The construction of the plant [120]:

1. March 2010 - Fundamental construction of the main fermenter and the post fermenter

2. May-June 2010, construction of the main fermenter and post fermenter

3. August-October 2010, final assembly of the plant and biological start

Figure 5-16: Construction of the Agraferm Technologies AG plant

2. Verbio Ethanol GmbH & CO. KG

Verbio is another bio-fuel producer and supplier in Europe. Approximately 450,000 Mg bio-diesel, 300,000 Mg bio-ethanol, and 500 GWh biogas are produced by Verbio annually [108]. Verbio Ethanol Schwedt GmbH & CO. KG in Zörbig is the second biggest bio-ethanol plant in Germany using mainly rye, wheat, triticale and maize as feedstock [87]. It is the first E-M-F-System in the world with bio-ethanol, biogas and bio-fertilizer system in one plant (07.2010), with an area of 12 ha. Together with VERBIO Ethanol Zörbig GmbH & Co. KG every year about 370 Mi. kWh biogas is stored in the natural gas net, which can supply about 37,000 modern households [87].

The biogas produced from stillage in Zörbig is used in a CHP unit to produce part of the steam required for bio-ethanol production. The rest of the required steam is produced by a straw-fired boiler. All the power generated by the CHP unit is fed into the mains grid and is remunerated per the EEG (German Renewable Energy Source Act). The required process power is thus purchased, whereby the Verbio business model stipulates the use of 'green' electricity [111].

Actually, about 2500 m^3/h biogas is stored in the high pressure MITGAS net. Verbio uses the agriculture remaining materials to produce biogas, which could save the energy and reduce the emission $CO_{2\text{-eq.}}$ at about 81 % for bio-ethanol compared with gasoline and at about 90 % for biogas, compared with fossil energy [109].

Based on the experience from the bio-ethanol plant with a capacity of 100,000 Mg bio-ethanol, 2,500m^3/h biogas and fertilizer production in Zörbig, in August of 2005, the Verbio Schwedt bio-ethanol plant was founded in North Brandenburg. There are two process variants possible at this location, which differ in the by-products produced. The stillage can be used to either generate biogas as it is done in Zörbig, or it can be used to produce the high-protein animal feed (DDGS). There is about 230,000 Mg bio-ethanol produced in Schwedt. The biogas plant is integrated in the bio-ethanol production plant, whereby generated biogas is not used in a CHP plant but rather cleaned and fed into natural gas network. The digestate is again treated in a composting plant to produce a fertilizer product [110]. It has a power output of 30 MW in the initial stage, and will be expanded to 75 MW [137].

The digestate produced from the biogas plant is returned exactly to the same fields - from which the processed grain originated, replacing mineral fertilizer and thus remaining in the system. A 100 % plant availability of the mineral nitrogen proportion contained in the digestate is assumed with the plant availability of the proportion of organic nitrogen at about only 20 %. Verbio is approved to construct a second Verbio biorefinery that combines bioethanol, biogas and bio-fertilizer. Multiple utilization of the raw materials used means that they can be almost entirely converted into energy [137]. From early 2011 onwards, Verbio has obtained around 500 GWh of biogas annually from the plants in Schwedt and Zörbig; production is projected to increase to 2,000 GWh by 2015 [137].

The following photos show the basic components of the VERBIO biological plants.

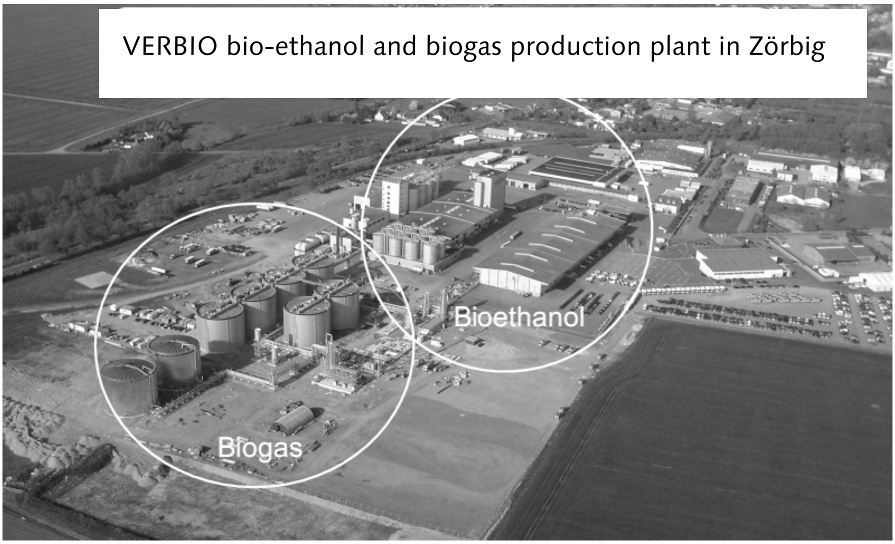

Figure 5-17: VERBIO bio-ethanol and biogas production plant in Zörbig

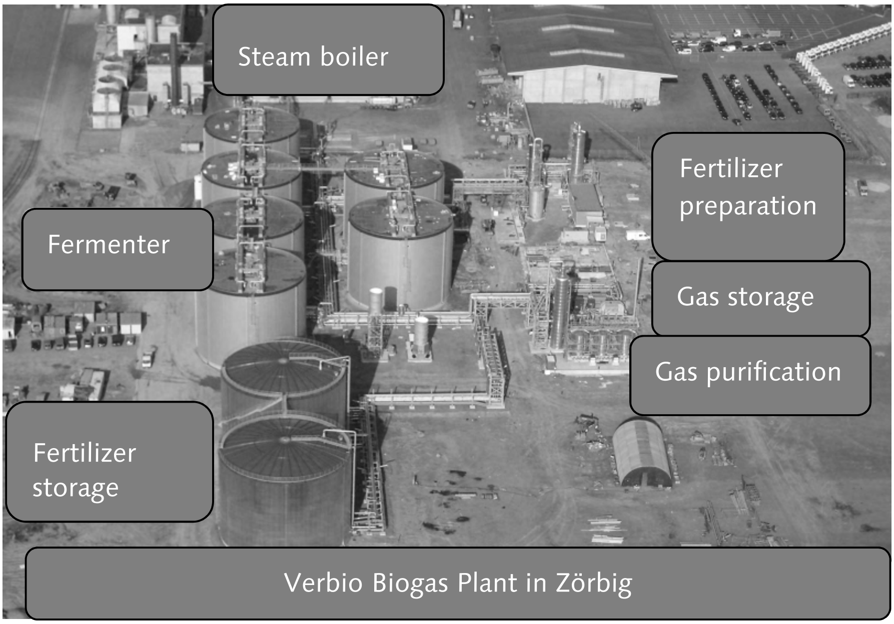

Figure 5-18: VERBIO biogas production plant in Zörbig

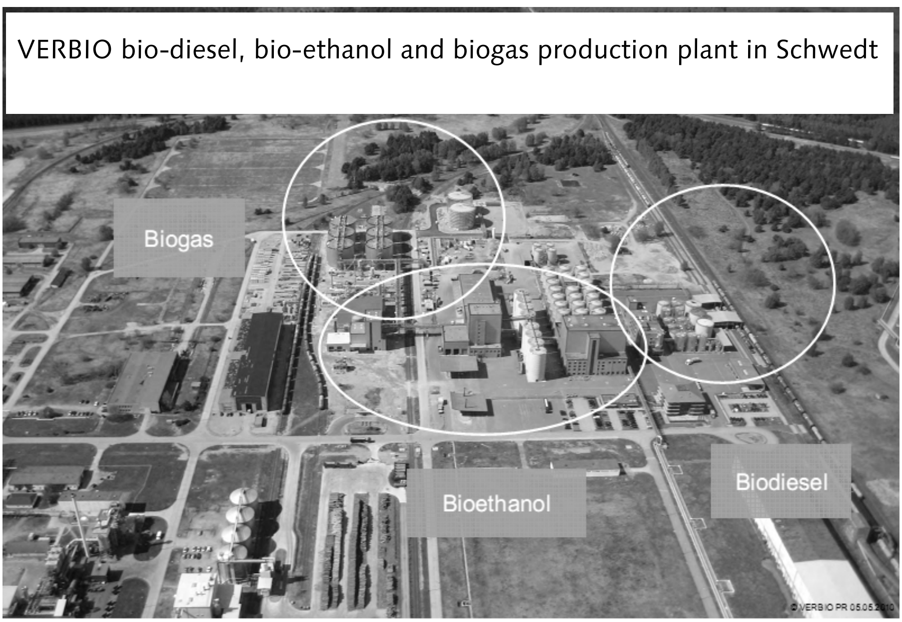

Figure 5-19: VERBIO bio-diesel, bio-ethanol and biogas production plant in Schwedt

5.6.2 E-M(-F) plant using sugar containing material as feedstock

The sugar factory Anklam has a white sugar quota of nearly 112,000 Mg in EU, which is equal to nearly 4 % of the total German sugar. About 60 % of the sugar beet growers have agreed to use beets as a raw material for bio-ethanol production. In total about 6 % of the agricultural area of the factory is used to plant sugar beets. About 11,250 Mg beets per day are used at first to produce 750 Mg white sugar and meanwhile 1,600 Mg thick juice, which is used further to produce bio-ethanol. The remaining thick juice is stored in two big tanks and used to supply the bio-ethanol factory as needed. Anklam Bioethanol GmbH & Danisco Sugar GmbH Germany had this business model since the beginning of 1994 [127].

High alcohol concentration in fermented mash is about 15 % (v/v). Vinasse recycle ratio is 50 % to reduce effluent load and water intake. Distillation is carried out under vacuum to utilize low pressure steam. The produced bio-ethanol is purified and stored in tanks in order to be mixed with petrol at a ratio of 10 % (E10). This brings a $CO_{2\text{-reduction}}$ of 52 %, which meets the effective requirements of the sustainability by 2017. This factory has been built strictly according to the requirements of environmental protection [127].

In total, every year about 112,000 Mg white sugar, 20,000 Mg melasse, 20,000 Mg vinasse, 28,000 Mg dry chip pellets, 125,000 Mg press chips, 12,000 chip round balls, 40,000 Mg fertilizer and 50,000-60,000 m^3 bio-ethanol are produced in this factory [127].

During the production of the products and by-products, a large amount of waste water is produced and there is a plan for it to be fully reused in this plant. There is a plan to build a biogas plant to use the dirty water to produce a good quality biogas that is burnt in its own boiler. This will meet the quality management requirement of ISO 90001:2000, ISO 14001:2004 and ISO 22000:2005. The biogas plant connected with the first two processes - sugar production and bio-ethanol production is being planned and will be built in the next few years. Due to a lack of experience in sugar beet stillage in the production of biogas, the research related to this plan is still in progress [127].

The plan for the remaining material from the sugar factory and potato wastes of 116,000 Mg/a is used to produce about 17 million m^3 biogas, which would be purified and filled into the natural gas net. It is designed that part of the produced biogas is used in its own vehicles. Another biogas plant is designed using 136,000 Mg/a vinasse as the input material to produce 22 million m^3 biogas [128]. The rest material from biogas production and part of vinasse can be further used as fertilizer [129].

5.6.3 Conclusion of the study of the E-M-F-System utilization plant

As another possibility for the stillage to produce more bio-energy rather than to be used as animal feed, stillage used in bio-ethanol, biogas and bio-fertilizer plants is being considered and plants are currently being built for this use. However, they are still in a starting phase and a lot of problems will arise during planning and operation, either in technological or economical aspects. In consideration of energy efficiency and ecological impact, there are still some unsettled areas. Related research and studies should be further carried out before further decisions are made to utilize such systems, although starch containing stillage as a biogas raw material is already underway.

Due to the lack of experiences both from technological and economical aspects, sugar containing stillage used in this system is still not popular and well accepted. The research related to this study should be further carried out in order to support the further development in this system.

The combination plants containing bio-ethanol, biogas and bio-fertilizer production are in principle mass and energy conservation positive. Besides, they can bring ecological benefits due to their simultaneous production of renewable energy.

Further consideration is required, if combination plants such as biogas plant and bio-fertilizer plants are planned to work with bio-ethanol plants, as well as if there is still additional benefit from energy, economical and ecological perspectives to build additional combination plants, if bio-ethanol plants have already been built. This means, energy, economic and ecological analysis must be considered according to plant design. Similarly, the basis analysis could be done on an individual basis as is done in this chapter.

6 Tool box for the implication of the E-M-F-System

In order to make the assessment of the E-M-F-System in Chapter 5 easier and more convenient to be used for new users researching other projects, a tool box has been designed. In the following sections, the purpose, basis, introduction, and manipulation of this tool box are illustrated in detail.

6.1 Purpose of the use of tool box

This tool box was developed to calculate the implications of the E-M-F-System, including the balances of

- Mass flow
- Energy demand and production and
- Carbon dioxide related emissions

This tool box provides a base for decision makers in order to obtain information about the environmental background of the E-M-F-System.

The tool box for this work is in the form of an excel table, which includes a sequence of instruction written to perform specified tasks. This tool defines the steps for execution of the E-M-F system, or details how processes happen and their results.

Currently, some programs such as GREET have been used in bio-energy production, but there is still no tools to assist with assessment of the combination of biological processes, specifically a tool for bio-ethanol, biogas and subsequent bio-fertilizer production.

This tool was specifically designed for the E-M-F-System in order to make it more systematic and simple, to provide a utilization platform for biomass to produce energy in all aspects and countries, and to develop and improve the biological combination processes for further utilization and practice.

Through the use of this tool, the concept of the E-M-F-System can be actively revealed in front and the mass flow, energy flow, and $CO_{2\text{-eq.}}$ emission can be conveniently calculated.

The tool box gives information about how much product can be produced from this system; while calculating the corresponding energy and emissions can be precisely calculated. As a means of contributing to subsequent decision making for the biomass utilization, this tool can help to decide biomass utilization methods, to assess $CO_{2\text{-eq.}}$ emission effect, to evaluate bio-energy production efficiency, and to make a better use of nutrient elements. Moreover, there is a good basis for improving this tool for biomass utilization.

This tool takes into account varying levels of technology has been developed not only to allow the users to analyze both existing and planned systems, but also to estimate the outcomes prior to construction of a complex plant. This tool box can also supply a platform to make decisions about extending existing plants as well. For example, a biogas plant could be assessed to see if the raw material should be used at first to produce bio-ethanol and then biogas or if only biogas production is better. This tool provides a good basis for decision-makers to assess and design efficient plants from technological, energy and ecological points of view.

This tool was designed to assist public understanding of the E-M-F-System; facilitating the further development of bio-energy industry, which can have the potential to increase land use efficiency, substitute for fossil energy, and contribute to a reduction of human-induced global warming.

6.2 Basis of the tool box

This tool was designed along with the processes of this system, including input biomass and output substances, energy and $CO_{2\text{-eq.}}$ emission accordingly. It was compiled based on the theory, practical experiences, and the basic technological research. This tool box was established on the base of the evaluation results of the balance analysis as shown in the last chapter. All the calculation rules listed in the last chapter have been adapted in this tool box. The basic structure of the mass, energy and $CO_{2\text{-eq.}}$ flow are outlined in this chapter.

Scope of this tool box: longitudinally, this tool originates from biomass, goes through three different kinds of biological processes, and then gains all kinds of bio-energies; vertically, all kinds of analysis of biomass balance, energy balance, $CO_{2\text{-eq.}}$ (including other trace greenhouse gases CH_4 and N_2O)-global warming reduction potential and other nutrient elements are illustrated in this tool box. In the tool box, there are three windows: mass balance, energy balance and $CO_{2\text{-eq.}}$ balance. In each window, the calculation is carried out for bio-ethanol production, biogas production and compost production.

Standard values of this tool box: all input units for this tool box must be harmonized, including the energy, mass, $CO_{2\text{-eq.}}$ emissions and the process related parameters, which are suitable for the tool to calculate the respective results.

For example, the unit in the window of mass balance is based on Mg for biomass and percent for the organic (oDM) and water content (100 % DM). All the calculations are based on this base value, so that it is easier and clearer for the users to obtain the suitable results. There is also a disadvantage to standardization, for example in some countries such as the United States bio-ethanol is by gallon. In such a situation, the necessary conversions must be made, or all the units in this tool box must be changed in order to make the calculation feasible. In the energy balance window, the unit is mainly MJ and Mg. But if the available unit from a local or subject area is not compatible, it must be converted to get final results. If the final energy produced from this system is the final aim of the study or calculation, then the unit used for energy from all of these three processes must be the same, and the according unit from the mass balance window must be adjusted as well.

Innovation of this tool box: compared with other tools for bio-energy production, this tool performs more than one processes, it deals with three different kinds of processes, using the same original raw material and ends with a circulation of this material. All details related to the processes are inclusive. In this tool box, it is possible to get a result from only one process, or from two processes, or from three processes. As shown in the tool box, it is colored in green, yellow and light blue. The following table shows mass balance for the degradation rate of wheat with data taken from chapter 5.

Table 6-1: Degradation rate used regarding to the E-M-F-System

Bio-degradation rate	Value of wheat	Unit
Bio-degradation rate (E)	54.48	% basis of input
Bio-degradation rate (M)	34.14	% basis of input
Bio-degradation rate (E+M)	88.62	% basis of input
Bio-degradation rate (F)	5.1	% basis of input
Bio-degradation rate (E+M+F)	93.72	% basis of input
Bio-degradation rate (E)	54.48	% basis of fresh mass
Bio-degradation rate (M)	75.0	% basis of fresh mass
Bio-degradation rate (D)	55.0	% basis of fresh mass

In this example table, just as from the mass balance of wheat, the degradation rate could be calculated just from bio-ethanol production (E) at 54.48 %, or cumulatively from the first two processes (E+M) which gives a result of (54.48+34.14) 88.62 %, or even with three processes (E+M+F) giving a result of (88.62+5.1) 93.72 %.

All of these calculations are based on the mass of raw input material – fresh wheat. This table supplies the possibility to obtain a single result from each process. Thus, it is possible to calculate not only the raw material degradation rate for the whole system, but also the material used in each process. Just as in the example table above, the degradation rate from biogas production is 75.0 %, and from composting 55 %, shown in italics.

Similarly, in the table showing energy and $CO_{2\text{-eq.}}$ balance, the results of net energy, energy ratio, net emission and emission reduction can be obtained from each individual process, the first two processes in combination, or from the whole system. Each calculation is clearly laid out in the table, and shown in different colors.

6.3 Instructions for using the tool box

Figure 6-1 explains the mass balance of the system. The arrows in the figure illustrate the mass flow – to be used further in the next process, just as in this thesis stillage is used to produce biogas, and the digestate from this process then used to produce compost. Separation of the digestate is assumed in this process.

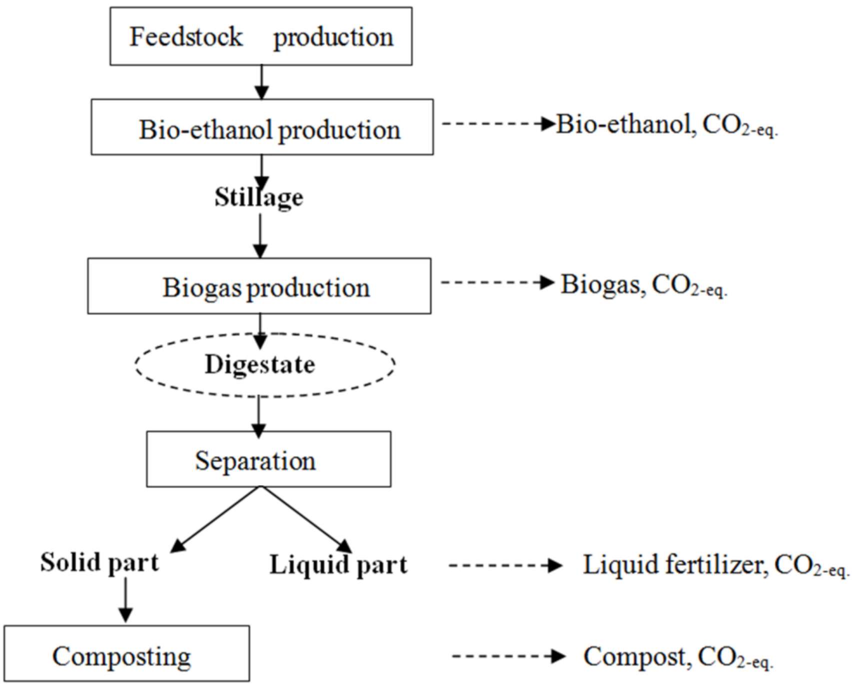

Figure 6-1: Mass flow of the E-M-F-System

Input data

The input data of raw materials for this tool is illustrated in the tool box as blank space. As the auxiliary substances for the process are little compared to the raw materials and the output materials, this data can be omitted. Just as shown in the mass balance, these substances have been termed auxiliary materials. Thus, if some other input turns out to be significant in a specific case or there is important data regarding input materials, there is still a place in the tool box to add them to the process for calculation.

Table 6-2: Auxiliary materials for the system

Auxilary materials		Unit/kg

Default values

Some of the data or formulas are set to be default value, and some of the data to be filled in is shown in an active state. Each disaggregated default value overwrites the active value. Therefore, blanks are not replaced with new data, default values will be used. The default values used here are taken from global or EU averages. For example, in Table 6.3, the data is mostly taken from pre-existing research, and it can be changed according to additional requirements, or used as the standard value in other calculations.

Table 6-3: Some kinds of popular default values for the system

CH_4 production	55.00	%
CO_2 production	45.00	%
Water in biogas	11.00	%

Co-input of various materials

If the input material is of several types, the data should be filled in separately. The results at the end of the tool box are taken from separate kinds of biomass. In the case study in the next chapter, sweet potato in Yongjing Hunan in China is taken as input raw material, but in other situations, it is possible that more than two kinds of raw materials are used. In this case, this input box could still be used, but results for each type of material need to be calculated separately. The disadvantage of this tool box is that, the inter-influences on the final result between or among different kinds of materials cannot be calculated or revealed.

Basis of emission

The energy calculations are based on low heating values (LHV), and the corresponding emissions are on the basis of LHV as well.

6.4 Manipulation of the tool box

This tool can be used for the calculation and assessment of bio-energy production systems in combination of different biological processes. All aspects of the processes can be easily updated, added to or replaced.

In the beginning of the tool box, there is an instruction window, in which the basic information about this tool and its manipulation are included. In this