Energy from waste an residues: LCI model of decentralized combined heat and power plants

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Abstract Energetic use of biogenic waste and residues becomes more and more important as one part of an energy system based on renewable sources. Nevertheless, combustion of biogenic residues is often difficult because of low heating values or low ash melting temperatures of the different fuels. Combustion of these fuels in waste incineration plants is possible but rather inefficient. In a research project at Karlsruhe Institute of Technology (KIT), development of a new decentralized plant for so-called difficult fuels is under way. Based on accompanying systems analysis work, a modular LCI model for this kind of plant has been developed which shall be applicable for modeling a broad range of combustion plants by combining different modules for fuel pretreatment, combustion and flue gas cleaning.

1 Introduction

Energetic use of waste and residues – notably if recycling is not applicable due to technological, economic or ecological constraints – is a generic strategy of climate mitigation as well as of waste policy. Incineration of waste is a wide-spread waste treatment option, however, from the energy point of view, rather inefficient. Therefore incineration is also combined with generation of heat and power, based mainly on grate combustion but with a multitude of diverse components for emission control. Above that, however, a broad range of residues are applicable for combustion in combined heat and power (CHP) plants. Several options exist for mono- as well as for mixed combustion. Research projects are under way which aim at several goals: broadening the scope of residues as to guarantee a continuous feed also if some residues may be available only seasonal; enhancing

energy efficiency; providing better treatment in terms of emission minimization for specific wastes.
In a research project at Karlsruhe Institute of Technology (KIT), development of decentralized plants for so-called difficult fuels is under way: these fuels are mainly residues with various disadvantages like low heating value or low ash melting temperature and may be renewable (e.g. straw, forest residues) or non renewable materials (e.g. refuse derived fuels, litter). This new kind of chp plant consists of a combination of two different types of combustion. First, there is a grate firing which can be used for nearly every kind of solid fuel. This kind of firing is also used in conventional municipal solid waste incineration plants. Because of the long retention time on the grate, this type of firing is operated in base load power and heat production. Second, a dust burner is implemented, which can be regulated very flexible. This attribute makes this kind of firing perfect for peak load power production.
Another challenge is the seasonal fluctuating availability of several biogenic residues like straw or forest residues.
To support technology development as well as strategic planning in decentralized energy concepts, LCA is a suitable tool. However, modeling has to be adapted to if technology option shall be compared on a rather detailed level.
Based on accompanying systems analysis work, a modular LCI model has been developed which shall be applicable for modeling a broad range of combustion plants by combining different modules for fuel pretreatment, combustion and flue gas cleaning.

2 Comparison of different types of LCI-models for municipal solid waste incineration

For municipal solid waste incineration plants as well as for other chp plants, four types of LCI models may be distinguished [1]:

1) Black box models
2) Linear transfer-coefficient models
3) Modular models
4) Complete process engineering simulation

The level of detail increases from type 1 to type 4: Type 1 models are specific for each plant and do not allow a look inside the plant. Any change in plant design or even in varying the feed leads to a new model. Type 2 models use linear

parameters between different process steps. These models allow for changes in feeds as well as changes in plant design. Nevertheless, the estimations are vague. Type 3 models allow for a detailed look on each process step using measurement data and rudimentary process engineering. They may be adapted to new plant designs very easy because of their modular structure. Type 4 models are detailed process engineering models. They allow a very detailed look on every part of the plant, and may be used for optimization of single parts. However, these models are usually not usable for LCA because of their high complexity.
The development time (and money) increases from type 1 to type 4. Usually, type 2 or type 3 models will be used for comparative life cycle assessment because type 1 is specific for one plant and further changes can't be estimated, type 4 models are to complex for comparisons.
In early stage of development, a modular model is the model of choice. With a modular model, problems in plant design may be identified early and these models can react flexible to changes in plant design.

3 Developed LCI model

A modular LCI model for a projected chp plant is realized in software umberto [3]. Because of the modular configuration, the model can be adapted very flexible to further changes in plant design. In Figure 1, the system boundary is shown. In the following the different parts of the LCI-model are described.

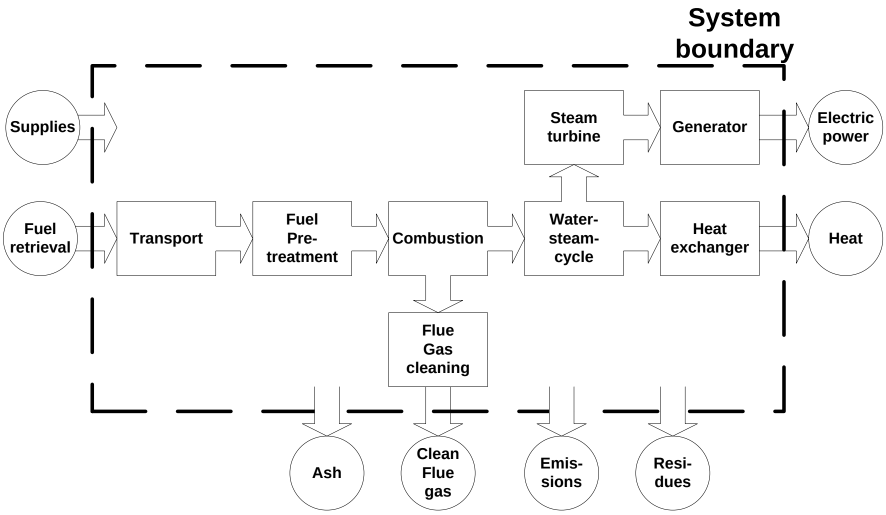

Figure 1: System boundary of the considered chp plant.

3.1 Fuel retrieval and fuel pretreatment

Because most of the expected fuels are residues, no fuel retrieval is considered at the moment. Any energy needed for crushig or drying the fuels is modeled "at plant", but may be done before transport as well. For sure, other fuel pretreatments may be included later.

For fuel transport, several transport options are possible. The residues may be transported by tractor, lorry, railway or ship, depending on the kind of fuel and on transport distance. Nevertheless, the transport distance for biogenic residues is expected to be within a radius of 100 km around the plant.

All fuels need to be crushed for combustion on a grate, as well as in a dust burner. For grate firing a particle size between 10 - 100 mm is necessary, which can be achieved by a chipper (e.g. woody biomass) or by pelletizing (e.g. straw).

For dust burners a particle size below 4 mm is necessary, which is usually achieved by a mill.

Drying the fuels can be done by using waste heat from the chp process, which increases the overall efficiency of the plant.

3.2 Combustion techniques

Two different types of combustion are implemented in this LCI model. First, there is a grate firing which can be used for nearly every kind of solid fuel. Because of the long retention time on the grate, this type of firing is operated in base load power and heat production. Second, a dust burner is implemented which is operated in peak load power and heat production. For both types of combustion data from laboratory and pilot scale plants, located at Karlsruhe Institute of Technology (KIT), is used.

3.3 Water-steam-cycle, heat exchangers and generator

The whole water steam cycle, including boiler, heat exchangers, steam turbine and feed water is simulated by thermodynamic equations. Electric power is produced by a steam turbine connected to a generator. Depending on temperature and pressure, three different types of useful heat may be produced: Process steam, district heating or waste heat for drying fuels. The type of produced heat depends on the infrastructure around the chp plant.

3.4 *Flue gas cleaning*

After combustion, the flue gas has to be cleaned to reach legal emission limits. Several emissions of components like NOx, SOx, HCl, ash and heavy metals are limited very strictly. Today, nearly all combustions plants needs filters (usually an electrical precipitator) to lower fly ash content. For biogenic fuels this is often enough reach the legal emission limits. Nevertheless, if emission limits for biogenic fuel combustion will get stricter in the future or if other (waste) fuels are combusted, several other flue gas cleaning techniques need to be adopted. The LCI-model consists of modules for selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR) of NOx with NH3, a desulfurization by chalk and several washing steps.

4 Fuels

The new kind of chp plant should be able to use different types of fuels depending on availability as well as economic and ecological conditions. Currently, only biogenic residues are used. Later, non-renewable fuels may be combusted in this plant as well. In Table 1, some fuels with corresponding properties are shown.

Tab.1: Examples for difficult fuels with fuel properties water content, ash content, ash melting temperature and difficulty ([2] and own measurements).

Fuel	Heating value (dry)	Water content	Ash content (dry)	Ash melting temperature	Difficulty
Wood chips	17.3 MJ/kg	Up to 60 %	3 %	1200 °C	Water content
Barley straw	17.2 MJ/kg	Up to 40 %	4.8 %	980 °C	Ash content; ash melting temperature
Rape pellets (residues from oil production)	17.9 MJ/kg	10 %	6.8 %	Not measured	Ash content, ash melting temperature
Rape coke	30.1 MJ/kg	0 %	11.8 %	Not measured	Ash content; ash melting temperature
Grass cuttings	14.1 MJ/kg	Up to 40 %	23.1 %	1200 °C	Ash content
Sewage sludge	10.8 MJ/kg	Up to 95 %	Not measured	Not measured	Water content; heavy metals

5 Conclusion

Different types of LCI models are available for municipal solid waste incineration plants. They range from black box models via linear transfer-coefficient and modular models up to complete process simulations. For LCA, linear transfer-coefficient models or modular models are usually used, depending on the scope of the LCA. However, for a new kind of chp plant, which combines grate and dust combustion, the existing models are not adequate and a new model is needed. A modular model is chosen because the considered chp plant is still in design process and further changes in plant design can be accomplished most easy with this kind of model. Although, challenges like fluctuating availability of the different fuels and production of base load and peak load power production in one plant can be handled with this model.

6 References

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[2] „Leitfaden Bioenergie: Planung, Betrieb und Wirtschaftlichkeit von Bioenergieanlagen“, Fachagentur nachwachsende Rohstoffe (Hrsg.) 2000.

[3] ifu Hamburg GmbH.