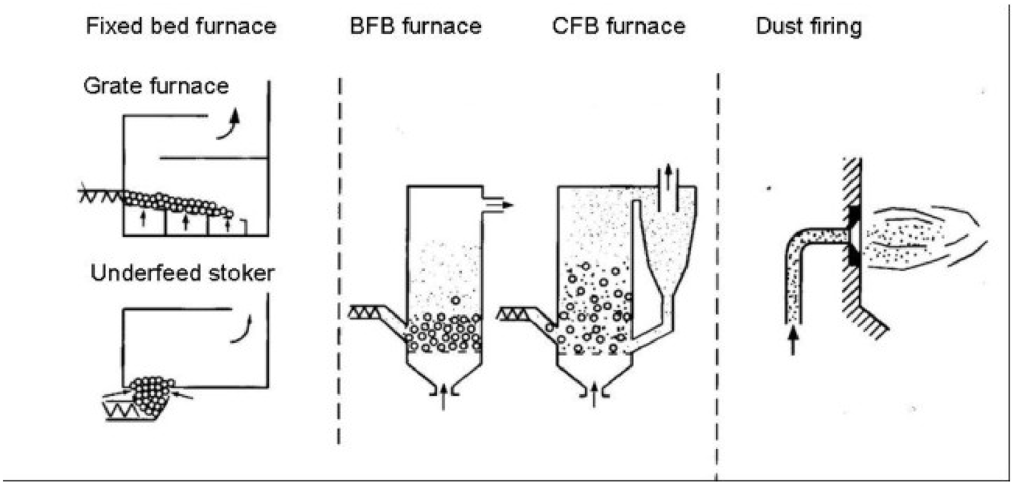


Figure 2.10: Principle combustion technologies for biomass [Loo, 2003]

Fixed-bed combustion

Fixed-bed combustion systems include grate furnaces (Figure 2.11) and underfeed stokers (Figure 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).

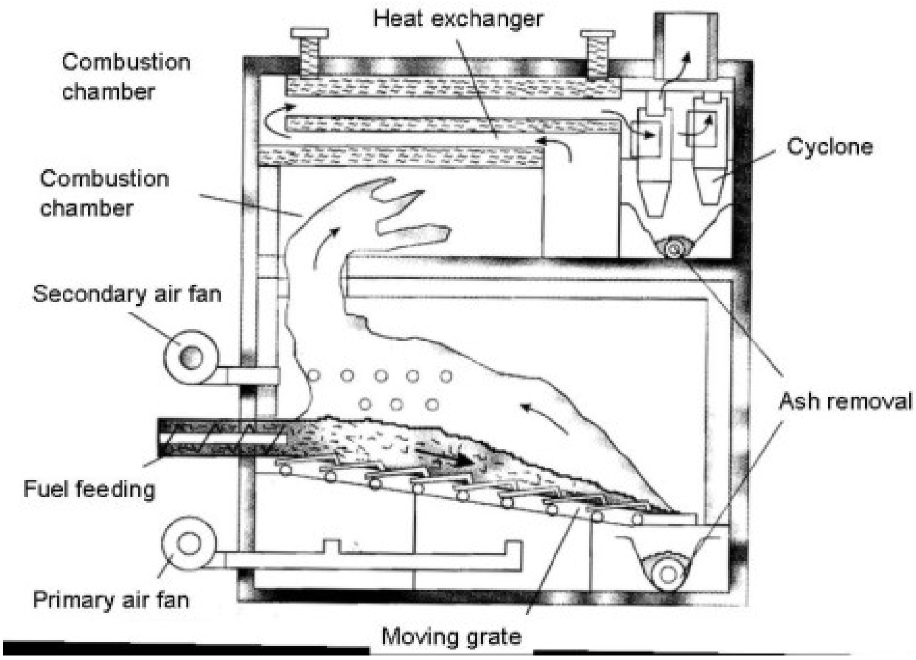


Figure 2.11: Grate combustion with counter-current flow (flame in the opposite direction as the fuel à suitable for wet biomass) [Kaltschmitt, 2001]

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]

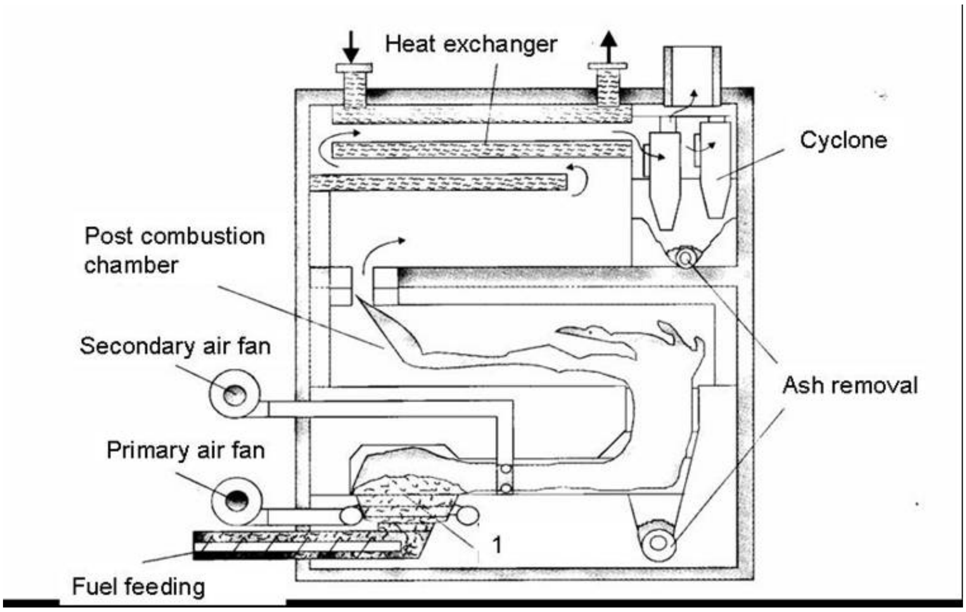


Figure 2.12: Diagram of an underfeed stoker furnace (1 = understoker zone with glow bed) [Kaltschmitt, 2001]

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.

Fluidised-bed furnace BFB

Within a fluidised-bed furnace (Figure 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.

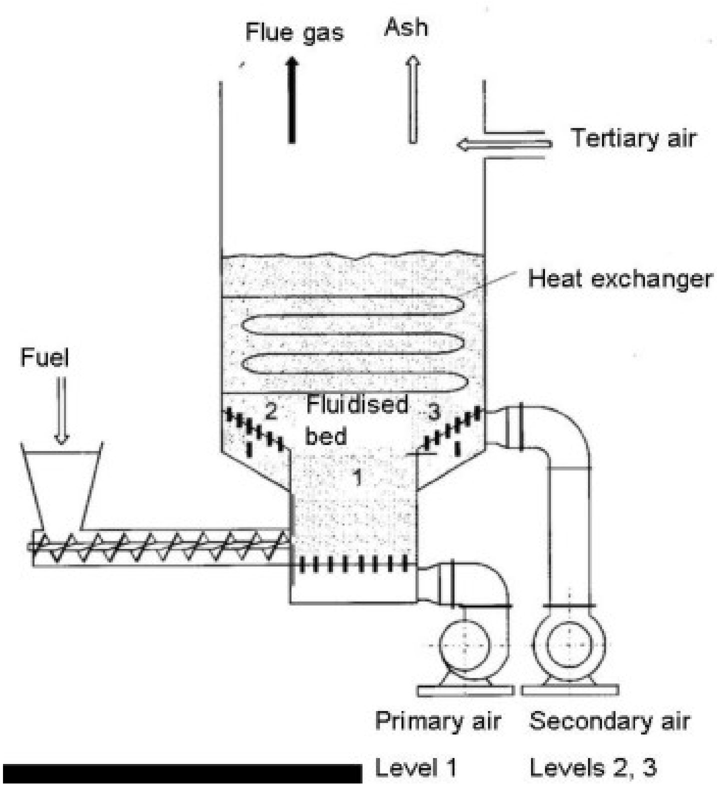


Figure 2.13: Diagram of a BFB furnace with three air introduction zones [Kaltschmitt, 2001]

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 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.

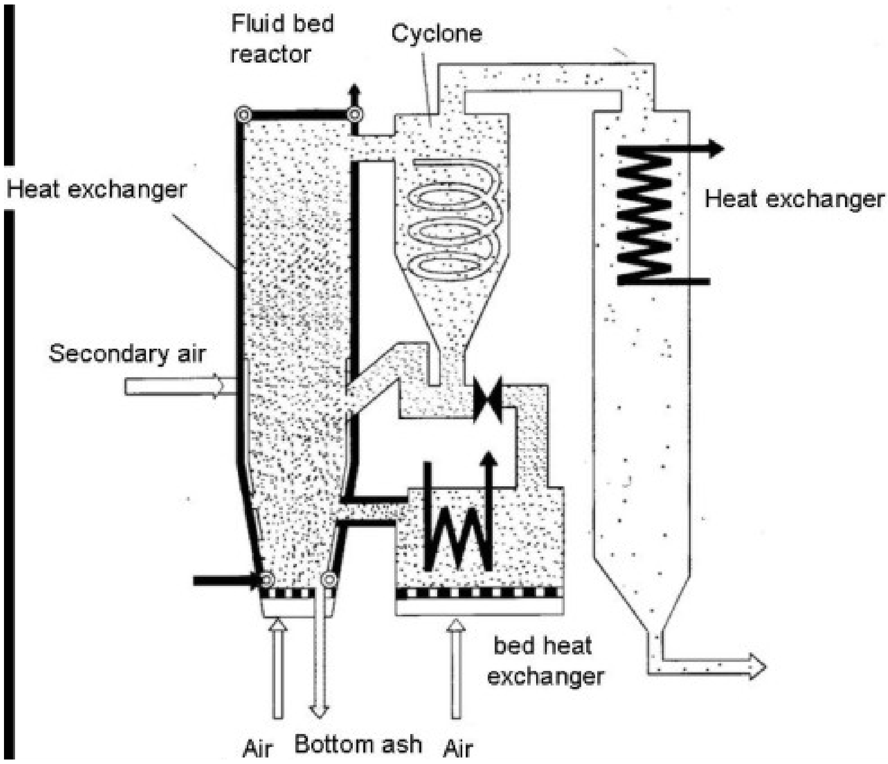


Figure 2.14: Diagram of a CFB furnace with steam boiler [Kaltschmitt, 2001]

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]

<u>Dust combustion</u>

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 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.

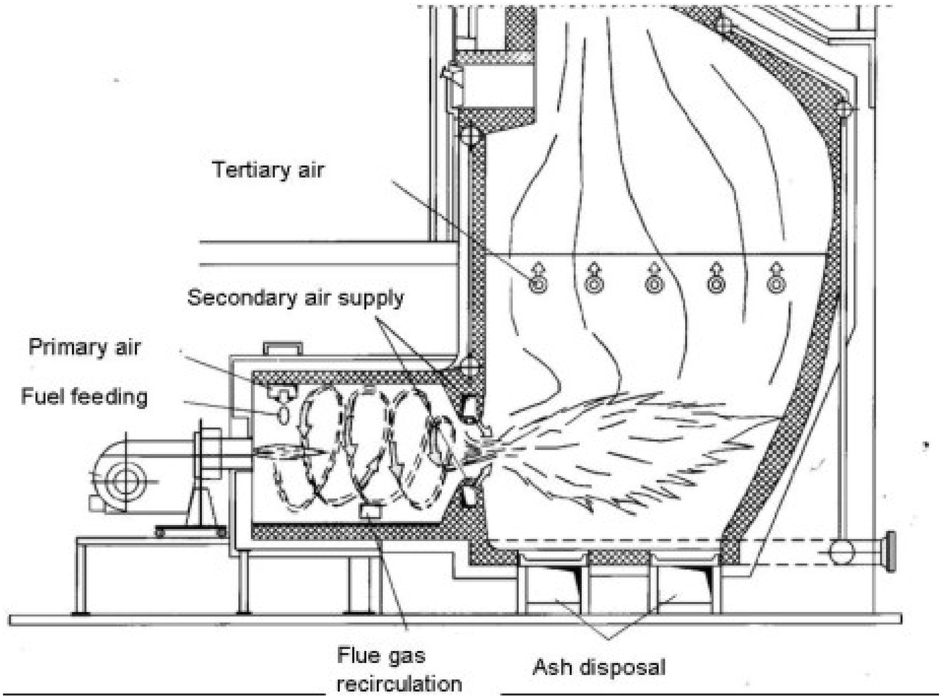


Figure 2.15: Diagram of a dust combustion plant [Kaltschmitt, 2001]

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.

Summary of different Technologies

The following tables provides an overview of relevant advantages and disadvantages (Table 2.7, Table 2.8), and fields of application of different biomass combustion technologies (Table 2.9).

Table 2.7: 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 2.8: 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 2.9: 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

2.3.2.4. Flue gas cleaning (FGC)

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).

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 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 be removed efficiently.

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.

Settling chamber

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 2.10)

Table 2.10: 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 2.11).

Table 2.11: 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 2.12).

Table 2.12: 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 uncollectible 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 2.13).

Table 2.13: 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 2.14).

Table 2.14: 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).

2.3.2.5. 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 2.16):

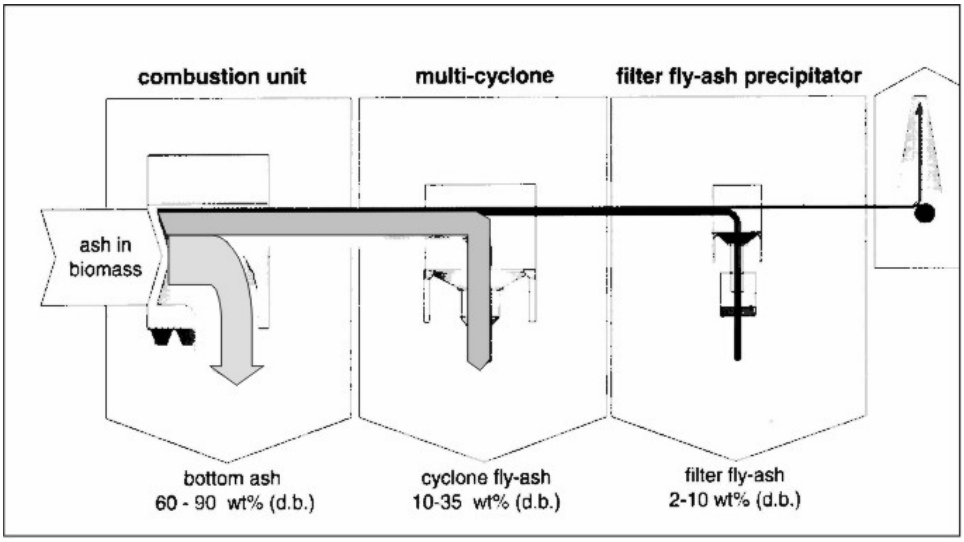


Figure 2.16: Various ash fractions produced in a biomass combustion plant (data are valid for fixed bed combustion units. In fluidised bed combustion units fly-ash is quantitatively dominant) [Loo, 2003]

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 2.15). Also the combustion technology is influencing the amount of ash produced (compare Chapter 3.2.4.2.2: Fluidised bed furnace).

Table 2.15: 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 2.17**) and nutrient concentration in various ash fractions (Figure 2.18).

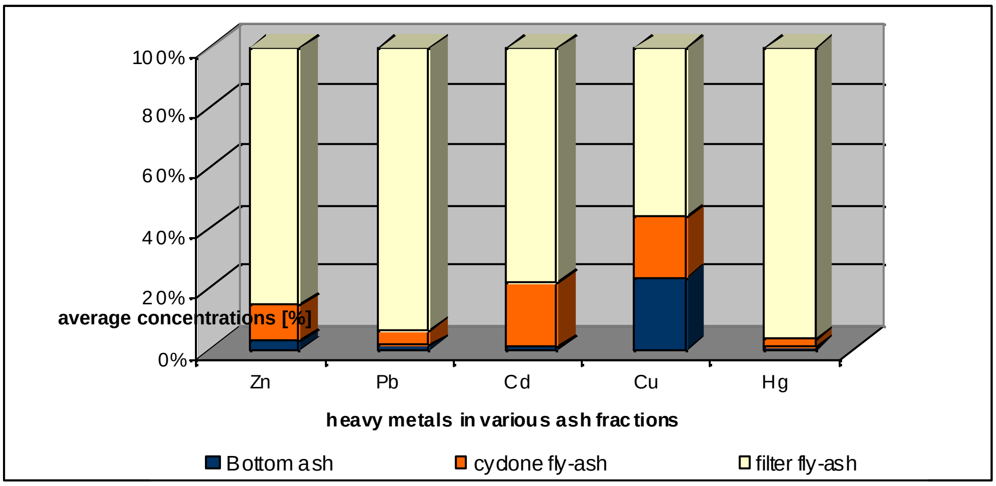


Figure 2.17: Average concentrations of heavy metals in various ash fractions of bark, wood chips and sawdust incinerators [Kaltschmitt, 2001]

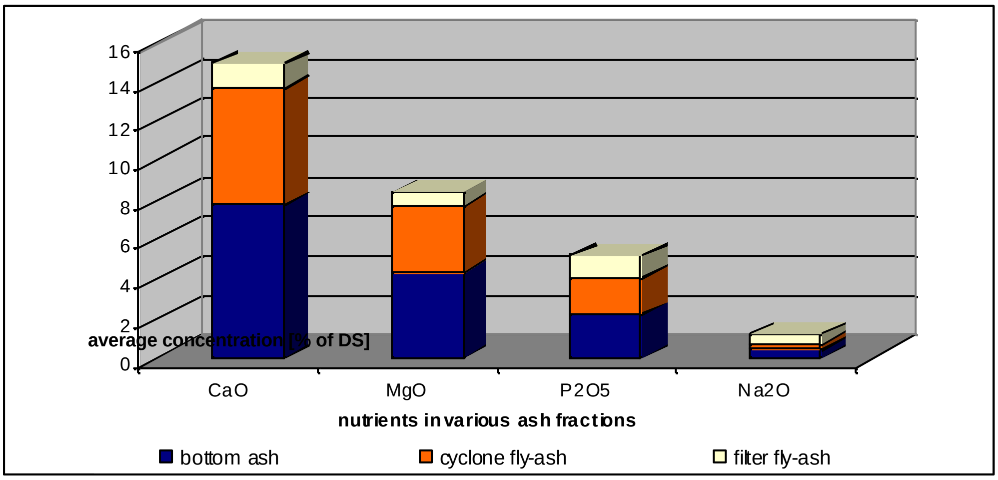


Figure 2.18: Average concentrations of nutrients in various ash fractions of straw incinerators [Kaltschmitt, 2001]

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.

2.3.2.6. Heat / Power generation

To fulfil its purpose combustion plants pass as much as possible of the generated heat 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 or heat and power.

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 fue 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]

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 ($?_{el}$ = 20-25% → 5-10 MW_{el}) [Loo, 2003].

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. Introduction into the Method of Feasibility Studies

In this section we will look at the methodology of feasibility studies, some reasons for doing one and how the study is embedded within the project development.

3.1. Definition

A feasibility study is a preliminary study undertaken prior to implementing a project in order to ascertain the likelihood of the project's success. As the name implies it is an analysis of the viability of an idea. The focus is on answering the essential question of whether one should proceed with a proposed project idea - all activities of the study are directed toward helping answer this question. A feasibility study is often also an analysis of possible alternative solutions to a given problem especially highlighting the different impacts of these alternatives and also includes a recommendation on what is, base on data and investigations, considered the best alternative.

In order to distinguish between different alternatives a feasibility study takes into consideration aspect such as the different economical, social and ecological impacts, and usually includes a risk assessment for each alternative. Feasibility studies can be used in many ways but primarily focus on proposed business ventures.

Definition of a feasibility study

A feasibility study is a study undertake prior to the implementation of a project. The aim is to analyse the viability and evaluate the impact of a project or idea. If there are several alternatives the risks of each option are assessed in order to assist the decision makers on whether or not and how to implement a project.

A feasibility study gives focus to the project and narrows the often vast number of alternatives, it might also identify reasons not to proceed with a project. The probability of success of a project is enhanced by addressing and mitigating factors early on that could affect the project. The study also provides quality information for decision maker as it provides documentation that the alternatives was thoroughly investigated which also helps in securing funding from lending institutions and other sources. A feasibility study is a critical step in the project assessment, if properly conducted, it may be a good investment and save money in the long run.

<u>A Pre-Feasibility Study</u>

Before starting a feasibility study a pre-feasibility study may be conducted first to help sort out relevant alternatives. In the case of project development for renewable energy from biomass a tool for such a pre-feasibility study exists: the Decision Support System (DSS). Pre-feasibility studies usually mean that money is saved as less alternatives are evaluated in the more comprehensive and costly feasibility study.

Decision Support System (DSS)

The DSS is a tool developed within the project BiWaRE (Biomass and Waste for Renewable Energy). This decision tool helps the developer of a renewable energy project to limit the number of potential sites and processes by evaluating the energy demand, site conditions, socio-economic implication, socio-cultural framework, policy, legislation and the economic viability. When planning biogas or biomass combustion plants additional factors need to be considered such as the availability of substrates, seasonal distribution of these and the logistics involving the transport of substrate. The DSS helps the decision maker to determine whether energy generating activities with biogas or biomass are at all feasible for the region under consideration. The DSS is based on a decision tree flow chart, additional information such as the handbook and tools, can be found at the projects webpage www.biware.hs-bremen.de.

It is also important to evaluate the market in which the project is placed with care; sometimes a feasibility study can be pre-empted when there is no sufficient economic incentive for a project. In the case of projects in energy production from biomass in ASEAN countries this assessment is relatively straight forward. In most lightly populated and rural areas reliable electricity as well as better waste management is needed. Even where supply already exists the demand is increasing with the continuously growing population. These two factors make regions where electricity generation is not viable the exception.

Once a pre-feasibility study has been done and it is clear that the project is generally possible and viable, the more detailed feasibility study of the remaining alternatives is undertaken.

3.2. Feasibility Study in the Context of Project Development

In the following we will give a brief general outline of the most important points when conducting a feasibility studies in project development, more details about the methodology are given in Chapter 4. Feasibility studies vary greatly according to the project and the country or even region it is set in. The listing below may not be a complete listing of the factors that should be considered in your specific situation. The success of a feasibility study is based on the careful identification and assessment of all of the important issues for the ventures success. Depending on the project, additional items may also be important. Remember, that the basic premise of a feasibility study is to determine the potential for success of a proposed development.

Outline of a feasibility study

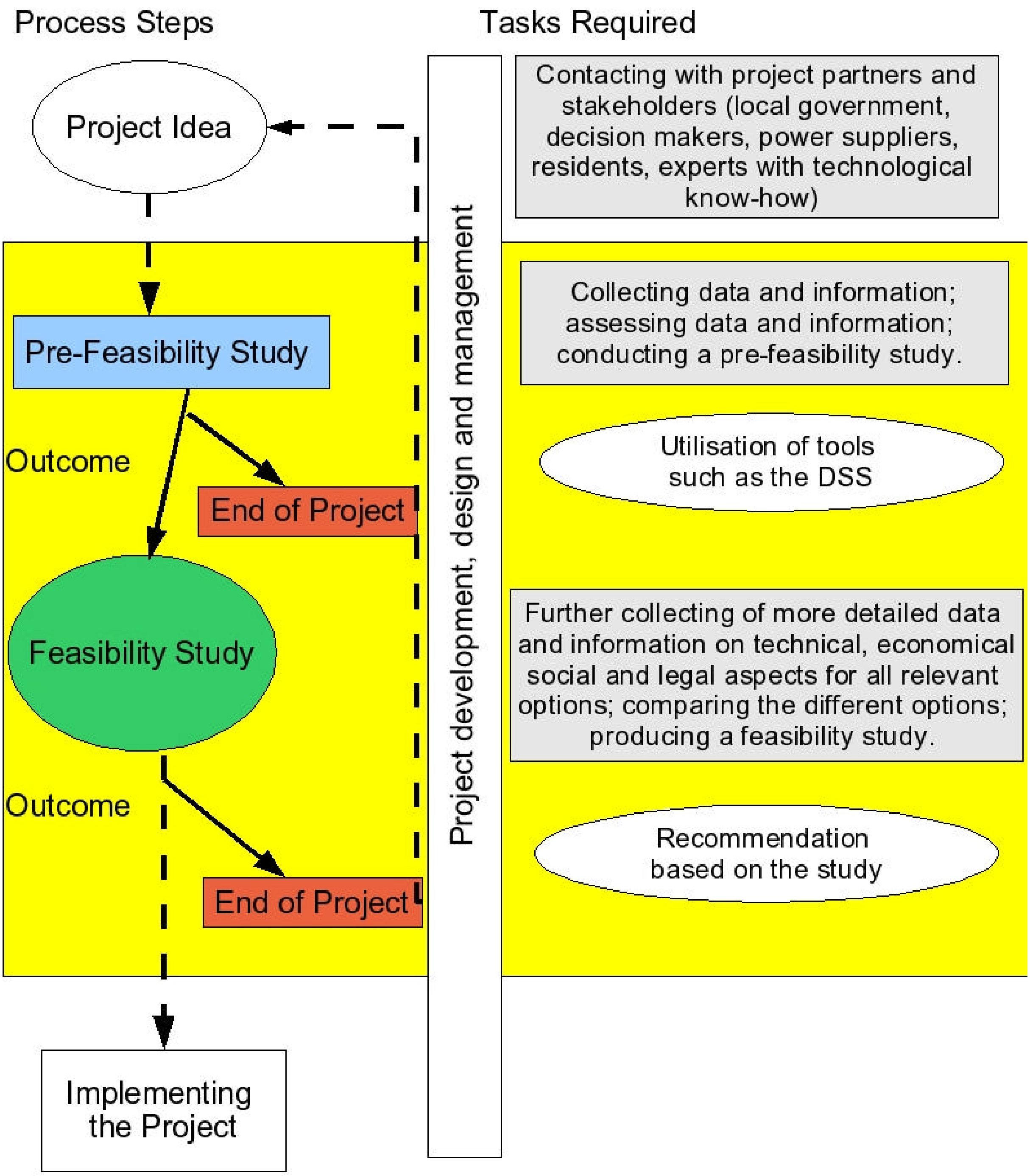
1. Introduction of the project and its scope, aims and objectives. It also includes the identification of different scenarios, including possible options and alternatives.
2. Detailed description of the project's basis. This entails an assessment of the location and the locally relevant framework conditions, which include general (geography, climate), legal (relevant governmental and legal structures), economic (dominant trade, employment structure), as well as an evaluation of the local energy and waste management sector. All this might be based on an assessment that is already completed. Elimination of scenarios that do not make sense.
3. Further definition, description and advantages of those ventures that have potential. This includes a project design as well as technical, economic, environmental and social assessment of for example different methods of energy generation that might be employed. It also includes a more detailed evaluation of the regulatory requirements.
4. Describing the risk involved. This requires to determine the risk criteria, discussing the risk and identifying measures to counter these.
5. Comparing of different alternatives and options. This means criteria for decision making, which involves weighting the risks highlighted earlier.
6. Finally a recommendation for a favourable option is given.

A feasibility study will not guaranty the "best" solution. Often, especially when comparing different options, it is hard to say which one would definitely be the best. Through the thorough assessment of the framework conditions and different possibilities however an invaluable insight is gained which will help making a firm recommendation even if the comparison is indifferent.

3.3. Development Process and Quality of Required Data

The Figure below shows how the feasibility study is embedded in the project development process and which steps need to be taken during such a study.

Figure 3.1: Graphical representation of the feasibility study within project development.



A Feasibility Study with in the Context of Project Development

Prior to a feasibility study a project idea needs to be present. In our context, that of generation of renewable energy from biomass in ASEAN countries, the basic project idea is already given. The project idea might be more specific like: the country and the region within it are known and maybe there is some clearer vision of what type of energy generation process is wanted or needed.

With the project idea the following should be clarified about the project:

- it is defined, understood, described and quantified
- it is significant, broad, and large enough to warrant group action
- it is capable of a solution for purely economic or technical reasons
- economically, culturally and socially fitting for the group
- considered a reasonable solution by the group members

Even before conducting a pre-feasibility study the project leaders are well advised to limit the number of options, at least by excluding unwanted options.
The list below gives and overview over the data required for conducting a **pre-feasibility study** using the Decision Support System (DSS). Please note that it is possible to do a feasibility study without a pre-feasibility study. Problem with this can arise since the general, technological viability of the project is not investigated thoroughly prior to the main study. If the project turns out to be infeasible in terms of substrate availability for example, then the main study is a much more expensive project to undertake, see quality of data discussion below.

Summary list – Data needed from the decision maker for conducting a pre-feasibility study with DSS

Question	**Main user input needed**	**Alternative user input (if main input not available)**	**Supporting Tools**
Category: **Technological considerations**			
1. What is the main intention of the RE power project?	Main intention of RE project - driven by energy demand - driven by availability of substrate		
2. How much and what type of energy is demanded?	a) Type of energy demanded b) Quantity of energy demanded - Thermal peak demand (kW) - Thermal annual demand (kWh) - Electrical peak demand (kW) - Electrical annual demand (kWh)	i) domestic energy demand - number of households - standard of living ii) industrial energy demand - steam demand [T], [p], [kg/h] - heat demand [T], [kWh/a] - demand for cooling [T], [kWh/a]	Tool 1: Calculation of energy demand
3. Available quantity of substrate for biomass-based power generation that can be secured in the long run (7-10a]	a) Type of substrate b) Quantity of substrate [Mg/a]	i) Number of animals ii) Type of industry - produced units [unit/a]	Tool 2: List of substrates; substrate characteristics Tool 3: Calculation of substrate quantity
4. Is the substrate primarily suitable for biomass combustion processes or biogas processes?	Selection of suitable process - biogas process - biomass combustion process		Tool 2: List of substrates; substrate characteristics

Question	**Main user input needed**	**Alternative user input (if main input not available)**	**Supporting Tools**
Category: **Technological considerations**			
5. How much energy can be generated from the substrate ?	No user input needed		Tool 4: Calculation of energy generation potential
6. How much surplus energy (netto production) is available?	No user input needed		Tool 5: Calculation on netto energy production
7. Is the generated energy sufficient to satisfy the demand?	No user input needed		
8. Is it possible to complement the energy generating capacity?	a) Complement possible - yes - no b) Type of complement		
9. Is the take-over of the produced energy secured?	Energy take-over secured - yes - no		
10. What is the required storage capacity?	Required storage capacity [m³], required space [m²]	i) variations of substrate supply ii) shelf-life of substrate	Tool 6: Calculation of the required substrate storage capacity
11. What type of pre-treatment is required for the substrate?	No user input needed		
12. Is there a requirement for feedstock sanitation ?	Feedstock sanitation required - yes - no	i) Related legislation	Tool 2: List of substrates; substrate characteristics
13. Is a wet or a dry fermentation process the most favourable option?	Process selection - wet fermentation process - dry fermentation process (or no selection)		
14. What is the required digester capacity?	No user input needed		Tool 7: Determination of digester capacity
15. Is there a requirement for exhaust air cleaning?	Exhaust air cleaning required - yes - no	i) local conditions - neighbouring housing ii) related legislation	
16. What type of exhaust air cleaning system is required?	Selection of exhaust air cleaning - example 1, etc.	i) Related legislation	
17. Which bigoas/biomass combustion plant concept could be suitable?	Selection of possible suitable plant concepts		

Question	**Main user input needed**	**Alternative user input (if main input not available)**	**Supporting Tools**
Category: **Policy framework and socio-cultural considerations**			
18. To what extend does the government support RE initiatives	Specification, classification and evaluation of the government support to RE initiatives		
19. Is there a strong support of the main project's stakeholders?	Strong support - yes - no		
20. Is it possible to get the support of the main project's stakeholders?	Possibility to get support - yes - no		
21. Are there any barriers taboos/defence mechanism hindering the application of biomass based power generation?	Identification and description of barriers/taboos/defence mechanism		
22. Can the barriers/taboos/defence mechanism be overcome?	Possibility to overcome barriers/taboos/defence mechanism - yes - no		
23. What is the overall socio-economic impact of the project?	Identification and description of the overall socio-economic impacts		

Question	**Main user input needed**	**Alternative user input (if main input not available)**	**Supporting Tools**
Category: **Environmental considerations**			
24. How much biogas slurry is generated?	No user input needed		Tool 8: Calculation of biogas slurry generation
25. Can the biogas slurry be utilized as fertilizer (land/pond application)	No user input needed		Tool 2: List of substrates; substrate characteristics
26. Is it possible to use the total quantity of biogas slurry as fertilizer?	Quantity of biogas slurry utilised as fertiliser [m³]	i) Direct land application [m³] ii) Sale as fertilizer [m³]	Tool 9: Calculation of maximum fertilizer load for land application
27. Are there other means of biogas slurry disposal?	a) Disposal possible - yes - no b) Means for slurry disposal	i) Related legislation	
28. Are there means of ash disposal?	a) Disposal of ash possible - yes - no b) Means of disposal	i) Related legislation	
29. Are there means of disposal for the generated filter ash?	a) Disposal of ash possible - yes - no b) Means of disposal	i) Related legislation	
30. What are the local/regional environmental impacts caused by the project?	Identification and description of local/regional environmental impacts		Tool 10: Local/regional environmental impacts caused by biogas/biomass combustion projects
31. What are the global environmental impacts caused by the project?	No user input needed		Tool 11: Determination of impact on res ource consumption Tool 12: Determination of global warming impact potential

Question	Main user input needed	Alternative user input (if main input not available)	Supporting Tools
Category: **Financial and economical considerations**			
32. What is the estimated investment cost and specific investment cost for the project?	No user input needed		Tool 13: Estimation of investment/specific investment cost
33. What are the expected costs for the project (annual costs)?	Annual costs [EUR/a]	i) Costs for plant operation [EUR/a]; [EUR/d] ii) Cost for substrate supply/provision [EUR/a], [EUR/unit] iii) Cost for slurry disposal [EUR/a], [EUR/unit]	
34. What is the expected revenue for the project (annual benefits)?	Annual benefits (revenue) [EUR/a]	i) Revenue for energy production [EUR/unit] ii) Prize for conventional fertilizer [EUR/unit] iii) Price for bio-fertilizer [EUR/unit]	Tool 14: Calculation of revenue for fertilizer
35. Which subsidies are available for the project?	a) Type of subsidies b) Financial revenue from subsidies [EUR],[EUR/a], [EUR/kWh]		
36. What are the financial indicators of the project?	- IRR - NPV - Payback-time	i) Interest rate ii) etc.	Tool 15: Calculation of financial indicators
37. Are the financial indicators acceptable/worth an investment?	Project economics acceptable - yes - no		
38. What is the specific energy generation cost?	No user input needed		Tool 16: Calculation of specific energy generation cost
39. Is the energy generation cost competitive to the current energy price?	Competitiveness of energy generation cost - yes - no	i) current energy cost	

After an outcome is generated via the pre-feasibility study the next project step is either the end of the project, if the initial idea is not feasible, or if it is, then the feasibility study itself is started. Should the pre-study lead to a negative result an evaluation of the project idea should be considered, maybe a different location or energy generation process would change the outcome. An in-depth description of such a study can be found in Section 4 and an example of a feasibility study is given in the appendix.

The last part we will consider in this section is the data collection prior to and during the feasibility study.

Quality of Data for a Feasibility Study

For an efficient data collection it is advisable to do a two step collection. The first step can be done via a pre-feasibility study. If no pre-study is done then the data collected in the first step should touch the following subjects

- renewable energy from organic waste (i.e. energy supply and demand, substrate availability . . .)
- policy framework (are there any major advantages or disadvantages for renewable energy projects)
- environmental considerations (environmental impact of the project)
- economic aspects (costs of the project, funding availability).

This are the points which are most important to determine the basic viability of the project. In the next step, for the main study, the data for the following additional subjects are collected:

- geographical and climatological data about the region in question
- social and cultural framework data
- in-depth investigation of the proposed sites, including logistical aspect .

Additional information about the first step data are also required, these are:

- legislative requirements, what are the permissions which are required, what regulations need to be considered
- economic background data, those that describe the framework of the economy present (employment, etc.)
- more details about the energy sector
- in-depth data about the waste management in operation at present
- financing and investment possibilities

If the outcome of the feasibility study is positive then the next step is to realised the project. This often means first to get an approval and then to actually implement the project. We will not discuss these issues here in any further detail.

3.4. Potentials and Limitations

The conclusions of the feasibility study should outline in depth the various alternatives examined and the implications, strengths and weaknesses of each. The project leaders need to study the feasibility study and challenge its underlying assumptions. This is the time to be sceptical.

A feasibility study generates in-depth information about a project and the factors that surround it. It serves the purpose of informing all members of the project about it. This will help the project leaders and decision makers to come to a decision on whether the project will be implemented and if so, which option or alternative is to be preferred. The results and information that has been accumulated during the study will also help to implement the project. The project leader knows now what the requirements of the proposed project are.

However, there will not be *an answer* or *one option* generated by a feasibility study. As you accumulate information and investigate alternatives, neither a positive nor negative outcome may emerge. The decision of whether or how to proceed often is not clear cut. Sometimes major weaknesses of the project are discovered some of which can be overcome. The study will mainly help to assess the trade-off between the risks and rewards of the project.

A feasibility study should not be confused with a business plan this is something that is developed later. The project idea should be clear before starting the feasibility study, as it does not generate project ideas. Neither should you start it with the assumption that the project will be implemented anyway as that will make it difficult to really evaluate whether the project can be successful.

4. Methodology for the Development of a Feasibility Study

In the following we will look at each step or chapter of the feasibility study. The main points are summarised in grey windows and important tools and action in yellow boxes for easier reference. Please feel free to add if needed or discard steps if they are not relevant for your specific project.

The first part of the study is the executive summary. This is a 2-3 page summary of the main points of the study, it should give the busy read a quick review of the project. The entire picture should be clear before reading the study in detail. This includes the setting and purpose as well as a description of the project, the technical features, the project benefits and costs, all major findings and recommendations.

4.1. Introduction

The Executive Summary

Should inform the reader about all major findings and recommendations of the feasibility study.

The introduction servers to introduce the project, this should be state clearly and short, giving the reader a brief overview on what to expect from the document.

The Description of the project

This part of the introduction should include:

1. A description of the nature of the project.
2. The general setting of the project location.
3. The proposed ownership, structure and the management
4. A look at the situation of the energy market and existing suppliers, as well as competitors.
5. Resource needed and generation of workplaces.

This will be done in cooperation with local decision-makers and stakeholders. Also, the detailed scope of the feasibility study will be defined. In this feasibility study all potentially feasible option will be assessed so that, after their comparison, the best one can be recommended. Therefore, in this work package, at least three options, plus sub-options will be determined. The options and sub-options will vary with regard to locations and technologies chosen (biogas process, biomass combustion process, or hybrid system, or a combination of both), energy utilisation, substrates, etc..The selection of the options will be done on the basis of a coarse screening, the first phase of the inventory (task 3). All options selected for further assessment will be described comprehensively. This will contribute to the establishment of common terms and forms the basis for assessing their feasibility.

4.1.1. Scope

The scope of a project or more specifically of the feasibility study within the project can be described by answering the following questions

- What is the reach, span, area that the study is concerned with, what does it entail?
- Where are possible limitations?

It could be seen like a very brief description of the feasibility studies content. This is closely linked, related and followed by the definition of the aims and objectives.

4.1.2. Aims and Objectives

The aims and objectives of the study should be identified. Please make sure to not confuse this with the aims of the project as the project might be terminated if the feasibility study gives a negative result. The following should be considered:

Question that need to be answered

- What is the aim of the study? These can be split according to main or secondary aims.
- What is the objective?
- Are there different aims and objectives for different stakeholders? Do these need to be considered separately?

When reading this part of the study the read should have a clear picture of what to await when reading on through the study.

4.1.3. Definition of Options

All possible options need to be identified and described. This is the place to discuss options which might have been thought about in the beginning of the project but will not be considered in any more detail as they seem enviable already.
The there can be multiple options, like highlighted in the box below there might be several locations and several technologies to choose from as a rule of thumb the total number of options is given by:

$$? \; l_i k_{ji} = Total\ \ Number\, of\ Options$$

where

$l_i = Location\, i$

$k_{ji} = Technology\ j\ possible\, at\ Location\, i$

i.e. The sum of the number of the locations each times the number of technologies possible at the location. So that 2 locations and two technologies will give four options. Unless for example the two locations are so similar according to geography, climate, logistics, existing development

Identifying Different Options:

1. What are possible locations?
2. What are the different technical options?
3. Which technology is possible fore what location?

4.2. Inventory of the Framework Conditions

The inventory can be carried out stepwise, starting with a coarse screening to more detailed data collection. For the selected options and sub-options, data with a high level of detail will be collected, which is needed for assessing the feasibility for each of these options and to compare the options among each other. A reliable and detailed database represents the backbone of a feasibility study.

Stepwise Data Collection:

1. Start with a coarse screening
2. Then decide about which aspects more detailed data collection shall be carried out

The aspects for which the data are collected are described in the subsections below.

4.2.1. General Framework Conditions

The general framework data require excellent local knowledge and are best collected by someone who knows the proposed location for the project development well. The general data about the location form the basis for the specific analysis regarding the energy generation from renewable sources, in this case biomass. It is therefore important to highlight especially those factors that can impact or will influence the project.

General points are the geological characteristics (latitude, longitude, altitudes etc.) and the local climate (temperature, rainfall, humidity), as well as the human background, which are administrative and cultural data and information such as the population, it's density, the growth and then immigration numbers. The natural resources are also part of the basis data the points of interest here include for example the soil, water (rivers, sea connection), forests and other natural vegetation, marine and mineral resources if they exist. The check list below can be used for this purpose.

Table 4.1: Checklist for the General Framework Conditions that need to be assessed.

General Framework Check List	Comment
Geology	
Climate	
Administrative unit and population	
Natural resource	
Soil	
Water	
Forest	
Marine Resource	
Mineral Resources	

4.2.2. Legislative Framework

Similar to the general framework information about the legislative framework is highly connected with local know-how. The legal information is vital for project development, a thorough investigation of legal aspects in needed to make sure that no major legal obstacle stands in the way of implementing the project. The following questions should guide you through some of the important points that need to be considered. Please remember that following these steps will not lead to a foolproof assessment of the legal situation, it is possible that you need specialists to help you even in at this point of the project development, i.e. prior to the implementation.

Question that could be considered:

- Is a renewable energy generating plant at all possible to implement?
- Have there been examples in the past where similar projects where implemented and could they be helpful?
- On which level are permission requests for renewable energy projects needed? (i.e. national, local . . .)
- Which legal bodies need to be asked for permission, or should be involved in the development of the project?
- Is there a plan for support of these types of project?
- And if so, where can one apply to get this support?
- What about planning permissions?

In particular:

1. What building regulations could be relevant for the project?
2. What environmental regulations are relevant?
3. Safety regulations, for power plants and workforce?

This part of the study is often tedious, as it requires the collection of relevant legal documents. It should however be handled with the greatest possible care.

4.2.3. Economic Framework

The economic framework gives the background information about all economic factors that are important for the study and the project. This means the focus is on industries that will impact or be impacted by the development of a renewable energy from biomass and biowaste plant, but the general economic data should also be included.

Some important Economic Data

1. Recent economic development
2. Predictions for the short and medium term economic development.
3. Economic structure, i.e. agriculture, industry, service . . .

After collecting these preliminary information's a more detailed look at the important industries of the region is necessary.
For example the size and activity of the agricultural sector plays an important role for biogas plants, the waste products of this industry are vital for the generation of the energy, while the by-product fertiliser that is generated by the plant can be a positive for the existing industry. The tourism of a region also play an important role. First, more waste will be generated during tourist season and for some rural regions the plan of a biogas plant will also mean the first time implementation of a waste management system

4.2.4. Planning and Development

It is important to evaluate the planning for the region in question. It might be that the project fits with the proposed plan for the region. Planning that can be seen as supportive of renewable energy generation for biomass is:

Supportive Planning Processes:

- Environmental conservation.
- Development of tourism.
- Support of the agricultural sector
- Support and expansion of the energy sector
- Expansion of the grid network
- Combating emission

4.2.5. Energy Sector

If a biogas plant is build anywhere it will be part of the energy sector of the country and the region, therefore the energy sector is assessed in it's own section here. It is now important to find out how big exactly the area in question is that the project deals with and what energy supply is present. When it comes to planning a project the future development of the energy demand should also be estimated.
The window below contains the main point that should be included when assessing the current energy supply.

Assessment of the existing Energy Supply:

1. Electricity supply: what type and number of electricity plant(s) present in the area, is the supply centralised or decentralised, are there independent small plants.
2. The grid line: is the area connected to the national main grid, how big is the local grid, are the lines middle or low voltage, what condition are the lines in, are all members of the local population connected to the grid, are there independent electricity generators which feed into the grid (private solar power, domestic biogas generators).
3. Electricity consumption: what is there development of the electricity consumption over the past years, who consumes how much electricity and how has this developed (industry, agriculture, domestic, offices . . .) , how will the demand most likely develop over the next 5, 10, 20 year.
4. Prices and tariffs: what is the present price of electricity, are the prices different for different users, is there any subsidy and if so how high is it, what is the price for a kWh from independent suppliers.
5. Other energy sources: what source is used for heating, cooking or other small processing activities, is there any other activity that would fall under energy generation.

4.2.6. Waste Management Sector

Like the energy sector the waste management sector is of specific interest when planning energy generation from biogas or biomass, as the household and other waste is part of or all the substrate that is needed to run the plant.

The waste management in any given area can be very different from another. Rural areas and scattered habitations often make waste collection and management difficult and expensive. The result is that the majority of the collected waste is from highly populated areas such as towns that have a good or better infrastructure. If the plan of implementing a biogas or biomass plant also includes, or is joint with, a new waste management program it is of interest to estimate the total waste (including the uncollected part). It is of interest for the project leaders to utilise all the generated waste and there are also huge environmental benefits.

Checklist for Evaluation of the Waste Management Sector		
	Comment	Notes
Solid Waste management	Is there a waste management; what does it include; how many people are employed by it; what equipment is present.	
Sources of Solid Waste	What are the waste sources, i.e. household, restaurants, hotels, offices, schools, factories, hospitals or construction.	
Solid Waste Components	The components are for example: plastic, glass, metal, food waste, organic waste or other quickly decomposed waste.	
Quantity of the generated and collected Waste	What is the estimated amount of the generated waste and collected waste over the last years; given a projection of population and industry growth, how will the amount of waste increase in the future.	
Solid Waste Collection	How is the waste collected (equipment, frequency); where is the waste collected i.e. is the waste collected everywhere; are there enough facilities for the temporary disposal of the waste before collection.	
Solid Waste Disposal	Where and how is the waste disposed (open unmanaged dump, landfill, etc.); is it treated before disposal.	

4.2.7. Financing and Investment

There are different possibilities and way to finance a renewable energy project, i.e. biogas or biomass plants. In the following we will look at some aspects of financing and investment, such as specific aspects of financing when planning a project in ASEAN countries, or different financing models which exist.

There may be three different possible cases for how the plant is positioned within the electricity market of the respective area

- Disposal of grid-electricity
- Acting as an IPP and selling surplus to the grid
- Energy production in an off-grid area

Depending upon the locality and the decision about the planned form of energy supply different questions has to be investigated while assessing the feasibility of the plant.

Where Asian banks look to while assessing the loan applicants (experiences from Asia after Gonzales (2001)):

- The developers managerial capability and competency
- The developers experience in managing an energy facility
- The developers family background
- The developers business associates
- The developers professional training
- The EPC contractors background and experience
- The O&M contractors experience
- The staff conducting the O&M
- The track record of the team working together
- Complementary or clashing skills among those who will be managing the project

There are several financing models which can be applied. Below is a list of a few possibilities open to the project leaders.

Financing Models:

1. <u>Conventional Financing</u> this includes equity participation, on-balance sheet financing and leasing.
2. <u>Project Financing</u> through the introduction of subsidies for renewable energy there is a shift away from the traditional corporate finance, a special purpose company is funded only for the implementation of the plant.
3. <u>Public Private Partnership</u> is one kind of models of project financing. The project company borrows from the lending institutions in order to finance the construction of the facility. The government pays back the loan and is the owner after the concession period.
4. <u>Financing with the help of CERs/ CDM,</u> which is a mechanism to promote investments in greenhouse gas (GHG) emissions reduction projects in developing countries.

The typical financial sources can be grouped into three main groups:

- Overseas development assistance (ODA): Multilateral Financing, Bilateral Financing
- Private Financial Sources: Private investment banks, companies active in the field of privatization, companies involved in PPP projects, foreign direct investment (FDI) companies
- Other relevant projects funding opportunities: Clean Development Mechanism (CDM)

The project leaders have to decide which option is best for their project or what financing option might suit which project alternative best. It is also important to find the financing source or program which involves only as much risk as the project leaders are willing to take.

4.3. Assessment of Feasibility

The main tasks within the study is the assessment of the feasibility of the selected options and alternatives. First of all the location and the technical concept will be developed and its feasibility assessed. The viability investigation should also include economic issues as well as global and local environmental, socio-economic, social and cultural impacts. Finally legislative aspects e.g. regarding permits for energy delivery into the net, permits for construction works or environment regulation will be evaluated.

4.3.1. Project Design and Technical Assessment

The assessment of the project design starts with the evaluation of the possible locations, if several options exist. The infrastructure, logistics and other background conditions are assessed and then compared. Based on this comparison a recommendation for a location is given.

The next step is the evaluation of the different technical options. The technical comparison is important if it is still open whether a biogas or a biomass combustion plant is build. If this the case the following aspects should be included under the technical assessment.

- Substrate supply chain: substrate condition for delivery, type of storage, types of treatment/ processing, etc.
- Process and facilities: number, type, size of plant, type of process, reactors, design parameter, operation parameter, process flow sheet, data on main technical components, etc.
- Construction aspects: floor space required, construction volume, building and facility placement plan, site concept, soil and building ground evaluation etc.
- Energy utilisation (in the form of electricity, heat, cooling, steam) and distribution aspects: capacity, locations/ distance of sub-stations, voltage level, conditions of the grid network, intake capacity of grid, possibility of electricity feed-in etc., conception of electro-technical aspects and control technology.
- The recycling/disposal of products or organic waste from the plants.

In the feasibility study that is attached to this guide as an example the technical as well as all the following assessments are conducted for each technical option separately, so that the reader is first guided through the complete assessment of one and then the other option(s). A comparison of the two technical processes is given at a later stage. The order of the assessment is mainly a question of personal preference.
Below we have gathered the main steps that should be included in the project design and technical assessment. Please keep in mind that this part requires expert knowledge and deep understanding of the technical process.

Main Points of the Technical Assessment are:

1. assessing the possible locations, including a comparison; and
2. evaluating the technical aspects of the different energy generating options.

4.3.2. Economic Assessment

Similar to the technical evaluation above the economic assessment is also concerned with the specifically chosen options only. The aim is to get a good overview over the financial benefits and burdens associated with each process option. After reading this part of the study the project leaders of decision makers should be able to evaluate the expected costs of each energy generating option.

The costs that should be included are:

1. investment costs,
2. operation and maintenance costs,
3. energy production costs,
4. revenue.

Furthermore the economic viability of the project and its financing options should be investigated. Another question is how the project will impact the existing economy, especially the energy sector and the waste management sector.

Economic Impact:

Who will win and who will loose then this project is successful? Sections of the local economy that might loose should receive special attention before implementing the project.

Discussing the economic impact with the local residents, business people and other who are affected will lead to a better acceptance of the project as a whole and pre-empt what might come up as protest in the future.

4.3.3. Assessment of Environmental Impact

Researching the environmental impact of the project thoroughly is an important aspect of the feasibility study. Often the interest in a renewable energy plant is paired with the idea of clean development and an increasing awareness of natural habitat that stakeholders would like to preserve, therefore often only a new development that can claim low environmental impact will be successful.
The following points should be evaluated separately:

- the local impact, which includes waste (waste reduction), air, water, soil, noise and odour
- global impact, which includes deforestation, CO2 saving potential and reduction of other green house gasses (GHG) such as methane and nitrous oxide

Under the light of GHG reduction it is possible to readdress the question of whether or not the project might have the potential for the Clean Development Mechanism (CDM) as a source of finance.

4.3.4. Regulatory and Permitting Requirements

Complying with the all relevant regulations and other permitting requirements is vital for the success of the project. There are several aspects of regulatory framework that the planning and building a power plant fall into.

Important regulations:

1. Building regulations
2. Environmental regulations
3. Operational safety regulations

In particular there are the following regulations which need to be checked:
There might be other specific regulations which apply in different countries, please make sure you check these thoroughly at this stage of the project.
Permissions for planning and building may need to be asked for at different levels. Depending on the national regulations national permission might be necessary or investment permission could be required (in case the national government supports the project in question financially). The required procedures for such permission processes need to be collected and described. You should also evaluate whether it is possible for the planned project to gain permission and conform to all the regulations, or whether there are obvious obstacles that need to be overcome in order to make the process feasible.

4.3.5. Social Impact Assessment

The social impact assessment is rather important when it comes to gaining acceptance of the local residents and other decision makers. It is important to evaluate and show how a new project will impact on the residence and the social structure. Projects that can guarantee an increase in the number of jobs over a long period of time have a natural advantage. Here it is also necessary to research how independent the country or region in question would be with the maintenance and security of the machinery in such an energy plant, it seems pointless to build a develop energy supply which cannot be maintained without expensive experts from abroad.

Impact on the Employment:

How many people will be employed and for how long; How skilled do the workers need to be; Which jobs outside the power plant will be affected by it, how many jobs might be lost or gained through this effect.

Example for Social Impact:
On the Island of Phu Quoc (Vietnam), for which the example feasibility study (see appendix) was conducted, an unknown number of poor people recycle the metal, plastic and paper from the now open dump by collecting and reselling it. The income that is generated through this recycling is unknown. It is also unknown how much of the generated solid waste is recycled this way.

4.4. Risk Assessment

Problems related to (renewable) energy systems are very complex. Therefore a major element of the feasibility study is the assessment of risks. This assessment comprises the so-called hard components (which are physical, technical, etc.) and soft components (which are environmental, social, political and others) into one evaluating overview. The following box shows the main three steps of a risk analysis:

The Three Steps of a Risk Assessment:

1. Identifying hazards and their consequences, i.e. anything what can cause a threat to the process or system.
2. Assessing the risk, i.e. the chance for occurrence of a particular hazard, this helps to comprises the characterisation of what is known and what is uncertain.
3. The evaluation of the risks, i.e. a judgement of the significance of the risk.

4.4.1. Definition of Criteria for Risk Assessment

Before any of the three steps listed above can be take the project leaders need to decide what criteria to use for the risk assessment. Below we will gather some aspects of risk which are commonly assessed when dealing with the development of a renewable energy plant.

Usual Risk Assessment Criteria for Renewable Energy Plants:

- health risks for the population living near by and the work force,
- environmental risks, such as emissions which can be calculated using software packages like GEMIS (Global Emission Model for Integrated Systems, see appendix),
- technological and operational risk,
- financial risk,
- risk of insufficient substrate supply.

Further categorisation can be done separating hard and soft risk components. Hard components include technical and physical risks and are associated mainly with the technology selected, while soft components consider environmental, social, political as well as managerial risks and are connected to the specific area conditions where the project is to be implemented as well as the technology selected in terms of environmental impacts. For each risk category different significance is assigned based on special local conditions. Where quantitative classification is not possible qualitative order should be used in terms of low to high risk classification. This provides a tool to local stakeholders to decipher between options presented during the decision making process.

4.4.2. Discussion of Risk

To discuss the risk involved in the different options or alternatives that have been introduced and described during a feasibility study the following can be done. We assume for now that data for the assessment and discussion have already been collected.

One tool for the assessment is what is called Life Cycle Analysis (LCA), which is used as a decision making tool for alternative processes compared to conventional solutions. Doing a LCA means a process, or activity is observed from “cradle to grave”. By taking a “snapshot” of the entire life cycle of a product from extraction and processing of raw materials through final disposal, LCA is used to systematically assess the impact of each component process. Assistance software like GEMIS is available for this type of evaluation.

Risk can be describe qualitatively or quantitatively, where quantitative assessment is much more common, as numerical estimation of risk is often difficult. It is however possible to calculate factors like the individual cancer risk or a hazard quotient (see the Example Feasibility Study for details).

To aid the decision maker with the comparison of the different options it helps to go through all risk criteria and risk assessment tools for each option and then compare the options under the weights for each of these criteria.

Ideas for Discussion Tools:

- a graph with the annual CO_2 or other emissions for the different options,
- table with the numerical health risk calculations for all the option.

4.4.3. Definition of Risk Control Measures

Once all the possible risks are identified it is important to define measures that will control the risk. Some of the risk will be the definition of risk not be controllable but others might be.
The health risk for example that is linked to emissions can be reduced if the emissions are decreased. Operational and technological risk can be bound by implementing safety protocols and using well tested technologies with minimal hazards. It is also advisable to highlight where and for which aspects of the project and it process insurances are available.

Example:
A risk that was identified as being high in the example feasibility study conducted for Phu Quoc was the risk of insufficient substrates. This is a risk that is not easily controlled as it highly depends on

other people, the producers of solid and other organic waste. If the majority of the substrate is supplied by the agricultural industry for example then a bad season can ruin the crops and possibly the substrate supply.

4.5. Comparison of Options

The next main task comprises the comparison of the options analysed with regard to their feasibility and their inherent risks. For this, the criteria for decision-making have to be defined. Then a concept for multi-criteria analysis is suggested, which is suitable for a comprehensive and clear decision-making process.

4.5.1. Definition of Criteria for Decision Making

In order to be able to make a decision or give a recommendation it is important to define the decision making criteria with care. The reader should be able to follow the arguments of the study and understand under which criteria a recommendation was made, or what weights where applied to each of these criteria. The task is to comprise all the collected information.
The list below shows some aspects for which details have been gathered it is up to the project leaders to decide how important these are.

Available Decision Input Criteria:

- social aspects and health
- potential environmental benefits or problems
- the potential to cover the energy demand present
- financial aspects, in in particular the energy generating costs and the CO_2 reduction costs
- technical sustainability

It is of cause possible that a different feasibility study in a different country will generate other sources of information which need to be considered under the decision making. The project leader now need to decide what information should be used and what weights these have. This is often a question of opinion and it is advisable to consider the opinions of as many stakeholders and decision makers as possible as these people will decide about the success of the project. Workshops where these topics are discussed can help develop a definition for the decision criteria.
Some points that are often is the foreground are whether the efforts (for example financially) needed to implement the project will be worthwhile, i.e. will the plant meet the energy demand and will it be viable.

4.5.2. Multi-Criteria-Analysis

The multi-criteria analysis (MCA) is a tool to determine overall preferences among alternative options and thus support the decision-making process. Complex situations or processes, such as biogas production and biomass combustion, are often connected to multiple criteria which can cause confusion when making a decision. The MCA is a structured approach based on the definition of objectives and corresponding attributes or indicators to overcome these uncertainties of the judgement. There are different techniques applicable to carry out a MCA. However all techniques imply the choice and definition of explicit objectives and measurable criteria and the application of scores or relative importance weights.

Below is an example for who such multi criteria analysis. The advantage is that due to the reduction of criteria to scores and weights it is often the case that the sum of the total weighted scores is bigger for one option than for the other one. This implies that, given the scores and weights that the project leaders decided on, the option with the greater sum is the favourable option.

Criteria	**Weighing of criteria for a renewable energy plant on Phu Quoc** [1 = low weight, 5 = medium weight 10 = high weight]	**Scoring of options regarding criteria** [0 = bad performance, 1 = medium performance, 2 = good performance]		**Results**	
		Option 1	**Option 2**	**Option 1**	**Option 2**
Investment costs	5	2	1	10	5
Power generation costs	10	2	1	20	10
Fexibility/ Stablity of process	5	1	1	5	5
				35	20

Table 4.2: Example of a multi criteria analysis.

As many criteria as appear to be needed or are feasible can be included in the analysis. There are different forms of scores or weights. If a simpler analysis is required a yes/no (or 0/1) scoring is possible. A more detailed scoring or weight can be achieved by for example using the full 1 to 10 scale for the weights and using a scale of 0 to 5 for the scores. This can be advisable if for example the end scores are the same under a simpler score system. Say both options for plants perform good, compared to usual standards, but when compared with one another one option is slightly better a score like 0= poor, 1= slightly better, 2= just below average, 3= average, 4= above average, 5= good, 6= excellent, might be able to reflect better the actual difference between the options. Please note that it is more complicated but possible to used different scores for different criteria as long as the same scores are applied for all options under the criteria.

4.6. Recommendations

The final part of the study is to come to recommendations regarding a renewable energy solution for the locality in question. Again a discussion of the recommendation with the local decision-makers and stakeholders in a workshop is advisable.

4.6.1. Definition of Favourable Option

As with the criteria earlier the difficult part of the recommendations is not to write them in the feasibility study but to make the recommendation. Tools like the multi-criteria analysis described above can give the project leaders some idea about which option is favourable but a decision still needs to be taken. This can be especially difficult if there are several options which are rather similar in risks and benefits, as before personal taste or preference comes to the foreground in discussions.

It should however at this stage be possible to define a favourable option, the recommendation of the study. This is based on the criteria for risk and decision making discussed earlier.
The favourable option should be stated and described clearly at this stage of the study so that it is obvious to the reader only interested in the recommendation why, in a nut shell, this option is favourable.

4.6.2. Recommendations for Project Development

Based on the definition and everything else that was presented and analysed earlier this section comprises all the effort that was up into the study to make a recommendation about how to proceed with the favourable option that has been identified.
The following point should be considered at this stage of the project.

Further Development of the Project:

- Definition of further actions; what needs to be done next to implement the project?
- Organisation; who is going to be responsible for what, what is the time frame, what man power and training is required, who is going to give funds, also a detailed financing plan might be required.
- Control procedures; what controls have to be implemented to go on with the project development.
- Identification of critical points; what are potential problems for the development.

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6. Appendix

Feasibility Study for the Generation of Renewable Energy from Organic Waste and Biomass on Phu Quoc Island, S.R. Vietnam