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Fuel Handbook		
Birgitta Strömberg		
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Fuel handbook

Birgitta Strömberg, TPS

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Translated by

Vattenfall AB

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Foreword

This handbook on renewable fuels has been commissioned by the Swedish organisations TPS Branschforskningsprogram för Energiverk (TPS Research Programme) and Värmeforsk (Thermal Engineering Research Institute). The project was carried out as a co-operation between TPS Termiska Processer AB and SEP Scandinavian Energy project AB. Birgitta Strömberg, Boo Ljungdahl, Torbjörn Nilsson, Frank Zintl and Niklas Berge from TPS, Solvie Herstad Svärd, Marianne Gyllenhammar and Sara Larsson from SEP have taken part in the project. The Swedish handbook was published as a Värmeforsk Report, no 911, March 2005. The handbook is a compilation of mainly Swedish literature from plants and energy authorities. The references can be found in the Swedish version of the fuel handbook.

In agreement with Värmeforsk and TPS Branschforskningsprogram, Vattenfall AB has selected parts of the handbook and financed the translation into English. The translation was made by Interverbum. This was performed as part of the Vattenfall Thermal Technology Research and Development Programme, TTP. The purpose of this handbook is to facilitate biofuel introduction at power and heat plants in the European Union.

The translated fuel handbook contains selected parts of the original handbook. The English version is divided into the chapters as seen below and the cross-reference list. Table 1 shows the chapters referring to the Swedish version.

- Chapter 1. Method to introduce new fuels in power and heat production
- Chapter 2. Legislation and taxes in the European Union
- Chapter 3. Methods for assessing combustion properties
- Chapter 4. Ash theory
- Chapter 5. Methods for assessing the likelihood of corrosion
- Chapter 6. Standards, handbooks and databases

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3.10	Skogsindustriella slam		Fibre sludge/Chemical sludge/Biological
5.17			treated sludge/De-inking sludge
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3.23	Kött- och benmiöl (MBM)		Meat and bone meal (MBM)
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Sammanfattning

Denna handbok för förnyelsebara bränslen har tillkommit på uppdrag av TPS Branschforskningsprogram för Energiverk och Värmeforsk och vänder sig till kraft- och värmeproducenter i Sverige. Bränslehandboken erbjuder en metod för att ur anläggningsägarens perspektiv bedöma olika bränslen på marknaden. Bränslehandboken omfattar förnyelsebara bränslen (dock ej hushållsavfall) som är tillgängliga på den svenska marknaden eller som bedömts ha en potential att bli tillgängliga inom en tidsperiod av 10 år.

Handboken omfattar 26 bränslen. Analysdata, speciella egenskaper, driftserfarenheter samt litteraturreferenser redovisas för samtliga bränslen. [Speciella egenskaper, drifterfarenheter och litteraturreferenser är inte inkluderade i den engelska versionen]

Handboken innehåller dessutom:

- En vägledning för hur man bör gå till väga när man planerar att introducera ett nytt bränsle, vilka analyser och tester man bör genomföra för att minska riskerna för problem. [Analyser och tester är inte inkluderade i den engelska versionen]
- Lagstiftning och skatter relevanta för energiproduktion finns sammanfattade, med hänvisningar till var aktuell lagtext går att återfinna. [Endast lagstiftning och skatter gällande EU är inkluderade]
- Teori och bakgrund för att bedöma bränslens förbrännings-, ask- och korrosionsegenskaper, samt olika metoder som kan användas för bedömningarna.
- Sammanställning av standarder, databaser och handböcker för biobränslen och andra fasta bränslen, där ytterligare information om bränslen kan hittas med hjälp av länkar till olika internetadresser.

I bilagorna finns:

- En experimentell undersökning av ett urval av bränslen. [Ej inkluderad i den engelska versionen]
- Ett förslag till mall för proveldning av bränslen.
- Beräkningsrutiner för bl.a. värmevärden, rökgassammansättning, nyckeltal och fri fall hasighet hos partiklar. Dessutom finns omräkningsrutiner mellan olika enheter för en mängd olika tillämpningar.
- Bränsleanalyser [Finns i appendixet i den engelska versionen]

Summary

This handbook on renewable fuels has been commissioned by TPS Branschforskningsprogram för Energiverk and Värmeforsk and is intended for power and heat producers in Sweden. This fuel handbook provides, from a plant owner's perspective, a method to evaluate different fuels on the market. The fuel handbook concerns renewable fuels (but does not include household waste) that are available on the Swedish market today or fuels that have potential to be available within the next ten years.

The handbook covers 26 different fuels. Analysis data, special properties, operating experiences and literature references are outlined for each fuel. [Special properties, operating experiences and literature references are not included in the English version]

The handbook also contains:

- A proposed methodology for introduction of new fuels. A recommendation of analyses and tests to perform in order to reduce the risk of problems is presented. [The recommendation of analyses and tests is not included in the English version]
- A summary of relevant laws and taxes for energy production, with references to relevant documentation. [Only laws and taxes regarding EU are included]
- Theory and background to evaluate a fuel with respect to combustion, ash and corrosion properties and methods that can be used for such evaluations.
- Summary of standards, databases and handbooks on biomass fuels and other solid fuels, and links to web sites where further information about the fuels can be found.

The appendices includes:

- An experimental investigation of a number of biomass fuels. [The investigation is not included in the English version]
- A methodology for trial firing of fuels.
- Calculations procedures for, amongst others, heating value, flue gas composition, key number and free fall velocity [Free fall velocity is not included in the English version]. In addition, conversion routines between different units for a number of different applications are provided.
- Fuel analyses [Can be found in the appendix in the English version]

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Appendices

- A METHODOLOGY FOR TRIAL FIRING OF FUELS
- **B** FUEL ANALYSES

1 Method to introduce new fuels in power and heat production

1.1 Check list for the introduction of new fuels

If a new fuel is introduced, the evaluation can be based either on a given fuel or on a given combustion plant. Table 1.1.1 gives a summary of important questions that arise when a new fuel or fuels are to be introduced, together with references to sections in which more detailed information can be found.

Table 1.1.1Checklist for the introduction of new fuels.

Questions	Section	Special information
Is the fuel a waste fuel?	1.1.1	
What combustion technique	1.2	Table 1.2.1, 1.2.2
should be used?		
What fuels are conceivable?	1.1.3, 1.3	Table 1.3.1
What applies to fuel mixtures?	1.1.4	
What applies to the working	1.1.5	
environment/safety?		

1.1.1 Is the fuel a waste fuel?

Regardless of the intended combustion technique, it is important to shed light on whether the fuel is a waste fuel that is covered by the rules for waste incineration or is covered by other special rules, such as for animal by-products. (See also chapter 2.5)

1.1.2 Choice of fuel to suit the combustion technique

Different combustion techniques make different demands on the fuel characteristics if problems are to be avoided and/or minimized. Table 1.2.1 gives a summary of the fuel characteristics that are important for different combustion techniques. The table is intended to serve as a guide for the requirements that should be made on the fuel properties for a certain combustion situation.

Table 1.2.2 summarizes the significance of various fuel parameters for combustion, operation and equipment requirements.

Once the fuel characteristics that are of significance for the plant are known and the fuel is to be tested, several methods are available for running these tests. Some of the tests can be carried out in the plant, while others require special laboratory resources.

The characteristics of the ash from the fuel are of great importance in respects such as deposits and corrosion, and there are a number of test methods that can be used. Just as

in the case of fuel characteristics, these methods also include those that are relatively simple to carry out in the plant, while others require special analysis facilities.

1.1.3 Choice of fuel on the basis of fuel class

Starting with a specific type of fuel, table 1.3.1 can be used to obtain the special properties of the fuels included in the Handbook. The table summarizes very briefly the information on selected fuels, and can be used as a first recommendation for fuels that are suitable for various types of combustion equipment. References are made to the relevant section in which more detailed information is available on the composition, operating experience, legislation and references.

Example: If I want to include bark in the fuel mix, I can expect increased NO_x emissions and must then know/ensure that my flue gas treatment equipment can cope with this.

1.1.4 Fuel mixtures

Only a few fuels are used as "pure" fuels. These include, for instance, wood pellets/briquettes, straw in special boilers, and liquid fuels such as tall oil, as well as animal and vegetable fats. Other fuels are generally co-fired in varying fuel proportions. An important reason for mixing fuels is to achieve a uniform calorific value. The makeup of the mixture often depends on availability and price. How the mixture is made up often depends on empirical evaluation of the fuels included.

The boiler design and the feed equipment are important for the type of fuel mixture that can be used. The physical properties of the fuel may determine the fuel or fuels that can be mixed.

Important parameters to be borne in mind are:

- Good mixing of the component fuels is very important in order to ensure, for example:
 - stable combustion
 - avoidance of local sintering
 - that the favourable properties of various fuels are put to use
 - utilization of the effect of fuels that have high sulphur contents, in order to avoid/reduce corrosion and deposits.
- Fuels that differ widely in particle size/form may require special treatment, such as extra fuel preparation in the form of mills or separate fuel feed systems.

- Wide differences in moisture content between the fuels may require special fuel feed arrangements.
- The dry solids content of the fuel mixture should be >45 % to ensure beneficial energy utilization in boilers without flue gas condensation.

The chemical composition of the fuel types comprised in the mixture is of great importance for determining how well a mixture will perform. As a general rule:

- Fuels with high sulphur content, such as peat, digested sludge and tyres, can improve the properties of wood fuels with high alkali contents.
- Fuels with high ash melting points can improve the properties of agricultural fuels such as straw and grain with low ash melting points.
- A very low proportion (< 2-3 %) of a "difficult" fuel added to a fuel mix that performs well does not normally cause problems. However, an exception is grain chaff at high combustion temperatures, which may cause sintering problems even in very small quantities.

Additional investments may have to be made to enable **refuse-derived fuels** to be fired in a biofuel fired boiler if the requirements of the waste incineration directive are to be met. This applies particularly to relatively small plants with simple flue gas treatment systems. The investments necessary for switching over to co-combustion depends on the type of plant and the fuels that are to be used:

- Suitable type of flue gas treatment equipment
- Measuring equipment
- Equipment for handling waste fuel (e.g., shredder, conveyor belt, crane, fuels stores)

The proportion of waste fuel mixed in is important to the profitability of the investments. For different flue gas treatment systems, calculations are available to show the difference in fuel prices necessary to achieve profitability for different proportions of admixture. Table 1.1.2 shows an example of the necessary difference in price between biofuel and waste fuel for the investment to be profitable.

Table 1.1.2	Necessary price difference in SEK/MWh between biofuel and waste fuel for
	achieving profitability of various types of flue gas treatment equipment in a 10
	MW plant.

Proportion of waste fuel*	Bag filter	Flue gas condensation	Dry treatment
10%	211	11	377
20%	107	8	195
30%	73	7	135
40%	56	6	104
50%	46	6	86

* Proportion of waste fuel in biofuel.

For smaller plants, it may also be difficult to meet the requirement for a residence time of 2 seconds at 850°C, particularly at low load. The cost of personnel resources and also of measuring equipment may also be high in relation to the amount of heat generated.

1.1.5 Working environment and safety

Working environment problems in combustion are mainly related to fuel reception and feed, and also the handling of ash and flue gas treatment residues.

Wood chips should be regarded as perishable, and storage for a longer period of time should be avoided. Damp wood chips are attacked by mould and break down. Breakdown can be arrested by drying the chips, but mould spores remain and are activated when the moisture returns to the appropriate value. Wood chips should be produced from dry raw material if the intention is to store them. If the moisture content is below the fibre saturation point of around 18 percent, the risk of break down will be avoided. Just like pellets and briquettes, the fuel can then be stored under cover without energy loss and without hygienic risks.

The raising of dust during unloading and handling of dry fuels with high proportions of fines may cause working environment problems and also the risk of dust explosions. The reception of fuel can be improved by dust extraction or by enclosed handling. Pellets can be sprayed with water to reduce the risk of dust explosions. The design of feed equipment is important. Vibrating conveyors and bucket elevators generate a great deal of dust and should be avoided.

Liquid fuel such as animal and vegetable fats and tall oil must be preheated and may cause burning injuries in the event of leakage. Tall oil is also classified as irritating (X_i) and may require protective equipment for handling.

The purpose of flue gas cleaning is to collect as much as possible of the pollutants in the flue gases. Flue gas cleaning residues is composed of fine-grained material consisting of ash, unburned carbon and possibly additives such as lime and activated charcoal. Flue gas cleaning residues can also be polluted with inorganic (e.g. heavy metals) and organic (e.g. dioxins) pollutants. Flue gas cleaning residues may also be aggressive due to its high pH. When handling flue gas cleaning residues, it is important to reduce the personnel exposure to dust and possibly the occurrence of ammonia, e.g. from NO_x treatment.

In order to reduce the risk of spontaneous ignition, the recommendations for the storage of fuel are as follows:

- Store different wood fuel types in different stacks. They should not even come into contact with one another.
- Minimize the spreading of moisture in the stacks.

- Do not pack the stacks with whole-tree chips, fragmented logging waste, bark or sawdust.
- Avoid metal objects in the stack
- Store wood fuels in elongated stacks, with the base of the stack cross-section equal to twice the stack height.
- Do not store bark in a stack higher than 7 m and sawdust, higher than 6 m.
- Bear in mind the angle of repose and frozen chips.
- A low turnover rate increases the risk of spontaneous ignition.
- The first signs of temperature rise may be steaming and the smell of smoke. The fuels stored should be measured mainly with a probe or a thermographic camera.

1.2 Type of plant

If a fuel is selected on the basis of the type of combustion plant, Table 1.2.1 gives a summary of the parameters that may be important to check. The table summarizes the demands made by different combustion techniques on the fuel properties. For every property, refer to the section in chapter 3, where more information is available on, for example, the significance of properties to the combustion process and the standards and methods available for determining these properties.

Information concerning the calorific value, moisture content and ash content does not apply to a specific boiler but to the technique as such. As regards moisture content, for instance, a given grate boiler cannot manage moisture content variations between 5 and 60 %. On the other hand, individual boilers may be designed to manage a specific moisture content area in this range. The same applies to the calorific value and ash content. As regards FB/CFB boilers, individual plants may manage much wider variations in these parameters than grate boilers.

Characteristics	Pulverized fuel boilers	Grate boilers	FB/CFB boilers
Calorific value	Medium to high > 15 MJ/kg	Wide range from about 5 MJ/kg to dry fuels, depending on refractory and boiler design.	Wide range from about 5 MJ/kg to dry fuels
Moisture content	< 15 % moisture content. Dry fuel necessary for quick ignition.	Relatively insensitive to moisture content. Range of 5–60 %, depending on boiler design.	High moisture contents may be acceptable. Range of 5–60 %, depending on design
Ash content	< 1 % for converted oil- fired boilers. Other pulverized fuel boilers more insensitive.	Travelling grate insensitive. Stationary grate – low ash content.	Insensitive to ash with high melting point. Low content if ash is difficult.
Volatiles content	Depends on boiler type, but > about 30 %.	Depends on grate design.	If high volatiles content – greater demands on fuel spreading.
Particle size (not coal)	Depends on fuel reactivity, but requires finely pulverized fuel. Particle size < 1 mm, about 20 % < 0.1 mm	Risk of fuel falling through the grate and entrainment with fine- grained fuels. Depends on grate design and primary air proportion. Can be designed for large particle size, up to 300–400 mm	Finely pulverized fuel may be entrained and will burn high up in the boiler. Particle size of 50 – 100 mm performs best.
Particle form	The particle form may affect the volatiles and feed properties. Irregular, spiky and fibrous particles increase the risk of bridging and irregular feed.	Has a certain influence on the pressure drop across the fuel bed. Long pieces (rags, strips) may cause problems on the grate and also in fuel feed.	May be of significance for how the fuel is spread on the bed.
Flow properties/Feed properties	May be of importance for the design of the conveyor system.	Of some importance to fuel feed	Must be suitable for handling by a rotary vane feeder Of some importance to the fuel feed
Strength	-	The fuel must not disintegrate and give a high proportion of fines.	The fuel must not disintegrate and give a high proportion of fines.
Density	May be of importance to the design of the conveyor system.	Affects fuel handling	Affects fuel handling. May be of importance to whether the fuel burns on the surface or inside the bed.
Alkali content	High content generally causes deposits. High combustion temperature causes alkali in the gas phase/fly ash.	High content generally causes deposits. High combustion temperature causes alkali in the gas phase/fly ash.	High content may lead to the risk of bed sintering and risk of deposits
Chlorine and sulphur content	Of general importance to high and low temperature corrosion and to the formation of deposits	Of general importance to high and low temperature corrosion and to the formation of deposits	Of general importance to high and low temperature corrosion and to the formation of deposits. Scope for effective sulphur capture in the bed.

 Table 1.2.1
 Important fuel characteristics for different combustion installations.

Table 1.2.2 provides guidance regarding the fuel properties that affect combustion, operation and equipment requirements. The information is obtained from the Thermal Engineering Research Institute (Värmeforskrapport) report 861.

Table 1.2.2	Significance of different fuel characteristics for combustion, maintenance, and
	equipment requirements.

Fuel characteristics	Effect/Influence	Design/design parameters
1) Composition	- Heat distribution in the boiler	- Fuel preparation
- % combustible	- Limit for autothermal	- Surface layer in the boiler
- elementary composition	combustion	and flue gas ducts
- calorific value	- Air, ash and flue gas flows	- Temperature control
	- Boiler rating	- Control and handling of air,
	- Deposits and corrosion	ash and flue gas flows
		_
2) Particle distribution and	- Drying time	- Need for further air supply
combustion properties	- Gasification and combustion	and supply points
- Moisture content	time	- Fuel preparation (particle
- Particle size	- Particle mixture and	size, mixture)
- Particle density	distribution	- Feed facilities
- Volatile/fixed carbon	- Combustion stability	- Residence time
- Oxygen/fixed carbon		- Combustion control
3) Ash characteristics	- Ash melting process	- Design and materials in the
- Melting/vaporization point	- Occurrence of	convection parts
- Grain size	compounds/substances with	- Particle size in the bed
- Chemical composition	low melting points	material and monitoring
- Physical composition	- Deposits	- Air supply
	- Particle size (FB)	- Dust removal
		 Possibility of using additives
4) Substances that may	- Emissions of NO_x , SO_x and	- Cleaning in/after combustion
cause atmospheric	HCI	- Choice of sorbents,
emissions	- Volatile heavy metals	quantities
- Sulphur		 Handling of solid waste
- Nitrogen		
- Chlorine/fluorine		
- Heavy metals		

1.3 Fuel class

Starting with a fuel, table 1.3.1 contains a summary of the fuels included in the Handbook, with specific characteristics, important parameters and suitable combustion technique for each fuel. The table can be used as a first recommendation for the fuels that may be suitable for a certain type of plant.

The general rules applicable to all fuels are:

• Storage of moist fuel may give rise to the risk of degradation of the fuel and mould formation.

- The particle size and the moisture content may affect the choice of combustion technique.
- If several types of fuel are used, good mixing is important in order to ensure stable combustion.
- A dry solids content >45 % is required for beneficial energy utilization in boilers without flue gas condensation.

Table 1.3.1Characteristics of different fuels. The recommendations within brackets indicate
that extra treatment of the fuel may be necessary or that the fuel has not been
tested with this technique. FB/CFB=(Circulating) Fluidized Bed, PF=Pulverized
fuel

Fuel class	Special characteristics	Important to bear in mind	Suitable for
Wood fuels			
Stem wood (sawdust, chips, powder)	Low proportion of ash and impurities Low bulk density The ash can be reused as fertilizer	Moist sawdust and fuels with high proportion of fines may be problematic. Emissions: NO _x , CO, hydrocarbons, dust	All types of boilers
Processed wood fuel (pellets briquettes)	Uniform particle size and good transport and feed properties. More expensive to purchase. The ash can be reused as fertilizer	Additives may cause problems in mills and deposits in the boiler. Dusting may be problematic during unloading. Emissions: NO _x , CO, hydrocarbons, dust	All types of boilers
Forest fuel (logging residues, forest chips, etc.)	High moisture content. Higher ash content than stem wood. Impurities both in the fuel and from accompanying materials. The ash can be reused as fertilizer	Risk of sintering in FB Risk of corrosion and deposits Emissions: NO _x , CO, hydrocarbons, dust	Grate, FB/CFB
Waste wood	Elevated contents of ash and impurities. Cheaper than other wood fuels. Irregular particle size. The ash may be polluted with heavy metals and may therefore have to be deposited as landfill or treated before reuse as fertilizer/other use	Waste wood is covered by the waste incineration directive if it includes heavy metals and/or halogenated organic pollutants. Highest proportion of impurities in the smallest particle fraction. Risk of corrosion and deposits. Emissions: NO _x , SO ₂ , HCI, CO, hydrocarbons, dioxins/furanes, heavy metals and dust. May require extra flue gas treatment in order to meet the legal requirements.	Grate, FB/CFB Waste and co- combustion plants
Energy forest (Salix)	Elevated contents of heavy metals High energy demand for milling Uniform particle size with low proportion of fines The ash may be polluted with	May give intensive combustion. A high proportion of bark affects the combustion properties. Emissions: NO _x , CO, hydrocarbons, dust, heavy	Grate and FB/CFB

		1	
	heavy metals and may therefore have to be deposited as landfill or treated before reuse as fertilizer/other use	metals (Cd)	
Bark	Ash content higher than in stem wood High moisture content Irregular particle size. Risk of "strips", e.g. with aspen bark High potassium content Nitrogen content higher than in stem wood Price roughly as logging residues (if <40 % DS) The ash can be reused as fertilizer	Screw conveyors and air injection pipes may give increased proportion of small particles. Risk of high temperature corrosion. Emissions: NO _x , CO, hydrocarbons, dust	FB/CFB Grate
Deciduous trees	Hard wood species High density High calorific value The ash can be reused as fertilizer	May give intensive combustion Emissions: NO _x , CO, hydrocarbons, dust	FB/CFB Grate
Agricultural fuels			
Straw	Low density High contents of ash, alkali and chlorine High transport and storage costs Price same as waste wood chips The ash can be reused as fertilizer	Risk of spontaneous ignition during storage of moist straw. Risk of corrosion and deposits Emissions: NO _x , CO, hydrocarbons, dust, HCl	Grate
Reed canary grass	The ash content depends on the place where the grass has grown and varies between 2 and 16 % Undoing bales causes dusting Large proportion of fine fraction during milling Somewhat more expensive than logging residues Low bulk density High nitrogen content The ash can be reused as fertilizer	Risk of sintering Risk of corrosion and deposits Emissions: NO _x , CO, hydrocarbons, dust, HCI	Grate PF (FB/CFB)
Hemp (industrial hemp)	The composition of the fuel is not well known. Wide variations in the analyses carried out so far. Low bulk density The ash can be reused as fertilizer	Voluminous fuel Fuel preparation important Lack of experience from combustion Emissions: NO _x , CO, hydrocarbons, dust, HCl	(Grate FB/CFB PF)
Grain	Uniform moisture (14 %) and ash (2–3 %) contents Good transport, storage and feed properties Price same as logging residues Low ash melting point High nitrogen content The ash can be reused as fertilizer	Must be protected against moisture and vermin during storage Risk of low-temperature corrosion Risk of deposits Risk of fuel dropping through the grate due to particle size Lime additive gives improved combustion conditions Emissions: NO _x , CO, hydrocarbons, dust	FB/CFB (Grate)
Grain chaff	High density	Risk of ash discharge	PF

	High ash content High in proportion of fines Characteristic smell High sulphur content High nitrogen content Better flow properties than wood The ash can be reused as fertilizer	problems Risk of deposits and sintering Emissions: NO _x , CO, hydrocarbons, dust	(FB/CFB)
Olive waste	High contents of alkali High contents of sulphur and chlorine High ash content Smell problem The ash can be reused as fertilizer	High risk of biological activity during storage, which may cause risk of fire High risk of deposits and corrosion Risk of sintering Emissions: NO _x , SO ₂ , CO, hydrocarbons, dust, HCl	PF FB/CFB
Cocoa beans	High calorific value High nitrogen content Uniform particle size The ash can be reused as fertilizer	Should be stored indoors due to the risk of agglomeration of fuel particles due to rain Emissions: NO _x , SO ₂ , CO, hydrocarbons, dust, HCl	FB/CFB
Citrus fruit waste	High density Pleasant smell High nitrogen content The ash can be reused as fertilizer	Emissions: NO _x , SO ₂ , CO, hydrocarbons, dust	FB/CFB PF
Shea nuts	Extremely high potassium content The ash can be reused as fertilizer	Risk of serious problems of deposits High risk of sintering Emissions: NO _x , SO ₂ , CO, hydrocarbons, dust, HCI	Can be used as admixture in small quantities
Waste products			
Digested sludge	Extremely high contents of moisture, ash and sulphur. High nitrogen content Very low calorific value High contents of precipitation chemicals (aluminium, iron, calcium, phosphorus and silicon) May contain heavy metals and environmentally harmful compounds, such as flame retardants. The ash may be contaminated with heavy metals and may therefore have to be deposited as landfill or treated before reuse as fertilizer/other use	Problem of large ash quantities Can reduce the risk of chlorine-induced corrosion Must be co-fired with fuels with higher energy contents Emissions: NO _x , SO ₂ , CO, hydrocarbons, dust, HCl and heavy metals	FB/CFB Grate Waste and co- combustion plants
sludge	virue variations between different types of sludge Often very high moisture and ash contents Low calorific value The nitrogen, sulphur and chloride contents may be elevated The ash from some types of sludge may be contaminated with heavy metals and may therefore have to be deposited as landfill or treated before reuse as fertilizer/other use	make demands on the ash handling Certain types of sludge may have beneficial effects on the deposits pattern Certain types of sludge are covered by the waste incineration directive Emissions: NO _x , SO ₂ , CO, hydrocarbons, dust, HCI and heavy metals	Grate Waste and co- combustion plants

Manure	The composition varies depending on type of animal and animal husbandry High contents of nitrogen, moisture, ash, chlorine and sulphur. Strong ammonia smell The ash can be reused as fertilizer	Risk of corrosion and deposit problems Risk of problems of smell during storage Emissions: NO _x , SO ₂ , CO, hydrocarbons, dust, HCl	Grate FB/CFB
Paper, wood, plastics	Inhomogeneous fuel High calorific value (varies with composition) High moisture and ash contents Often high chlorine content (depending on type of plastic) Zinc and lead contents may be high The ash may be polluted with heavy metals and may therefore have to be deposited as landfill or treated before reuse as fertilizer/other use	The inhomogeneity can be improved by good fuel preparation Risk of deposits and corrosion problems Paper, wood, plastics are covered by the waste incineration directive Emissions: NO _x , SO ₂ , CO, hydrocarbons, dust, HCI, heavy metals	Grate FB/CFB Waste and co- combustion plants
Rubber tyres	High calorific value High sulphur content High ash content Minimal moisture content Homogeneous fuel Cheaper than coal Low nitrogen content Contain metal, principally zinc and iron The ash may be polluted with heavy metals and may therefore have to be deposited as landfill or treated before reuse as fertilizer/other use	Tyres should be cut with "clean" cuts to minimize the problems of steel wire in the cord. Should be thoroughly mixed with other fuels to improve combustion stability. Bottom ash must be discharged frequently Emissions: NO _x , SO ₂ , CO, hydrocarbons, HCI, heavy metals	Cement kilns FB/CFB Grate Waste and co- combustion plants
Leather waste	High contents of sulphur, nitrogen and chlorine High contents of chromium Risk of environmental toxins (pentachlorophenol) and carcinogenic colouring agents (azo colouring agents) The ash may be contaminated with heavy metals and may therefore have to be deposited as landfill or treated before reuse as fertilizer/other use	Covered by the waste incineration directive Emissions: NO _x , SO ₂ , CO, hydrocarbons, HCI, heavy metals	Grate FB/CFB Waste and co- combustion plants
Cardboard rejects	High moisture and ash contents High chlorine content Low density Pollutants The ash may be polluted with heavy metals and may therefore have to be deposited as landfill or treated before reuse as fertilizer/other use	Risk of corrosion Risk of feed problems due to metal impurities Problem of material flying around during storage and feed Emissions: NO _x , SO ₂ , CO, hydrocarbons, HCI, heavy metals	Grate FB/CFB Waste and co- combustion plants
Animal			
products			
meal (MBM)	High calorific value Low moisture content High ash content	of Agricultural regulations The material must be	FB/CFB Grate PF

	High nitrogen and chlorine contents Low contents of trace elements Unpleasant smell The ash can be reused as fertilizer	protected against birds and vermin Spillage must be collected so that it will not leak out into water and soil MBM can "cake together" in handling system Unpleasant smell may cause problems Serious risk of deposit problems Emissions: NO _x , SO ₂ , CO, hydrocarbons, HCl	
Animal fat (liquid) Other fuels	High calorific value Low sulphur content High ash content High flash point	Covered by Swedish Board of Agriculture regulations. The material must be protected against birds and vermin. Spillage must be collected so that it will not leak out into water and soil. Must be kept heated during transport Must be preheated to 65°C without local overheating Risk of clogging of pumps and filters Risk of deposits Emissions: CO, hydrocarbons	Oil burners
Tall oil	Viscous Corrosive at elevated temperature Has a strong and pungent smell Is harmful to health, class X _i (irritating)	Risk of deposits in the furnace and convection sections Acid resistant stainless steel must be used in the fuel system May cause allergic reactions on protracted contact Emissions: CO, hydrocarbons, SO ₂ , dust	Oil burners
Vegetable fat (liquid)	High calorific value Low sulphur content High ash content High flash point	Must generally be kept heated during transport Risk of clogging of filters and pumps Risk of deposits Emissions: CO, hydrocarbons	Oil burners
Peat	Low density High ash content High nitrogen and sulphur contents The ash can be reused as fertilizer	Mixing of peat with wood fuels often reduces the problems of deposits and corrosion. Storage outdoors may cause raising of dust and the risk of explosion Emissions: NO _x , SO ₂ , CO, hydrocarbons	All types of boilers
Peat, processed Briquettes/pellets	High ash content High nitrogen and sulphur contents Higher price than unprocessed peat The ash can be reused as	Mixture of peat with wood fuels often reduces the problem of deposits and corrosion Risk of dust raising, with the risk of explosion during	All types of boilers

fertilizer	milling	
	Best suited for larger plants	
	Emissions: NO _x , SO ₂ , CO,	
	hydrocarbons	

2 Legislation and taxes in the EU

2.1 Legislation on waste

Legislation on waste deals with waste and its management. Other ordinances or regulations include further provisions for certain types of waste and certain waste management. Include criteria for disposal of waste to landfill.

EC legal document	Council <u>directive 75/442/EEC</u> of 15 July 1975 on waste Amended by <u>directives 91/156/EEC, 91/692/EEC</u> (reporting directive). Commission decision <u>96/350/EC</u> .	
	Council directive 2003/33/EC <u>Decision in Swedish</u> : Council decision on 19 December 2002 on criteria and procedures for the reception of waste in waste landfills in accordance with article 16 i. and appendix II to directive 1999/31/EC Council <u>directive 1999/31/EC</u> dated 26 April 1999 on disposal of waste to landfill.	

2.2 Legislation on incineration of waste

EC legal document	European Parliament and council directive 2000/76/EC of 4 December 2000 on
	incineration of waste

2.3 Legislation on hazardous waste

EC legal document	Council directive 91/689/EEC of 12 December 1991 on hazardous waste
	Amended by directive 94/31/EEC

2.4 Legislation on large combustion plants (> 50 MW)

These regulations cover the combustion of solid, liquid and gaseous fuels in combustion plants with an installed power input of 50 MW or more. Combustion plants in which the products of combustion are used directly in manufacturing processes are not covered. Among others, digester liquor boilers in the forest industry are not covered.

EC legal document	Council directive 2001/80/EC of 23 October 2001 on limitation of emissions of
	certain pollutants to atmosphere from large combustion plants.

2.5 Legislation on animal by-products not intended as food

This law sets special rules for the incineration of animal carcasses, one of which is that the products must be handled in such a manner that nothing will be able to leak out into the soil and water. The regulations for incineration are similar to those for the incineration of waste, with a residence time of 2 seconds at 850°C.

EC legal document	European Parliament and Council regulation (EC) No. 1774/2002 of 3 October
-	2002 on health regulations for animal by-products that are not intended as food.

2.6 Law on emission rights

Trading in emission rights is a system that covers the emission of carbon dioxide from fossil fuels such as coal, oil, natural gas, etc. The law states that emission rights must be obtained corresponding to the amount of carbon dioxide emitted. If emissions are reduced, emission rights can be sold.

EC legal document	Directive <u>2003/87/EC</u> for greenhouse gases in the Communities and on amending Council directive 96/61/EC
	The <u>Commission's decision of 29 January 2004</u> on guidelines for the monitoring and reporting of emissions of greenhouse gases in accordance with European Parliament and Council directive 2003/87/EC
	European Parliament and Council regulation (EC) No. <u>1882/2003</u>

3 Background/Theory: Methods for assessing combustion properties

The combustion properties of a fuel depend on several chemical and physical conditions that are unique or are linked. These properties can also make the fuel more or less appropriate for firing in certain types of equipment. Sufficient information must be available for optimal use of a fuel with regard to efficiency, environmental impact and economy.

If only one type of fuel is used, it is usually sufficient to characterize the fuel only once, and then periodically determine only the moisture content, for instance. On the other hand, if different fuels are used, the picture is much more complicated, and continual characterizations of the fuels supplied may be necessary.

For all determinations of both chemical and physical parameters, it is of vital importance that sampling and sample preparation is done correctly before the corresponding analysis is carried out. Common European standards are in the course of preparation for both solid biofuels and solid recovered fuels (see Chapter 6). Both a sampling plan and a sample preparation plan should be prepared in order to ensure that each individual particle has the same opportunity of being included in the analysis samples. The origin and size of the fuel and the sampling place (truck, heap, etc.) determine how sampling, sample reduction and sample preparation should be carried out. A chapter on the sampling of solid materials such as fuels and ash is planned for the new version of the Measuring Handbook to be published by the Thermal Engineering Research Institute.

The calorific value of the fuel is probably the most important parameter, since it determines how much energy can be extracted and also what combustion temperature can theoretically be achieved. The calorific value is determined not only by the chemical make-up of the fuel, but also its content of other heat-consuming materials, such as ash content, and moisture. The size and size distribution of the fuel particles are of great importance from the practical aspect. A fuel that has very small particles in its normal condition is hardly suitable for firing on a grate, may possibly be fired in a fluidized bed, and may be very suitable for pulverized fuel firing.

This section deals with the various fuel parameters, how they can be investigated, and some particulars of the available standards.

3.1 Chemical characterization

Chemical analysis is routinely carried out more or less comprehensively. It is usual that only the moisture content and ash content are determined, and the calorific value and nitrogen and sulphur contents are often included in the analysis. The chlorine content and trace elements are sometimes also analyzed.

3.1.1 Moisture content

The moisture content is the parameter that has the greatest influence on the calorific value of a fuel. The pricing of fuels is therefore often related to the moisture content. A high moisture content may also cause the combustion temperature to be lowered but the flue gas volume to be increased, which displaces the heat transfer from the furnace to the convection section. The increased flue gas volume may also cause a reduction in the boiler power output due to the modified heat transfer.

3.1.2 Ash content

The ash content is of great importance to how well a fuel performs in a given plant. High ash contents increase the costs for the ash handling system and also for the disposal of the ash formed.

3.1.3 Calorific value

The calorific value determines the usability of the fuel in various combustion situations. Pulverized fuel boilers generally require fuel with a higher calorific value, whereas grate and FB boilers can also use fuels with lower calorific values. When the calorific value is determined, the calorimetric calorific value is measured, including the latent heat of condensation of the water under standardized forms. The effective (lower) calorific value is calculated.

3.1.4 Volatiles content

The volatiles content is of great importance to the way in which the fuel will behave during combustion. A fuel with a high content of volatiles, for example, will have a combustion process that largely consists of heating, gasification and combustion in the gas phase. On the other hand, combustion of fuels with low volatiles contents will mainly take place in the solid phase on the surface of the fuel particles or in the fuel bed. Most biofuels have a high volatiles content. Examples of fuels that have low volatiles contents are various types of bituminous and anthracitic coals. The volatiles content is of major importance to the design of the combustion equipment and to the way that air is supplied.

3.1.5 Chemical composition

The chemical composition of fuels is usually divided into elementary analysis, major elements and trace elements. Coming standardized methods of determining the chemical composition of fuels are given in table 3.1.1.

Number	Title	Expected finished	to	be
335 025	Solid Biofuels: Methods for the determination of carbon (C), hydrogen (H) and nitrogen (N) content	2005-04		
335 026	Solid Biofuels: Methods for the determination of sulfur (S) and chlorine (Cl) content	2005-08		
335 027	Solid Biofuels: Methods for the determination of water soluble chloride (CI) content	2004-05		
335 028	Solid Biofuels: Methods for the determination of the content of major elements (AI, Si, K, Na, Ca, Mg, Fe, P and Ti)	2005-08		
335 029	Solid Biofuels: Methods for the determination of the content of minor elements (As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Mn, Ni, Pb, Se, Te, V and Zn)	2005-08		

 Table 3.1.1
 Future European standards for chemical characterisation of bio fuels.

3.1.6 Major elements

Al, Ca, Fe, Mg, P, K, Si, Na, Ti and also Mn and Ba are regarded as major elements. Many of these elements are problematic in the combustion context, especially in biofuels.

Standardization of these elements in biofuels and recovered fuels is in progress. According to the proposed methods, the sample is dissolved in a closed vessel by means of reagent, heating and pressure. Dissolving is carried out in accordance with a standardized method at 550°C, either on the fuel or on ash obtained.

Standardized methods are used for the analysis of each element. Different methods are available, but all of them involve the use of advanced analysis instruments, and the samples therefore cannot be analyzed in situ, but must be sent to a specialist laboratory.

3.1.7 Trace elements

Trace elements are the inorganic compounds included in low contents. Many of the heavy metals are included in this group. In ordinary biofuels, the contents are usually low, but the high contents in certain waste fuels may require special treatment of the ash before disposal to landfill.

The most common trace elements for which fuels/fuel ash are analyzed are Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sn, V and Zn.

Standardization work on these components in biofuels and waste fuels is in progress. See table 3.1.1.

For the analysis, the sample is dissolved in a closed PTFE vessel, and standardized methods are then used for analyzing the dissolved sample. Different methods are

available, but all of them involve the use of advanced analysis instruments, and the samples therefore cannot be analyzed in situ, but must be sent to a specialist laboratory.

3.1.8 Determination of the proportion of biomass in the fuel

For waste fuels (recovered fuels), it is important for the proportion of biomass in the fuel to be known for calculating the electricity certificate. A draft version of a European Standard in which the proportion of biomass in waste fuel is determined according to weight, energy content or carbon content is available and will be sent to the member states for voting before it is adopted as a technical specification that will become a standard at a later date.

3.2 Determination of physical properties

Physical properties of fuels include particle size and particle form, feed properties and durability, grindability (Hardgrove index), density, dusting, and reactivity.

3.2.1 Particle size and particle form

The particle size and particle form depend on the method of preparation and the morphology of the fuel before preparation. Fuels that originate from biomass often have a distinctly anisotropic structure (i.e. the material has different properties in different directions), which is due to the way in which plants and trees build up long, slender cells that are oriented in the longitudinal direction of the stem.

Standard	Title	Last revised
Particle size ar	nd form	
SS 197174	Biofuels and peat – Determination of size distribution	1990
NEN2560	Particle size distribution	
NEN 5753	Soil – Determination of clay content and particle size distribution of soil samples	
ASTM D-4749	Performing the sieve analysis of coal and designating coal size.	1994
ASTM D197	Test method for sampling and fineness test of pulverized coal	
ISO 1953:1994	Hard coal – Size analyse by sieving	1994
DIN 66 165	Particle size analysis – sieving analysis	1987

 Table 3.2.1
 Existing standards for determination of particle size distribution.

3.2.2 Feed properties and durability

The feed properties and durability of a fuel depend principally on the method of preparation and the moisture content. A high moisture content (> 30 %) creates the conditions for microbial decomposition caused by bacteria and mould fungi. Microbial

decomposition consumes combustible substance, may cause working environment problems, and generates heat that can easily lead to spontaneous ignition. As an example, moist bark should normally be consumed within a month or two after it has been stacked on a pile if spontaneous ignition and working environment problems are to be avoided. Dried fuels, such as pellets, and fuel made from dried wood generally have much better storage properties. However, storage may affect, for example, the grindability of pellets.

Air-borne fuel feed is suitable principally for dry, fine-grained fuels such as powder and crushed pellets. Transporting moist and coarse fuel by air is appreciably more energy-intensive than using conveyor belts, screw conveyors and stoker feed. Air-borne fuel pipes generally give rise to much greater noise problems than conveyors, screw conveyors and stokers.

High moisture content generally results in "stickier" and more compact fuel that may be more difficult to feed uniformly into the boiler. The admixture of drier fuel may then provide a more uniform fuel feed.

However, the mixture of different fuel types is not always devoid of problems. Reasonably similar particle size and form are generally required. As an example, mixing a "prickly" fuel such as crushed waste wood with coarsely shredded paper may give rise to stratification and difficult feed problems from the fuel hopper.

3.2.3 Strength of pellets and briquettes

The strength of pellets and briquettes is important both to the combustion properties of the fuel and to the working environment. If the strength is poor, the proportion of fine particles entering the boiler will increase, which may give rise to problems of entrainment and poor burn-up or combustion too high up in the boiler. Dusting may also cause problems to the workers who handle pellets and briquettes.

3.2.4 Buoyancy

The buoyancy of a fuel affects the feed properties and thus also combustion. The fuel feed system must be adapted to the buoyancy properties of different fuels in order to ensure good combustion.

3.2.5 Grindability

The grindability of fuels is of vital importance in pulverized fuel plants, since the particle size must be less than 1 mm. In FB boilers, the fuel must generally be suitable for feeding with rotary vane feeders, and it must therefore be possible to crush large pieces of fuel.

3.2.6 Density

The density of fuels is of great importance for the design of the fuel transport system, and may also be of major significance to the way in which the fuel burns in special combustion equipment.

3.2.7 Reactivity

The reactivity of a fuel is of importance principally in combustion equipment in which the fuel particle residence time is limited, such as in a pulverized fuel flame in which the entire combustion process must be completed during the travel of the fuel particle through the flame. In slow reaction systems such as gasifiers, the reactivity of the fuel is also of relativity great importance to the design of the equipment.

4 Background/Ash theory

4.1 What is ash?

Most fuels contain more or less high proportions of ash-forming substances, i.e. substances that form residual products that are in solid form at room temperature. So what are these substances? Analysis of the most common fuels will reveal that more than half of the elements are in the periodic system. However, the contents of most are very low at a few mg per kg of dry fuel. Figure 4.1.1 shows how the minerals that form ash are emitted during various stages of the combustion process.



Figure 4.1.1 Release of minerals from a fuel during combustion

4.1.1 Ash-forming non-metals: Chlorine and sulphur

Chlorine can form HCl and leave the combustion plant in gaseous form, but it can also be bound to ash during salt formation, particularly in alkaline ash. Chlorine is therefore an ash-forming component, although chlorine is not always bound to the ash. It is not uncommon that Cl fluctuates between gaseous form (as HCl or as a vaporized chloride) and ash-bound form (as a salt). The chlorine transformation in a plant is also highly dependent on the form in which it is bound in the fuel. In certain cases, chlorine may also form toxic chlorinated organic compounds, such as small chlorohydrocarbons, chlorinated dibenzodioxins and dibenzofuranes, and chlorinated phenol. Since most of these organic compounds have low volatility, they tend to collect on the ash (principally fly ash), and thus become ash components. Sulphur may form H_2S (on sub-stoichiometric combustion), SO_2 and SO_3 , and also "follow-on products". In plants in which there is high risk of high emissions of SO_2 (+ SO_3), there are generally extra desulphurization stages that usually also bind HCl.

In a reducing environment, sulphur mainly forms hydrogen sulphide that can be bound to alkaline ash during sulphide formation. Since hydrogen sulphide is a weak acid, there is a need for either a strong alkaline ash or metal ions in the ash with particularly high affinity to sulphide sulphur. Such metals are, for example, Cd, Hg, Pb and Zn.

In an oxidizing environment, mainly SO₂ is formed together with minor quantities of SO₃ (usually < 5 %). Both can bind to alkaline ash, although SO₂ is a weaker acid than SO₃ and therefore binds more loosely. However, the main product SO₂ can be arrested during binding to alkaline ash if it is oxidized up to SO₃ simultaneously with the desulphurizing stage. A product is then a sulphate instead of the less stable sulphide. However, sulphur has a low tendency to form toxic organic compounds in or after the combustion environment.

In addition to chlorine and sulphur, the non-metals that can bind to the ash are hydrogen, oxygen and carbon in the form of water and carbon dioxide. Water is bound in the form of crystal water or by chemical reaction, e.g. "slaking" of lime. However, very little water from combustion is normally bound in the ash, although it is common that water is added while ash is discharged, and the ash will thereby contain water. Carbon dioxide can be bound to ash if the ash is sufficiently alkaline and is allowed to remain in contact with flue gas for a longer period of time. It can also be bound to the ash in the form of light metal carbonate (CaCO₃, K₂CO₃ or Na₂CO₃). However, the quantities involved are small, and water and carbon dioxide are therefore not regarded as ash-forming substances.

4.1.2 Ash-forming light metals: Al, Ca, K, Mg and Na

Most fuels contain light metals in some form. These are ash forming and some of them (alkali metals K and Na) can also form volatile forms (e.g. chlorides) that can periodically be vaporized, only to condense back at a later stage.

Light metals normally occur in the fuel in some chemically bound form, e.g. as organic (calcium oxalate, calcium tartarate), inorganic (KCl) salts or dissolved in biomass cell fluid. The light metal compounds may originate from the fuel material itself, but also from accompanying impurities, such as earth (feldspars), building materials (plasterboard), paint and adhesive, etc. Calcium and potassium are the light metals that occur in biofuels in the highest contents. The binding forms, occurrence and properties of calcium are summarized in Table 4.1.1, and corresponding data for potassium can be found in Table 4.1.2. Sodium generally occurs in much lower contents than calcium and potassium, but has a great influence on ash-related problems in combustion plants. See Table 4.1.3. Aluminium is an important light metal that can be included in the ash-forming fraction in a number of forms. See Table 4.1.4.

Binding form	Occurrence	Properties
Metallic	Does not occur	
Sulphate	In demolition wood and in certain types of waste paper.	Mostly has inert behaviour except when other sulphate formers occur (K, Na or others). In the latter case, sulphate eutectic with low melting point can form. The situation is even worse when chlorides also come into the picture.
Organically bound as salts of organic acids, such as oxalic acid or tartaric acid	Occurs abundantly in biofuels from both plants and animals	This calcium generally forms CaO but then reacts further, e.g. with silicic acid (formation of silicates that contain Ca) or with S or Cl or other salt formers.
Limestone	From entrained calcareous earths or from lime additives in the furnace	Leads to complete or partial calcination, depending on the furnace temperature. Forms CaO that can then react further just like biofuel-bound calcium. Non-decomposed or reformed calcium carbonate may sometimes serve to lower the melting point. Common mineral forms of calcite and calcium feldspar.
Calcium feldspar	Usually from entrained silicate- rich earths. Also included in many bed sands.	Has a high melting point, is non- reactive and not hazardous.
Calcium phosphates	Occur in sludge after chemical phosphate precipitation with calcium reagent. Is also contained abundantly in biofuels from animals, mainly in bone meal.	May lead to lower melting points in salt mixtures.

 Table 4.1.1
 Form, occurrence and properties of calcium in fuels

Table 4.1.2 Form, occurrence and properties of potassium in

Binding form	Occurrence	Properties
Metallic	Does not occur	
Chloride	Often in straw and other crops that have been fertilized with fertilizer containing KCI.	Is very volatile and tends to cause problems of deposits on heat transfer surfaces. Serves to lower the melting point of salt mixtures.
Organically bound as salts of organic acids or anionic macro- molecules.	Always occurs in biofuels from both plants and animals (slaughterhouse waste). In biological material from animals, for instance, it is abundant in nerve tissue.	This potassium generally forms K_2O or KOH that can then react further, e.g. with silicic acid (formation of silicates containing K) or with S or Cl or other salt formers. The proportion that reacts with Cl forms highly volatile KCl. The proportion that reacts with SiO ₂ can form potassium silicate or mixed silicate with low melting point with, for instance, Ca and Na. This can take place by reaction with SiO ₂ from the fuel ash or in the bed material in FB firing.
Potassium feldspar	Generally from entrained silicate- rich earths. Is also included in many bed sands.	Normally has a high melting point, is non-reactive and harmless

Binding form	Occurrence	Properties
Metallic	Does not occur	
Chloride	Principally in domestic refuse (table salt) in poorly sorted compostable material. Can also be included in fuels that have been in contact with sea water or coastal atmosphere or have been harvested in the winter close to salted roads.	Is highly volatile and tends to give rise to problems of deposits on heat transfer surfaces. Serves to lower the melting point in salt mixtures.
Organically bound as salts of organic acids or anionic macro- molecules	Seldom occurs in biofuels from plants, but always in biofuels from animals (slaughterhouse waste)	This sodium generally forms Na ₂ O or NaOH that can then react further, e.g. with silic acid (formation of silicates that contain Na) or with S or Cl or other salt formers. The proportion that reacts with Cl forms readily volatile NaCl. The proportion that reacts with SiO ₂ can form potassium silicate or mixed silicate with low melting point with, for instance, Ca and K. This can take place by reaction with SiO ₂ from the fuel ash or in the bed material in FB firing. The melting point of silicate is at its lowest when Na and K are included together.
Sodium feldspar	Generally from entrained silicate- rich earths. Also included in many bed sands.	Normally has a high melting point, is non-reactive and harmless.

 Table 4.1.3
 Form, occurrence and properties of sodium in fuels

Table 4.1.4	Form, occurrence	and properties	of aluminium in fuel	ls
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Binding form	Occurrence	Properties
Metallic	Common in recycled fuels, particularly demolition timber	Aluminium metal, for example, does not normally oxidize or oxidizes only to a very limited extent on the surface. On the other hand, it forms a metal melt, since the melting temperature of aluminium is about 660°C. In aluminium alloys, the melting temperature is often even lower. Aluminium metal can clog bottom nozzles, smudge grates or fuse together bed material particles.
Mineral bound	Usually as "entrained" earth (aluminosilicates) or mineral additives (such as kaolin). However, most of what is reported as aluminium content in fuel often originates from pollutants (filler, entrained earth, aluminium parts, pigment, precipitation chemicals, etc.).	Aluminium in combustion processes normally forms no volatile compounds. It therefore occurs in bottom ash or reasonably uniformly distributed between bottom ash and fly ash. However, finely distributed aluminium forms, such as very fine clay earths and kaolin, can be entrained with flue gas without any gasification and is thus "enriched" to fly ash and dust in a purely physical way.

Biofuels	Occurs in low contents. Binding	See above
	form unclear. However, much of	
	the reported aluminium in biofuel	
	ash probably initially originates	
	from entrained clay earths.	
Free salt form	Aluminium is a distinctly acid-	
	based amphoteric and can react	
	with acids or bases while forming	
	aluminium salts or while forming	
	aluminates or aluminium salts.	
Phosphate	Ordinary sludge precipitated out	Aluminium in phosphate form
	after the addition of a soluble	(from phosphate precipitation in
	aluminium salt. Aluminium then	sludge) is more or less inert.
	precipitates phosphate as AIPO ₄	
Organically bound or finely	Can form reactive alkali, either	Can lead to elevated melting
dispersed fuel aluminium (reactive	alone (formation of aluminate) or	points and thus counteract
aluminium)	together with silicic acid	problems caused by molten ash.
	(formation of aluminiosilicate).	

4.1.3 Heavy metals in ash

Waste fuels and recovered fuels (such as demolition wood) can also include significant contents of other metals, often from pigments or metal parts. Metals that can then cause problems due to silicate melt or salt mixtures with low melting points are principally copper, lead and zinc. Both lead and zinc occurred abundantly, for example, in paint pigments in old paints. Zn was also used as anti-corrosion agent on ferrous objects. Lead sometimes occurred as red lead for heavy anti-corrosion treatment. Copper occurred principally in copper wire, and copper and zinc together in brass objects.

Copper is a problem mainly in salt mixtures and possibly in chlorine-rich environments as catalyst for in-situ synthesis of chlorinated toxic aromatics (PCDD, PCDF). Lead and zinc lower the melting point of salt mixtures and, in certain circumstances, also of mixed silicates. Moreover, lead represents a sanitary problem due to its toxicity.

4.2 Empirical indices and key numbers

Coal literature is full of empirical indices for the determination of the tendency of ash to melt, based on the chemical composition of the ash. None of the indices available for coal perform particularly well for biofuels, although it ought to be justifiable to develop a general index for biofuels, since their ash-forming elements are not bound to minerals.

4.2.1 Alkali index according to Miles

The Miles index in table 4.2.1 is calculated from the sodium and potassium oxide contents of the ash, divided by the energy content of the fuel in GJ. The calculated values are related to experience from combustion trials with different biofuels. This has resulted in the following criteria (Table 4.2.1):
Miles index, kg alkali/GJ	Comments
0 – 0.17	Usable fuels
0.17 – 0.33	Doubtful fuels
> 0.34	Unusable fuels

Table 4.2.1Miles index

4.2.2 Fouling index

The fouling index in table 4.2.2 indicates the likelihood of the ash to form deposits and is calculated from the ratio of the basic and acidic components of the ash in oxide form, and multiplied by the sodium content of the ash in oxide form. In spite of its link to coal, the fouling index has proved to provide a good indication in the use of biofuels such as straw. The following criteria apply (Table 4.2.2):

Table 4.2.2 Fouling index

Fouling index	Interpretation
RF < 0.2	insignificant deposits
RF = 0.2 – 0.5	intermediate deposits
RF = 0.5 – 1.0	heavy deposits
RF > 1	critical deposits

4.2.3 The T₁₅ method

The T_{15} concept is based on the empirical experience that, when 15 % of the ash has assumed molten state, accelerated growth of deposits will occur and will be interrupted only when 75 % of the ash is molten (T_{75}), when it will run off the boiler surfaces. T_{15} can be calculated from modified equilibrium calculations based on the composition of the ash. These calculations are part of the Carl Bro fuel simulation package developed in order to assess the combustion and gasification properties of biofuels. Figure 4.2.1 shows an example of such calculation for wheat straw.



Liquid phases in the combustion of straw (5 MW) with 15 % moisture at 5 % O2

Figure 4.2.1 T_{15} based on the calculation of the liquid phase in the ash from wheat straw.

4.2.4 Key numbers

The coal literature index has been the starting point in the development work of key numbers that relate the various substances in the ash to one another. Key numbers based on the relative mole numbers give an opportunity to find out the critical quantity relationships between different substances that can be directly related to risk components or risky mixtures of components. Key numbers with a brief description of what they predict are given in Table 4.2.3 and Table 4.2.4.

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(shows the proportion of a kinal that call cashy	IX + ING		he vanorized as volatile chloride)
> 0.3: high risk of the formation of corrosive			> 0.3 high risk of the formation of corrosive
chloring-rich denosits			chlorine-rich denosits
> 1: high risk of the formation of other volatile			> 1: high risk of the formation of other volatile
chloride than with Na and K. Also high risk of			chloride than with Na and K. Also high risk of
homogeneous chloride-induced corrosion or			homogeneous chloride-induced corrosion or
Iow-temperature corrosion with CL admixture h			low-temperature corrosion with CL admixture by
			excess HCI
2Si Feldsnar number 1 < 6: all silicate can be present as or form	2Si	Feldspar number 1	< 6: all silicate can be present as or form
Al silvation of feldenar			aluminosilicate or feldspar
> 6' narte of the eilieic acid may form alkali	7.4		> 6: narts of the silisic acid may form alkali
silicate with low melting point			silicate with low melting point
Silicate with low theiting point < 6: generally good > 6: often noor but not			< 6. denerally good > 6. often noor but not
alwave			always
ΔI Feldenar number 2 > 1. All alkali is bound or can be bound to the	Δ١	Feldsnar number 2	> 1: All alkali is bound or can be bound to the
K + Na	<u>гч</u> К + Na		aluminosilicates of feldenar type and with

		relatively high melting point > 1: Often good < 1: Often poor
<u>2 (K + Na)</u> 3Si	Vitrification number (soda lime glass number)	0.5 – 1: High risk of the formation of glass phases with low melting points (melting point around 750°C) 0.2 – 0.5 and > 1: minor risk < 0.2: little risk (low proportion of melt)
<u>Na</u> K + Na	Eutectic number 1	Close to 1 or close to 0: good 0.2 – 0.8: poor
<u>Ca</u> Ca + Mg	Eutectic number 2	Close to 1 or close to 0: good Close to 0.5: not so good

* Can only be interpreted when the quantity of free alkali is lower than the quantity of sulphur + chlorine or Salt ratio 1 > 1. Free alkali can be lower than the quantity of chlorine + sulphur, e.g. in deposits formed when volatile alkali chlorides condense.

Table 4.2.4	A selection of ke	y numbers with	hazardous regions.
			<u> </u>

Key number	Interpretation	Risk
Alkalinity number	Risk of alkaline attack on siliceous bed material	> 0.8
Alkali proportion	Level of melting points in salts and silicates	> 0.3
Salt ratio	Formation of salt mixtures with low melting points	0.2 – 4
Eutectic	Melting point reduction in salts or silicates	0.2 – 0.8
Feldspar number	Occurrence or formation of light metal aluminosilicates	> 6
Vitrification number	Risk of the formation of soda lime glass with low melting point in the ash	0.2 - 1

Table 4.2.4 shows a selection of key numbers that may provide guidance in the assessment of fuels. The assessment should start with consideration of the <u>alkalinity</u> <u>number</u> that shows whether the ash has a surplus or shortfall of alkaline elements (Ca, Mg, Na, K, Fe) compared with acidic mineral formers (Al, Si, Ti, P). The number is important for assessing whether there is a risk of sintering when the fuel is fired in quartz sand, for instance. Values > 0.8 are then a warning sign that indicate that there may be a great deal of reactive alkaline light metal oxides that can attack the silicic acid in bed materials that are rich in silicic acid, which may lead to vitrification and sintering of the bed. Values below 0.8 may also be poor, but the problem may then lie in vitrification with proportions in the fuel of, for instance, Si that forms silicic acid.

The risk of such silicate vitrification with the silicic acid in the ash is illustrated in four key numbers:

In the <u>feldspar number</u>, the relationship is calculated between Si and Al in the ash. Values < 6 indicate low risk. These are the areas that are typical for aluminosilicates. Such aluminosilicates of K or Na, for example, melt at higher temperatures than pure silicates of the same light metals. Their formation is therefore preferable to the formation of silicates with low melting points without a proportion of Al. A value < 6 indicates that feldspar-like aluminosilicates may be present or may form in the ash instead of silicates with lower melting points. At values > 6, the Al proportion is insufficient, and Si will be left over for forming pure silicates with lower melting points.

Values < 6 give no safety guarantee and values above 6 do not arouse an automatic alarm signal, but a strong link exists. On the other hand, the feldspar number is of no value for certain waste fuels, where parts of the aluminium proportion shown by the analysis actually occurs in metallic form, for example. Typical example: Demolition wood.

The <u>alkali proportion</u> is a ratio of the proportion of alkali metal (Na + K) to the total proportion metals (Na + K + Ca + Mg + Fe). The higher the proportion of metals that consists of Na and/or K, the lower the melting point that can be expected. As mentioned earlier, this relationship applies regardless of whether the mixtures formed are silicate mixtures (glass system) or salt mixtures. All numerical values > 0.3 are therefore definitely poor. The ratio cannot theoretically be higher than 1.

The <u>eutectic number</u> is a ratio of the content of Na to the sum of Na + K. Values around 0.5 are most hazardous, but the entire range 0.2 - 0.8 is a hazardous range. The problem is that the presence of both alkali metals in comparable contents leads to particularly low melting temperatures, and this applies BOTH to silicate melts (glass formation) AND to salt melts.

Many biofuels contain much K but little Na and are therefore outside the most hazardous area. The contrary may apply to some waste fuels, such as domestic waste. It is dangerous to have co-combustion of such fuels so that the contents of Na and K are of the same magnitude. But there are also fuels in which Na and K occur in similar contents right from the start. In all certainty, these fuels are high-risk fuels.

The <u>salt ratio</u> shows the risk of the formation of salt mixtures with sulphur (sulphate) and chlorine (chloride). Four salt ratios have been defined, and the one that takes into account the formation of sulphate and chloride with Na and K (one of the "most hazardous" systems) is presented here. Other salt ratios also take into account Ca and/or P (phosphate system).

The hazardous numerical range is unfortunately wide (0.2 - 4). The fact that values > 1 should also be regarded as critical is related to the frequently high contents of Ca, particularly in biofuels. This Ca can also be bound to salt mixtures with S and Cl with low melting points. Low values right down to 0.2 are critical, since the admixture of phosphate can also give a quantity increase. This can be assessed more easily if consideration is also given in the calculation to the salt ratios that include phosphate.

A <u>vitrification number</u> is a ratio of the sum of alkali metals to silicon. Silicon denotes here the silicon contained in the fuel itself and does not include the silicon in the bed sand, for example. All values between 0.2 and almost 1 can be unfavorable, whereas values > 1 and < 0.2 may be regarded as less harmful.

In other words, the vitrification number shows how much alkali glass (such as soda lime glass) can be formed in the fuel ash itself. The glass formation risk is thus described in furnaces that operate without bed sand, i.e. all with the exception of FB furnaces.

A low vitrification number (< 0.25) shows that little glass can be formed in the ash. In addition, it begins to form at higher temperatures than at high numerical values. A high numerical value (anything above 0.5) shows that much glass can be formed in the ash and that the ash may thereby be sticky. Typical temperatures at which this vitrification begins is around 750°C or, if much Ca is added, from 800°C. At unfavorable values of eutectic number, the melting temperature may drop to a minimum of about 550°C.

4.2.4.1 Other key numbers

The molar ratio of calcium to sulphur, Ca/S, in the fuel gives an indication of whether inherent adsorption of sulphur can be expected in the furnace of a fluidized bed boiler.

The molar ratio S/CI provides an indication of whether there is sufficient surplus sulphur to reduce the risk of corrosion in conjunction with alkali chlorides. It has been found from experience that if the molar ratio S/CI is between 2 and 4, the risk of chloride-induced corrosion will be reduced. The addition of sulphur, e.g. in the form of ammonium sulphate, is commonly made to ensure that the molar ratio S/CI is > 4.

High alkali contents in a fuel involve the risk of problems of deposits and sintering (particularly for sulphur-deficient fuels with high chloride contents). However, a fuel with low alkali content can also give rise to problems in the long term if the alkali content in the ash is high, i.e. if the ash content is simultaneously low, e.g. in forest industry fibre sludge. The key number Na + K mg/kg of ash gives a rough measure of this, and is particularly useful in comparisons between fuels that have different ash contents.

5 Methods for assessing the likelihood of corrosion

The term corrosion here denotes the corrosion that may occur on the flue gas side of a combustion plant between the fuel feed and the chimney stack. In a combustion plant, corrosion attack may occur on almost all metallic structural parts that are in contact with the fuel and combustion air or flue gas, and residual products of combustion. Such attack is generally associated with the fuel and its chemical composition.

Some liquid biofuels also give rise to corrosion in tanks and fuel pipes upstream of the burners.

Laboratory experiments can be made in a controlled manner as regards experiment duration, temperature, flow, gas composition, dust load and composition. However, some reality aspects may be lost, since the irregularity in the process environment may also be an important reason for corrosion attack (e.g. fluctuation between an oxidizing and reducing atmosphere). In addition, laboratory experiments allow for accelerated tests by creating and maintaining experimental conditions in which corrosion is suspected of proceeding more rapidly than under operating conditions. Field trials and operating trials often require long exposure time. In any cases, this may be unacceptable, and some form of accelerated corrosion testing may therefore have to be employed. The acceleration of testing should then be carried out by moderate changes, e.g. to temperature, exposure time or content of corrosive substance.

5.1 Superheater corrosion

Serious corrosion attack on superheater surfaces has been reported from a number of steam boilers fired with biofuel. The corrosion is usually taken to be related to the composition of the fuel and the boiler steam conditions. However, no consistent pattern has emerged, possibly with the exception of the fact that all of the boilers generate steam at 500°C.

Superheater corrosion often occurs due to high material temperatures in combination with alkaline compound phases with low melting points and a reducing atmosphere, which may occur if the fuel is not completely burned when it reaches the superheater. Four main reasons for corrosion attack have been identified:

- Initial melting point of the ash
- Efficiency of final combustion
- Surface temperature of superheater tubes
- Unbalance on the steam and flue gas sides

The melting point of the ash depends on the ash composition, where principally enrichment of potassium and chloride is of significance. The temperature of the superheater tubes is determined by the steam temperature and also by the flue gas temperature and by the boiler design. If the boiler is fired by waste fuels, such as waste wood, other problematic compounds often also occur and these contain, for example, zinc, lead and tin.

One form of superheater corrosion that has long been known is described as coal ash corrosion. The name originates from coal firing, but the same type of corrosion may also occur when the boiler is fired with other fuels. A prerequisite for coal ash corrosion is that the fuel has a substantial sulphur content (also reckoned on the ash). A deposit of low melting point sulphates of Na and K may form on the superheater surfaces. This sulphate melt attacks the passivating oxide film on the metal (principally Fe) and exposes the unprotected metal surface to corrosion attack. This sulphate corrosion type occurs within the temperature range of 566 - 732 °C.

Many new and older fossil-fired plants built for or converted to biofuel-based power (or CHP) generation have suffered superheater corrosion problems soon after commissioning. A common denominator is that the plants have relatively advanced steam conditions, generally with superheater temperatures of 480 - 500°C, and that they use 100 % biofuels.

The corrosion situation deteriorates if Cl is available in the fuel system. Superheater deposits then begin to form at lower temperatures, and the formation of deposits often begins with condensation of low-volatility chlorides (of K and Na) on the superheater surface. The corrosion mechanism in this Cl-induced superheater corrosion is also related to sulphates and the interaction of several reactions:

- Formation of chloride melts
- Sulphating of the chloride melts under the influence of SO_x
- Local formation of HCl and of Cl₂ close to the metal
- Transfer of the metal in metal chlorides and sulphates
- Oxidation of these primary products to metal oxides ("rust"), while the chlorine partially reverts back to the corrosion mechanism

This mechanism in which Cl participates may begin at temperatures that are 50°C lower than the pure sulphate mechanism in coal ash corrosion.

The situation is even worse when the melting point and thus the threshold for the formation of salt melts on the superheater surfaces are lowered further. This can take place when transition metals that may form volatile chlorides and sulphates with low melting points are included in the fuel system in significant quantities. Examples of such melting point lowering elements are Cu, Pb and Zn. These commonly occur in industrial waste and other industrial recovered fuels, and also in demolition wood, for instance.

5.2 Low-temperature corrosion

Many plants on which SNCR is used experience corrosion problems in the lowtemperature range downstream of the boiler. Corrosion problems have been reported in the economizers, air preheaters, dust filters and flue gas ducts. Problems have been experienced on boilers fired with mixed fuels with high moisture contents and low combustion temperatures, whereas plants fired with clean, dry biofuels have operated without problems. Analysis of deposits has shown that all of them contain substances that are typical for compounds with low melting temperatures, such as sulphur, chlorine and ammonia.

A distinctive feature for plants on which problems have been experienced is that corrosion also occurs if the plants were designed so that the material temperatures in the low-temperature region were above the water dew point. Corrosion problems nevertheless occur at thermal bridges in the flue gas ducts and dust filters, at points where cold air leaks into air preheaters, or in the coldest parts of the economizer. Plants in which problems occurred earlier, these problems have often been solved by raising the material temperature, e.g. by installing steam air preheaters upstream of the flue gas/air preheater. In a number of cases, the material was changed at the same time.

5.3 Furnace corrosion

Combustion engineering measures for NO_x reduction, such as combustion in stages, can result in locally <u>reducing</u> conditions and increases the risk of furnace corrosion that comprises various conceivable mechanisms jointly designated as CO corrosion. The name CO corrosion originates from the fact that it occurs at high CO contents in the gas, which is a direct consequence of oxygen deficiency. The most important mechanism in CO corrosion is a reaction between the carbon from CO, for instance, with the structural metals. CO (or C in some other form) can be adsorbed on the metal surface where it begins to react, when C is formed. This C diffuses into the metals and forms so-called inclusion carbides (carbides: compounds of carbon and some metal). Inclusion carbides are also known as interstitial carbides. Examples of inclusion carbides that may form are:

Iron:	Fe ₃ C (cementite, iron carbide)
	Fe ₂ C
Chromium:	$Cr_{23}C_6$
	Cr_7C_3
	Cr_3C_2
Nickel:	Ni ₃ C

The first of these carbides is a common constituent of carbon steels. But crystallization and grain formation problems occur when these carbides are formed in excessive quantities. This is what happens in CO corrosion, whereby the metal alloy is fragmented by the gradual formation of inclusion carbides that form their own grains in a metal structure and gradually burst the as yet unaffected metal matrix. The mechanism is also described in 1 .

As shown by the table above, all important alloying metals in high-grade structural steels can be attacked by the formation of inclusion carbides.

In the presence of sulphur, hydrogen sulphide corrosion is the most important corrosion mechanism under reducing conditions. The formation of metal sulphides and oxides is determined by equilibrium relationships. The formation of sulphides is promoted when the partial pressure of sulphur is high and the oxygen partial pressure is low. High chlorine contents are a secondary contributory factor. In this case too, measures for NO_x reduction can also affect corrosion. As in the case of superheater corrosion, molten ash constituents may dissolve the protective oxide film and contribute to corrosion. Since the material temperature on the furnace walls is lower than in the superheater, parts of the ash must still be molten at that particular temperature. Under reducing conditions, the slag formation properties of the ash are changed and the melt temperature may be lowered. Suppliers consider that corrosion problems can be avoided by designing the burners and air supply in such a manner that reducing conditions at the walls will be avoided. Care must be given to the distribution of the fuel between different burners and to the fuel particle size distribution. Distorted distribution at the fuel entry may lead to locally reducing conditions.

In fluidized beds, the corrosion rate varies locally in the bed. This is related to the varying partial pressure of oxygen. Even if the bed is run with excess air overall, local zones with sub-stoichiometric conditions occur. The risk of corrosion increases if a sulphur absorber is added. At low local oxygen concentrations, the equilibrium between calcium sulphate and calcium oxide may lead to the release of corrosive sulphur, which may lead to sulphuration of the metal components in the bed. If waste fuel such as waste wood is fired, difficult compounds containing zinc, lead and tin may also occur.

5.4 How can corrosion be avoided?

5.4.1 Superheater corrosion

Some measures for reducing high-temperature corrosion problems have been identified in:

- Adjust the fuel mixture or use additives
- Use high-alloy materials
- Regard the last-stage superheater as a wear part
- Place the last-stage superheater in a sand trap

¹ Grabke, H.J. Corrosion by carbonaceous gases. Carburization and metal dusting and methods of prevention. Meterials at high temperatures 17 (4). 483-487 (2000)

- Use an external superheater that is fired separately with a non-corrosive fuel
- Gasification of the corrosive fuel and gas treatment, followed by co-combustion of the fuel gas in a conventional existing boiler.
- Place the superheater in an internal circulating fluidized bed.

5.4.2 Low-temperature corrosion

A simple measure for reducing the risk of low-temperature corrosion is to eliminate the cold spots that cause local condensation of acidic gases. This may be done by eliminating any thermal bridges that may be present in the shell and load-bearing structures by insulation, and by sealing the boiler or duct so that cold air does not leak in. The direction of flow in some of the economizer stacks may be altered to avoid the coldest surfaces. It may even be possible to increase the inlet water temperature to the boiler, e.g. by shunting. In the air preheater, it may be sufficient to raise the inlet air temperature slightly by means of a steam or hot-water preheater.

To counteract low-temperature corrosion, it may also be advisable to replace simple plain carbon steel by a somewhat more highly alloyed steel with better anti-corrosion properties.

Since low-temperature corrosion is often linked to sulphur compounds, principally condensed sulphuric acid or a mixture of sulphuric acid with, for instance, ammonium sulphate, a suitable countermeasure may be to reduce the occurrence of sulphur in the flue gas. Countermeasures may then be to:

- Add lime downstream of the superheater and upstream of dust collection to convert the sulphate sulphur to less corrosive compounds.
- Fire (or co-fire) with low-sulphur fuels.

However, under certain circumstances, it has proved beneficial to the entire combustion process to increase rather than reduce the sulphur content in the fuel mixture. This applies particularly to chlorine-rich fuels in which chlorine-related corrosion, principally in the superheater, is counteracted by a high degree of sulphating (conversion of chlorides to sulphates). In these cases, the use of the above methods may be rendered difficult or impossible.

5.4.3 Furnace corrosion

The most important measure for reducing corrosion in the furnace is to avoid, as far as possible, a reducing gas environment adjacent to the tube walls. This type of problem is accentuated by low NO_x firing, in which parts of the furnace are often substoichiometric in order to promote nitrogen conversion towards N_2 instead of NO_x .

Some practical measures may be taken to check that the flames from the burners are not so long or do not have such a shape that some part of the flame is likely to come into contact with a cooled wall surface. In low NO_x firing in burners, efforts are often made to supply the final combustion air so that it mixes slowly into the flame, which may be beneficial. However, in furnaces in which over fire air (OFA) is used instead, significant parts of the furnace will operate under oxygen deficiency or very low excess oxygen conditions.

In grate or FB boilers, there will be serious risk of sub-stoichiometric zones occurring, at least in the lower part of the furnace. These parts often have ceramic linings and the problem will therefore not be equally serious. It is then a matter of choosing a ceramic material that can withstand exposure to such an environment. In the event of problems in the upper part of the furnace, it may be necessary to use tube materials that can withstand corrosion. It has become relatively common to replace plain carbon or low-alloy tube materials with compound tubes, in which the surface material is corrosion resistant. Hot spraying or weld deposition of corrosion-resistant material in particularly exposed areas is also used with varying results.

Since furnace corrosion is often accelerated by reducing conditions, it is beneficial to maintain a certain oxygen concentration at the wall surface. In boilers in which there is a surplus of secondary/tertiary air registers, one of these can be used for injecting air at low velocity so that the air merely "floats" up along the wall surface. The method has been used for a relatively long time in large pulverized coal fired boilers into which special air registers are incorporated only for the purpose of maintaining oxidation along the walls. The method has also been tested in a waste wood chip boiler with promising results.

6 Standards, handbooks and databases

6.1 European standards

Trade in biofuels between European countries is increasing at an accelerating pace. Both the authorities and the market have therefore expressed strongly the need for common standards for terminology, classification, sampling and analyses of biofuels. The CEN (Comité Européen de Normalisation, European Committee for Standardisation) has been running a project since the autumn of 1999 within CEN TC 335, in which Sweden has the chairmanship. The project is aimed at developing these common standards, and most countries in Europe participate in this work. The work of drawing up technical specifications is pursued in various working committees and is expected to be completed around the year 2005. Final standards will take about a further year. Corresponding work is in progress for Solid Recovered Fuels (SRF), in which Finland has the chairmanship. The project began about a year later than Solid Biofuels, which means that the time schedule for technical specifications and standards is somewhat later on in time.

It became clear at an early stage that more research results were needed for the sampling and analysis methods used today. Moreover, the need emerged for a common quality assurance system, which resulted in the setting up of the BioNorm project. Almost 40 parties from 12 countries participate in the project that has a total budget of around SEK 52 million. The project is coordinated from the Institute for Energy and Environment (IE) in Germany. A great deal indicates the need for research even after the end of the project time, and new applications are being planned.

Table 6.1 shows an overview of the standards for solid fuels on which work is in progress in the CEN (Comité Européen de Normalisation), which is an institution in the EU that is responsible for standards. They have advanced to different stages in the approval procedure by all EU member states.

Number	Title	Planned publication	Technical specification no
335 001	Solid Biofuels – Terminology, definitions and description	2003-05	2003-12-17/
			SIS-CEN/TS 14588:2003
335 002	Solid Biofuels - Fuel specifications and classes	2004-12	
335 003	Solid Biofuels - Fuel quality assurance	2005-07	
335 004	Solid Biofuels - Methods of sampling	2005-01	
335 005	Solid Biofuels - Methods of sampling delivered in lorries	2005-01	
335 006	Solid Biofuels - Methods for preparing sampling plans and sampling certificates	2005-01	
335 007	Solid Biofuels - Methods of sample reduction	2005-01	
335 008	Solid Biofuels - Methods for the determination of calorific values	2004-09	prCEN/TS 14918
335 009	Solid Biofuels - Methods for the determination of bulk density	2005-04	

Table 6.1 Standards in progress by CEN.

335 010	Solid Biofuels - Methods for the determination of moisture content – Oven dry method – Part 1: Total moisture – Reference method	2004-07	2004-09-01 prCEN/TS 14774-1
335 011	Solid Biofuels - Methods for the determination of moisture content – Oven dry method – Part 2: Total moisture – Simplified procedure	2004-07	2004-09-01 prCEN/TS 14774-2
335 012	Solid Biofuels - Methods for the determination of moisture content - Oven dry method – Part 3: Moisture in general analysis sample	2004-07	2004-09-01 prCEN/TS 14774-3
335 013	Solid Biofuels - Methods for the determination of the content of volatile matter	2005-08	
335 014	Solid Biofuels - Methods for the determination of ash content	2004-07	2004-09-01 prCEN/TS 14775
335 015	Solid Biofuels - Methods for the determination of ash melting behavior	2006-04	
335 016	Solid Biofuels - Methods for the determination of particle size distribution. Part 1: Oscillating screen method using screen apertures of 3.15 mm and above	2005-03	
335 017	Solid Biofuels - Methods for the determination of particle size distribution. Part 2: Oscillating screen method for small particles using screen apertures of 3.15 mm and below	2005-03	
335 018	Solid Biofuels - Methods for the determination of particle size distribution. Part 3: Rotary screen method	2005-03	
335 019	Solid Biofuels - Methods for the determination of impurities		
335 020	Solid Biofuels - Methods for the determination of the particle density	2005-08	
335 021			
335 022	Solid Biofuels - Methods for the determination of the durability for pellets	2005-08	
335 023	Solid Biofuels - Methods for the determination of the durability for briquettes	2005-08	
335 024	Solid Biofuels - Methods for the determination of bridging properties	2005-12	
335 025	Solid Biofuels: Methods for the determination of carbon (C), hydrogen (H) and nitrogen (N) content	2005-04	
335 026	Solid Biofuels: Methods for the determination of sulfur (S) and chlorine (Cl) content	2005-08	
335 027	Solid Biofuels: Methods for the determination of water soluble chloride (CI) content	2004-05	
335 028	Solid Biofuels: Methods for the determination of the content of major elements (Al, Si, K, Na, Ca, Mg, Fe, P and Ti)	2005-08	
335 029	Solid Biofuels: Methods for the determination of the content of minor elements (As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Mn, Ni, Pb, Se, Te, V and Zn)	2005-08	
335 030	Solid Biofuels- Calculation of different bases	2006-02	

Table 6.2 Additional standards and reports in Solid recovered fuels.

Number	Title	Planned publication	Technical specification no
	Solid Recovered Fuels – Quality management system- Particular requirements for their application to the production of SRF		
	Solid Recovered Fuels – Method for the determination of biodegradeable/biogenic material	2005-12	prCEN/TS 14980
	Solid Recovered Fuels – Report on relative difference between biodegradeable and biogenic fractions of SRF	2004-09-20	

Solid Recovered Fuels – Guidelines on occupational health aspects	2005-12
Solid Recovered Fuels – Methods for the determination of metals with a melting point below 700°C	
Solid Recovered Fuels – Determination of combustion behavior	
Solid Recovered Fuels - Methods for the digestion of material before chemical analysis	

Table 6.3 Existing standards for biofuels, peat and coal.

Standard	Title	Last revised
Heating values		
SS-ISO 1928	Solid mineral fuels – Determination of calorific value by the bomb calorimetric method, and calculation of net calorific value.	1996
ASTM D1989-97	Gross calorific value of coal and coke by microprocessor controlled isoperibol calorimeters.	1997
ASTM D2015-96	Standard test method for Gross calorific value of coal and coke by the adiabatic bomb calorimeter.	1996
DIN 51 900	Determination of gross calorific value and calculation of net calorific value.	1998
Sampling and sample p	preparation	
SS 187113	Biofuels and Peat - Sampling	1998
SS 187114	Biofuels and Peat - Sample preparation	1992
ISO		1988
ISO		1988
Bulk density		
SS 187178	Biofuels and peat - Determination of raw bulk density and calculations of dry raw bulk density	1990
SS 187179	Biofuels and Peat - determination of raw bulk density and calculation of dry raw bulk density	1990
ASTM E 873-82 (1992)	Bulk density of densified particulate biomass fuels.	1992
DIN 51705	Determination of bulk density of solid mineral fuels.	1979
Moisture content		
SS 187170	Biofuels and peat - determination of total moisture content.	1997
SS 187184	Biofuels and peat - determination of moisture content in analyse sample	1990
ISO 331	Coal - Determination of moisture in analyses sample	
ISO 579	Coal – Determination of total moisture and the moisture content in the analysis sample	
DIN 51718	Testing of solid fuels – Determination of the water content and the moisture of analysis sample	1995
ASTM D4442-92	Test method for direct moisture content measurement of wood and wood base materials	1992
Volatile content		
SS ISO 562	Hard coal and coke - determination of volatile matter content.	1990
ASTM D3175	Standard test method for volatile matter in the analysis sample of coal and coke.	1993
ASTM E 872-82	Standard test method for volatile matter in the analysis sample of particulate wood fuels	1992
DIN 51720	Testing of solid fuels – Determination of volatile matter	
Ash content		
SS 187171	Biofuels – determination of ash content	1984

VÄRMEFORSK

ISO1171-1981	Solid mineral fuels – determination of ash.	1981
ASTM D3174-97	Ash in the analysis sample of coal and coke from coal.	1997
ASTM E-1534-93	Determination of ash content in particulate wood fuels.	1993
DIN 51719	Testing of solid fuels - Determination of ash content	1997
Fusibility of ash		
SS-ISO 540	Solid mineral fuels - Determination of fusibility of ash – High temperature tube method.	1996
ASTM D 1857	Fusibility of coal and coke ash.	1994
ASTM E 794-85 (1989)	Test method for melting and crystallization temperatures by thermal analysis	1989
ASTM E 793-85 (1989)	Standard test method for heats of fusion and crystallization by differential scanning calorimetry	1989
DIN 51 730	Testing of solid fuels – fusibility of fuel ash	1998
Particle size and form		
SS 197174	Biofuels and peat – Determination of size distribution	1990
NEN2560	Particle size distribution	
NEN 5753	Soil – determination of clay content and particle size distribution of soil samples	
ASTM D-4749	Performing the sieve analysis of coal and designating coal size.	1994
ASTM D197	Test method for sampling and fineness test of pulverized coal	
ISO 1953:1994	Hard coal – Size analyse by sieving	1994
DIN 66 165	Particle size analysis – sieving analysis	1987
Impurities		
A305:001E *	Method for classification of recycled wood by hand (not official standard)	1998
Pellet density and mech	hanical strength	
SS 187180	Biofuels - Determination of mechanical strength in pellets and briquettes	1999
DIN 51731	Testing of solid biofuels; briquettes of wood; requirements and testing	1996
ASEA S269.1	Durability of pellets	
NS 3166 Biofuel	Biofuel – Determination of mechanical strength of pellets	1999
NS 3167 Biofuel	Biofuel - Determination of moisture content in laboratory samples of pellets	1999
Classification		
SS 187120	Biofuels and Peat - Classification	
ISO		1928
Flowability		
SLU	Biofuel powder; "Funnel method" S. Kastberg SLU (Not official standard)	
SLU	Bridging properties J_E Mattsson SLU: Large container with adjustable bottom opening. (Not official standard)	

*AnalyCen Nordic AB. L. Andersson

6.2 Handbooks

In many cases, handbooks on combustion and fuels are available on the Internet.

6.2.1 Handbook of Biomass Combustion and Cofiring (Task 32)

In the Task 32 project, the IEA has produced a handbook on combustion and co-firing of biofuels. This is available for viewing on the Internet (http://www.ieabcc.nl/)

On the home page, there are several reports and a calculation program, "Fuelsim Average V1.1". Fuelsim-Average is a relatively simple but usable calculation program for combustion processes, and is written in MS-EXCEL format.

Figure 6.2.1 Handbook of Biomass Combustion and Cofiring

Handbook of Biomass Combustion and Cofiring

Prepared by Task 32 of the Implementing Agreement on Bioenergy under the auspices of the International Energy Agency Sjaak van Loo and Jaap Koppejan (eds.) Reprint of first edition with minor corrections, 2003, paperback edition. 352 pages. isbn 9036517737 Price € 25.00 excl postage



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- 1 Introduction
- 2 Basic Principles of Biomass Combustion
- 3 Biomass Fuel Supply and Pre-Treatment
- 4 Domestic Wood Burning Appliances
- 5 Industrial Combustion
- 6 Power Generation and Co-Generation
- 7 Co-Combustion
- 8 Environmental Aspects of Biomass Combustion
- 9 Research and Development Needs and Ongoing Activities

6.3 Fuel databases

Several databases with analyses of fuels and ashes are available on the Internet. In some cases, complete analyses are given of the fuels, with references to published articles. In other cases, only some individual parameters may perhaps be given. It should be borne in mind that the units vary in the various databases, and direct comparisons are sometimes difficult to make.

6.3.1 Phyllis

Phyllis is designed and maintained by ECN Biomass (http://www.ecn.nl/phyllis/) with (http://www.novem.org/). support from Novem Shell Global Solutions (http://www.shellglobalsolutions.com/) and HoSt (http://www.host.nl/) 2003 dramatically increased the volume of biochemical data by cooperation with Innovations Agrotechnology Food and ΒV (http://www.agrotechnologyandfood.wur.nl/). The database currently contains about 2275 data entries. Phyllis is continuously updated and expanded. If data from Phyllis is used, reference should be made to "Phyllis database for biomass and waste. http://www.ecn.nl/Phyllis Energy research Centre of the Netherlands".

The database can also be used for searching and finding analyses of a large number of fuels or groups of fuels. In addition, reference is made to articles and other scientific literature for a variety of data. Examples of the search function and search results are shown in figure 6.2.1 and 6.2.2.

6.3.2 BIOBIB – A Database for Biofuels

The work of setting up the BIOBIB database (http://www.vt.tuwien.ac.at/biobib/search.html) began back in 1992. The Institute of Chemical Engineering, Fuel and Environmental Technology, Vienna, Austria will expand and check the data already in or coming into the database. The database currently contains 331 different fuels and comprises energy crops that may be of interest to Europe, wood fuel, and waste from biomass, such as waste wood, shells and chaff have also recently been included.

Additional analyses are required for introduction into the database, and new data or views on the database² will gratefully be received. Examples of search functions and analyses are shown in figure 6.2.3.

6.3.3 BioBank

BioBank (<u>http://www.ieabcc.nl/database/biobank.html</u>) comprises three databases on the chemical composition of fuels, ashes and condensate. The database was originally set up by BIOS BIOENERGIESYSTEME GmbH, but is continually updated with data for member countries in IEA Bioenergy Task 32.

This currently contains information on about 1000 biofuels, 560 ashes and 30 condensates. The database has been developed in cooperation with the university in

² Univ.Prof.Dr.Herman Hofbauer, University of Technology Vienna, Institute of Chemical Engineering, Fuel and Environmental Technology, Getreidemarkt 9/159, A-1060 Vienna, e-mail: <u>hhofba@fbch.tuwien.ac.at</u>

Graz, and they will be pleased to receive new data³. Examples of search results are shown in figure 6.2.4 and 6.2.5.

6.3.4 Biofuel database

A database from Australia, developed by CSIRO Energy Technology (<u>http://det.csiro.au/science/energyresources/biomass.htm/</u>) contains fuels such as wood fuels, agricultural waste, fruit waste, domestic refuse and fossil fuels. Some exotic fuels such as mimosa and acacia are included, since the database contains data from Australia. The database contains more or less comprehensive analyses of about 100 fuels. The database is fairly slow.

The database contains:

- Proximate and ultimate analysis
- Calorific value
- Ash analyses
- Ash melting temperatures
- Deposit and corrosion properties
- Gasification properties
- Properties for the production of liquid fuel

Examples of search results are shown in figure 6.2.6 and 6.2.7.

³ Ingwald Obernberger, Institute of Chemical Engineering Fundamentals and Plant Engineering, Graz University of Technology, Austria (http://www.ieabbc.nl/members/ingwaldbernberger.html/

ECN		
PHYLLIS		
e composition of biomass ar omposition of a single n	nd waste. naterial.	
ep 1 of 3: Select a group	Step 2 of 3: Select a subgroup	Step 3 of 3: Select a material
Group	Subgroup	Biomass
algae	C _{bark}	sieved 0.075- 0.09 mm
char	C beech	sieved 0 125-0 18 mm
fossil fuel		
grass/plant		
husk/shell/pit	cork	Willow
manure	fir/pine/spruce	wood
non organia rasidua	leaves	wood, cilinders 10*10
non-organic residue	needles	
organic residue/product	C oak	wood, salıx
others	• other hard wood	wood, small fraction, saw dust (smaller than 2*2 mm)
RDF and MSW	C ather soft wood	(diameter * length)
sludge		wood, willow
straw (stalk/cob/ear)	others	wood, willow tops
treated wood	park waste wood	wood, willow variety
untreated wood	poplar	wood willow 5-9 mm
untreated wood	tropical hard wood	
	C willow	wood, willow, bark + wood
		wood, willow, cilinders
		10*40 mm (diameter * length)
		wood, willow, white

Figure 6.2.1 Examples of search routes in Phyllis database.



PHYLLIS

the composition of biomass and waste <u>home</u> | general information | <u>how to use Phyllis</u> | <u>definitions used in Phyllis</u> | <u>preferences</u> <u>composition of a single material</u> | <u>average composition of a group of materials</u> | <u>selection via</u> <u>NTA 8003</u> | <u>search for materials</u>

General information

Sample information

Group	untreated wood
Subgroup	willow
Material	Willow
ID-number	2715
Reference:	ECN laboratories.
Remarks:	Wilg (oostvaarderhoeve)

Material composition

Proxima	te anal	ysis (w	t. %)	Ultimate analysis (wt. %)													
	drv	daf	ar		drv	dəf	ar		El	ement	al an	alys	is (mg	/kg sa	amp	ole (d	ry))
	ury	uai	aı		ury	uai	ai		Al	18.9	Msr	Fe	30	Msr	Pb	1.9	Msr
Ash	1.3		1.2	С	44.7	45.3	39.6	Msr	As	0.7	Msr	Hg	-	ND	Sb	2.9	Msr
Water			11.3	Н	5.7	5.8	5.1	Msr	B	5.8	Msr	K	1420	Msr	Se	20.6	Lim
Volatiles	80.6	81.7	71.5	0	46.2	46.8	40.9	Msr	Ba	1.2	Msr	Mg	378	Msr	Si	69.1	Msr
				NT	0.2	0.2	0.10	Man	Ca	3899	Msr	Mn	12	Msr	Sn	0.2	Msr
				IN	0.2	0.2	0.18	MSF	Cd	1.9	Msr	Mo	0.2	Lim	Sr	14.4	Msr
Calori	fic valu	ue (kJ/l	kg)	S	0.03	0.03	0.03	Msr	Co	0	Msr	Na	127.2	Msr	Те	-	ND
	dry	daf	ar	Cl	0.01	0.01	0.009	Msr	Cr	2.1	Msr	Ni	11.2	Msr	Ti	2.1	Msr
HHV	19100	19352	16942	F	0.001	0.001	0.001	Msr	Cu	3.1	Msr	Р	651.6	Msr	V	0.2	Msr
LHV	17856	18091	15562	Br	-	-	-	ND							Zn	61.8	Msr
HHV _{Milne}	17199	17425	15255	Total:	98.1	98.1	98.3										



BIOBIB - search categories

The BIOBIB is divided into three categories:

wood

grasses

waste material

Please choose one of them to get information about the ultimate analysis and combustion data. An <u>alphabetically sorted list</u> is also available.



UNIVERSITY OF TECHNOLOGY VIENNA

Institute of Chemical Engineering, Fuel and Environmental Technology

Getreidemarkt 9/159 A-1060 Vienna Austria

HOME SEARCH LITERATURE NOMENCLATURE INFO

willow

The calorific value and the elementary analysis refers to dry biomass.

calorific value

gross: 19153 kJ/kg <u>statistics...</u> **net:** 18420 kJ/kg

elementary analysis

C: 47.66 wt.%,dm <u>statistics...</u> H: 5.72 wt.%,dm <u>statistics...</u> N: 0.43 wt.%,dm <u>statistics...</u> S: 0.03 wt.%,dm <u>statistics...</u> Cl: 0.01 wt.%,dm <u>statistics...</u> O: by difference

trace elements

Mg: Ca: Al: Si: P: Fe: As: Cr:

Figure 6.2.3 Example of search routes and analysis in data base Biobib.

BioBank Biobank is a set of three databases on the chemical composition of biomass fuels, ashes and condensates from flue gas condensors from real-life installations. The dataset was originally compiled by <u>BIOS</u> <u>BIOENERGIESYSTEME GmbH</u> , Graz, Austria, but is continuously expanding using data from other member countries of IEA Bioenergy Task 32. It currently contains approximately 1000 biomass samples, 560 ash samples and 30 condensate samples. Select the appropriate database:					
Biomass Ash Condensate					
 Version 2.4, © BIOS Bioenergiesysteme GmbH, Graz, Austria Development of the database has been done in cooperation with the Institute of Chemical Engineering Fundamentals and Plant Engineering, Graz University of Technology. In case you wish to submit data, please contact <u>Ingwald Obernberger</u>. <u>References</u> to the data used. <u>Fill databases</u> 					

Figure 6.2.4 First page of data base BioBank

S	Fuel type		Speci	es		Count	y	Location			
S	Wood chips			x 🚽		Sw ed	en 🚽		All	F	
5	Results of the above selection:	:									
E	Stat. Data:	<u>sam</u> j	<u>oles</u>	<u>min</u> value	<u>max</u> value	<u>average</u>	<u>median</u>	<u>first</u> quartile	<u>last</u> quartile	<u>1.5xIQD</u>	<u>std</u> dev
0	GCV [kJ/kg]										
	Volatiles [mass % db]										
	<u>Ash [mass % db]</u>		7	2.5	4.2	3.3	3.0	2.8	3.7	0.0	0.6
	<u>C [mass % db]</u>										
	<u>H [mass % db]</u>										
	<u>N [mass % db]</u>										
	<u>O [mass % db]</u>										
	<u>S [mass % db]</u>		7	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.0
	<u>Cl [mass % db]</u>		7	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	<u>F [mg/kg db]</u>										
	<u>Si [mg/kg db]</u>										
	<u>Ca [mg/kg db]</u>										
	<u>Mg [mg/kg db]</u>										
	<u>K [mg/kg db]</u>		7	3,303.0	3,947.0	3,625.4	3,591.0	3,566.5	3,702.0	203.2	195.0
	<u>Na [mg/kg db]</u>		7	37.0	53.0	42.6	42.0	38.5	44.5	9.0	5.6
	<u>P [mg/kg db]</u>										
	<u>B [mg/kg db]</u>										
	<u>Al [mg/kg db]</u>										
	<u>Fe [mg/kg db]</u>										
	<u>Mn [mg/kg db]</u>										
	<u>Cu [mg/kg db]</u>		7	4.0	7.0	5.3	5.0	5.0	5.5	0.8	1.0
	Zn [mg/kg db]		7	54.0	58.0	56.9	57.0	57.0	57.5	0.8	1.3
	<u>Co [mg/kg db]</u>										
	<u>Mo [mg/kg db]</u>										
	<u>As [mg/kg db]</u>										
	<u>Ni [mg/kg db]</u>										
	<u>Cr [mg/kg db]</u>										
	<u>Pb [mg/kg db]</u>		7	1.0	5.0	2.3	2.0	1.0	3.0	3.0	1.5
	<u>Cd [mg/kg db]</u>										
	V [mg/kg db]										
	Hg [mg/kg db]										
	Ba [mg/kg db]										
	<u>Ti [mg/kg db]</u>										
	<u>Fusion temp., oxidising</u> [°C]										

Figure 6.2.5 Example of results from a search in data base BioBank.

CSIRO ENERGY	TECHNOL	OGY				
unique en	ierg	y sol	utior	IS TO	rthe	Tuture
Home I science and solud	ions I Mina	inces (Pab	incacións (5	obs (Moode	ds Hews	
	Data Samp	abase ole ID	e San 1	iple E)etail	S
	Details	of sam	ple			
Greenhouse Office	ID					1
	Short D Full Des	escription scription				Radiata pine chips Radiata pine chips
Database Home	Type Commo	in Name o	r Category			Wood or tree derived Softwood
About Database	Species	or Plant 1	lype			Pine Ward China
Search	Origin a	and Date	readient			Hunter Valley Savmills. April 1999
Coal & Biomass Mixtures	State Country	,				NSW Australia
Analysis Results -	Date Er	ntered				2002-01-26
						Click to anlarge image
	Biomass (Externa	Resource I link to B	s in Austra ioenergy A	ilia : (tlas)	Forest bi	omass, current plantation extent and plantation potential
	Back to t	top				
ample Analysis						
nalvsis Basis		(ar)	(ad)	(db)	(daf)	[guiding values for un
roximate Analysis	(wt 96)	41.2	94	1	()	
sh	(wt.%)	0.6	1.0	111	1	
platile Matter	(wt. %)	47.6	73.4	81.0	81.9	1
xed Carbon	(wt.%)	10.6	16.2	17.9	18.1	
ross Calorific Value	(MJ/kg)	12.08	18.62	20.55	20.78	
	(kcal/kg)	2886	4448	4908	4964	
timate Analysis						
arbon	(wt.%)	28.6	44.0	48.6	49.1	
lydrogen	(wt.%)	3.68	5.67	6.26	6.33	
Nitrogen	(wt.%)	0.12	0.18	0.20	0.20	
Total Sulfur	(wt.%)	0.01	0.01	0.01	-	
Oxygen (by difference)	(wt.%)	25.8	39.7	43.8	-	
Chlorine	(mg/kg)	65	100	110		
nalysed in accordance wit otal sulfur and chlorine in uitable for analysis. The C	h Australia biomass (SIRO pro-	an Standaro were deterr cedures are	l Methods A nined by IC 1 NATA certi	S1038.1, AS P-AES. Biot fied.	\$1038.3, AS nass was c	1038.5, A\$1038.7(draft) imbusted in the presence of Eschka's mixture and the residue dissolved in a
(ar) = "as received" basis,	(ad) = "a	air dried" bi	asis, (db) =	= "dry basis	", (daf) = '	dry, ash free" basis
Note: The chemical cons nutrients, etc, and	tituents d thus car	of biomas re should l	s samples be taken in	can vary w using this	idely, eve informati	within a particular biomass type, due to growing location, weather constraints of the second seco
 				-		

Figure 6.2.6 Biofuel database- example of ultimate analysis.

VÄRMEFORSK

Ash Anabaia							
ASIT ATO YOS [guiding values for unproblematic conversion]							
net % of ach //							
Oxides from elements (Measured)							
Na ₂ O 0.84 Na 0.62							
Mgo 4.93 Mg 2.97							
A ¹ 2 ⁰ 3 4.73 AI 2.50							
sio ₂ 16.1 si 7.52							
P ₂ o ₅ 0.39 P 0.17							
κ ₂ ο 4.15 κ 3.45							
cao 32.6 ca 22.6							
Tio ₂ 0.48 Ti 0.29							
Mn_04 0.91 Mn 0.65							
Fe ₂ O ₃ 363 Fe 2.54							
The major elements of the ash were determined by CSIRO Energy Technology using a MATA certified method based on a borate fusion/ICP-RES procedure							
Ash (1.45%) obtained at 500°C from air-dried material							
Sum of all oxidas do not add up to 100% mainly due to carbonata matter not being removed during oxidation at 500%							
Back to top							
Ash Fusion							
Ash Fusion Temperatures (Oxidising Atm)							
Deformation (°C) N/A							
Sphere (°C) N/A							
Hemisphere (*C) N/A							
Flov (*C) 11/A							
Red to too							
Fouling and Corrosion Overview							
Sample combusted (a.r. basis) 200 (g)							
Ash (dry basis) 1.1 (vt.%)							
Extinate of comparing (categories) and the second							
Fouling / Corresion scale: Negligible - Minor - Moderate - Major							
Fouling and Covining Massurgments - Full Dataile							
Rack to too							
Gasification of Biomass Overview							
Char yield at 600°C 29.2 (vt.% dry basis)							
Estimate of chargesification reactivity Very Fast Reactivity scale							
Very Slow - Slow - Moderate - Fast - Very Fast							
Gasification Measurements - Full Details							
Back to top							
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Copyright @ 2002 CSIRO Energy Technology Legal Notice							

Figure 6.2.7 Biofuel database - example of ash analysis.

A Methodology for trial firing of fuels

In the work on the Handbook, it has been difficult to obtain comprehensive data on fuels. The analyses often had serious shortcomings, with wide deviations in the reporting. As a result, many analyses were unusable for compilations and fuel compositions. The documentation for combustion plants has frequently been somewhat more comprehensive, but important information was often also lacking.

Thermal Engineering Research Institute report No 469⁴ includes suggestions for the analysis that should be carried out and parameters that should be documented in the testing of fuels and combustion plants.

The Thermal Engineering Research Institute Measuring Handbook⁵ contains a summary of what should be included in the documentation for various tests and trials in plants.

If the suggested patterns had been used at least in projects run by the Thermal Engineering Research Institute, the quantity of data in the Handbook for fuels would have been more comprehensive and would have given further opportunities for the exchange of experience for various plants.

⁴ includes the following suggestions for important analyses, tests, investigations and descriptions that should be included in an investigation.

A.1 Fuel data

A careful analysis of the relevant fuel should be carried out before trial firing. This analysis should comprise:

- Ash content
- Moisture content
- Calorific value
- Elementary composition
- Major elements
- Trace element analysis
- Density
- Particle size
- Ash melting behaviour
- Sintering properties

⁴ Rydén A., Olofsson J., Erfarenheter från försökseldning med alternative biobränslen, Agro-bränslen, Värmeforskrapport nr 469, 1993.

⁵ Gustavsson L., Nyquist G. Värmeforsk Mäthandbok 2000. Värmeforskrapport 694, 2000.

A.2 Fuel handling system

Critical system components that should be documented are:

- Design of chutes and transfer stations
- Fuel stores
- Transport/feed system
- Fire incidents

A.3 Power output

The maximum power output on change-over to a new fuel should be investigated and reported.

A.4 Loss through grate and unburned fuel content

During trial firing on a grate, the proportion of material that drops through the grate and the content of unburned material in the ash should be documented.

A.5 General operating and environmental data

Trial firing without documentation of the operating and environmental data is of doubtful value.

A.6 Suggestion for documentation in the Thermal Engineering Research Institute Measuring Handbook

The Thermal Engineering Research Institute Measuring Handbook⁵ (revision of the contents is in progress and a new version will be issued in 2005) includes a suggestion for what should be included in the documentation of measurements:

After completion of measurements, the results should be compiled in a report. The contents of the report are dependent on the purpose of the investigation, how extensive the measurement programme has been, and the number of components measured. An example of the points that can be included in a report is given below.

Purpose of the measurement, e.g.:

- requirements of the authorities and the like
- process follow-up

Date, time and place

Description of the plant and process:

- load
- type of fuel
- excess air
- temperature
- treatment chemicals flow

Description of the treatment plant, such as:

- type, make, flow diagram or sketch
- technical data, e.g. collecting efficiency, pressure drop, etc.
- brief description of operation

Description of measuring equipment, e.g.:

- type and make
- diagrammatic arrangement
- gas flow measuring equipment
- type of dust sampling filter
- location of dust filters in the sampling equipment (outside or inside the duct)
- filter conditioning and weighing technique
- gas analyzers

- production date and concentration of the reference gases, and manufacturer and issuer of certificate

Sampling conditions, such as:

- sketch of the location of the measurement plane in the duct, with particulars of the straight sections of duct before and after the measurement plane

- duct dimensions and number of measurement points in the measurement plane
- temperature of the sampling filter during sampling (dust measurement)
- sample gas line temperature (gas analyses)
- duration of the measurement period
- barometric pressure
- pressure in the gas meter (dust measurement, flow measurement)
- temperature in the gas meter (dust measurement, flow measurement)
- probe diameter (dust measurement)
- isokinetic deviation (dust measurement)
- test gas volume

Comments concerning observations that may have an influence on the measurement results, e.g.:

- production condition, production disturbances
- operating disturbances in the treatment plant
- metrological disturbances

Report on the measurement data and results, such as:

- temperature in the duct
- moisture content
- pressure in the duct
- gas velocity
- gas flow
- dust concentration
- dust flow
- gas concentrations
- mass flows and specific flows or gaseous components, e.g. NO_x and SO₂
- uncertainty assessments
- comparisons between test results and requirements

A.7 Proposal for a form for documenting the tests

The survey for the Fuel Handbook can be used with some modifications for summating the results of tests on new fuels/fuel mixtures. This is of a general make-up that will suit all types of plant. If the data below is filled in following tests on fuels, it will be possible to use the information more readily for possible future updating of the Fuel Handbook.

1. Information on the plant and liaison person

Company/plant: Filled in by: Phone: E-mail: Date

2. Information on the fuel

What fuel/fuels were included in the test?	
Who delivered the fuel/fuels?	
Fuel analyses carried out:	Attach the analysis report
• Elementary analysis	
Major elements	
• Trace element analysis	
• Calorific value, moisture and ash	
contents	
Other tests carried out	Attach an analysis report
Examples: density, ash melting point,	
sintering test, particle size	
What laboratory/laboratories were	
retained?	
What criteria were used for assessing the	
new fuels?	

3. Information on the plant

-									
Туре о	of comb	oustion							
technique	 grate/BFE 	B/CFB							
Supplier									
Rating				MW	√ th	tonnes of steam/h			
Outlet ste	am conditi	ons –			°C		bar		
temp./pres	S.								
Are there	any superl	neaters							
located el	sewhere th	nan in							
the rear up	take? Wher	e?							
State the s	team and flu	ue gas temp	eratures at/	in the super	heater and	convection	section, in		
the direction	on of flue ga	as flow from	n the furnac	e (e.g. SH1	, SH2, econ	omizer) at f	ull load:		
Tube									
section									
Flue gas	°C	°C	°C	°C	°C	°C	°C		
temp.									
Steam	°C	°C	°C	°C	°C	°C	°C		
temp.									
Type of flu	ue gas treatr	nent							

Normal fuel? Moisture content?	
Do deposits occur when normal fuel is	
burned? Where?	

3. Test results

Fuel	
Degree of admixture? [%	
energy]	
Co-combustion fuel?	
Load?	
Was an additive dosed?	
Yes/no If yes, which?	
Fuel feed/handling:	
Did the ordinary feed work	
or did it have to be	
modified? If so, how?	
If problems occurred,	
which? Describe	
Combustion properties:	
Did operating disturbances	
occur? State which.	
Emissions (NO _x , CO, SO ₂ ,	
others)? Lower or higher?	
Where did deposits occur?	
Did corrosion occur?	
Where?	
Ash feed/handling:	
Did operating problems	
occur? Which?	

4. Other comments

B Fuel analyses

Fuel	Moisture	Ash	Sulphur	Chlorine	Hhigher	Bulk
	% by weight	% by weight DS	% by weight DS	% by weight DS	MJ/kg (dry, ash- free)	density kg DS/m ³
Wood fuels					,	
Wood	8 - 60	0.4 - 0.6	0 - 0.3	0 - 0.05	16 – 18	200 - 350
(sawdust.			0 010	0 0100		
chips,						
powder)						
Wood	9 – 10	0.4 – 0.8	0 – 0.3	0 – 0.05	19 – 21	550 – 700
(pellets,						
briquettes)			0.00	0.00	40.04	000 050
Logging	35 – 55	1 – 5	0.02 -	0.02 -	19 – 21	200 – 350
residues	2 50	2 16	0.05	0.05	20 24	200 250
wood	3 - 50	3 - 10	0.04 - 0.3	0.04 - 0.2	20 – 24	200 - 350
Salix	25 - 50	1-5	0.005 -	0.01 - 0.1	18 - 20	200 - 350
Cullx	20 00		0.03	0.01 0.1	10 20	200 000
Bark	21 – 65	2-6	0 - 0.1	0 - 0.02	20 – 25	300 – 550
Deciduous	20 - 40	0.3 – 1.7	0.01 –	0.005 -	19 – 21	440 - 580
trees			0.04	0.06		
Agricul-						
tural fuels						
Straw	10 - 20	4 – 10	0.05 – 0.2	0.05 – 1.5	18 – 20	Low
Reed	10 – 15	3 – 7	0.05 – 0.2	0.1 – 0.2	17 – 20	200 – 300
canary						
grass Homp	15 75	16 63	0.03	0.04 0.1	10	
петтр	15 - 75	1.0 - 0.3	0.03 – 0.07	0.04 - 0.1	19	LOW
Grain	14	2-4	0 – 0.5	0.02 – 2.3	17 – 22	250 – 390
Grain chaff	12	10	0.2	0.2	20	High
Olive	0 – 21	0.4 – 16	0.01 – 0.3	0 – 0.4	19 – 25	High
waste	7		0.0	0.00	20	405
Locoa	1	5	0.3	0.02	30	495
Citrus fruit	8 - 10	1 _ 7	0.2	0.02	21	600
waste	0 - 10	4 - 7	0.2	0.02	21	000
Shea nuts	3.3 – 7.6	6 – 7	0.3	0.1	23	700
Waste		-		-	-	
fuels						
Digested	53 – 77	35 – 50	0.2 – 5	0.05 – 1.5	15 – 24	Low
sludge						
Forest	41 – 84	2 – 60	0.1 – 2.4	0.01 – 0.3	17 – 23	Low
Industries						
Sludge	4 02	15 40	02 11	06.24	10 01	
Paper	4 - 92	10 - 42 5 - 12	0.3 - 1.1	0.0 - 2.4	19 - 21	Low
wood,	10 - 55	5 - 15	0.07 - 0.5	0.01 - 1.5	10-31	LUW
plastics		ļ				
Rubber	0.6 - 4.3	5 – 26	1.3 – 3.3	0.06 - 0.9	36 – 43	High
Leather	54	25	26	12	19	
waste	U T	2.0	2.0	1.2		
Milk carton	42 – 64	10 – 27	0.03 – 0.2	0.07 – 0.6	12 – 20	Low

 Table 2.3.2
 Fuels included in the Handbook. Some important parameters and properties.

Animal						
fuels						
Meat and	7	30	0.7	0.5	23	High
bone meal						
Animal fat	0.1 - 0.6	0.1	0.02	0	39	
Other						
fuels						
Vegetable	0 – 1.2	0 – 0.1	0	0	39	
fats						
Tall oil	0.1 – 0.3	0.2 – 0.4	0.2 – 0.3	0	40	
Peat	38 – 58	2 – 9	0.1 – 0.5	0 – 0.1	19 – 27	300
Peat	10 – 15	2 – 8	0.25		20 – 27	
(briquettes,						
pellets)						

B.1 Wood fuel

Table 1	Analysis of wood fuel
---------	-----------------------

Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)	Pellets		Min	Max	
Moisture	9,4	8	7,2	12,4	13
Ash (% dry)	0,6	0,6	0,5	2	13
Volatile substances (% dry, ash-free)	84,4	84,2	81	84,5	9
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	20,41	20,3	19,44	20,67	13
Hhigher (ar)	18,38	18,4	17,63	19,08	13
Hlower (dry, ash-free)	19,05	18,97	18,15	19,27	13
Hlower (ar)	16,93	16,93	16,3	17,63	13
Elementary analysis (% dry, ash-free)					
C (carbon)	50,8	50,6	49,65	51,46	13
H (hydrogen)	6,24	6,24	5,82	6,43	13
O (oxygen)	42,84	42,88	42,26	44,17	13
S (sulphur)	0,01	0,03	<0,01	0,31	13
N (nitrogen)	0,1	0,1	<0,1	0,2	13
Cl (chlorine)	0,01	0,01	<0,1	0,64	13
Ash analysis (mg/kg of ash)					
Al (aluminium)	25985	16046	4191	40221	9
As (arsenic)	<13				
Ba (barium)	1490	2290	812	3310	7
Ca (calcium)	192967	238708	98628	261578	9
Cd (cadmin)	25				1
Co (cobalt)	<8	13,8	<8	17,4	7
Cr (chromium)	88	80,6	40	118	7
Cu (copper)	165	97,7	67,7	165	7
Fe (iron)	24830	11925	8743	24830	9
Hg (mercury)	<2				1
K (potassium)	83015	80690	67491	89656	9
Mg (magnesium)	30516	31360	16645	33591	9
Mn (manganese)	11185	20353	9479	33935	9
Mo (molybdenum)	<6	9,7	< 0,6	33,1	7
Na (sodium)	4414	4581	2533	7307	9
Ni (nickel)	18	56,5	11,7	147	7
P (phosphorus)	10211	12372	10211	100368	9
Pb (lead)	67				
Sb (antimony)					
Si (silicon)	115464	73860	57031	235135	9
Ti (titanium)	1139	603	366	1349	9
Tl (thallium)					
V (vanadium)	25	10,3	9,6	25	7
Zn (zinc)	1867	2570	1867	3130	7

B.2 Forest residues

|--|

Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	47,9	51,2	47,9	54,8	7
Ash (% dry)	2,7	2,6	1,7	2,8	7
Volatile substances (% dry, ash-free)					
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	21,18	20,58	20	21,18	7
Hhigher (ar)	10,74	9,63	8,89	10,74	7
Hlower (dry, ash-free)	19,89	19,13	18,78	19,89	7
Hlower (ar)	8,91	7,73	6,95	8,91	7
Elementary analysis (% dry, ash-free)					
C (carbon)	53,13	50,6	49,6	53,13	7
H (hydrogen)	5,96	5,95	5,8	6,2	7
O (oxygen)	40,55	39	38,1	40,8	7
S (sulphur)	0,04	0,05	0,04	0,06	7
N (nitrogen)	0,31	0,7	0,31	0,8	7
Cl (chlorine)		0,03	0,02	0,03	6
Ash analysis (mg/kg of ash)					
Al (aluminium)	20000				
As (arsenic)	3				
Ba (barium)	2704				
Ca (calcium)	192074				
Cd (cadmin)	0				
Co (cobalt)	0				
Cr (chromium)	111				
Cu (copper)	111				
Fe (iron)	8333				
Hg (mercury)	0				
K (potassium)	76259				
Mg (magnesium)	20963				
Mn (manganese)	15926				
Mo (molybdenum)	4				
Na (sodium)	8556				
Ni (nickel)	37				
P (phosphorus)	17148				
Pb (lead)	74				
Sb (antimony)	-				
Si (silicon)	113074				
Ti (titanium)	1074				
Tl (thallium)	-				
V (vanadium)	0				
Zn (zinc)	2000				
B.3 Demolition wood

Table 3	Analysis of demolition woo	d
	Analysis of demontion woo	'n

Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	33,7	23,25	11,1	39,1	12
Ash (% dry)	4,8	5,8	3,2	15,9	12
Volatile substances (% dry, ash-free)					
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	20,86	20,92	20,34	23,75	12
Hhigher (ar)	13,19	15,28	11,91	16,8	12
Hlower (dry, ash-free)	19,49	19,55	18,98	22,26	12
Hlower (ar)	11,48	13,71	10,19	15,43	12
Elementary analysis (% dry, ash-free)					
C (carbon)	51,68	51,9	50,2	56,5	12
H (hydrogen)	6,3	6,29	6,12	6,9	12
O (oxygen)	41,05	40,25	36,17	42,02	12
S (sulphur)	0,07	0,08	0,04	0,29	12
N (nitrogen)	0,84	1,17	0,12	1,56	12
Cl (chlorine)	0,05	0,055	0,04	0,22	12
Ash analysis (mg/kg of ash)					
Al (aluminium)	27229	26992	7972	33340	12
As (arsenic)	1271	430	41,5	2750	12
Ba (barium)	3500	3316	860	13094	12
Ca (calcium)	71583	67689	45303	123757	12
Cd (cadmin)	7	8	2,9	278	12
Co (cobalt)	11	20	6,9	70,5	12
Cr (chromium)	2438	948	80,6	3191	12
Cu (copper)	854	594	75	1912	12
Fe (iron)	24042	22508	9306	60394	12
Hg (mercury)	1	1	0	3,13	12
K (potassium)	22042	20494	10020	26291	12
Mg (magnesium)	14688	11729	5340	29563	12
Mn (manganese)	2479	1688	755	2538	12
Mo (molybdenum)	10	8	0,28	17,2	12
Na (sodium)	16521	14357	5800	19127	12
Ni (nickel)	42	39	14	106	12
P (phosphorus)	1875	1787	755	2758	12
Pb (lead)	563	544	140	28611	12
Sb (antimony)	14	13	2,5	53	12
Si (silicon)	118646	116107	54444	171971	12
Ti (titanium)	18333	17582	4333	47500	12
Tl (thallium)	0	0	0	3,13	12
V (vanadium)	81	39	11,9	109	12
Zn (zinc)	6313	10393	2420	184167	12

B.4 Willow

|--|

Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	51	56	51	61	2
Ash (% dry)	1,9	2,9	1,9	4,2	4
Volatile substances (% dry, ash-free)	80,8	79,2	77,5	80,8	2
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	19,5	19,97	19,5	21,4	4
Hhigher (ar)	9,38	8,4	7,47	9,38	2
Hlower (dry, ash-free)	18,15	18,62	18,15	20,01	4
Hlower (ar)	7,48	6,48	5,48	7,48	2
Elementary analysis (% dry, ash-free)					
C (carbon)	48,9	49,8	48,9	52,1	4
H (hydrogen)	6,22	6,26	6,12	6,57	4
O (oxygen)	44,37	43,2	41,09	44,37	4
S (sulphur)	0,04	0,033	0,02	0,05	4
N (nitrogen)	0,41	0,39	0,21	0,61	4
Cl (chlorine)	0,03	0,026	0,02	0,41	4
Ash analysis (mg/kg of ash)					
Al (aluminium)	635	2170	635	44402	4
As (arsenic)	<1	4,5	1	8	2
Ba (barium)	-	806			1
Ca (calcium)	247999	242996	134362	275156	4
Cd (cadmin)	92	82	72	92	2
Co (cobalt)	-				
Cr (chromium)	16	20	16	249	3
Cu (copper)	135	118	96	155	4
Fe (iron)	839	1854	839	62670	4
Hg (mercury)	0,4				
K (potassium)	158558	123277	38104	158558	4
Mg (magnesium)	23882	23339	21530	27681	4
Mn (manganese)	1896	2032	1264	2332	4
Mo (molybdenum)	-				
Na (sodium)	1484	2504	1484	7752	4
Ni (nickel)	54	54	21	79	3
P (phosphorus)	35871	36940	15972	40583	4
Pb (lead)	9	10.5	9	12	2
Sb (antimony)	-	-	-	_	
Si (silicon)	31367	93260	31367	159406	4
Ti (titanium)	60	150	60	8691	4
TI (thallium)	_	_	-	-	
V (vanadium)	3	3	3	222	3
Zn (zinc)	2850	3145	1930	3500	4

B.5 Conifer bark

Test	Example Dried	Median	Range		ian Range Number of analyses	Number of analyses
Fuel content (% by weight)			Min	Max		
Moisture	0,3	57,1	49,7	64,7	10	
Ash (% dry)	3,0	3,0	1,7	4,0	17	
Volatile substances (% dry, ash-free)						
Calorific value (MJ/kg)						
Hhigher (dry, ash-free)	21,7	21,5	19,9	22,4	16	
Hhigher (ar)		8,8	6,9	10,8	10	
Hlower (dry, ash-free)	20,4	20,3	18,8	21,3	16	
Hlower (ar)		7,1	4,9	8,9	10	
Elementary analysis (% dry, ash-free)						
C (carbon)	53,6	53,7	49,3	55,4	16	
H (hydrogen)	6,2	6,1	5,8	6,7	16	
O (oxygen)	39,7	39,9	38,3	44,1	16	
S (sulphur)	0,04	0,03	0,00	0,10	16	
N (nitrogen)	0,46	0,31	0,02	0,52	16	
Cl (chlorine)	0,02	0,01	0,00	0,02	14	
Ash analysis (mg/kg of ash)						
Al (aluminium)	13 100	20 108	4 551	53 452	8	
As (arsenic)	20	21	2	68	4	
Ba (barium)	2 600	2 600			1	
Ca (calcium)	263 000	263 000	59 320	349 378	7	
Cd (cadmin)	9	9			1	
Co (cobalt)	11	13	10	41	4	
Cr (chromium)	64	64	48	122	3	
Cu (copper)	180	161	116	180	3	
Fe (iron)	6 800	9 265	1 749	58 053	8	
Hg (mercury)		1			1	
K (potassium)	5 020	40 530	5 020	64 162	8	
Mg (magnesium)	2 010	18 564	2 010	39 568	7	
Mn (manganese)	9 200	9 100	1	20 811	4	
Mo (molybdenum)	10	62	10	57 576	3	
Na (sodium)	4 800	4 800	4 568	7 107	3	
Ni (nickel)	27	105	27	21 212	3	
P (phosphorus)	11 900	12 952	6 000	20 990	6	
Pb (lead)	71	57	12	71	3	
Sb (antimony)		6 061			1	
Si (silicon)	72 400	72 727	5 985	244 998	7	
Ti (titanium)	1 000	740	42	5 946	6	
Tl (thallium)		12 121			1	
V (vanadium)	15	32	15	48	2	
Zn (zinc)	3 800	3 636	3 541	3 800	3	

Table 5Analysis of conifer bark

B.6 Birch bark

Table 6	Analysis of birch bark
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Test	Example	Median	Range		n Range Number of analyses
Fuel content (% by weight)			Min	Мах	
Moisture	21,1	50,0	21,1	50,0	4
Ash (% dry)	3,2	3,3	1,6	4,0	4
Volatile substances (% dry, ash-free)					
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	21,3	23,8	22,2	24,6	4
Hhigher (ar)	15,8	11,4	11,4	17,4	4
Hlower (dry, ash-free)		22,2	20,9	23,1	4
Hlower (ar)		9,5	9,4	15,8	4
Elementary analysis (% dry, ash-free)					
C (carbon)	55,5	55,8	55,5	57,5	4
H (hydrogen)	6,4	6,9	6,2	7,2	4
O (oxygen)	37,4	36,9	27,4	37,4	4
S (sulphur)	0,04	0,03	0,00	0,05	4
N (nitrogen)	0,6	0,80	0,04	8,13	4
Cl (chlorine)	0,02	0,00	0,00	0,02	4
Ash analysis (mg/kg of ash)					
Al (aluminium)	10 600				
As (arsenic)	20				
Ba (barium)	2 600				
Ca (calcium)	228 000				
Cd (cadmin)	10				
Co (cobalt)	11				
Cr (chromium)	15				
Cu (copper)	119				
Fe (iron)	5 200				
Hg (mercury)					
K (potassium)	53 700				
Mg (magnesium)	20 800				
Mn (manganese)	9 300				
Mo (molybdenum)					
Na (sodium)	6 800				
Ni (nickel)	14				
P (phosphorus)	11 700				
Pb (lead)	38				
Sb (antimony)					
Si (silicon)	71 200				
Ti (titanium)	600				
Tl (thallium)					
V (vanadium)	12				
Zn (zinc)	3 600				

B.7 Aspen bark

Table 7	Analysis of aspen bark
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Test	Example Dried	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	12,0				
Ash (% dry)	3,1	4,4	3,1	5,7	2
Volatile substances (% dry, ash-free)					
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	21,7				
Hhigher (ar)					
Hlower (dry, ash-free)	20,3				
Hlower (ar)					
Elementary analysis (% dry, ash-free)					
C (carbon)	53,3				
H (hydrogen)	6,3	6,3	6,3	6,4	2
O (oxygen)	39,8				
S (sulphur)	0,04	0,0	0,0	0,0	2
N (nitrogen)	0,62				
Cl (chlorine)	0,01	0,0	0,0	0,0	2
Ash analysis (mg/kg of ash)					
Al (aluminium)	1 700	26 727	1 700	51 754	2
As (arsenic)	20	20			1
Ba (barium)	1 500	1 500			1
Ca (calcium)	288 000	214 789	141 579	288 000	2
Cd (cadmin)	21	21			1
Co (cobalt)	14	14			1
Cr (chromium)	16	16			1
Cu (copper)	64	64			1
Fe (iron)	1 800	10 988	1 800	20 175	2
Hg (mercury)					
K (potassium)	86 300	65 694	45 088	86 300	2
Mg (magnesium)	33 400	24 858	16 316	33 400	2
Mn (manganese)	24 600	24 600			1
Mo (molybdenum)	10	10			1
Na (sodium)	12 500	14 671	12 500	16 842	2
Ni (nickel)	41	41			1
P (phosphorus)	13 400	11 437	9 474	13 400	2
Pb (lead)	140	140			1
Sb (antimony)					
Si (silicon)	99 000	169 868	99 000	240 737	2
Ti (titanium)	1 300	1 300			1
Tl (thallium)					
V (vanadium)	24	24			1
Zn (zinc)	3 170	3 170			1

B.8 Birch

Test	Example	Median	Ra	Number of analyses	
Fuel content (% by weight)			Min	Мах	
Moisture	11,1	12,4	5	35,6	5
Ash (% dry)	0,4	0,5	0,2	2,2	16
Volatile substances (% dry, ash-free)	79	86,6	79	94,9	4
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	19,79	19,6	18,2	20,4	8
Hhigher (ar)	17,53				
Hlower (dry, ash-free)	18,63				
Hlower (ar)	16,23				
Elementary analysis (% dry, ash-free)					
C (carbon)	48,9	49	47,7	50,9	12
H (hydrogen)	6,4	6,21	5,6	7,6	12
O (oxygen)	44,6	44,5	40,5	45,8	12
S (sulphur)	0	0,1	0	0,5	8
N (nitrogen)	0,08	0,19	0,08	0,5	10
Cl (chlorine)					
Ash analysis (mg/kg of ash)					
Al (aluminium)	100				
As (arsenic)					
Ba (barium)					
Ca (calcium)	275000				
Cd (cadmin)					
Co (cobalt)					
Cr (chromium)					
Cu (copper)	550				
Fe (iron)	1500				
Hg (mercury)					
K (potassium)	250000				
Mg (magnesium)	45000				
Mn (manganese)					
Mo (molybdenum)					
Na (sodium)	750				
Ni (nickel)	100				
P (phosphorus)	32500				
Pb (lead)	200				
Sb (antimony)					
Si (silicon)	250				
Ti (titanium)					
Tl (thallium)					
V (vanadium)					
Zn (zinc)	550				

B.9 Straw

Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	12,6	12,4	11,5	24	6
Ash (% dry)	3,9	4,95	3,8	5,9	6
Volatile substances (% dry, ash-free)					
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	18,69	18,86	18,16	19,7	6
Hhigher (ar)	15,70	15,89	12,99	16,41	6
Hlower (dry, ash-free)	17,40	17,56	16,93	18,37	6
Hlower (ar)	14,31	14,51	11,52	15,01	6
Elementary analysis (% dry, ash-free)					
C (carbon)	48,07	48,32	47,72	49,74	6
H (hydrogen)	5,93	5,93	5,63	6,11	6
O (oxygen)	45,04	44,89	43,27	45,56	6
S (sulphur)	0,1	0,08	0,07	0,1	6
N (nitrogen)	0,7	0,6	0,4	0,7	6
Cl (chlorine)	0,16	0,12	0,05	0,23	6
Ash analysis (mg/kg of ash)					
Al (aluminium)	2434	2434	1535	3017	6
As (arsenic)					
Ba (barium)					
Ca (calcium)	90766	77187	67896	109348	6
Cd (cadmin)					
Co (cobalt)					
Cr (chromium)					
Cu (copper)					
Fe (iron)	4057	1888	1259	4057	6
Hg (mercury)					
K (potassium)	152747	56450	9132	152747	6
Mg (magnesium)	20505	12062	12062	20505	6
Mn (manganese)	620	387	387	697	6
Mo (molybdenum)					
Na (sodium)	6677	6862	5564	7419	6
Ni (nickel)					
P (phosphorus)	23565	16583	13964	7419	6
Pb (lead)					
Sb (antimony)					
Si (silicon)	217371	303853	217371	339380	6
Ti (titanium)					
Tl (thallium)					
V (vanadium)					
Zn (zinc)					

B.10 Canary Grass

	Table 10	Analysis of Reed Canary Grass
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Test	Example pellets	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	12,7	14,4	12,7	19,9	9
Ash (% dry)	2,5	5,9	2,5	10	9
Volatile substances (% dry, ash-free)	80,9				
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	20,12	19,01	17,27	20,12	9
Hhigher (ar)	17,12	15,22	13,69	17,12	9
Hlower (dry, ash-free)	18,78	17,66	15,97	18,78	9
Hlower (ar)	15,76	13,84	12,28	15,76	9
Elementary analysis (% dry, ash-free)					
C (carbon)	50,5	48,6	44,9	50,5	9
H (hydrogen)	6,15	5,95	5,89	6,16	9
O (oxygen)	42,3	43,7	42,3	47,1	9
S (sulphur)	0,10	0,18	0,1	0,25	9
N (nitrogen)	1,0	1,16	0,93	1,18	9
Cl (chlorine)	0,01	0,82	0,1	1,22	9
Ash analysis (mg/kg of ash)					
Al (aluminium)	7832	2805	1323	7832	9
As (arsenic)	21				1
Ba (barium)	1192				1
Ca (calcium)	99199	66466	40737	99199	9
Cd (cadmin)	3				1
Co (cobalt)	3				1
Cr (chromium)	34				1
Cu (copper)	91				1
Fe (iron)	13849	3287	1818	13849	9
Hg (mercury)	1				1
K (potassium)	57447	129503	57447	189274	9
Mg (magnesium)	22071	21710	14473	26535	9
Mn (manganese)		387	310	587	8
Mo (molybdenum)	37				1
Na (sodium)	2077	7047	2077	8902	9
Ni (nickel)	10				1
P (phosphorus)	50626	32292	16146	50626	9
Pb (lead)	51				1
Sb (antimony)	-				
Si (silicon)	248677	218306	167253	254769	9
Ti (titanium)	360				1
Tl (thallium)	-				<u> </u>
V (vanadium)	10				1
Zn (zinc)	2432				1

B.11 Hemp

Table 11Analysis of hemp

Test	Example Median Range		Number of analyses		
Fuel content (% by weight)			Min	Мах	
Moisture	56,6				
Ash (% dry)	6,3				
Volatile substances (% dry, ash-free)					
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	19,38				
Hhigher (ar)	7,88				
Hlower (dry, ash-free)	17,99				
Hlower (ar)	5,93				
Elementary analysis (% dry, ash-free)					
C (carbon)	48,8				
H (hydrogen)	6,4				
O (oxygen)	43,1				
S (sulphur)	0,1				
N (nitrogen)	1,4				
Cl (chlorine)	0,28				
Ash analysis (mg/kg of ash)					
Al (aluminium)	4968				
As (arsenic)	3				
Ba (barium)	238				
Ca (calcium)	166667				
Cd (cadmin)	1				
Co (cobalt)	2				
Cr (chromium)	46				
Cu (copper)	86				
Fe (iron)	3778				
Hg (mercury)	0				
K (potassium)	263222				
Mg (magnesium)	25825				
Mn (manganese)	365				
Mo (molybdenum)	7				
Na (sodium)	4222				
Ni (nickel)	21				
P (phosphorus)	28841				
Pb (lead)	35				
Sb (antimony)	1				
Si (silicon)	36508				
Ti (titanium)	397				
Tl (thallium)	1				
V (vanadium)	8				
Zn (zinc)	603				

B.12 Wheat

Table 12	Analysis of wheat
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Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	13,9	10,5	0	18	42
Ash (% dry)	1,7	6	1,2	13,5	33
Volatile substances (% dry, ash-free)		81,3	76,5	87	33
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	18,11	19,3	16,6	21,7	87
Hhigher (ar)	15,33				
Hlower (dry, ash-free)	16,72	17,9	15,2	20,5	57
Hlower (ar)	13,81				
Elementary analysis (% dry, ash-free)					
C (carbon)	45,17	49,1	44,5	52,6	64
H (hydrogen)	6,41	5,93	3,2	6,42	64
O (oxygen)	46,30	43,9	39,4	50,1	64
S (sulphur)	0,40	0,15	0	0,46	59
N (nitrogen)	1,73	0,7	0,25	2,08	68
Cl (chlorine)		0,459	0,021	2,316	56
Ash analysis (mg/kg of ash)					
Al (aluminium)	1058				
As (arsenic)	41				
Ba (barium)	349				
Ca (calcium)	24585	29089	24585	33594	2
Cd (cadmin)					
Co (cobalt)	15				
Cr (chromium)	97				
Cu (copper)	263				
Fe (iron)	3147				
Hg (mercury)					
K (potassium)	219989	152344	116596	219989	3
Mg (magnesium)	72007		14844	72007	2
Mn (manganese)	1471				
Mo (molybdenum)	47				
Na (sodium)	334	2979	334	78125	3
Ni (nickel)	29				
P (phosphorus)	174553		6250	174553	2
Pb (lead)	25				
Sb (antimony)					
Si (silicon)	17296				
Ti (titanium)	60				
Tl (thallium)					
V (vanadium)	<5				
Zn (zinc)	1527				

B.13 Crop residues

Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Мах	
Moisture	12				
Ash (% dry)	9,8				
Volatile substances (% dry, ash-free)	74,3				
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	19,8				
Hhigher (ar)	15,7				
Hlower (dry, ash-free)	16,6				
Hlower (ar)	14,3				
Elementary analysis (% dry, ash-free)					
C (carbon)	43,4				
H (hydrogen)	5,8				
O (oxygen)	39,1				
S (sulphur)	0,21				
N (nitrogen)	1,7				
Cl (chlorine)	0,16				
Ash analysis (mg/kg of ash)					
Al (aluminium)	5293				
As (arsenic)	0,13				
Ba (barium)	186				
Ca (calcium)	41810				
Cd (cadmin)	0,042				
Co (cobalt)	0,11				
Cr (chromium)	38,8				
Cu (copper)	5,33				
Fe (iron)	8463				
Hg (mercury)	<0,01				
K (potassium)	107589				
Mg (magnesium)	17850				
Mn (manganese)	0,39				
Mo (molybdenum)	<6				
Na (sodium)	8309				
Ni (nickel)	0,69				
P (phosphorus)	33082				
Pb (lead)	0,73				
Sb (antimony)					
Si (silicon)	279995				
Ti (titanium)	0,40				
Tl (thallium)					
V (vanadium)	8,71				
Zn (zinc)	49				

Table 13Analysis of crop residues

B.14 Olive residues

Table 14 Analysis of olive residue

Test	Example Median Range Numb	Range		Number of analyses	
Fuel content (% by weight)			Min	Max	
Moisture	20,8	8,1	0	20,8	15
Ash (% dry)	8,7	4,5	0,4	16,2	20
Volatile substances (% dry, ash-free)	78,6	79,6	66,1	97	14
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	21,47	21,7	18,7	24,5	18
Hhigher (ar)	15,53				
Hlower (dry, ash-free)	20,14	20,3	17,4	23,3	17
Hlower (ar)	14,06				
Elementary analysis (% dry, ash-free)					
C (carbon)	53,67	51,1	38,4	58,4	20
H (hydrogen)	6,13	6,4	5,49	7,76	20
O (oxygen)	38,25	41,4	33	54,4	20
S (sulphur)	0,12	0,14	0,01	0,31	17
N (nitrogen)	1,75	1,33	0,37	3,82	19
Cl (chlorine)	0,08	0,141	0,00	0,37	12
Ash analysis (mg/kg of ash)					
Al (aluminium)	14356	14356	10993	24771	3
As (arsenic)	3				
Ba (barium)	103	139	103	174	2
Ca (calcium)	137188	137188	119266	142939	3
Cd (cadmin)	< 0,1				
Co (cobalt)	8				
Cr (chromium)	104				
Cu (copper)	256				
Fe (iron)	15516	15516	12653	21101	3
Hg (mercury)	< 0,1				
K (potassium)	100190	211111	82569	276471	5
Mg (magnesium)	11091	35636	11091	46789	3
Mn (manganese)	363	431	363	431	3
Mo (molybdenum)	1				
Na (sodium)	4042	7615	4042	20588	5
Ni (nickel)	63				
P (phosphorus)	8728	10791	8728	12844	2
Pb (lead)	13				
Sb (antimony)	-				
Si (silicon)	225136	128440	68420	225136	3
Ti (titanium)	896	775	654	896	2
Tl (thallium)	-				
V (vanadium)	26				
Zn (zinc)	508		29	43,8	2

B.15 Cocoa beans and shells

Test	Example	Median	Ra	Number of analyses	
Fuel content (% by weight)			Min	Max	
Moisture	6,5	7,35	6,5	13,4	4
Ash (% dry)	5,2	8,3	5,2	10,5	5
Volatile substances (% dry, ash-free)		74,95	74,1	75,8	2
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	29,92	20,54	20,1	29,92	5
Hhigher (ar)	26,52	17,01	15,9	26,52	4
Hlower (dry, ash-free)	27,93	19,26	18,7	27,93	5
Hlower (ar)	24,60	15,72	14,6	24,6	4
Elementary analysis (% dry, ash-free)					
C (carbon)	61,7	52,6	50,2	61,7	5
H (hydrogen)	9,28	6	5,7	9,28	5
O (oxygen)	25,41	37,6	25,41	39,7	5
S (sulphur)	0,33	0,22	0,13	0,33	5
N (nitrogen)	2,95	3,32	2,95	3,7	5
Cl (chlorine)	0,11	0,087	0,016	0,11	3
Ash analysis (mg/kg of ash)					
Al (aluminium)	2117	7309	2117	12500	2
As (arsenic)		77	10	144	2
Ba (barium)		9263			
Ca (calcium)	45740	45740	20952	50000	3
Cd (cadmin)		14,5	10	19	2
Co (cobalt)		40	14	66	2
Cr (chromium)		524	35	1013	2
Cu (copper)	577	577	333	2113	3
Fe (iron)	4896	8073	4896	11250	2
Hg (mercury)		2,5	1	4	2
K (potassium)	386019	257143	8750	386019	3
Mg (magnesium)	65735	46667	5000	65735	3
Mn (manganese)	769	800	769	1038	3
Mo (molybdenum)		95			
Na (sodium)	5564	5564	276	8750	3
Ni (nickel)	212	212	93	400	3
P (phosphorus)	126114	30476	1250	126114	3
Pb (lead)		3891	31	7750	2
Sb (antimony)		250			
Si (silicon)	6077	50000	6077	72381	3
Ti (titanium)		7500			
Tl (thallium)					
V (vanadium)		79	20	138	2
Zn (zinc)	1385	1385	857	10363	3

Table 15Analysis of cocoa beans and shells

B.16 Citrus pulp

Table 16 Analysis citrus pu	Table 16	Analysis citrus pulp
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Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	7,82	8,91	7,82	10	2
Ash (% dry)	4,44	4,47	4,2	9,5	4
Volatile substances (% dry, ash-free)		75,7	68,9	77,7	3
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	20,80	22,62	20,8	22,82	4
Hhigher (ar)	18,33				
Hlower (dry, ash-free)	19,35	21,04	19,35	21,43	3
Hlower (ar)	16,85				
Elementary analysis (% dry, ash-free)					
C (carbon)	50,27	55,7	50,27	58,5	4
H (hydrogen)	6,7	6,65	6,1	6,9	4
O (oxygen)	41,67	35,7	33,6	41,7	4
S (sulphur)	0,21	0,21	0,03	0,22	3
N (nitrogen)	1,13	1,93	1,13	2,18	4
Cl (chlorine)	0,02				
Ash analysis (mg/kg of ash)					
Al (aluminium)	1058				
As (arsenic)	2				
Ba (barium)					
Ca (calcium)	238207				
Cd (cadmin)					
Co (cobalt)					
Cr (chromium)					
Cu (copper)	151				
Fe (iron)	3287				
Hg (mercury)					
K (potassium)	144861				
Mg (magnesium)	16162				
Mn (manganese)	270				
Mo (molybdenum)					
Na (sodium)	5972				
Ni (nickel)	50				
P (phosphorus)	15535				
Pb (lead)	38				
Sb (antimony)					
Si (silicon)	17296				
Ti (titanium)	659				
Tl (thallium)					
V (vanadium)	45				
Zn (zinc)	1622				

B.17 Shea nuts

Table 17	Analysis of shea nuts
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Test	Example Sheakaka	Example Shea meal	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	3,3	7,6			
Ash (% dry)	6,7	7			
Volatile substances (% dry, ash-free)					
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	22,99				
Hhigher (ar)	20,74				
Hlower (dry, ash-free)	21,55				
Hlower (ar)	19,36				
Elementary analysis (% dry, ash-free)					
C (carbon)	55,3				
H (hydrogen)	6,6				
O (oxygen)	34,5				
S (sulphur)	0,27	0,28			
N (nitrogen)	3,2	3,01			
Cl (chlorine)	-	0,10			
Ash analysis (mg/kg of ash)					
Al (aluminium)	12800				
As (arsenic)	< 20				
Ba (barium)	300				
Ca (calcium)	41200	27143			
Cd (cadmin)	< 1				
Co (cobalt)	-				
Cr (chromium)	56				
Cu (copper)	97				
Fe (iron)	17300				
Hg (mercury)	-				
K (potassium)	272000	371429			
Mg (magnesium)	32100	31429			
Mn (manganese)	500				
Mo (molybdenum)	< 10				
Na (sodium)	7900				
Ni (nickel)	44				
P (phosphorus)	33300	31429			
Pb (lead)	48				
Sb (antimony)	-				
Si (silicon)	121000				
Ti (titanium)	1600				
Tl (thallium)	-				
V (vanadium)	-				
Zn (zinc)	520				

B.18 Sewage sludge

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Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	77,2	73,9	53	77,2	6
Ash (% dry)	42,8	43	35	49,8	14
Volatile substances (% dry, ash-free)	90,9	88	82,2	97,6	14
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	23,2	22,8	15,3	23,9	13
Hhigher (ar)	3,03	3,32	3,03	4,04	3
Hlower (dry, ash-free)	21,6	20,7	13,03	21,93	7
Hlower (ar)	0,94	1,21	0,94	2	3
Elementary analysis (% dry, ash-free)					
C (carbon)	52,4	52,25	46,1	54,9	14
H (hydrogen)	7	7,35	6	8,5	14
O (oxygen)	31,1	31,3	27,6	36,7	14
S (sulphur)	2,62	2,05	0,22	5,33	14
N (nitrogen)	6,65	6,8	5,48	8,08	14
Cl (chlorine)	0,087	0,12	0,05	1,51	14
Ash analysis (mg/kg of ash)					
Al (aluminium)	46496	51443	18400	82400	4
As (arsenic)	9,64	16	9,64	20	3
Ba (barium)	799	1000	799	1111	3
Ca (calcium)	59114	53557	27200	108333	4
Cd (cadmin)	1,05	3,2	1,05	4	3
Co (cobalt)	6,41	18	6,41	23	3
Cr (chromium)	43,3	79	43,3	178	3
Cu (copper)	447	930	447	1250	3
Fe (iron)	210813	146556	73800	210813	4
Hg (mercury)	0,93	3,47	0,9	6	2
K (potassium)	1102	4035	1102	15100	4
Mg (magnesium)	11131	10705	4180	11900	4
Mn (manganese)	574	1000	574	1125	3
Mo (molybdenum)	6,19	12,1	6,19	19	2
Na (sodium)	4871	4658	602	8500	4
Ni (nickel)	16,6	56	16,6	472	3
P (phosphorus)	105030	64367	38800	105030	4
Pb (lead)	30,5	100	30,5	500	3
Sb (antimony)	-	10,5	1	20	2
Si (silicon)	84860	87708	48800	142000	4
Ti (titanium)	4678	2923	538	4700	4
Tl (thallium)	-	-	-	-	
V (vanadium)	29,8	39	29,8	87	3
Zn (zinc)	494	1560	494	2583	3

B.19 Fibre sludge

Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	67,0	69,0	60,1	78,0	7
Ash (% dry)	2,4	7,9	1,6	31,9	7
Volatile substances (% dry, ash-free)	81,8	84,7	81,8	87,6	2
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	21,0	19,8	18,9	22,8	7
Hhigher (ar)	6,8	5,2	3,1	7,5	7
Hlower (dry, ash-free)	19,6	18,7	17,4	21,4	7
Hlower (ar)	4,7	3,9	1,0	5,5	7
Elementary analysis (% dry, ash-free)					
C (carbon)	52,20	50,32	47,5	54,5	7
H (hydrogen)	6,50	6,48	6,1	6,7	7
O (oxygen)	40,59	42,78	38,0	46,1	7
S (sulphur)	0,26	0,23	0,1	0,3	7
N (nitrogen)	0,44	0,35	0,2	0,6	7
Cl (chlorine)	0,01	0,01	0,0	0,0	7
Ash analysis (mg/kg of ash)					
Al (aluminium)	84 100	77 400	17 900	168 000	7
As (arsenic)		20	20	80	6
Ba (barium)	1 200	800	200	4 000	7
Ca (calcium)	94 600	90 650	35 400	217 000	7
Cd (cadmin)		4	1	18	6
Co (cobalt)		8	3	20	6
Cr (chromium)		170	147	228	6
Cu (copper)		150	3	370	6
Fe (iron)	23 300	9 900	4 000	27 000	7
Hg (mercury)		0	0	1	3
K (potassium)	9 500	8 050	1 300	9 500	7
Mg (magnesium)	10 900	11 450	4 200	85 400	7
Mn (manganese)	1 100	900	300	4 000	7
Mo (molybdenum)	0	28	0	250	7
Na (sodium)	108 000	54 500	4 200	108 000	7
Ni (nickel)		90	61	112	6
P (phosphorus)	14 200	5 450	2 000	24 100	7
Pb (lead)		56	10	98	6
Sb (antimony)		13	0	20	5
Si (silicon)	116 000	164 000	74 600	244 000	7
Ti (titanium)	4 800	3 700	1 000	8 000	7
Tl (thallium)		39	0	49	5
V (vanadium)		45	9	92	6
Zn (zinc)		524	240	1 040	6

Table 19Analysis of fibre sludge

B.20 Chemical sludge

Table 20	Analysis of chemical sludge

Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	64,0	68,7	45,0	75,6	9
Ash (% dry)	12,4	12,4	7,3	22,2	9
Volatile substances (% dry, ash-free)		72,7	72,1	77,4	3
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	22,3	21,5	18,2	18,2	9
Hhigher (ar)	7,0	6,5	4,9	4,9	9
Hlower (dry, ash-free)	20,8	20,1	16,8	22,3	9
Hlower (ar)	5,0	4,5	2,8	6,1	9
Elementary analysis (% dry, ash-free)					
C (carbon)	54,3	52,4	45,8	58,0	9
H (hydrogen)	6,7	6,5	6,4	7,2	9
O (oxygen)	37,2	38,2	32,5	46,9	9
S (sulphur)	0,5	0,9	0,5	2,4	9
N (nitrogen)	1,1	0,6	0,3	2,3	9
Cl (chlorine)	0,06	0,04	0,01	0,12	9
Ash analysis (mg/kg of ash)					
Al (aluminium)	146 000	238 000	146 000	317 000	9
As (arsenic)	20	20	20	22	6
Ba (barium)	700	400	200	1 370	9
Ca (calcium)	100 000	41 096	1 200	151 000	9
Cd (cadmin)	4	5	1	8	6
Co (cobalt)	10	13	3	76	6
Cr (chromium)	140	156	74	2 600	6
Cu (copper)	95	143	90	230	6
Fe (iron)	15 100	15 100	7 700	25 100	9
Hg (mercury)	0,40	0	0	0,6	4
K (potassium)	11 800	6 300	1 000	17 808	9
Mg (magnesium)	7 400	7 400	4 400	40 000	9
Mn (manganese)	900	741	100	1 370	9
Mo (molybdenum)	19	10	0	25	7
Na (sodium)	30 300	11 700	7 200	83 562	9
Ni (nickel)	63	32	0	190	7
P (phosphorus)	11 000	6 300	1 300	20 000	9
Pb (lead)	30	37	5	49	6
Sb (antimony)		8	5	10	2
Si (silicon)	154 000	110 000	64 900	169 863	9
Ti (titanium)	3 500	13 699	2 963	36 400	9
Tl (thallium)		41	10	71	2
V (vanadium)	73	62	16	93	6
Zn (zinc)	530	703	61	1 185	6

B.21 Biological treated sludge

Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	-
Moisture	70,1	78,3	70,1	84,0	5
Ash (% dry)	29,7	20,4	14,4	36,8	5
Volatile substances (% dry, ash-free)		83,0	82,9	83,1	2
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	22,8	22,6	19,8	24,0	5
Hhigher (ar)	4,8	3,4	2,4	4,8	5
Hlower (dry, ash-free)	21,4	18,5	17,9	22,5	5
Hlower (ar)	2,8	1,3	0,2	2,8	5
Elementary analysis (% dry, ash-free)					
C (carbon)	53,5	49,5	47,8	56,2	5
H (hydrogen)	6,7	6,5	6,4	7,0	5
O (oxygen)	31,9	39,3	29,4	41,6	5
S (sulphur)	2,2	1,6	1,4	2,2	5
N (nitrogen)	5,4	3,3	2,7	5,4	5
Cl (chlorine)	0,30	0,03	0,02	0,30	5
Ash analysis (mg/kg of ash)					
Al (aluminium)	141 000	110 000	108 000	143 000	5
As (arsenic)	20	20	20	20	4
Ba (barium)	200	500	200	1 700	5
Ca (calcium)	13 500	44 300	13 500	180 000	5
Cd (cadmin)	5	11	3	28	5
Co (cobalt)	24	14	8	24	5
Cr (chromium)	148	95	42	148	5
Cu (copper)	46	110	46	145	5
Fe (iron)	142 000	96 400	16 800	142 000	5
Hg (mercury)					
K (potassium)	6 900	10 800	6 900	17 700	5
Mg (magnesium)	13 200	19 700	12 300	38 600	5
Mn (manganese)	1 100	4 300	1 100	7 300	5
Mo (molybdenum)	10	11	10	120	5
Na (sodium)	8 100	13 700	8 100	32 600	5
Ni (nickel)	70	40	35	72	5
P (phosphorus)	12 400	12 400	4 500	25 700	5
Pb (lead)	85	54	25	92	5
Sb (antimony)	12	16	10	20	4
Si (silicon)	171 000	112 000	100 000	186 000	5
Ti (titanium)	10 800	3 600	1 100	10 800	5
Tl (thallium)	25	20	0	25	5
V (vanadium)	221	40	30	221	5
Zn (zinc)	880	660	500	1 060	5

Table 21Analysis of biological treated sludge

B.22 De-inking sludge

Table 22	Analvsis of de-inking sludge
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Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	41,1	43,0	41,1	58,0	3
Ash (% dry)	59,4	55,0	48,1	59,4	3
Volatile substances (% dry, ash-free)	96,8	96,8	96,8	96,8	1
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	23,2	23,2	22,3	23,5	3
Hhigher (ar)	5,5	5,5	5,1	5,7	3
Hlower (dry, ash-free)	21,6	21,6	20,8	22,0	3
Hlower (ar)	4,2	4,2	3,4	4,3	3
Elementary analysis (% dry, ash-free)					
C (carbon)	67,5	63,9	55,5	67,5	3
H (hydrogen)	7,4	7,0	6,8	7,4	3
O (oxygen)	24,0	28,1	24,0	36,4	3
S (sulphur)	0,2	0,3	0,2	0,3	3
N (nitrogen)	0,9	0.9	0,7	1,0	3
Cl (chlorine)	0.09	0,08	0,0	0,1	2
Ash analysis (mg/kg of ash)	,			,	
Al (aluminium)	49 000	48 300	47 600	49 000	2
As (arsenic)	20	20	20	20	2
Ba (barium)	200	200	200	200	2
Ca (calcium)	250 000	244 000	238 000	250 000	2
Cd (cadmin)	1	1	1	1	2
Co (cobalt)	9	7	4	9	2
Cr (chromium)	72	53	33	72	2
Cu (copper)	530	455	380	530	2
Fe (iron)	4 800	4 400	4 000	4 800	2
Hg (mercury)			0	0	
K (potassium)	2 800	4 300	2 800	5 800	2
Mg (magnesium)	28 800	25 800	22 800	28 800	2
Mn (manganese)	200	250	200	300	2
Mo (molybdenum)	10	8	5	10	2
Na (sodium)	2 000	3 850	2 000	5 700	2
Ni (nickel)	80	47	13	80	2
P (phosphorus)	700	750	700	800	2
Pb (lead)	32	26	19	32	2
Sb (antimony)		10	10	10	1
Si (silicon)	102 000	98 150	94 300	102 000	2
Ti (titanium)	1 700	1 550	1 400	1 700	2
Tl (thallium)		10	10	10	1
V (vanadium)	18	14	9	18	2
Zn (zinc)	150	135	120	150	2

B.23 Cow manure

Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	14		14	74	3
Ash (% dry)	16		16	42	3
Volatile substances (% dry, ash-free)	84		84	92	2
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	20,6		19,6	20,6	2
Hhigher (ar)	14,9		8,5	14,9	2
Hlower (dry, ash-free)	19,2		18,2	19,2	2
Hlower (ar)	13,6		7,3	13,6	2
Elementary analysis (% dry, ash-free)					
C (carbon)	54		44,9	54	3
H (hydrogen)	6,4		6,2	6,4	2
O (oxygen)	36,8		36	36,8	2
S (sulphur)	0,34		0,34	1,06	2
N (nitrogen)	1,14		1,14	3,9	3
Cl (chlorine)	1,38		1,38	2,31	2
Ash analysis (mg/kg of ash)					
Al (aluminium)					
As (arsenic)					
Ba (barium)					
Ca (calcium)					
Cd (cadmin)			3		
Co (cobalt)					
Cr (chromium)			129		
Cu (copper)			207		
Fe (iron)					
Hg (mercury)					
K (potassium)	122642		27306	122642	2
Mg (magnesium)					
Mn (manganese)					
Mo (molybdenum)					
Na (sodium)	15094		15094		2
Ni (nickel)			44		
P (phosphorus)			31734		
Pb (lead)			114		
Sb (antimony)					
Si (silicon)					
Ti (titanium)					
Tl (thallium)					
V (vanadium)					
Zn (zinc)			253		

B.24 Pig manure

Table 24	Analysis pig manure
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Test	Example Median		Range		Number of analyses
Fuel content (% by weight)			Min	Max	-
Moisture	12,7		12,7	92,1	2
Ash (% dry)	15,2		15,2	35,4	2
Volatile substances (% dry, ash-free)	74,2		74,2	79,4	2
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	21,0		21	21,3	2
Hhigher (ar)	15,6		1,09	15,6	2
Hlower (dry, ash-free)	20,0		19,9	20,0	2
Hlower (ar)	14,5		1,23	14,5	2
Elementary analysis (% dry, ash-free)					
C (carbon)	51,5		51,5	54,1	2
H (hydrogen)	4,9		4,9	6,8	2
O (oxygen)	39,5		33	39,5	2
S (sulphur)	0,57				1
N (nitrogen)	2,91		1,14	3,9	3
Cl (chlorine)	0,59		0,59	1,84	2
Ash analysis (mg/kg of ash)					
Al (aluminium)	5066				
As (arsenic)	13				
Ba (barium)	132				
Ca (calcium)	54605				
Cd (cadmin)	1				
Co (cobalt)	5				
Cr (chromium)	58				
Cu (copper)	658				
Fe (iron)	9868				
Hg (mercury)					
K (potassium)	96503				
Mg (magnesium)	28289				
Mn (manganese)	987				
Mo (molybdenum)	13				
Na (sodium)	13816				
Ni (nickel)	39				
P (phosphorus)	40132				
Pb (lead)	39				
Sb (antimony)	7				
Si (silicon)	41447				
Ti (titanium)	336				
Tl (thallium)					
V (vanadium)	16				
Zn (zinc)	1974				

B.25 Chicken litter

Test	Example	Median	Range		Number of
Fuel content (% by weight)			Min	Мах	
Moisture	3,9				
Ash (% dry)	27,4				
Volatile substances (% dry, ash-free)	84,5				
Calorific value (MJ/kg)	,				
Hhigher (dry, ash-free)	19,0				
Hhigher (ar)	13,2				
Hlower (dry, ash-free)	17,5				
Hlower (ar)	12,1				
Elementary analysis (% dry, ash-free)					
C (carbon)	49,5				
H (hydrogen)	6,9				
O (oxygen)	37,7				
S (sulphur)	1,06				
N (nitrogen)	4,9				
Cl (chlorine)					
Ash analysis (mg/kg of ash)					
Al (aluminium)	3577				
As (arsenic)					
Ba (barium)					
Ca (calcium)	222628				
Cd (cadmin)					
Co (cobalt)					
Cr (chromium)					
Cu (copper)					
Fe (iron)	4745				
Hg (mercury)					
K (potassium)	114234				
Mg (magnesium)	28102				
Mn (manganese)	1825				
Mo (molybdenum)					
Na (sodium)	17153				
Ni (nickel)					
P (phosphorus)	68613				
Pb (lead)					
Sb (antimony)					
Si (silicon)	17153				
Ti (titanium)	201				
Tl (thallium)					
V (vanadium)					
Zn (zinc)					

Table 25Analysis chicken litter

B.26 Paper-wood-plastics

Table 26	Analysis of paper-wood-plastics
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Test	Example Median Range		Number of analyses		
Fuel content (% by weight)			Min	Max	
Moisture	9,8	22,7	9,8	54,9	11
Ash (% dry)	12,9	10,5	5,2	12,9	11
Volatile substances (% dry, ash-free)					
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	21,4	21,4	18,3	31,2	11
Hhigher (ar)	16,8	14,9	13,0	16,8	11
Hlower (dry, ash-free)	20,0	20,0	19,0	29,2	11
Hlower (ar)	15,5	13,5	10,8	15,5	11
Elementary analysis (% dry, ash-free)					
C (carbon)	51,4	51,9	50,6	62,1	11
H (hydrogen)	6,4	6,9	5,8	9,3	11
O (oxygen)	40,2	40,3	28,2	52,2	11
S (sulphur)	0,32	0,32	0,07	0,52	11
N (nitrogen)	1,26	0,85	0,27	1,26	11
Cl (chlorine)	0,36	0,34	0,01	1,54	11
Ash analysis (mg/kg of ash)					
Al (aluminium)	58 600	58 600	53 600	215 000	6
As (arsenic)	150	97	20	1 300	6
Ba (barium)	6 400	2 798	700	6 400	3
Ca (calcium)	161 000	166 250	131 000	174 000	4
Cd (cadmin)	6	8	2	58	6
Co (cobalt)	36	53	21	130	4
Cr (chromium)	240	764	200	1 200	8
Cu (copper)	300	658	300	3 600	7
Fe (iron)	18 600	18 600	11 910	27 300	6
Hg (mercury)	1	1	1	1	2
K (potassium)	16 100	16 100	6 600	23 769	6
Mg (magnesium)	13 300	14 500	11 200	60 337	5
Mn (manganese)	1 000	1 000	944	1 923	6
Mo (molybdenum)					
Na (sodium)	26 300	19 700	16 292	26 300	6
Ni (nickel)	45	57	43	100	6
P (phosphorus)	2 400	2 700	1 100	3 258	5
Pb (lead)	1 200	1 145	350	2 000	7
Sb (antimony)					
Si (silicon)	166 000	160 500	38 327	168 700	6
Ti (titanium)	14 500	17 100	13 700	25 056	5
Tl (thallium)					
V (vanadium)	67	71	64	87	4
Zn (zinc)	1 800	1 900	1 700	5 981	8

B.27 Processed tyres

Table 27	Analysis of processed tyres
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Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	4,3	1,3	0,6	4,3	7
Ash (% dry)	12,6	7,1	4,8	26	7
Volatile substances (% dry, ash-free)		70,5	70,4	70,6	2
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	36,03	39,9	36,0	43,1	7
Hhigher (ar)	30,41	36,2	30,1	39,5	6
Hlower (dry, ash-free)	34,4	38,3	34,3	41,3	7
Hlower (ar)	28,6	34,2	28,6	37,8	6
Elementary analysis (% dry, ash-free)					
C (carbon)	88,1	86,44	76,9	88,7	7
H (hydrogen)	7,78	7,75	7,2	12,7	7
O (oxygen)	1,54	3,50	1,5	8,5	7
S (sulphur)	2,17	1,79	1,3	3,3	7
N (nitrogen)	0,34	0,37	0,2	0,9	7
Cl (chlorine)	0,06	0,25	0,06	0,94	4
Ash analysis (mg/kg of ash)					
Al (aluminium)	5540				
As (arsenic)	2				
Ba (barium)	140				
Ca (calcium)	28 405				
Cd (cadmin)	20				
Co (cobalt)	782				
Cr (chromium)	233				
Cu (copper)	360				
Fe (iron)	36 016				
Hg (mercury)	1				
K (potassium)	4921				
Mg (magnesium)	3230				
Mn (manganese)	206				
Mo (molybdenum)	3				
Na (sodium)	3952				
Ni (nickel)	31				
P (phosphorus)	1635				
Pb (lead)	172				
Sb (antimony)	0				
Si (silicon)	58 365				
Ti (titanium)	825				
Tl (thallium)	1				
V (vanadium)	5				
Zn (zinc)	124 603	124 603	46 597	318 750	3

B.28 Waste leather

Table 20 Analysis Of Wash		
Test	Example	Median
Fuel content (% by weight)		
Moisture	40,4	47,4
Ash (% dry)	0,7	1,6
Volatile substances (% dry, ash-free)	96,7	

Table 28 Analysis of waste leather

Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	40,4	47,4	40,4	54,3	2
Ash (% dry)	0,7	1,6	0,7	2,5	2
Volatile substances (% dry, ash-free)	96,7				
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	17,17	17,97	17,17	18,76	2
Hhigher (ar)	10,16	9,37	8,57	10,16	2
Hlower (dry, ash-free)	15,98	16,86	15,98	17,73	2
Hlower (ar)	8,47	7,52	6,57	8,47	2
Elementary analysis (% dry, ash-free)					
C (carbon)	45,6	44,1	42,6	45,6	2
H (hydrogen)	5,4	6,1	5,4	6,8	2
O (oxygen)	35,2	32,7	30,2	35,2	2
S (sulphur)	1,61	2,11	1,61	2,61	2
N (nitrogen)	7,1	10,5	7,1	14	2
Cl (chlorine)		1,2			
Ash analysis (mg/kg of ash)					
Al (aluminium)					
As (arsenic)	286				
Ba (barium)					
Ca (calcium)					
Cd (cadmin)	4000				
Co (cobalt)					
Cr (chromium)	23714				
Cu (copper)	26571				
Fe (iron)					
Hg (mercury)	857				
K (potassium)					
Mg (magnesium)					
Mn (manganese)					
Mo (molybdenum)					
Na (sodium)					
Ni (nickel)					
P (phosphorus)					
Pb (lead)	21429				
Sb (antimony)					
Si (silicon)					
Ti (titanium)					
Tl (thallium)					
V (vanadium)					
Zn (zinc)	36143				

B.29 Recycled carton

Table 29	Analysis of recycled carton
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Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	43,1	49,1	42,0	64,4	8
Ash (% dry)	13,7	16,1	10,2	27,1	8
Volatile substances (% dry, ash-free)					
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	20,19	16,89	12,23	20,19	8
Hhigher (ar)	9,92	7,71	6,43	9,92	8
Hlower (dry, ash-free)	17,84	14,73	9,44	17,84	8
Hlower (ar)	7,71	5,48	0,88	7,71	8
Elementary analysis (% dry, ash-free)					
C (carbon)	71,2	69,3	66,0	71,7	8
H (hydrogen)	11,0	10,0	9,6	11,0	8
O (oxygen)	14,66	19,7	17,7	23,5	8
S (sulphur)	0,03	0,11	0,03	0,22	8
N (nitrogen)	0,01	0,23	0,01	0,45	8
Cl (chlorine)	0,13	0,18	0,07	0,57	8
Ash analysis (mg/kg of ash)					
Al (aluminium)	201212	215036	127151	273793	8
As (arsenic)	2	2,7	1,23	17,7	8
Ba (barium)	416	610	559	174	8
Ca (calcium)	221584	223089	219186	137188	8
Cd (cadmin)	1	0,83	0,39	2,57	8
Co (cobalt)	5	6,1	4,6	14,0	8
Cr (chromium)	0,5	76,1	53,8	2118	8
Cu (copper)	49	162,4	117	4074	8
Fe (iron)	6022	7221	4333	92906	8
Hg (mercury)	0	0,29	0,16	1,24	8
K (potassium)	2489	3654	2488	22416	8
Mg (magnesium)	7474	7702	6388	19256	8
Mn (manganese)	226	271	147	1020	8
Mo (molybdenum)	6	6,2	5,5	112	8
Na (sodium)	4015	6969	4015	30446	8
Ni (nickel)	19	20,8	16,7	88,1	8
P (phosphorus)	336	381	147	3942	8
Pb (lead)	55	92,0	36,3	565,2	8
Sb (antimony)	7	3,6	0	23,6	8
Si (silicon)	67102	94344	66546	362064	8
Ti (titanium)	14073	13990	8478	28961	8
Tl (thallium)	0	0,12	0	0,67	8
V (vanadium)	23	22,0	7,3	182	8
Zn (zinc)	555	796,1	519	1168	8

B.30 Meat and bone meal (MBM)

Table 30	Analysis Meat and bone meal	(MBM)
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Test	Example	Median	Range		Number of
				T	analyses
Fuel content (% by weight)			Mix	Max	
Moisture	7,4	3,45	1,6	7,4	4
Ash (% dry)	29,7	23,1	15,3	29,7	4
Volatile substances (% dry, ash-free)	88,7	89,55	88,7	90,4	2
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	23,04	24,75	23,04	26,12	4
Hhigher (ar)	15,0	18,74	15	20,8	4
Hlower (dry, ash-free)	21,51	23,03	21,51	24,32	4
Hlower (ar)	13,82	17,35	13,82	19,32	4
Elementary analysis (% dry, ash-free)					
C (carbon)	54,77	56,2	54,77	56,9	3
H (hydrogen)	7,11	8,1	7,11	8,3	3
O (oxygen)	22,33	22,33	21	27,8	3
S (sulphur)	0,67	0,74	0,67	0,8	2
N (nitrogen)	14,65	11,82	10,19	14,65	4
Cl (chlorine)	0,47	0,93	0,47	1,118	4
Ash analysis (mg/kg of ash)					
Al (aluminium)	2011	1549	1087	2011	2
As (arsenic)	0				
Ba (barium)	481				
Ca (calcium)	343767	309783	281046	343767	3
Cd (cadmin)					
Co (cobalt)		12			1
Cr (chromium)	77	59	41	77	2
Cu (copper)	29	116	29	203	2
Fe (iron)	5470	6902	5470	13072	3
Hg (mercury)					
K (potassium)	15358	36413	15358	39216	3
Mg (magnesium)	7418	9239	7418	13072	3
Mn (manganese)	101	132	101	163	2
Mo (molybdenum)					
Na (sodium)	10831	44565	10831	65359	3
Ni (nickel)	3	11	3	19	2
P (phosphorus)	136587	136587	111111	160870	3
Pb (lead)	31	24	17	31	2
Sh (antimony)	-				
Si (silicon)	5750	5321	4891	5750	2
Ti (titanium)	108	106	103	108	2
TI (thallium)					-
V (vanadium)					
Zn (zinc)	370	636	370	902	2

B.31 Animal fat

Table 31	Analysis of animal fat
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Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	0,6	0,4	0,1	0,6	2
Ash (% dry)	0,1	0,1			3
Volatile substances (% dry, ash-free)					
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	39,1	39,6	39,1	39,6	4
Hhigher (ar)	38,8				
Hlower (dry, ash-free)	36,5				
Hlower (ar)	36,2				
Elementary analysis (% dry, ash-free)					
C (carbon)	76,4	76,7	76,4	77,0	2
H (hydrogen)	12,5	12,1	11,7	12,5	2
O (oxygen)	11,0	11,0			
S (sulphur)	0,02	0,02			
N (nitrogen)	0,06	0,07	0,06	0,10	3
Cl (chlorine)	0,00	0,00			1
Ash analysis (mg/kg of ash)					
Al (aluminium)					
As (arsenic)					
Ba (barium)					
Ca (calcium)					
Cd (cadmin)					
Co (cobalt)		392			1
Cr (chromium)		980			1
Cu (copper)					
Fe (iron)					
Hg (mercury)					
K (potassium)					
Mg (magnesium)					
Mn (manganese)					
Mo (molybdenum)					
Na (sodium)					
Ni (nickel)	10 060	10 060			1
P (phosphorus)	85 126	85 126			1
Pb (lead)	1 548	1 548			1
Sb (antimony)	3 095	3 095			1
Si (silicon)					
Ti (titanium)					
Tl (thallium)		784			1
V (vanadium)					
Zn (zinc)	1 548	2 343	1548	3137	2

B.32 Vegetable fat

	Table 32	Analysis vegetable fat
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Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)					
Moisture	1,2	0,6	0,0	1,2	2
Ash (% dry)	0,0	0,1	0,0	0,1	2
Volatile substances (% dry, ash-free)					
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	39,1	39,1	39,1	39,1	2
Hhigher (ar)	38,6	38,6			
Hlower (dry, ash-free)	36,6	36,9	36,6	37,1	2
Hlower (ar)	36,1	36,1			
Elementary analysis (% dry, ash-free)					
C (carbon)	76,7	76,2	75,7	76,7	2
H (hydrogen)	11,9	11,8	11,7	11,9	2
O (oxygen)	11,3	12,0	11,3	12,6	2
S (sulphur)	0,00	0,0	0,0	0,0	2
N (nitrogen)	0,10	0,10	0,10	0,10	2
Cl (chlorine)					
Ash analysis (mg/kg of ash)					
Al (aluminium)					
As (arsenic)					
Ba (barium)					
Ca (calcium)					
Cd (cadmin)					
Co (cobalt)					
Cr (chromium)					
Cu (copper)					
Fe (iron)					
Hg (mercury)					
K (potassium)					
Mg (magnesium)					
Mn (manganese)					
Mo (molybdenum)					
Na (sodium)					
Ni (nickel)					
P (phosphorus)					
Pb (lead)					
Sb (antimony)					
Si (silicon)					
Ti (titanium)					
Tl (thallium)					
V (vanadium)					
Zn (zinc)					

B.33 Tall oil pitch

Table 33	Analysis	Tall oil	pitch
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Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	0,2				
Ash (% dry)	0,4				
Volatile substances (% dry, ash-free)					
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	40,04				
Hhigher (ar)	39,8				
Hlower (dry, ash-free)	38,23				
Hlower (ar)	38				
Elementary analysis (% dry, ash-free)					
C (carbon)					
H (hydrogen)	10,7				
O (oxygen)					
S (sulphur)	0,27				
N (nitrogen)					
Cl (chlorine)					
Ash analysis (mg/kg of ash)					
Al (aluminium)	675				
As (arsenic)					
Ba (barium)					
Ca (calcium)	300				
Cd (cadmin)					
Co (cobalt)					
Cr (chromium)	100				
Cu (copper)					
Fe (iron)	6250				
Hg (mercury)					
K (potassium)					
Mg (magnesium)					
Mn (manganese)					
Mo (molybdenum)					
Na (sodium)					
Ni (nickel)					
P (phosphorus)	3750				
Pb (lead)					
Sb (antimony)					
Si (silicon)	150				
Ti (titanium)					
Tl (thallium)					
V (vanadium)	75				
Zn (zinc)	100				

B.34 Peat

Table 34	Analysis of peat
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Test	Example	Median	Range		Number of analyses
Fuel content (% by weight)			Min	Max	
Moisture	38,1	48,9	37,6	58,4	10
Ash (% dry)	8,9	5,2	1,6	8,9	15
Volatile substances (% dry, ash-free)		72,2	58,1	88,4	13
Calorific value (MJ/kg)					
Hhigher (dry, ash-free)	22,0	22,4	19,1	26,5	15
Hhigher (ar)	12,4	11,4	8,9	22,1	15
Hlower (dry, ash-free)	20,8	21,2	18,0	25,1	15
Hlower (ar)	10,8	10,8	7,1	20,7	15
Elementary analysis (% dry, ash-free)					
C (carbon)	55,8	56,1	52,6	57,8	15
H (hydrogen)	5,9	5,8	2,9	6,3	15
O (oxygen)	36,0	35,8	33,3	40,6	15
S (sulphur)	0,24	0,28	0,10	0,46	15
N (nitrogen)	2,0	2,16	0,9	4,4	15
Cl (chlorine)	0,05	0,05	0,00	0,12	15
Ash analysis (mg/kg of ash)					
Al (aluminium)	13 483	50 806	2 646	106 667	13
As (arsenic)	73				
Ba (barium)	584				
Ca (calcium)	191 011	110 063	61 333	191 011	13
Cd (cadmin)	3				
Co (cobalt)	58	46	34	58	2
Cr (chromium)	674	397	120	674	2
Cu (copper)	989	608	228	989	2
Fe (iron)	58 427	89 528	58 053	193 333	13
Hg (mercury)	1				
K (potassium)	9 551	7 149	3 959	15 948	13
Mg (magnesium)	14 607	8 570	4 965	42 308	12
Mn (manganese)	1 494				
Mo (molybdenum)					
Na (sodium)	5 618	2 667	1 338	7 107	13
Ni (nickel)	494	298	102	494	2
P (phosphorus)	6 180	9 600	6 180	13 702	11
Pb (lead)	393	229	64	393	2
Sb (antimony)	24	24			
Si (silicon)	134 831	189 827	105 333	244 998	13
Ti (titanium)	2 292	1 955	839	3 716	12
Tl (thallium)					
V (vanadium)	28	81	28	134	2
Zn (zinc)	2 135	1 181	227	2 135	2

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M6-635

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