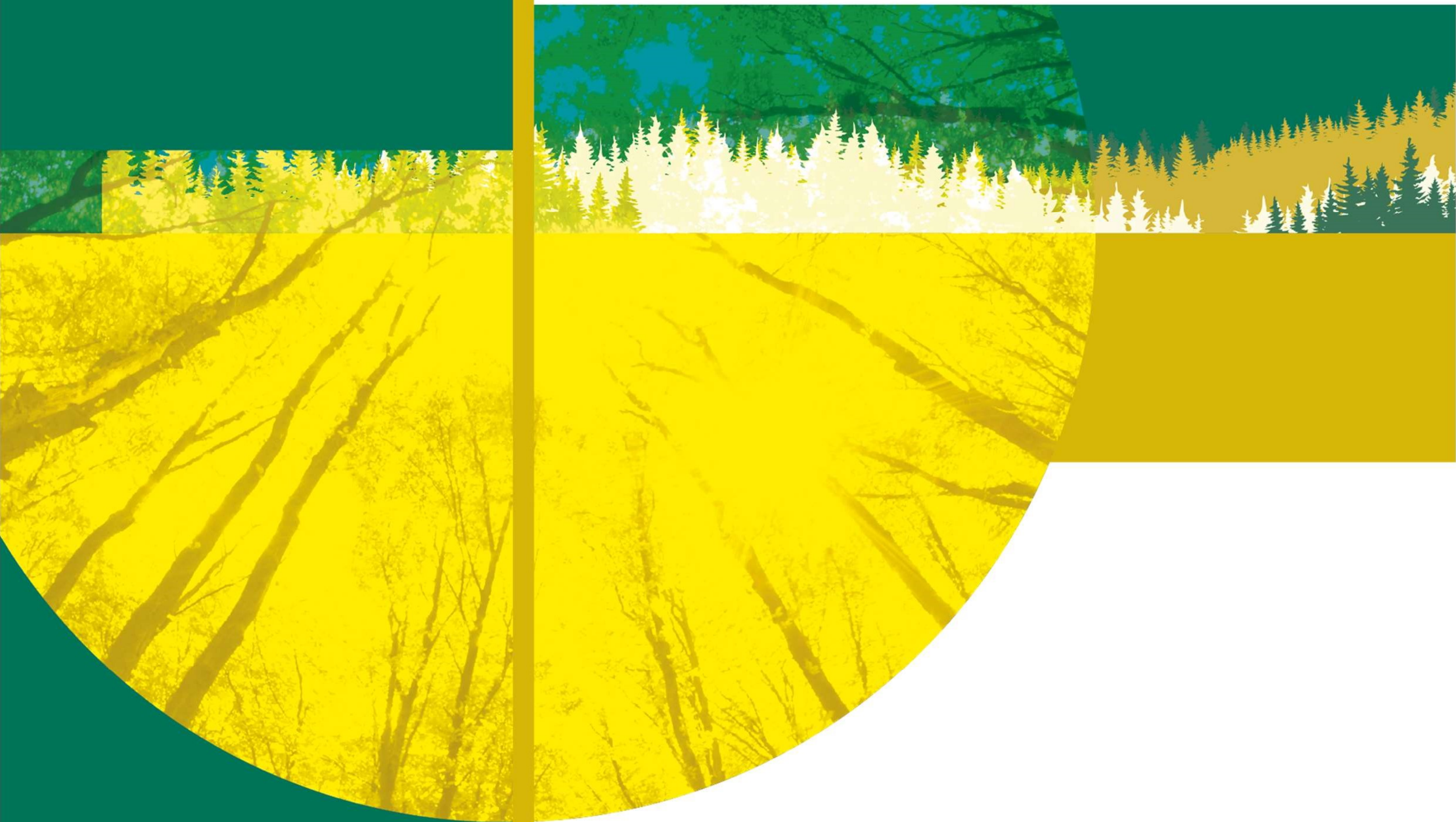
Valorization of By-Products from Small Scale Thermal Gasification

White Paper elaborated 2016-2018 under IEA Bioenergy, Task 33 Thermal Gasification of Biomass and waste



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Valorization of By-Products from Small Scale Thermal Gasification

White Paper elaborated 2016-2018 under IEA Bioenergy, Task 33 Thermal Gasification of Biomass and waste

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Abstract

This White Paper “Valorization of by-products from small-scale thermal gasification” was elaborated by the IEA Bioenergy under Task 33 (Thermal Gasification). For the last years appeared more commercial available gasifier units on the market. In Central Europe in the year 2018, we face about 1100 operating small-scale gasifier units.

As energy prices are under threat, the temptation to valorize the by-products from small-scale gasification is a logical step in cost saving for better economic situation.

CONTENT:

1 The thermal gasification process and by-products

The aim of Small Scale Gasification is to transform bioenergy-containing feedstock into power and heat. This are the so-called main products.

But generally, in any transformation processes there are several inputs and several outputs. Such transformation processes are rarely seen without unwished output, side effects or by products.

As the energy prices are under thread and the wide use of gasification units on a commercial base, a more closer view of optimization is ongoing. In this context, it is a logic consequence that operators, owners and supplier search for economic and ecological improvement of their existing small-scale gasification processes and equipment.

The valorization of the by-products is one of this approach. This paper shall help to frame out the chances and obstacles for this approach. It is mentioned for owners, operator, investors and decision-maker as well.

1.1 TYPICAL CHP GASIFICATION PROCESS

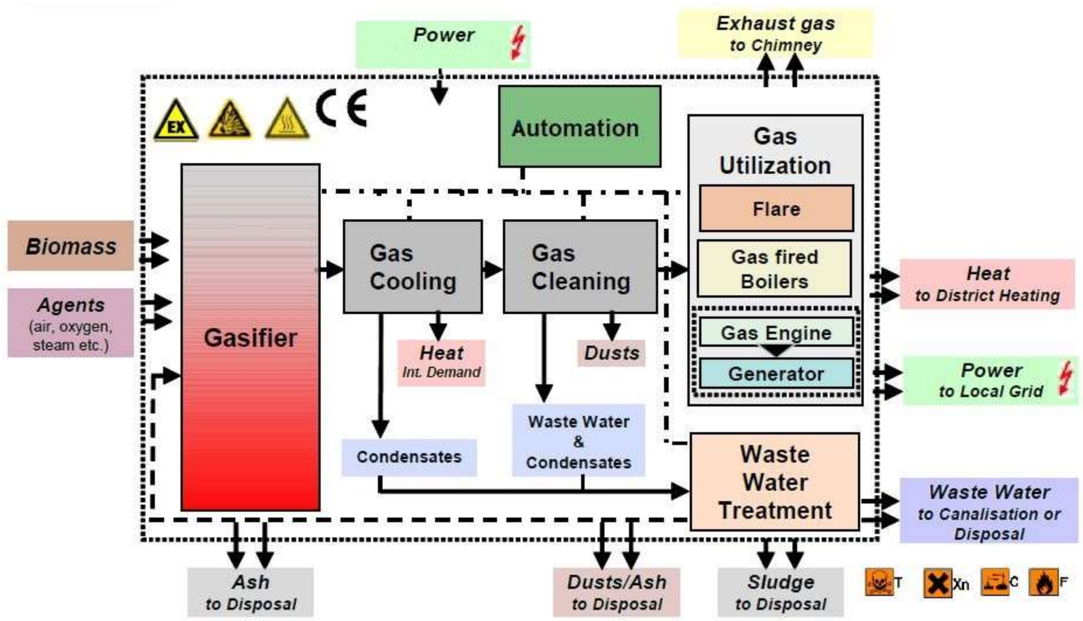

Figure 1: Example of a small-scale CHP gasifier unit with boundaries, input and output points (Fig: from [7] page 10, adapted)

The former idea to produce el. power only out of Biomass was never efficient and sustainable enough, so to consider about using "heat" was necessary. The next development step was recovering and valorizing the heat with that well-known implementation of **CHP-Unit** as seen in Figure 1 above.

Interesting is, that this "**waste heat"** is the first successfully widely used by-product. The overall efficiency and economical value were increased. Therefore, we see that this two products, **power and heat**, as normal business in gasification conversion processes.

In 2018, approximately 1'300 CHP units are in operation in central Europe.

1.2 HISTORY OF SMALL SCALE GASIFICATION PROCESS

History of application for small-scale gasification is quite interesting and can be grouped in the following steps:

	produces	aim		driver
Step 1	Fuel gas	fuel for transportation and stationery gas engines	1930-1950 1950-1980	War time 1 000 000 units fuel shortage (third world)
Step 2	Fuel gas and heat	CHP stationary	1973 - 1990	Oil crises
Step 3	Fuel gas and heat	CHP stationary	1990 - present	CO_2
Step 4	Fuel gas, heat and coal (by-product)	CHP stationary plus by-product	2010 - present	CO_2 + costs 1300 small-scale CHP units in Europe in operation 2018

Table 1: Historical steps of implementation

As a summary and historical conclusion of that table: nobody would use a more complex process if simpler technology is available. Only believed shortage of energy, high prices and smaller impacts are the driver of that gasification technology.

1 Biomass combustion is established

– for heat at reasonable cost but with PM and NO_X

– for CHP with low electrical efficiency and at high cost

2 Biomass gasification exhibits a potential

– for heat with faster operation and low PM and NO_X

– for CHP with higher electrical efficiency and at lower cost

3 Gasification exhibits a gap between the claim and the reality

– Advantages (PM, NO_X, el. efficiency) have been demonstrated

– Costs and complexity are claimed to be low (TRUE or FALSE ?)

– Reliability is claimed to be high (TRUE or FALSE ?)

Table 2: Concluded the overview of T. Nussbaumer Verenum CH, during WS T33 Luzern

There are clear advantages of gasification, but for what additional price and reliability is not always so clear. The numbers of newly installed small-scale TG CHP units showing in this direction that at least cost and reliability for both solution coming closer together, so the better efficiency and lower emissions are pushing factor to implement more gasification units.

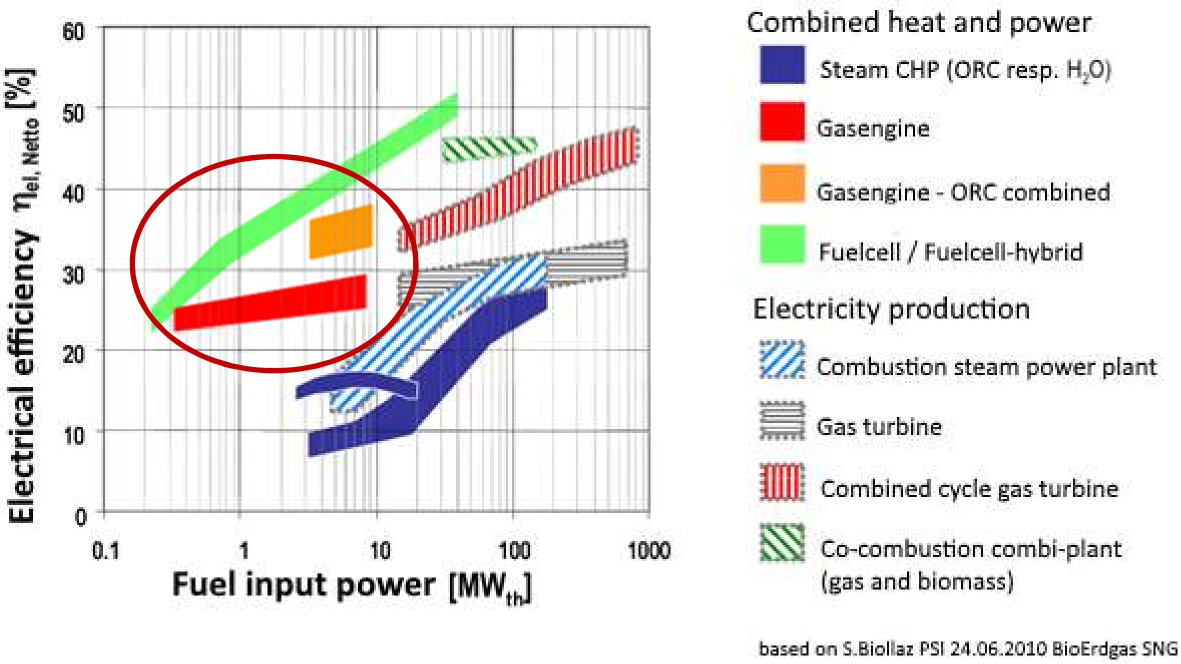

Figure 2: Biomass fuel and its conversion efficiency in different system

The only available commercial biomass conversion technologies for small-scale CHP application is the thermal gasifier combined with a gas engine. The conversion efficiency for electrical power from the feedstock is reasonable. Combined the waste heat with ORC the efficiency for electrical power can lifted but reduces the heat application. (See Figure 2 above).

1.3 IMPLEMENTATION OF SMALL-SCALE CHP UNITS 2017

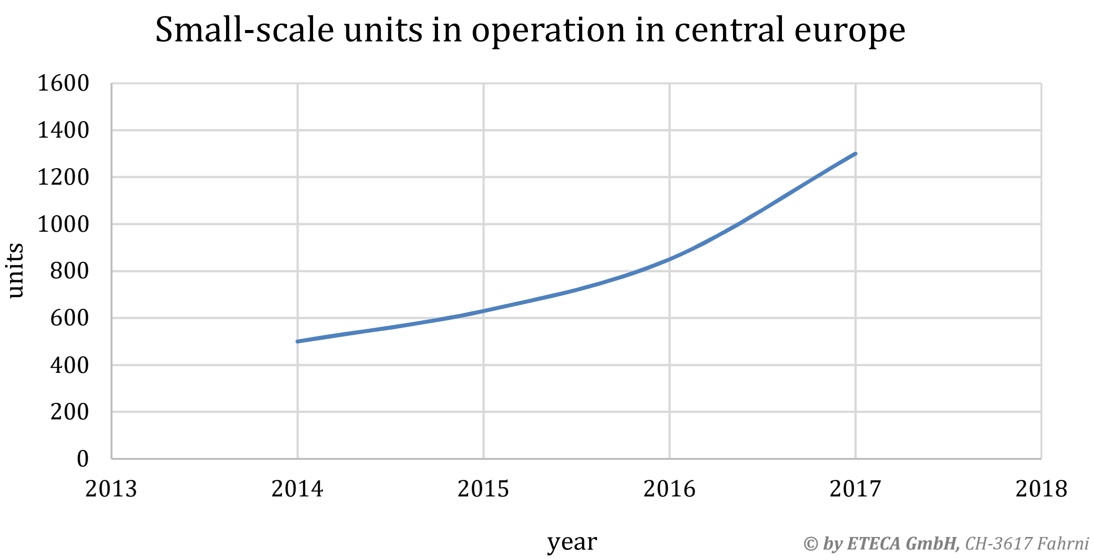

Figure 3: Small-scale CHP thermal gasifier units in operation

The increasing numbers of small-scale CHP gasifier units are based on the seriously developed systems, industrialized production of entire turnkey units, as well on the awareness of CO2 impact of fossil fuel and the substitution by renewables such as Biomass.

1.4 INPUT AND OUTPUT OF SMALL-SCALE CHP UNITS

1.4.1 Biomass as a fuel

Generally, it can be said that homogenous fuel is one of the most important factor to run a gasifier plant successfully and smoothly. But, homogenous bioenergy fuel is in most cases not the fact. Tolerances of humidity, quality, size, wood structure and type are wider than wished. Even pellets, today the most normative biomass fuel available on the energy market with smallest tolerances have remarkable changes of humidity, heating value and physical stability after storage.

If we speak about fuel for combustion engines, then it is most obvious that nobody would use diesel for a gasoline (petrol) engine or gasoline (petrol) for a diesel engine.

For a thermal biomass gasifier fuel shift by purpose or accidently is a similar issue as for combustion engines. Fuel quality shift for gasifier will always lead to problems sooner or later.

Operating a gasifier with bioenergy means with chips, saw dust, pellets etc. it is highly advised to consider about constant fuel quality very strongly. Fluctuating fuel quality affects in a negative way the energy production, the number of shut downs, efficiency, wear and tear and the operating costs. It also influences dramatically the quality and quantity output of waste and by-products.

1.4.2 Output, products, waste and by-product

Output includes everything what comes out of the thermal gasification process.

Products are named: the output from a transformation

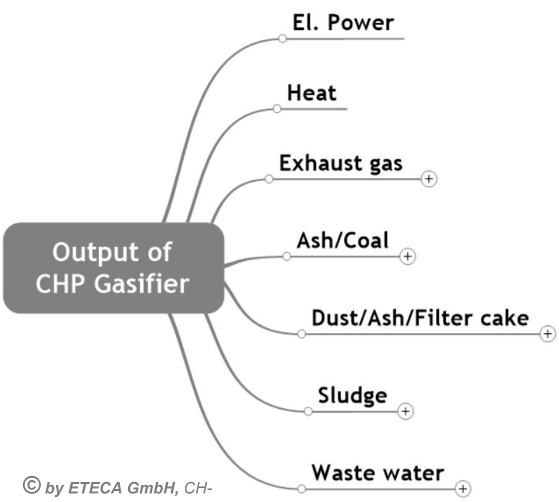

Figure 4: Output of a compact small-scale CHP gasifier unit

The products electricity and heat are not discussed in this paper!

Definition of Waste:

Generates disposal costs, to get rid of, has a negative impact to the environment from that transformation process or is unwished output due to technical transformation process.
See in next Figure 5 marked with:

Definition of By-products:

Marketable by-product from the small-scale gasification process (by side the main product)

In other words, if output has value, we understand it as a product; if output is a cost factor, we usually call it waste.

The question is always how we can reduce waste and costs or if not, how can we valorize the waste. That means, waste can be analysed, checked and if possible shifted into valuables. Overall the process should bring an additional benefit somehow. Behind todays understanding it is also common sense that cascading processes are more valuable and sustainable. In fact, that is the normal optimization for most economical activities.

It is only logic that we observe now the tendency to valorize more by-product out of the thermal gasification process and its combinations.

Generally, unwished output from the conversion of the thermal gasification process are the exhaust gas, ash/coal, dust/ ash, sludge and wastewater.

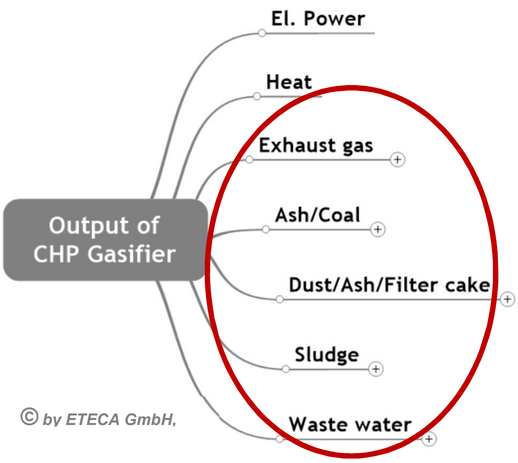

Figure 5: Output it can be Waste or by-product depending the inner value or application

Theoretically every unwished output can be looped, recycled, processed, reprocessed and integrated to reduce waste, but normally it is limited to costs and installation complexity and finally, waste will be accepted and tolerated in within legal boundaries. So, it makes no sense to reduce output to the maximum. Optimizing within legal frame is fair enough.

To discover and understand potential of the inner value of by-product it is helpful to investigate the mass flow and energy flow diagram from a certain plant.

1.4.3 Mass flow Sankey-diagram

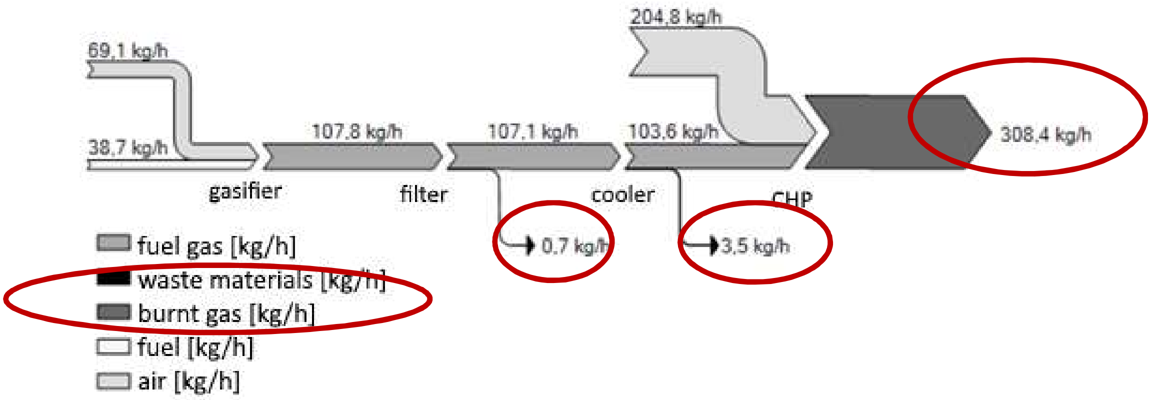

Figure 6: Mass flow of CHP Gasifier shows also by-products in quantity/h (Fig: from [8] page 64, adapted)

The mass flow diagram gives an Idea about the different output in quantity, which may be available for a by-product.

1.4.4 Energy Sankey-diagram

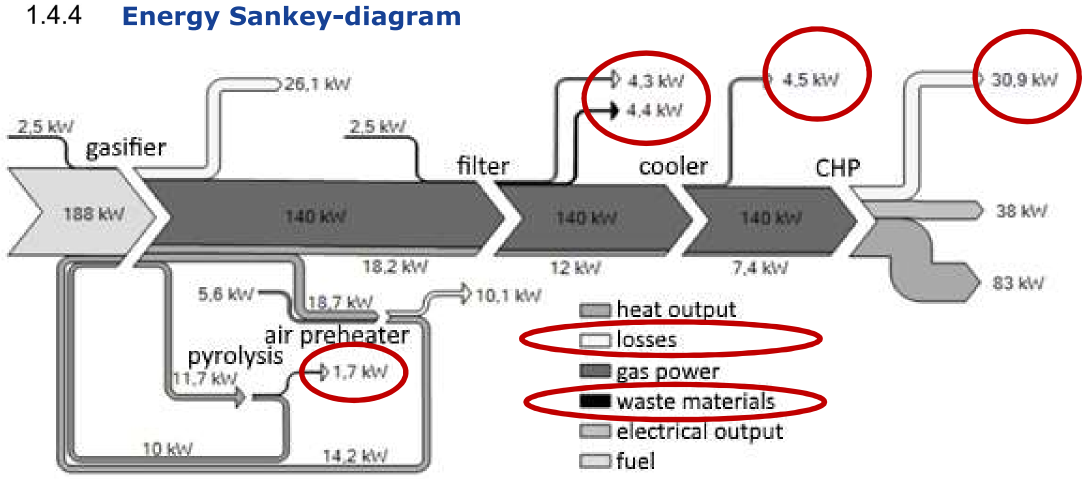

Figure 7: Energy flow of CHP Gasifier shows also by-products (red) with the energy content

The energy diagram is important to consult to get the energy value of the discussed by-product. With a Sankey diagram, is easy to discover potentials for heat recovery or looping. In addition, it is good instrument to see overall shift as well influences in the process itself.

1.4.5 **Shift waste towards a marketable by-product**

Lifting waste to product over the price:

To valorize a by-product there is not only the needed fact that a product can be sold on a market, but also the additional investments in the process for particular by-products as well the additional costs for labor, maintenance, handling, packing etc. must be covered.

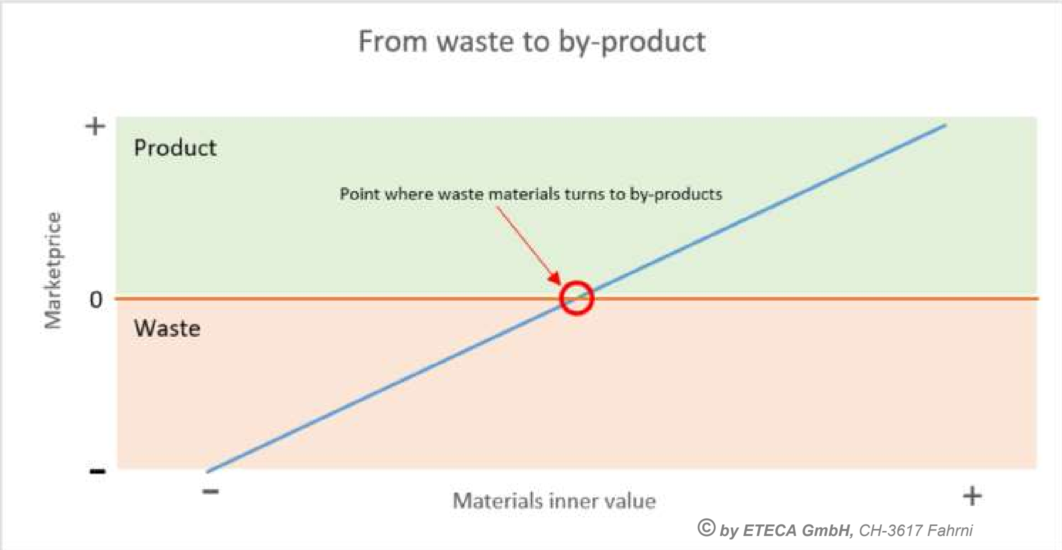

Figure 8: By-product is output it can be Waste or a product depending the inner value

Often, we are tempted by simplifying facts and short-term considerations. Shifting waste to a by-product, it is to consider, that there must exist a long-term stable market, which allows investing, so the by-product is less in danger to drop back to waste.

1.4.6 **By-products and overall complexity of the Installation**

As the illusion is very common, those problems will be solved with more technology and more complex installations and so the CHP-Unit will be more beneficial. We recommend going into the Pierre Fornallaz wisdom that each technology has its beneficial optimum. If we build a more complex system, then often we get no additional benefit, in contrary we lose time, money reliability and the overall efficiency drops (see below)!

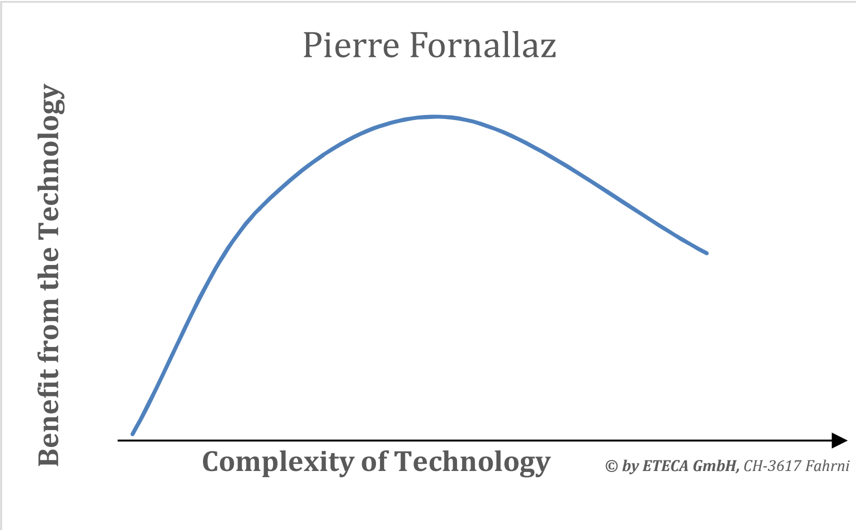

Figure 9: Benefit from rising technical complexity

Also, it is to consider that two conversion steps combined it means usually not the double challenges (problems) for success, it means that we multiple the challenges for success. If you have three products, it is even more dramatic because of the exponential growing of challenges, which must be solved with the depending factors of each product in combined system. To be aware of that fact leads to an external solution. That means less integration and collected output, which is brought to special centralized treatment plants for sludges, filter ashes or cakes.

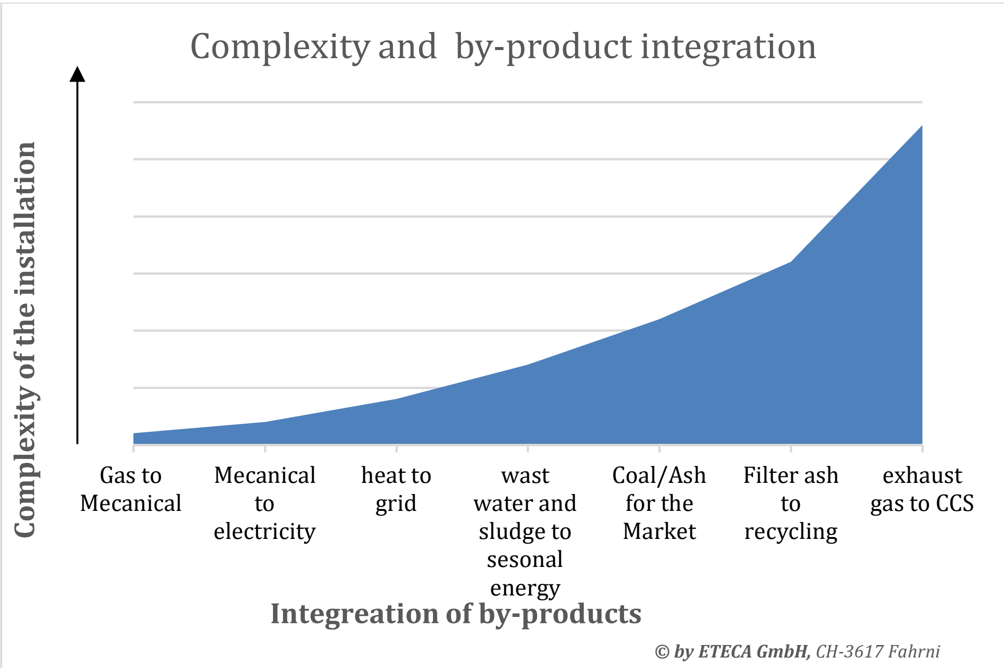

Figure 10: Integration of additional by-product and rising complexity

So, integration of additional by-product and rising complexity means also higher investment.

1.4.7 Small-scale CHP gasifier units in operation optimized for heat and power

According to high number of implemented industrial developed CHP Biomass Gasifier units, owners and operators are rising interest for solution concerning costly waste. Recycling, reusing and valorization is ongoing for this waste. Shifting waste to a by-product is more than an adequate solution.

Fact is that the most CHP units in operation today are designed for heat and power optimum. So, if there is an approach to shift waste to a by-product, owners must pay a prudence look for his installation and actual process before implementing by-product and new investments. This whole procedure is not so easy because of regulations and aftertreatment for marketable products. New by-products are forcing normally to additional investments, adaption and new procedures for the existing equipment.

1.4.8 Small-scale CHP gasifier units build and designed for one or more by-product

There are today already CHP units on the market or in development, which concerns to producing an additional by-product such as charcoal for a certain market. Here are two examples:

Commercially available are Plant from:

Syncraft Austria www.syncraft.at

A plant in development and early, industrial implementation:

Xylowatt www.xylowatt.com

1.4.9 The common issues between gasification and combustion

Biomass combustion is a longer and wider used application of energy transformation. Therefore, it is wise to consider about their unwished output as well.

There are two output groups mainly

1. From the combustion bed or combustion chamber

   - Ashes containing minerals, chemicals, metals and carbon

   The common way is to bring this material to disposal areas. Optional is, that this materials after recycling, upgrading and laboratory checks could be used as a fertilizer. Officials in Europe see the pathway of this group as practicable and there is a legal framework to reuse this material as agriculture or forest fertilizer under certain conditions.

2. Fly dust and aerosols in the exhaust stream

   - Filter dust and ashes
   - Filter cake
   - Wastewater from washers
   - Sludges from heat exchangers

   This group can contain all ugly metals, PAH, hydrocarbons and chemicals.

Officials in Europe see reusing this group as non-practicable and there is no legal framework to reuse this material as agriculture or forest fertilizer without very costly and intensive recycling procedure. In Switzerland reuse of fly dust, it is declared as an absolute no go. For this group inert disposal only is accepted up to now.

The first group can be compared with the ashes out of the gasification process, the second group is like the output of gas cleaning and mechanical, electrostatic producer gas filters.

2 Potential and possible valorization of by-products

2.1 BY-PRODUCTS DISCUSSED FROM CHP-UNITS

Generally, see the overview of the potential by-products of the small-scale CHP-units.

	from	Quantities	Containing	Official laws regulations	Discussed valorization
Ash/Coal	Gasifier	Approx. 1-10% of input	C, minerals, chemicals Metals,	Yes, in Europe for disposal	Carbon for different application
Dust/Ash	Gas Filter	Minor	Minerals, chemicals Metals, C, PAH	Yes, for disposal	Fertilizer Chemicals
Sludge	Gas Washer Leaks	Minor	Tars, C, Minerals, PAH	Yes, for waste water	Energy seasonal shift
Waste Water	Gas Washer	Depending System	Tars, C, Minerals, PAH	Yes, for waste water	Energy
Exhaust Gas	Gas engine	High volume	CO_2 + N	Yes, for Emissions	CCS

Table 3: Overview potential by-products

Following the different waste groups are shown in separate graphical mind maps. They show the theoretical possible value chains or valorization options.

How far the value chains are implemented, it is mentioned on the different waste groups.

Commercially Implemented

Means there is a by-product successfully on the market available.

Internal Implementation

Means that the waste is used or reduced internally in within the plant. There is no by-product on the market.

Research ongoing in the different value chains see also Annex 4

Generally, there are several reasons and drivers of research activities in this waste field of gasifier and the reuse of waste as a by-product:

- Optimization of the gasifier CHP process
- Higher rentability of the gasifier process
- Re-looping, recycling, no waste strategy
- CO_2 reduction
- Hypes such as:
    - "Terra Pretta"
    - Power to gas
    - RES Hybrids due to low energy costs and missing electrical transport capacity
    - Power on demand over biomass conversion
- Academical exercises and self-supporting strategies of research groups

In within this paper that topic research is not discussed. Research-reports and activities with certain relation to by-products are listed in Annex 4

2.1.1 Charcoal containing ashes

General approach of value chains:

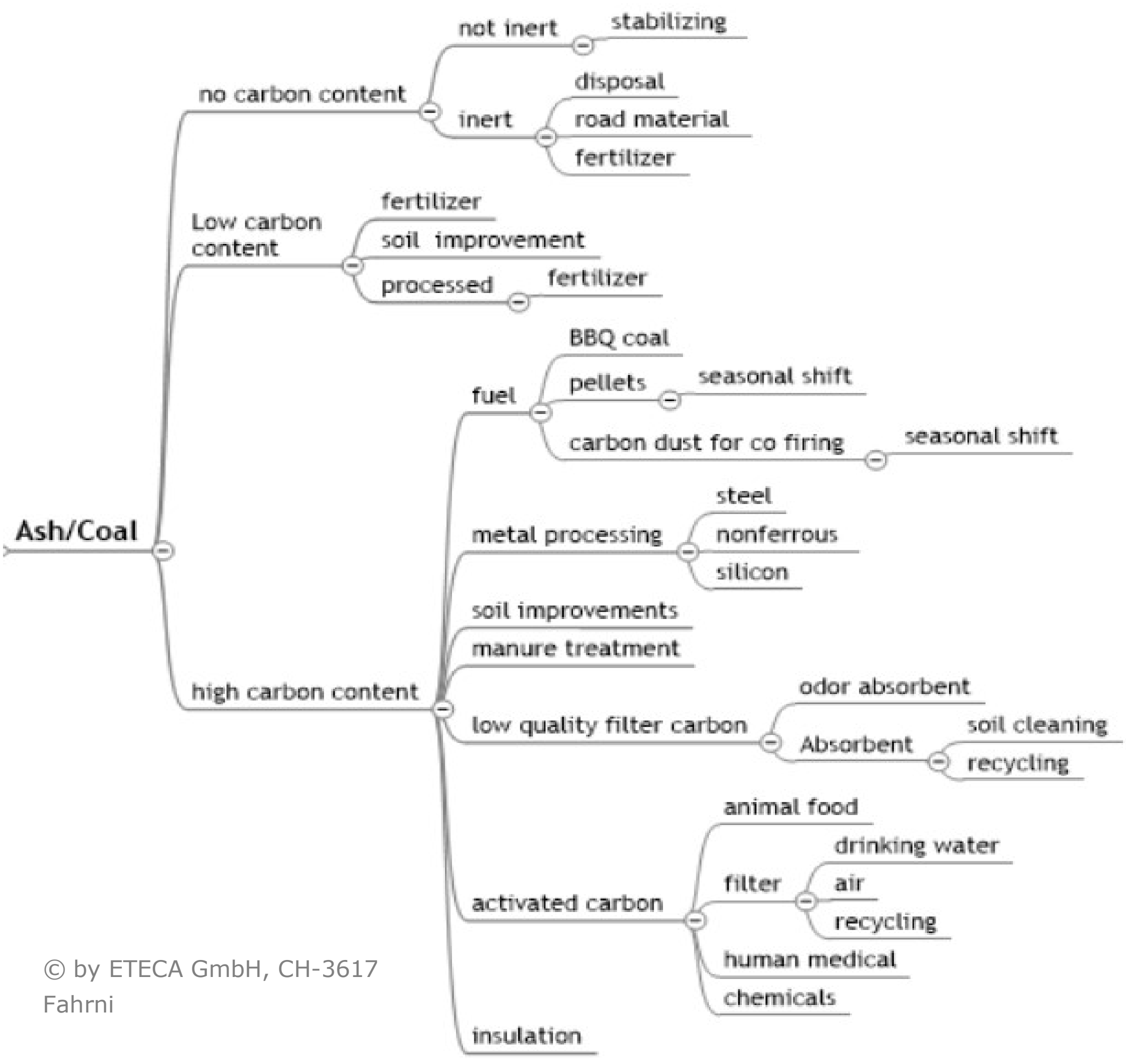

Figure 11: Treatment chain and potential by-product carbon containing ash

Commercially implemented value chain:

Different small-scale CHP plants loop the high containing charcoal ash as an energy carrier direct or as seasonal energy shift.

Coal as a by-product is used and sold for barbecue charcoal and as animal food additives.

Example of internal implementation [12]:

- Wila Switzerland (plant in operation 2007-2011)
  reburned the coal containing ash in a coal burner (seasonal shift)

- In some small-scale gasifier CHP units for district heating with biomass peak load combustion boiler it is seen that coal containing ash is relooped in the boiler.

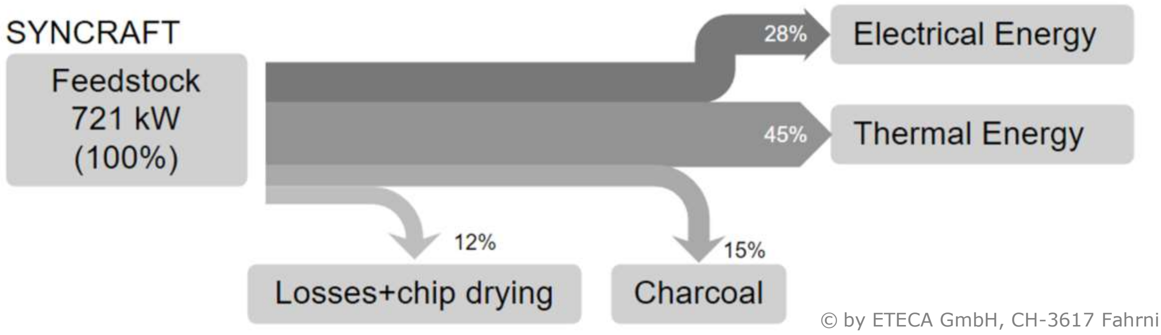

Figure 12: Sankey diagram energy flow CHP unit

Example of implementation [12]:

- Syncraft sells the by-product coal as charcoal and animal food additivs
- Xylowatt by-product charcoal shall be sold (future commercial concept)

2.1.2 Ashes and dusts from filter or filter cake

General approach of value chains:

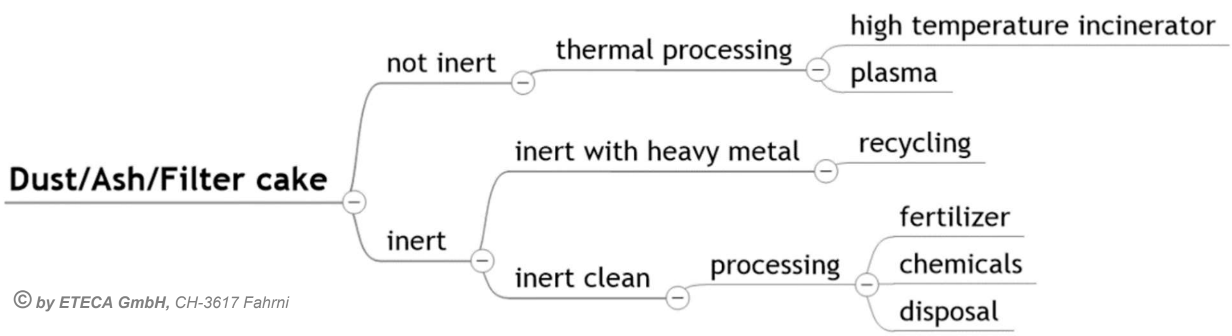

Figure 13: Treatment chain and potential by-product carbon containing dust and filter cake

This output is the most problematic one because its:

- fluctuating in composition over time
- problematic contents PAH, heavy metals, Phenol, S, etc.
- relatively small quantity
- etc.

Almost all this waste is brought today to disposal. Other solutions are complex, often more costly and not at all for wide implementation.

Here is a lot of research going on out of different approaches, but finally all results serve only to a specific equipment, a specific process with a specific fuel. So here research results are not for general use and must be interpreted very carefully.

As the similar challenges are found in the combustion technology, it may be also option to collect dusts and ashes from many incinerator-, combustion- and gasification plants and go to a centralized dust and ash recycling plant who can treat, divide and loop that waste more professional.

Commercially implemented value chain:

Not known so far, that any of this waste from filter or filter cake from small-scale CHP unit are commercially valorized as a by-product.
Many options are discussed, wide research have been done.

Example of implementation:

Not known as legal approved by authority and during long-term solution.
Standard is still disposed as waste.

2.1.3 Sludges

General approach of value chains:

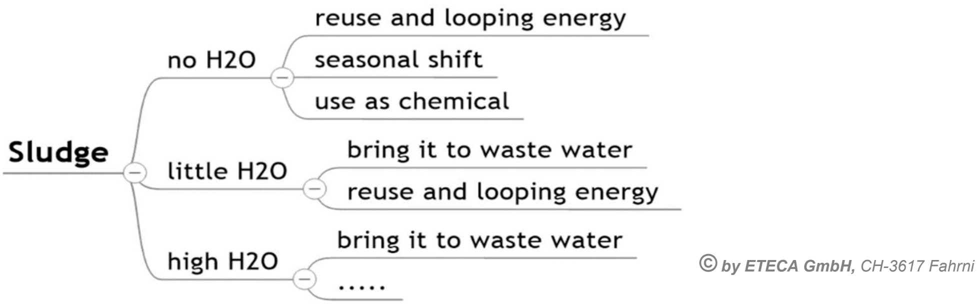

Figure 14: Treatment chain and potential by-product sludge

Commercially implemented value chain:

Not known so far, that sludge is valorized from small-scale CHP unit and commercially implemented as a by-product.
Often reused and looped internally in the CHP units or brought to wastewater.
Many new options are discussed, wide research have been done.

Example of internal implementation [12]:

- Harboure, 20 years in successful operation, seasonal energy shift
- Stans, 10 years in operation re-looped

2.1.4 Waste water

General approach of value chains:

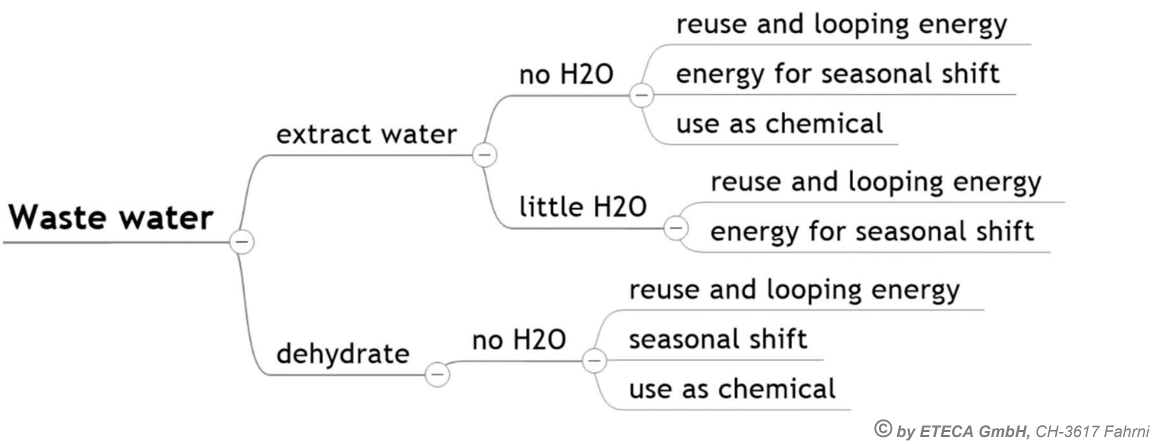

Figure 15: Treatment chain and potential by-product waste water

There are four main group of wastewater depending on their type made from small-scale CHP units

- Wastewater (Energy containing liquids)
- Wastewater (heavy metal and mineral containing liquids)
- Wastewater (toxic Material containing liquids)
- Wastewater (Energy, toxic and heavy metal and mineral containing liquids)

Commercially implemented value chain:

Not known so far, that wastewater is valorized from small-scale CHP unit and commercially implemented as a by-product.
Often reused and looped in the CHP units internally or brought to wastewater processing plant.
Many new options are discussed, wide research have been done.

Example of internal implementations [12]:

- Harboure, 20 years in successful operation, internal seasonal energy shift.
- Wila Switzerland (plant in operation 2007-2011)
  re-looped tar fraction from processed wastewater.
- EMPA Switzerland never completed due to its too costly wastewater recycling and re looping system based on the Wila know-how.

2.1.5 Exhaust gas (CO2 containing)

General approach of value chains:

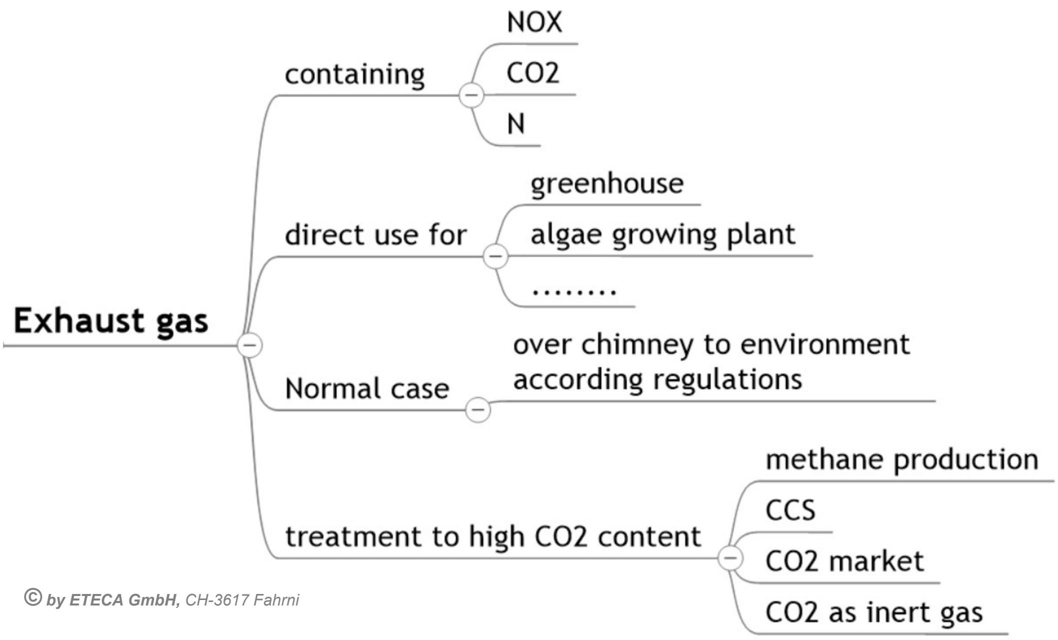

Figure 16: Treatment chain and potential by-product exhaust gas

Commercially implemented value chain:

Not known so far, Exhaust gas as by-products from small-scale CHP unit are commercially implemented. Many new options are discussed, wide research have been done.

Example of implementation:

Not known so far.

2.2 LEGAL FRAME

Following see an example for “Technical Specification of by-product”. This list is to understand as a guideline and is not complete. It shall help for crosschecks and negotiations in between plant owner’s farmers, forest owners and the different officials of the government who sign legal prove for by-product reused in medicine, for animal food, as fertilizer in forestry and agriculture.

Helpful therefore is to include detailed specifications certificates to underline information and avoid misunderstanding.

Following diagram shows the general procedure to follow for legal permission. As seen, different departments are involved, depending the designated use of the by-product.

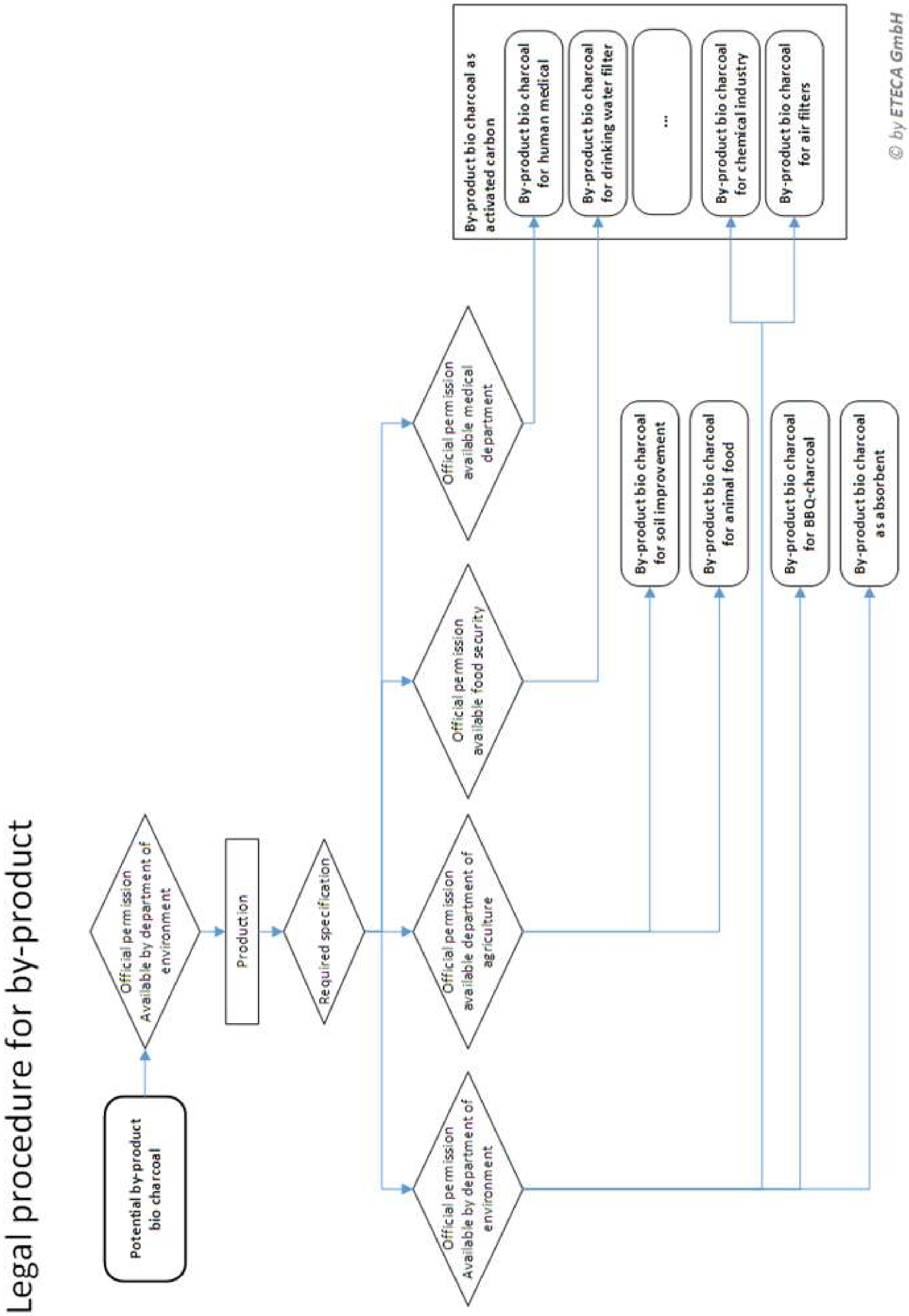

Figure 17: Legal procedure for by-product in Switzerland as an example

3 Economical aspects

Bioenergy conversion is a complex matter and under that aspect to consider that economical aspects are crucial.

The following chapter describes the activities and the considerations, which must be done before focus on the by-product optimization of a gasifier.

3.1 MARKETING PRODUCTS AND BY-PRODUCTS

The potential by-products are listed in chapter 2. Some of those are promising an economical benefit, when brought to the market. But before any decision is made to invest in a production of e.g. charcoal as a by-product, multiple objects must be verified. To give a view to the important questions, the classical marketing Method "PPPP" [11] (product, price, place, promotion) is expanded with a 5th "P" for the power plant.

Product

- Which amount of the by-product can be produced in which time?
- Is the quality of the by-product adequate to the chosen market?
- Has the by-product to be pre-treated before brought to the market?

Price

- What price can be achieved on the market for the by-product?
- Who transports the by-product to what conditions?
- What work force must be invested to the by-product production?

Place

- Is a market available to sell the by-product?
- Is the market in nearby?
- Is the market open for a new supplier?

Promotion

- Which efforts/investments must be done to get access to the market?

Plant

- What changes must be done to the existing plant?
- What investments must be done to de existing plant?
- Is there discrimination to the main products (thermal- & electrical energy) due to the production of by-products

- Is the operation restricted due to the production of by-products?

This (non-exhaustive) enumeration points out, that an operational concept should be deployed even before a plant is selected. Changing an already existing plant is linked with major investments and operational changes.

Also, it is advised to sign long term agreements, besides the obvious contracts for fuel, thermal and electricity also for the potential by-products.

3.2 FINANCIAL ASPECTS

The financial aspect must be elaborated individually for each project. Early consideration helps to make a project successfully.

Financial goals with a gasifier project are expected. Therefore it is important to elaborate during evaluation budgets not only for investments, but also for yearly operation, including electricity in and out, heat, water, consumables, lubricants, additives, waste and by-products (such as water, ash, filter cakes ...) maintenance, needed spare parts, costs for staff etc. All this calculation is based one expected full load hours for one year. Nice to have are sensitive analyses for fuel prices and operating hours.

To have a high overall efficiency, respectively a good ratio between input and marketable output is in most cases also promising a high financial yield.

As Figure 18 shows, the Syncraft plant has an overall efficiency of 88%, what is promising. Also, the Syncraft plant has a comparatively high production of charcoal. All the work and financial effort for this by-product can be spread to the hole amount of charcoal. This leads to lower specific expenses.
Compared with the plant of Wegscheid (both are operating with wood-chips) which has an efficiency of 78%, here only 2.7% of the energy input is incurred as charcoal. So, all efforts which must be done to collect, treat and sell the charcoal increase its specific price drastically. With a plant like this (or also the Burkhardt plant), it is important to collaborate with other producers of similar waste/by-products, to split the efforts to a bigger amount of material.

3.2.1 Different plant concepts

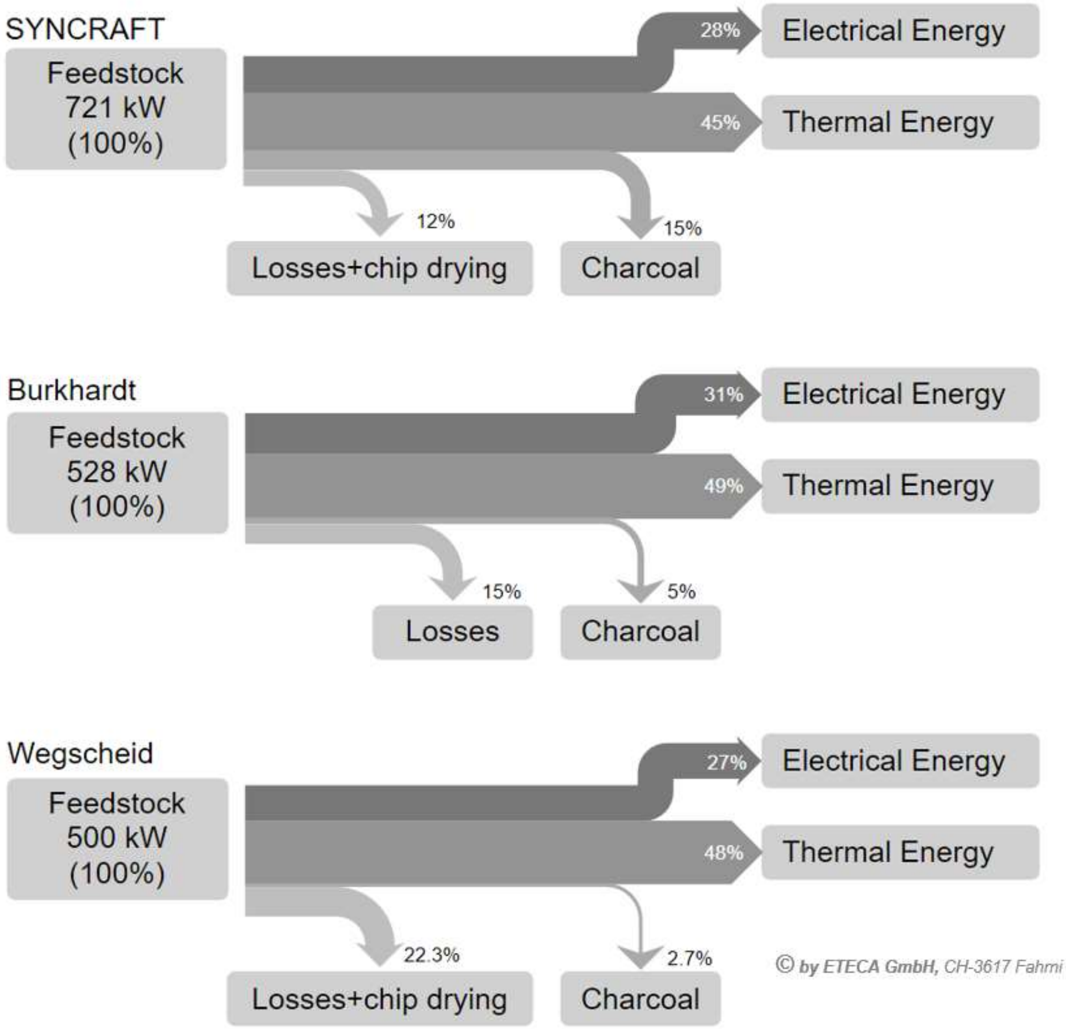

Figure 18: Sankey diagram different CHP applications

The overall energy efficiency from can be different from each CHP unit. As an example, Syncraft leads with charcoal together with 88%, Burkhardt with 85% and Wegscheid with 78%. With the CAPEX, OPEX and yearly operating hour it will be a different economical result for each approach. Each example must be considered separately for its financial and economic figures.

3.2.2 LCOE sensitivity analysis: charcoal production

Following diagram shows the calculated LCOE (Levelized cost of electricity) of a Syncraft gasifier (data calculated by M.Huber [5]) with three different prices for the by-product charcoal. These different prices are depending on the quality of charcoal and the intended use (Biochar, BBQ-coal, animal feeding).

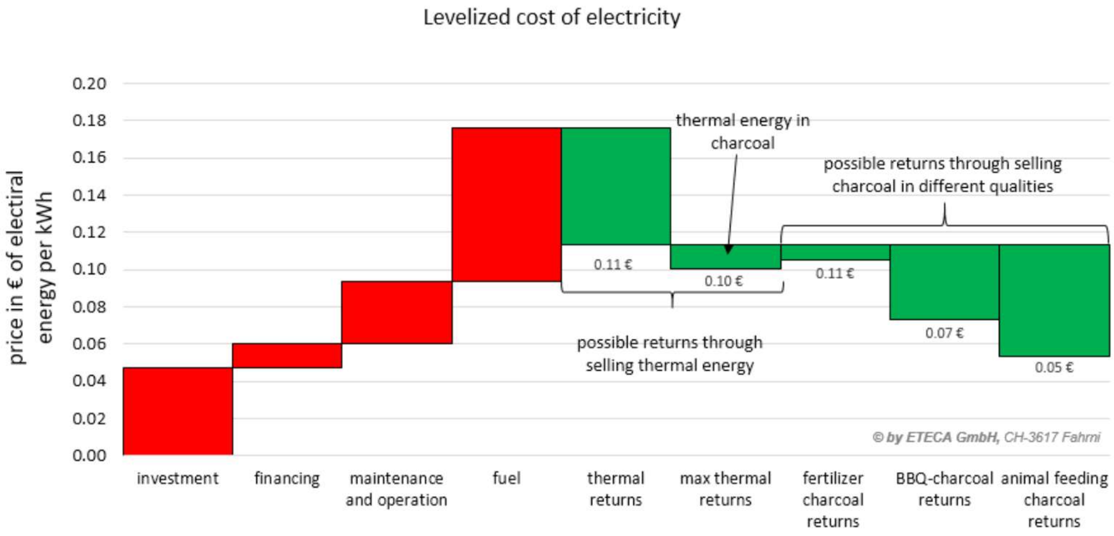

Figure 19: LCOE of Syncraft gasifier

As seen, the LCOE can strongly be reduced by selling charcoal. But as Figure 18 shows, not every plant is suitable to e.g. produce charcoal. Also, the Figure 19 shows, that with production of charcoal the thermal return decreases. So, if charcoal production is a goal, also long-term agreements for the output must be signed and the production costs must be calculated.

3.2.3 LCOE sensitivity analysis: aftertreatment of charcoal

Depending on the quality of the charcoal, there must be an aftertreatment before it can be sold. So, in cases an increased thermal-energy production can be financially rewarding, instead of producing charcoal!

Following Figure 20 shows, how a costly aftertreatment of a by-product can destroy a good-looking calculation (values of aftertreatment costs are exemplary estimated).

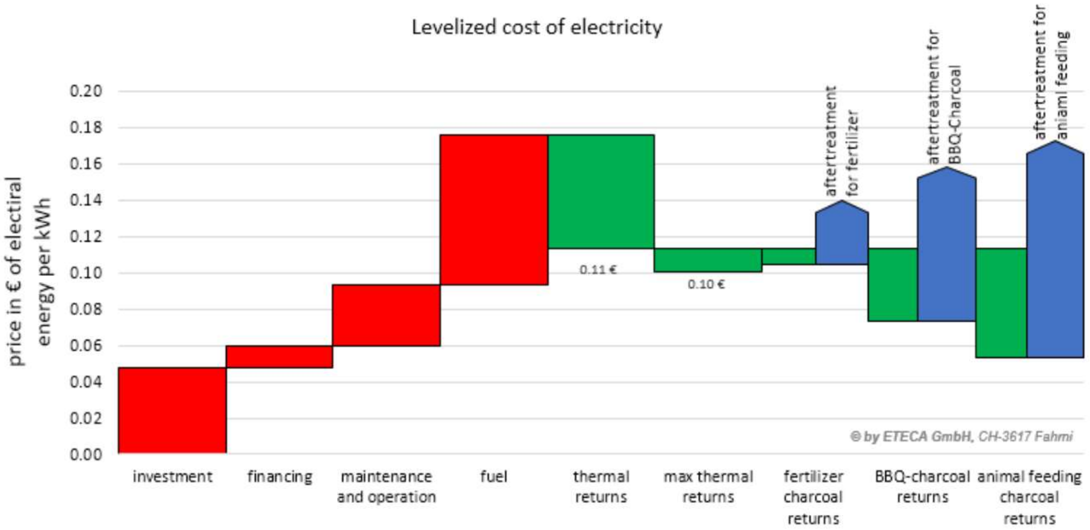

Figure 20: Impact of additional carbon aftertreatment

3.2.4 LCOE sensitivity analysis: optimized operating time

The examples above are all calculated with constant annual operating hours. In cases it makes more sense to try to rise the annual operating hours than to start experiments with by-products.

Following Figure 21 shows the impact of rising or reducing the operating hours by 20%.

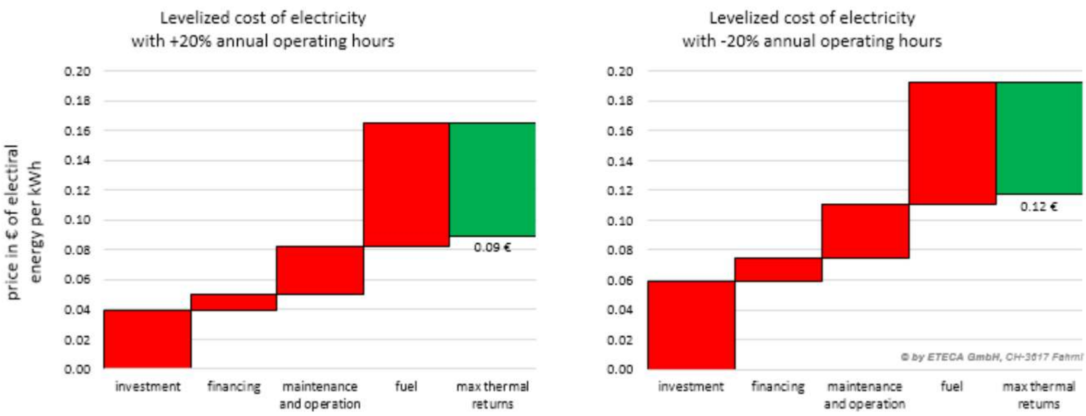

Figure 21: Sensitivity of fluctuating operating hours

The comparison with Figure 19 shows, that increasing the annual operational hours results in a lower LCOE than by selling cheap fertilizer charcoal as by-product.

Similar calculations can be done with variable fuel prices.

4 Standards and specification for by-products and fuel

As Bioenergy conversion is new technology there are not many specific implemented standards concerning bioenergy CHP gasifier. Standards for some parts and equipment of thermal gasifier are existing, but those are not (or only limited) applicable for small-scale gasifier. For small-scale gasifier CHP standards are no publications at all found.

4.1 BIOENERGY FUEL STANDARDS

For solid biofuel, standards are available from CEN and ISO (see [5] and [6]). Pellets and wood chips where covered in EN14961-1 this standard is replaced with CEN/TC335. Standards for biofuel as gas and for natural gas are under ISO/TC238.

4.2 BY-PRODUCTS STANDARDS

Not known so far, for by-products from small-scale CHP unit.

4.3 CHARCOAL STANDARDS

See Annex 2.

4.4 GENERAL SEARCH LINK CEN STANDARDS

https://standards.cen.eu/dyn/www/f?p=CENWEB:105::RESET::::

4.5 GENERAL SEARCH LINK BS STANDARDS (BRITISH EN-STANDARDS)

https://shop.bsigroup.com/

5 Conclusions & Recommandations

5.1 GENERAL

- There is no energy conversion without unwished side effects, such as exhaust, waste, by-products and environmental impact.
- Conversion of solid biomass to heat is the oldest and today large widely used RE conversion technology. Ashes and exhaust gases are the side effects for combustion and thermal gasification.
- Conversion of the biomass to electrical power only is a no go. The valorization of the heat as a by-product makes the conversion today more or less feasible for small units.
- Conversion of solid biomass for transportation (or mechanical power) is not applicable any more, only there were 1 million units in operation during and between the two world wars.

5.2 VALORIZATION OF BY-PRODUCTS

- Valorization of other by-products is an approach for better commercial and a sustainable issue.
- Valorization of by-products rises always the complexity of the conversion process.
- Not every plant is capable and optimized to produce the same valuable by-products.
- On an existing operating CHP-unit to valorize a by-product is substantial time and resources consuming for adaption, marketing and legalization etc. Very successful implementation is not known.
- Successful by-product implementation is shown in designed for "by-product-plants" new built and implemented already during first concepts.
- Optimizing a plant to a high energy efficiency (thermal and electric), or annual operational hours can be more profitable than experiment with by-products.
- Selling a by-product leads to work and expenses (marketing, collecting, packing, aftertreatment, transport, investments etc.).
- Energy containing by-products reduce the heat and electric power outputs and must be seriously considered in sensitivity analysis.
- As smaller the yearly amount and value of a by-product, as harder it is to turn waste in a business case.
- With by-products in small amounts it can be worthwhile to collaborate with other biomass conversion installations (combustion and TG) and treat all collected "waste" (e.g. ashes) in bigger amount in a special adapted plant which produces inert waste and recycled fertilizer material or carbon fractions.
- To legalize a by-product for producer, dealers, farmers and end-customers it is normally a time-consuming procedure, cause officials of different governmental departments are involved.

6 By-Product related Research Activities

See Annex 4

7 Literature

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http://standards.cen.eu/dyn/www/f?p=204:7:0::::FSP_ORG_ID:19930&cs=17158638AB0C35D5E52A369017E54A1D6

List of published standards under CEN/TC 335 Solid Biofuel:

http://standards.cen.eu/dyn/www/f?p=204:32:0::::FSP_ORG_ID,FSP_LANG_ID:19930,25&cs=19F087DBDE0BACDFD4078ABA84D4941DC

[10] DIN EN 14 961-1 *Solid Biofuels* is replaced by EN ISO 17 225-1 to EN ISO 17225-7:2014 see List of [9]

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8 Tables

9 Figures

10 Abbreviations

BECCS	Bio Energy Carbon Capture and Storage
CCS	Carbon Capture and Storage
CEN	European Committee for Standardization, German: Europäische Norm (EN)
CHP	Combined Heat and Power Small-scale gasifier CHP mentioned in this paper mentioned means: up to 10 MW biomass feedstock input or approx. 3 MW_{el} output
IEA	International Energy Agency
LCOE	Levelized Cost of Electricity
ORC	Organic Rankine Cycle
PAH	Polycyclic aromatic hydrocarbon
PM	Particle Matter
R&D	Research & development
RE	Renewable Energy
SCCER	Swiss Competence Center for Energy Research
TG	Thermal Gasification
LCOE	Levelized cost of electricity

11 Annexes

1. Market Coal, Charcoal, Active-carbon

    a. Soli improvement

    b. Charcoal, BBQ-coal

    c. Activated coal

    d. Animal Food

    e. Medical Coal

2. Analytic, Checks, Tests and Examples of Coal containing ashes

    (see separate document)
    Analytic, Checks, Tests and Examples of Coal containing residues and by-products out of small-scale thermo-chemical wood gasification CHP plants

    Elaborated by
    Dipl.-Ing. Dieter Bräkow
    Working Group Gasification of Biomass of the FEE e.V.
    Society for the Promotion of Renewable Energies FEE e.V.
    English Version & Deutsche Fassung

3. Small-scale CHP Unit Examples build for charcoal production

4. Research

Further Information

IEA Bioenergy Website
www.ieabioenergy.com

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