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Development of test methods for non-wood small-scale combustion plants

Gottfried Eder, Walter Haslinger, Lara Carvalho
Austrian Bioenergy Centre GmbH

Wieselburg, Juni 2008

Ein Projektbericht im Rahmen der Programmlinie

ENERGIESYSTEME der Zukunft

Impulsprogramm Nachhaltig Wirtschaften

Im Auftrag des Bundesministeriums für Verkehr, Innovation und Technologie

Vorwort

Der vorliegende Bericht dokumentiert die Ergebnisse eines Projekts aus der Programmlinie ENERGIESYSTEME DER ZUKUNFT*.* Sie wurde 2003 vom Bundesministerium für Verkehr, Innovation und Technologie im Rahmen des Impulsprogramms Nachhaltig Wirtschaften als mehrjährige Forschungs- und Technologieinitiative gestartet. Mit der Programmlinie ENERGIESYSTEME DER ZUKUNFT soll durch Forschung und Technologieentwicklung die Gesamteffizienz von zukünftigen Energiesystemen deutlich verbessert und eine Basis zur verstärkten Nutzung erneuerbarer Energieträger geschaffen werden.

Dank des überdurchschnittlichen Engagements und der großen Kooperationsbereitschaft der beteiligten Forschungseinrichtungen und involvierten Betriebe konnten bereits richtungsweisende und auch international anerkannte Ergebnisse erzielt werden. Die Qualität der erarbeiteten Ergebnisse liegt über den hohen Erwartungen und ist eine gute Grundlage für erfolgreiche Umsetzungsstrategien. Mehrfache Anfragen bezüglich internationaler Kooperationen bestätigen die in ENERGIESYSTEME DER ZUKUNFT verfolgte Strategie.

Ein wichtiges Anliegen des Programms ist, die Projektergebnisse – sei es Grundlagenarbeiten, Konzepte oder Technologieentwicklungen – erfolgreich umzusetzen und zu verbreiten. Dies soll nach Möglichkeit durch konkrete Demonstrationsprojekte unterstützt werden. Deshalb ist es auch ein spezielles Anliegen die aktuellen Ergebnisse der interessierten Fachöffentlichkeit leicht zugänglich zu machen, was durch die Homepage **www.ENERGIESYSTEMEderZukunft.at** und die Schriftenreihe gewährleistet wird.

Dipl. Ing. Michael Paula
Leiter der Abt. Energie- und Umwelttechnologien
Bundesministerium für Verkehr, Innovation und Technologie

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Kurzfassung

In mehreren europäischen Ländern kommen verstärkt feste Nicht–Holz-Biomassen (Getreide und dessen Nebenprodukte, Energiepflanzen wie Miscanthus, usw.). als Brennstoff in Kleinfeuerungsanlagen zum Einsatz. Die Entwicklung von entsprechenden Feuerungstechnologien ist im Gange. Während bei Holzbrennstoffen standardisierte Messmethoden hinsichtlich des Ablaufes von Prüfungen von Kleinfeuerungsanlagen und dem Einsatz geeigneter Messgeräte existieren und auch angewandt werden, fehlen bei Verwendung von Nicht-Holz-Brennstoffen klare Vorgaben. Folglich ist die Vergleichbarkeit von Messergebnissen nur eingeschränkt möglich.

In diesem Projekt wurden einleitend die fördernden und hemmenden Faktoren sowie der Stand der gesetzlichen Rahmenbedingungen in den teilnehmenden Ländern für den Einsatz von Nicht-Hölzern erhoben. Gleichzeitig wurde ein Überblick über den gegenwärtigen Stand der Technik bei Kleinfeuerungsanlagen, die mit Nicht-Holz-Brennstoffen betrieben werden, erstellt mit dem Fokus auf die im Projekt teilnehmenden Länder.

Auf drei Messständen wurde die Eignung gegenwärtig gebräuchlicher Messgeräte und Messmethoden experimentell untersucht und statistisch ausgewertet. Die Ergebnisse dieser Untersuchungen waren die Basis für einen Vorschlag für eine europaweite einheitliche Prüfmethode beim Einsatz von Nicht-Holz-Brennstoffen in Kleinfeuerungsanlagen (Best practice guideline).

Abschließend erfolgte die Planung eines Ringversuches und die Identifizierung weiterer notwendiger F&E Aktivitäten für die Entwicklung von vergleichbaren Testmethoden in zwei Workshops der Projektpartner.

Für den Einsatz in Kleinfeuerungsanlagen gibt es eine Reihe von Biomassen, die in der Europäischen Vornorm CEN/TS 14961 erfasst und klassifiziert sind. In den Ländern der in diesem Projekt teilnehmenden Partner existieren Potenziale für Energiepflanzen und Nebenprodukte, v.a. Stroh aus der Produktion von Getreide. Eine Potenzialsteigerung kann bei Energiepflanzen erwartet werden. Gegenwärtig sind für eine energetische Nutzung Strohpellets und Pellets aus Miscanthus oder Reed canary grass besonders interessant. Die Nachfrage nach Energiegetreide ist stark von den Marktpreisen für Getreide ab.

Für einen stärkeren Einsatz von Nichtholzbrennstoffen ist eine Weiterentwicklung der Verbrennungstechnologien vor allem im Bereich der Brennstoffflexibilität und der Flexibilität bei der Wärmeleistung notwendig, um Betriebsstörungen wie Verschlackung, Anbackungen, Korrosion und hohe Schadstoffemissionen zu vermeiden.

Die Zulassung von Nichtholzbrennstoffen in den beteiligten Ländern wird recht unterschiedlich gehandhabt. Diese reichen von genereller Nichtzulassung über eine Zulassung in Abhängigkeit von der Nennleistung der Feuerung bis hin zu nicht notwendiger Zulassung.

Kleinfeuerungsanlagen werden in den Partnerländern durchwegs gemäß EN 303-5 überprüft, die hinsichtlich biogener Brennstoffe nur Holzbrennstoffe einschließt.

Regelungen hinsichtlich Nichtholzbrennstoffe fehlen in den meisten Fällen. Teilweise sind Regelungen auf freiwilliger Basis implementiert.

Abhängig von den zukünftigen Emissionsgrenzwerten in den Partnerländern werden für den Einsatz von diesen Brennstoffen primäre und/oder sekundäre Rauchgasreinigungssysteme notwendig sein, um sie einhalten zu können. Zusätzlich wird für eine verstärkte Marktdurchdringung dieser Systeme auf die Bedürfnisse des Betreibers (z.B geringer Zeitaufwand für Wartung der Feuerung) einzugehen sein.

Bezüglich Staubemissionen liegen eine Reihe von Fehlerursachen, Einflussfaktoren und Wechselwirkungen (Filterbehandlung, Filtervorbereitung, Art der Messgeräte, Isokinetik, Position der Probenentnahme im Abgasrohr, Volumenstrombestimmung, asymmetrische Staubverteilung im Abgasrohr,…) vor. Eine Bewertung der einzelnen Fehlerquellen ist schwierig, zumal die Wiederholbarkeit der Staubmessung generell gering ist. Weitere F&E-Aktivitäten sind im Bereich der Staubmessung unumgänglich.

Die in diesem Projekt erstellte Best practice guideline für die Prüfung von Kleinfeuerungsanlagen, die mit Nichthölzern betrieben werden, basiert auf der EN 303-5. Um eine möglichst breite Akzeptanz zu bekommen wurden die Adaptionen zur EN 303-5 so gering wie möglich gehalten. Weitere notwendige Veränderungen dieser Guideline bedürfen weiterer Untersuchungen, etwa in Form des im Projekt geplanten und kalkulierten Ringversuches.

Sechs Labors haben das Interesse an einem derartigen Ringversuch bekundet. Dazu werden zwei Brennstoffe (z.B. Miscanthuspellets oder –briketts, Weizenstrohpellets oder –briketts) ausgewählt, die in einer Feuerungsanlage mit maximal 100 kW Nennwärmeleistung eingesetzt werden. Die durchzuführenden Messungen werden gemäß der Best practice Guideline durchgeführt. Aufbauend auf die Erkenntnisse aus dem Ringversuch erfolgt ggf. eine Überarbeitung der Guideline.

Dieser Ringversuch und die Überarbeitung der Guideline sind ein zentraler Teil weiterer F&E-Aktivitäten, die im Rahmen des ERA-net Programmes bearbeitet werden sollten. Im Rahmen des Ringversuches ist vor allem auf die Methoden und das Prozedere der Staubmessung ein besonderer Schwerpunkt zu legen.

Das Konsortium des Projektes „Development of test methods for non wood small-scale combustion plants“ empfiehlt nachdrücklich die Erstellung eines Europäischen Standards, der die Anforderungen an die Prüfung von Kleinfeuerungsanlagen für biogene Nichtholzbrennstoffe regelt.

Abstract

In several European countries increasing efforts are recently made to use non wood biomass (cereal crops and their residues, energy crops like miscanthus, etc.) as solid biofuel in small-scale furnaces. New technological approaches regarding the appropriate combustion technologies are on the way, but the verification of any such development is difficult and there is a large uncertainty about testing procedures and equipments. While for wood combustion standardized European measuring regulations are available and broadly applied, the testing of non wood biomass fuel combustion installations is generally not following a commonly accepted procedure. Consequently the results of such measurements are not fully comparable.

Initially a study of the driving forces and barriers for the use of non wood fuels was done in order to evaluate and choose the most promising fuels for small-scale boilers. Furthermore, information on regulations of the authorities in the participating countries relevant for the project as well as other related European documents were gathered. In parallel an overview and further compilation of the current state of technology for small-scale non wood fuels appliances in Europe, with focus on the participating countries, was done.

Measurement equipment and methods were analyzed and evaluated experimentally at three test stands. The validation was done by applying statistical methods on the experimentally derived results. The overall results are the basis for a proposal (best practice guideline) for a Europe-wide standard for testing non wood fuels in small-scale boilers.

Finally, a round robin test was planned and the further R&D required for the development of uniform and comparable tests methods was identified in two joint workshops of the project partners.

There is a wide range of biomass sources which is relevant for the application in small-scale combustion plants and which is classified in the European pre-directive CEN/TS 14961. In the project partner countries in general there are potentials for energy crops and several residues, especially straw from grain production. A potential increase can be expected for energy crops. Most interesting biomasses for use in smale-scale combustion units are straw-pellets as well as pellets from miscanthus or reed canary grass. The demand on energy grain will depend very much on market prices for grain.

To meet an increased use of non-wood fuels, there is a need of technical development and of increased knowledge to improve the performance. Development is needed with respect to improved fuel and load flexibility to avoid sintering, fouling, corrosion and high emissions.

The granting of a license for the fuels is handled differently in the partner countries. Regulations reach from no licence for non-wood fuels over a dependence to the plant size up to no licence necessary.

Boiler testing is orientated on EN 303-5 in the partner countries, but there is no valid regulation concerning boilers for non-wood fuels in most cases. Some voluntary labelling systems are implemented.

Depending on future emission limits in the different countries, primary and/or secondary means will need to reduce emissions.Beside combustion and emission performance, it is important that future technique will meet also the users' demands for convenience (e.g effort for operating combustion plant).

Regarding dust measurements numerous sources of error and a high number of influencing factors and interactions (filter treatment, filter preparation, type of equipment, isokinetics, sampling positions in the exhaust pipe, volume flow determination, asymmetrical particle distribution, etc.) are given. An isolated consideration of a single influence is difficult, particularly as the repeatability of dust determinations is generally relatively low. Further R&D must attach importance on that topic.

For the best practice guideline the European Standard EN 303-5 was used as basis. In order to ensure a wide-spread acceptance of this guideline changes and amendments to the existing EN 303-5 were kept as low as possible. The work has focussed on derivation and evaluation of measurement principles and procedures.

Six laboratories have expressed interest to participate in a following round-robin test. Two fuels will be chosen (e.g. miscanthus pellets/briquettes and wheat straw pellets/briquettes) and combusted in a max. 100 kW boiler according to the proposed guideline. Further adaptations of the guideline will be done on the basis of the round robin results where appropriate.

For further R&D research activities on measurement methods for non wood small scale combustion plants should be continued categorically. Next step is to start a round robin project within the ERA-net programme to evaluate compiled results and improve the best practice guideline.

In the course of the round robin test measurement methods regarding dust measurements have to be evaluated again and experience of participating laboratories should be unified to common European wide dust measurement method.

The consortium of the ERA-net project "Development of test methods for non wood small-scale combustion plants" strongly recommends the establishment of a European standard regulating the requirements for testing small scale furnaces for biogenic non woodfuels.

1 Preface

In several European countries increasing efforts are recently made to use non wood biomass (cereal crops and their residues, energy crops like miscanthus, etc.) as solid biofuel in small-scale furnaces. New technological approaches regarding the appropriate combustion technologies are on the way, but the verification of any such developments is difficult and there is a large uncertainty about testing procedures and equipments. While for wood combustion standardized European measuring regulations are available and broadly applied, the testing of non wood biomass fuel combustion is generally not following a commonly accepted procedure. Consequently the results of such measurements are not fully comparable. This applies particularly for the international level, which is here of particular relevance due to the fact that a combustion technology development for a niche application can only be economically viable, if a sufficiently large marketing area can be taken into focus.

Whilst wood fuel combustion in small-scale applications is state of the art, non wood biomass combustion in small-scale appliances has by far not achieved a comparable state of technology. The legal and regulatory frameworks with respect to

- licensed non wood biomass fuels,
- standards for non wood biomass fuels (incl. measurement methods),
- certification of non wood biomass boilers (incl. measurement methods and testing procedures)
- and even emission thresholds for non wood biomass combustion systems

do practically not exist or are not applied. This creates uncertainties which result in uncontrolled grey market activities herewith by-passing environmental standards, safety aspects and consumer protection. These are major drawbacks for the market introduction of new technologies, which need to be overcome.

The project is carried out by 6 partners from 4 different countries:

- Austrian Bioenergy Centre (ABC), Austria
- Institut für Umwelt GmbH (IE), Germany
- Swedish National Testing and Research Institute (SP), Sweden
- Technologie- und Förderzentrum Nachwachsende Rohstoffe (TFZ), Germany
- HBLFA – Francisco Josephinum Biomass Logistics Technology (FJ BLT), Austria
- Technical Research Centre of Finland (VTT), Finland

This report insists on a summary of every single working package after an elaboration of the project scope and a description of the working packages. The full versions of the WP-reports are added in the form of annexes. Afterwards conclusions of project results are drawn followed by future prospects and recommendations.

2 Project scope

For measuring institutions and research applications the European measuring standard EN 303-5 only applies for woody solid biofuels but not for straw and cereal crops. This is due to several reasons. On the one hand so far no specification has been made for the applicable test fuel (straw and cereal crops) therefore the test results may differ because of differences in the fuel used. On the other hand the existing measuring procedures and methods need to be adapted and specified particularly for such difficult solid biofuels.

The project is on small-scale boilers with a typical rated heat output of 20 to 60 kW for energy grain and for pellets made from agricultural biomass like straw, miscanthus or similar annual and perennial crops. Test work is carried out with automatically stoked boilers available on the market. The scope of the proposed test procedure covers the power range up to 400 kW.

By means of the results of the working packages a “Best practice guideline” for suitable measurement methods and test procedures for testing small scale boilers for non wooden biomass is generated.

3 Work packages

The work packages, incl the (sub-)tasks, and the responsible partner are depicted below:

- **WP1: Project co-ordination and project management – responsible ABC**
  - Task 1.1: Co-ordination, organization, presentation of project (e.g. at ERA-NET workshop, conferences), reporting
  - Task 1.2: Project controlling
  - Task 1.3: Set-up and maintenance of project homepage, organization of data exchange and communication via homepage
- **WP 2: General conditions, analysis, advice on measurement techniques and standardization – responsible IE**
  - Task 2.1: Basic conditions for the use of non wood biomass fuels in small-scale combustion systems
  - Task 2.2: Combustion characteristics and derivation of relevant recommendations for measurement techniques
  - Task 2.3: Analysis of the regional availability and potential reserves of non wood biomass fuels
  - Task 2.4: Economical framework conditions
  - Task 2.5: Derivation of relevant recommendations for measurement technology and standardization
- **WP 3: State of the technology – responsible SP**

- Task 3.1: Manufacturers and products
- Task 3.2: Available scientific results on the operation of non wood biomass boilers
- Task 3.3: Systematic characterization of boiler technologies
- Task 3.4: Overview on the work carried out in the participating countries
- Task 3.5: Preparation of a summary report on state of the art non wood biomass combustion technologies

- **WP 4: Measurement methods – responsible TFZ**
  - Task 4.1: Inventory of measuring hazards and elaboration of detailed testing plan
  - Task 4.2: Measurement equipment and measurement techniques testing
  - Task 4.3: Evaluation and quantification of influences
- **WP 5: Development of test procedures – responsible FJ-BLT**
  - Task 5.1: Identification of the state of the art of national and international testing rules
  - Task 5.2: Selection and adaptation of most appropriate testing standard for non wood fuels
  - Task 5.3: Selection of appropriate boilers and execution of boiler tests
  - Task 5.4: Requirements for testing procedures
  - Task 5.5: Preparation of a draft proposal for a Europe-wide standard including measurement methods and state of the art
- **WP 6: Identification of further R&D required and preparatory work for a round robin test – responsible VTT**
  - Task 6.1: Elaboration of a work plan for a round robin test
  - Task 6.2: Identification of interested laboratories
  - Task 6.3: Cost budget for the round-robin tests
  - Task 6.4: Identification of further R&D required

4 Work plan

WP / assigned staff-hours			partners involved																			
		WP Leader	ABC	FJ BLT	IE	SP	TFZ	VTT	Jan 07	Feb 07	Mär 07	Apr 07	Mai 07	Jun 07	Jul 07	Aug 07	Sep 07	Okt 07	Nov 07	Dez 07	Jan 08	Feb 08	Mär 08
WP 1	**Project co-ordination and project management**	**ABC**	300	25	30	32	30	70	M1.1		M1.2			D1.1								M1.3	D1.2
Task 1.1	Co-ordination, organization, presentation of project (e.g. at ERA-NET workshop, conferences), reporting	ABC							x					x								x	x
Task 1.2	Project controlling	ABC																					
Task 1.3	Set-up and maintenance of project homepage, organization of data exchange and communication via homepage	ABC									x												
WP 2	**General conditions, analysis, advice for measurement techniques and standardization**	**IE**	67,5	25	700	40	80	35		M2.1		D2.1								D2.2			
Task 2.1	Basic conditions for the use of non wood biomass fuels in small-scale combustion systems	IE										x								x			
Task 2.2	Combustion characteristics and derivation of relevant recommendations for measurement techniques	IE										x								x			
Task 2.3	Analysis of the regional availability and potential reserves of non wood biomass	IE								x		x								x			
Task 2.4	Economic basic conditions	IE																		x			
Task 2.5	Derivation of relevant recommendations for measurement techniques and standardization	IE																		x			
WP 3	**State of the technology**	**SP**	67,5	25	120	320	90	35		M3.1				D3.1									
Task 3.1	Manufacturers and products	SP												x									
Task 3.2	Available scientific results on the operation of non wood biomass boilers	SP												x									
Task 3.3	Systematic characterization of boiler technologies	SP												x									
Task 3.4	Overview on the work carried out in the participating countries	SP								x				x									
Task 3.5	Preparation of summary report on state of the art non wood biomass combustion technologies	SP												x									
WP 4	**Measurement methods**	**TFZ**	135	25	150	40	1600	42				M4.1						D4.1					
Task 4.1	Inventory of measuring hazards and elaboration of detailed testing plan	TFZ										x						x					
Task 4.2	Measurement equipment and measurement techniques testing	TFZ																x					
Task 4.3	Evaluation and quantification of influences	TFZ																x					
WP 5	**Development of tests procedures**	**FJ BLT**	472,5	895	110	30	250	245		M5.1	M5.2 M5.3									D5.1			
Task 5.1	Identification of the state of the art of national and international testing rules	FJ BLT								x										x			
Task 5.2	Selection of appropriate standard and adaption for the new type of biofuel	FJ BLT								x	x									x			
Task 5.3	Selection of appropriate boilers and execution of boiler tests	FJ BLT									x									x			
Task 5.4	Requirements for testing procedures	FJ BLT																		x			
Task 5.5	Preparation of a draft proposal for a Europe-wide standard (incl. measurement methods and state of the art)	FJ BLT																		x			
WP 6	**Identification of further R&D required and preparatory work for a round robin test**	**VTT**	67,5	25	20	30	60	140													D6.1	M6.1	D6.2
Task 6.1	Elaboration of a work plan for a round robin test	VTT																			x		
Task 6.2	Identification of interested laboratories	VTT																			x		
Task 6.3	Cost budget for the round-robin tests	VTT																			x		
Task 6.4	Identification of further R&D required	ABC																				x	x
	Total assigned hours		**1110**	**1020**	**1130**	**492**	**2110**	**567**															

5 Activities and results

5.1 WP1 – Project coordination and project management (responsible ABC)

ABC is responsible for WP1. The relevant activities within the reporting period on a per-task-basis have been:

- Task 1.1: Co-ordination, organization, presentation of project (e.g. at ERA-NET workshop, conferences), reporting
  The most relevant activities of ABC within task 1.1 have been the organisation of meetings, keeping the minutes, distribution of minutes and distribution of other project-relevant information to the project partners and the national funding institution. In more detail, the most relevant activities have been:
  - Organisation of the kick-off meeting at the premises of FJ-BLT in Wieselburg on February 14th, 2007, including taking of minutes and distribution to partners. Participants from ABC: Lara Carvalho, Gottfried Eder, Walter Haslinger, Elisabeth Wopienka. Participant from FJ-BLT: Leopold Lasselsberger. The other project partners were present with at least one person per partner.
  - Representation of project at ERA-NET Bioenergy Small-scale Combustion – Workshop in Jyväskylä, May 23rd – 24th, 2007. ABC was represented by Lara Carvalho and Gottfried Eder.
  - Participation in a trilateral (ABC, FJ-BLT, TFZ) meeting at the premises of TFZ in Straubing on June 28th – 29th, 2007, including taking of minutes and distribution to partners. ABC has participated with Gottfried Eder, Walter Haslinger, Elisabeth Wopienka. FJ-BLT has participated with Harald Baumgartner, Helmut Buchmasser, Leopold Lasselsberger, Wolfgang Rainer.
  - Presentation of project within strategy workshop „Brennstoffe der Zukunft“ (Biomass Fuels of the Future) of company KWB in St. Margarethen/Raab on July 2nd, 2007. Project presentation by Walter Haslinger.
  - Preparatory work for the project meeting, which was to be held in Leipzig, on September 24th – 25th 2007.
  - Preparation of draft consortium agreement and distribution to partners. The final version of the consortium agreement was accepted and signed by all partners.
  - Preparation of mid-term report until August 31st, 2007.
  - Project meeting on September 24th - 25th at IE Leipzig. ABC has participated with Gottfried Eder and Walter Haslinger. FJ-BLT has participated with Leopold Lasselsberger.

- o Organisation of and participation in a trilateral meeting in Wieselburg (ABC, FJ BLT, TFZ) on January 10th, 2008 including taking of minutes and distribution to partners. ABC has participated with Gottfried Eder and Walter Haslinger. FJ-BLT has participated with Leopold Lasselsberger.
- o Working out of proposals for best practice guideline, distribution to the partners, coordination of inputs and continuous updating until final version (December 2007 – June 2008).
- o Project meeting on September 21st, 22nd 2007 at SP in Boras including taking of minutes and distribution to partners. ABC has participated with Gottfried Eder and Walter Haslinger. FJ-BLT has participated with Leopold Lasselsberger.
- o Final project meeting on March 10th, 11th, 2008 at TFZ in Straubing including taking of minutes and distribution to partners.
- o Organisation of a telephone conference concerning final version of best practice guideline with all project partners on May 5th, 2008, including taking minutes and distribution to partners.
- o Additional workshop on June 4th 2008 in Valencia including taking of minutes and distribution to partners. ABC has participated with Gottfried Eder and Walter Haslinger. FJ-BLT has participated with Leopold Lasselsberger. Workshop was for finalizing best practice guideline and identification of further R&D required.
- o Keeping contact to national funding institution and to the ministry (bmvit).
- o Information of national standardisation bodies / authorities
- o Collection of WP-reports and preparation of full version of project report.

- Task 1.2: Project controlling
  Based on the milestone plan defined in the working programme ABC is continuously monitoring the progress of the project, both related to own responsibilities and also related to the other partners' responsibilities. No significant deviations from the working programme and the milestone plan need to be reported.
- Task 1.3: Set-up and maintenance of project homepage, organization of data exchange and communication via homepage
  ABC has set-up a project internal communication platform, which may be accessed through ABCs homepage (www.abc-energy.at). The project partners may login to this internal communication platform with username and password. All project relevant data and valid information is stored there in its most recent version.

5.2 WP2 – General conditions, analysis, advice for measurement techniques and standardization (responsible IE)

5.2.1 Methods and data

Task 2.1 is based on data provided by the project partners concerning their country and were collected via survey. In task 2.2 the technical fuel properties of the raw material or pellets are specified where available as a minimum and maximum span or a typical value, derived from bibliographical sources and summarized in information sheets. In addition this information is used for classifying the corresponding fuel according CEN/TS 14961. In addition to specify the fuel properties, the information sheets also include the combustion characteristics found in literature. For the compilation of the information sheets the references of the project partners as well as other literature were used. Data of task 2.3 are based on literature investigations, provided information of project partners and the outcomes of the workshop held on September 25th, 2007 in Leipzig. In task 2.4 data from literature and relevant homepages. Calculations concerning economical competitiveness are done by IE Leipzig. Finally in task 2.5 the results of task 2.1-2.4 are summarized. The most important non wood biofuels are identified and additional information of measurement technologies and standardization are given.

5.2.2 Results

There is a wide range of biomass sources which is relevant for the application in small-scale combustion plants and which is classified in the European pre-directive CEN/TS 14961. All of these biomass sources have to be treated as fuels, not as waste, according to 199/31/EC.

In the partner countries in general there are potentials for energy crops and several residues, especially straw from grain production. A potential increase can be expected for energy crops. Straw potentials will remain constant or decrease. The use of these potentials is a political aim in the partner countries, there are support programmes both concerning research and development and market implementation.

The granting of a license for the fuels is handled differently in the partner countries. Regulations reach from no licence for non-wood fuels over a dependence to the plant size up to no licence necessary. Boiler testing is orientated on EN 303-5 in the partner countries, but there is no valid regulation concerning boilers for non-wood fuels in most cases. Some voluntary labelling systems are implemented.

Similar variety can be found regarding emission thresholds. The conditions for the demand of emission limits, measurement standards and the values itself differ significantly from country to country and can hardly be compared.

According to these facts, it can be concluded that usable and supported potentials for non-wood biomass fuels in small-scale combustion plants exist in the project partner countries. There are some guidelines existing for standardisation, e.g. CEN/TS 14961 concerning biomass classification, EN 303-5 for boiler certification, supplied by several

European directives concerning emission regulations and biomass management. The national implementations, especially due to non-wood fuels and small-scale combustion units, have to be harmonised to become applicable for the development of standard measurement methods.

Most interesting biomasses for use in smale-scale combustion units are straw-pellets as well as pellets from miscanthus or reed canary grass. The demand for energy grain will depend very much on market prices for grain.

Development of measurement technologies have to consider especially particle emissions for all biofuels and in some cases additionally HCl and PCDD/F. The toxicity of the particles will probably get more important in the future. Therefore any standardization related to fine dust sampling would be helpful.

5.3 WP3 – State of the technology (responsible SP)

5.3.1 Methods and data

In task 3.1 a list of manufacturers of combustion appliances for small-scale non-wood fuels in the participating countries Sweden, Finland, Germany and Austria and also in Denmark was compiled during the autumn 2007. Denmark was included because it is known to combust especially straw and cereals in small-scale, and the market is close to the participating countries. Only manufacturers with appliances smaller than 300 kW were included.

In task 3.2 results from scientific articles and reports regarding tests and measurements of small-scale combustion appliances for non wood biofuels are summarized. Mainly laboratory tests are included. The focus is on implications of agricultural fuels on operation and emissions. Furthermore properties of non-wood solid biofuels and the implication on small-scale combustion technology are discussed. To facilitate overview, reports regarding combustion of grain in Sweden and Denmark, and reports regarding agricultural fuels are summarized.

For task 3.3 it was planned to include a workshop about state-of-the-art hold at SP. Manufacturers, distributors, fuel producers, users, authorities and others interested in the subject would be invited. Based on discussions and information gathered during the workshop about today's technology used for non wood biofuels, strengths and weaknesses in available technologies would be systematically characterized. Due to the world-wide increase in price for agricultural products, and especially for grain, in autumn 2007, the interest for small-scale combustion of non wood fuels went down drastically and it was not possible to gather interested manufacturers etc for a workshop. Instead, information was gathered by telephone interviews to a selected number of manufacturers and experts known to have experience in the area in Sweden. A questionnaire was prepared with questions, and the answers were analyzed and condensed. The questionnaire included four types of questions: What is your experience, technical bottlenecks for the technique, non-technical bottlenecks for an expansion of combustion of combustion of non wood biofuels and the need of a standard/testing method for appliances for agri-fuels was prepared. Five manufacturers and two experts were interviewed, and the answers are condensed here.

In task 3.4 ongoing research concerning appliances for non wood small-scale combustion in the countries participating in this project is summarized. Only publicly financed work that is not secret is included.

5.3.2 Results

There is presently in Europe an increasing interest for non-wood solid biofuels for small-scale combustion (SSC) (here defined as < 300 kW), caused by an increased sale of small-scale pellet devices as well as a growing demand for woody biomass in other sectors. The wood pellets on the market today are made from residues from the saw mills and are – from a combustion point of view – a high quality fuel. Non-wood fuels such as residuals from agriculture (straw, etc) and cultivated energy crops (energy grain, Miscanthus, hemp etc) have in general other properties than wood. The different physical properties vary, but common properties compared to stem wood are summarized as lower heating value, higher content of nitrogen, sulphur, and chlorine, high ash content, high content of alkali metals, (potassium, and sodium), many times low ash fusion temperature, and sometimes high content of phosphor. These properties affect the combustion process and resulting emissions and must be met by the combustion technique.

The aim of this work package was to compile information of the current state of technology for small-scale non wood biofuels appliances in Europe, with focus on the four participating countries. The compilation was a foundation for finding strengths and weaknesses in available technologies and therefore crucial for developing adequate test methods.

The current state of technology for small-scale non wood biofuels appliances in Europe is summarized with:

- There is already on the market appliances adapted for non-wood fuels. Test results vary, but show that it is possible to reach good and stable combustion performance with low emissions of carbon monoxide and hydrocarbons using an appliance designed and optimised for a certain fuel.
- To meet an increased use of non-wood fuels, there is a need of technical development and of increased knowledge to improve the performance. Development is needed with regard to fuel and load flexibility to avoid sintering, fouling, corrosion and high emissions.
- Depending on future emission limits in the different countries, fuel specific emissions will need primary and/or secondary means to be reduced.
- Beside combustion and emission performance, it is important that future technique will meet also the users demands for convenience (e.g. effort for operating combustion plant)

In this work package, a list of manufacturers of appliances for small-scale non-wood fuels in the participating countries Sweden, Finland, Germany and Austria and also in Denmark was compiled during the autumn 2007. Altogether 42 manufacturers were found, including some appliances manufactured for wood fuels but used also for non wood fuels.

The list might be incomplete, but it gives a good picture of the appliances manufactured in the countries in the autumn 2007.

The appliances were characterized into four types:

1. Automatically fed boilers with stoker, burner and/or grate. Twenty-nine manufacturers were found and this is the main product in Germany and Austria and also common in Denmark. The appliances can be separated into boilers for dry fuels (mostly pellets and grain) and boilers for wetter fuels (wood chips, shavings, olive seeds etc). A majority of these boilers were “high-tech”, provided with automatic ignition system, integrated storage container, automatic ash removal, Lambda probe, some arrangement to avoid problem with sintering such as stirring/pushing the glow bed or flue gas recirculation, and ceramic parts. The appliances were marketed as comfortable for the users, only ash has to be taken care of on a regular basis. Furthermore, four boilers with moving grates intended for larger buildings or district heating systems were found (> 100 kW).
2. Manually fed boilers for straw bales. One is found in Germany and the rest in Denmark. The boilers are made for bales of different size.
3. Combined oil press and burner for rape cake. Rape seed is pressed to bio diesel and the remainings are pressed into a pellet and instantly combusted in a burner. One appliance was found in Denmark.
4. Separate burner for energy grain. The burner is applied to an existing boiler. Seven appliances were found, five in Sweden and two in Finland. This is the main product in Sweden.

Available results from scientific articles and reports regarding tests and measurements of small-scale appliances for non wood biofuels were summarized, with focus on implication on operation and emission by agricultural fuels. Grain from cereals has been a popular fuel in Sweden and in Denmark, combusted in appliances similar to wood pellet appliances, adapted for cereals. In general, tested grain appliances in Denmark and Sweden show good combustion results with high efficiency and low emissions of carbon monoxide and hydrocarbon, since grain is a dry, homogeneous and well defined fuel. The lower melting temperature of cereals (except of oat) is increased by addition of lime stone. Reported problems with chlorine corrosion is avoided by generally accepted strategies (high boiler temperature, high flue gas channel temperature, use of pressure regulator) or by installing a corrosion resistant flue gas channel. Reported fuel specific emissions vary, but are in general higher than emissions from wood pellet combustion. Nitrogen oxides are reported from 100 to 2200 mg/Nm^3. Both fuel sulphur and chlorine are to a large degree converted to gaseous species. Sulphur dioxide is reported up to 400 mg/Nm^3 and hydrochloric acid up to 76 mg/Nm^3. Emission of particles are typically between 100 and 350 mg/Nm^3 [1].

Several tests with a number of non-wood fuels in several appliances are reported from Germany and Austria. The results show that, in general, appliances designed and optimised for wooden fuels require improvements to reach the same level of operational performances with agricultural fuels. Especially, stable combustion in some cases could

[1] All emission values refer to 13 % O_2 in flue gas.

only be accomplished with a controlling technology (e.g. lambda controlling for combustion air). High combustion performance could be achieved but depended on fuel sort and combustion device. High CO-emission occurred especially when no control system was applied and when slag and ash caking occurred. The ability to remove ash and slag from the combustion zone depended on the technology. A clear correlation between fuel nitrogen and formed NO_x was demonstrated, with about 200 mg/Nm^3 for miscanthus and up to 600 mg/Nm^3 for wheat bran. Also measured SO_2 and HCl clearly followed the fuel concentrations. Corrosion risk were pointed out, but not investigated in any of the reports. The fuel type impact on dust emission was strong, from below 150 mg/Nm^3 up to 400 mg/Nm^3.

By telephone interviews with five manufacturers and two experts, the need in Sweden for technical development and/or more knowledge concerning appliances for small-scale combustion of non-wood fuels were summarized as development of:

- fuel-flexible appliances by means of control or technical solutions,
- part load control adapted to specific fuels,
- use of additives and ”designed” pellets to prevent sintering, fouling and corrosion,
- knowledge about high temperature corrosion,
- primary and secondary means to reduce emissions, especially particles and nitrogen oxides.

It was generally considered by the interviewed that non-wood fuels are considered troublesome compared to wood pellets, and that the competition from other, more convenient techniques such as heat pumps, is evident. Also, insecurity about future fuel prices is a disturbing element. Harder emission limits were expected from some of the interviewed, but not from all. The need for a standard on test methods was stressed by less than half of the interviewed, and if such a standard is developed it should be adapted for many different kinds of fuels.

Ongoing research concerning appliances for non wood small-scale combustion in the countries participating in this project was summarized. In Sweden nothing was found directly concerning technical performance, but some studies about ash chemistry, particle formation, corrosion and emissions during combustion of ash rich fuels and non wood fuels. In Austria and Germany several ongoing or recently presented studies were listed.

5.4 WP4 – Measurement methods (responsible TFZ)

5.4.1 Methods and data

In WP4 it was thus the goal to identify existing problems with the currently applied measuring equipment and procedures for the testing of non-wood furnaces and to make use of good practise experience as available from each involved partner's measuring expertise. During the performed project workshops mainly two working areas were targeted in WP4:

- Measuring uncertainties of gaseous emissions
- Dust determination methods (testing of influencing variables)

The measuring uncertainties were calculated by each partner separately. This was done by using a jointly elaborated method which is described in the annex of the here elaborated measuring guideline (see: Best practice guideline, ANNEX A: Suggestion for calculation methods for measurement uncertainties). The calculation method for uncertainties was internally applied by each partner as applicable for the respectively used equipment and procedure. The results of each partner's achievable uncertainty levels were kept as a confidential internal information, but the procured data served as a basis for the discussion and finally for the agreement on the maximum uncertainties as proposed in the best practice guideline (see: Best practice guideline, chapter 5.2 Measurement uncertainties). No further details on the individual uncertainty results are therefore compiled in this WP-report.

Furthermore, the discussion in the project workshops about the relevant measuring parameters and their determination clearly revealed that the total particle matter concentration in the flue gas can be seen as the most problematic and critical measuring parameter having the least reliability and reproducibility. It was thus decided, that the research programme which was to be conducted here, should focus on this parameter.

Research programme on measuring total particle matter was done with following focuses:

- Filter trials without dust loading,
- temperature treatment of loaded filters,
- combustion tests trials (dust determination equipment testing),
- washing of particle deposition in sampling probe.

5.4.2 Results

Due to numerous sources of error and a high number of influencing factors and interactions (filter treatment, filter preparation, type of equipment, isokinetics, sampling positions in the exhaust pipe, volume flow determination, asymmetrical dust distribution, etc.) an isolated consideration of a single influence is difficult, particularly as the repeatability of dust determinations is generally relatively low. Nevertheless, from the here conducted trials the following conclusions can be drawn:

- When stuffed filter cartridges are used for total dust collection – as it is required when high particle mass concentrations are prevailing in an untreated flue gas from herbaceous crop combustion – they should always be combined with a downstream plane filter in order to prevent any losses of fine particles through the quartz wool, whose retention capacity is insufficient for an exclusive use. This is true, even when a wet insertion of the quartz material into the filter cartridge is done or when the highest possible density of the package is achieved.
- Different temperatures of the post-treatments of a dust loaded filter can lead to variable results of total dust determinations. A fixation of these filter treatment

temperatures is useful. If temperatures of post-treatment are higher than temperatures during sampling, a certain share of total particle mass cannot be determined.

- An isokinetical sampling operation is generally desirable, but the possible measuring deviation in non-wood fuel combustion is low.
- The treatment of unloaded filters (blank samples) usually contributes little to the overall error as long as the filters are not built-in into the filter casings. The latter phase of the filter process can however be regarded as the actual error relevant phase of the application process. For error adjustment purposes it is therefore advisable to perform parallel blank filter tests along the full process rather than only observing empty filters during the drying and weighing phases.
- In measurements applying an out stack sampling equipment – as it is common for residential furnaces with low exhaust pipe diameters – the error from neglecting the particle deposition on the inner surface of the nozzle, the elbow and the connecting tube can reach the order of 20 %, particularly at higher dust emission levels of around 160 to 230 mg/Nm³ (13 % O_2). Depending on the aim of the boiler test and on the regarded emission levels it can thus be required to apply a washing procedure in order avoid an excessive error from any particle depositions before the filter(s).

5.5 WP5 – Development of test procedures (responsible FJ-BLT)

5.5.1 Methods and data

For identification of the state of the art of national and international testing rules in task 5.1 a questionnaire in the participating countries was done by FJ-BLT supported by Austrian Bioenergy. Interview partner were involved project partner due to their competence in this area. Most of them collaborate in the respective national committees for creation testing rules. Additionally the situation in legislation regarding fuel classification, emissions, efficiency, safety, and other regulations in the participating countries were recorded. Afterwards a list of possible standards which could be used as a basis for a new test rule is established. Finally the national and CEN standardization process was described.

On the basis of the questionnaire result in task 5.2 the most common testing standard for smale scale boilers was chosen for combustion tests with non wood biofuels done in task 5.3.

Seven boilers were chosen for the testing with non wood solid fuels. Additionally combustion test with wood pellets as reference test in some of those boilers were done. Following boilers and fuels were used:

code	fuels	nominal heat output [kW]	feeding system	type of grate
A	wood pellets	14,9	under feed	ring plate (no cleaning system)
	straw pellets			
B	wood pellets	30	horizontal feed	moving grate
	barley			
	grain pellets			
	straw pellets			
C	wood pellets	100	horizontal feed	moving grate
	barley			
D	wood pellets	140	horizontal feed	moving grate (turning grate)
	miscanthus pellets			
	miscanthus chips			
E	wood pellets	35	horizontal feed	moving grate
	miscanthus pellets			
	barley			
F	miscanthus pellets	28	horizontal feed	moving grate (turning grate)
	miscanthus chips			
G	miscanthus pellets	59	horizontal feed	moving grate
	miscanthus chips			

Table 1: Selected boilers for combustion tests

Additionally the list of results was completed with existing results of tests with automatically boilers of ABC, TFZ and SP where also straw, grain and miscanthus were used. Furthermore results from hay combustion at ABC are included.

In task 5.4 the requirements for testing procedures were defined. Basically test procedure of EN 303-5 was used. Amendments for requirements in testing with non wood biomass were added.

In task 5.5 FJ-BLT and ABC coordinated the preparation of a “Best practice guideline” for testing small scale combustion plants with non wood biomass. This was done by modification of EN 303-5 on the basis of the results of WP2-WP5. Requirements on the modifications were discussed with project partners during project meetings and workshops.

5.5.2 Results

Small scale boilers for log wood, wood chips and pellets have gained a high stage of development for the last fifteen years. Since the release of the EN 303-5 wood boilers have been tested and evaluated according to this standard. Log wood, chipped wood, compressed wood (pellets) and saw dust are those solid fuels, which are admitted for testing.

The questionnaire in the partner countries show that for testing small scale boilers in all partner countries EN 303-5 is used.

Emission limits and requirements on efficiency for small scale boilers up to 400 kW exist only in Austria, Germany and Sweden. In Finland emissions are limited for boilers with more than 1 MW nominal heat output.

Fuel specifications are based on the CEN/TS 14961 in all partner countries. Additionally national product standards for wood fuels (wood chips, wood pellets/briquettes, energy grain, miscanthus pellets/briquettes) exist in Austria, Germany and Sweden.

In Austria and Germany regulations regarding safety are in force whereas in Sweden recommendations for installation of new appliances and in Finland voluntary guidelines for small wood pellets and wood chips combustion plants are published.

For standardization on European level the CEN established the TC 335. This committee is arranged in five working groups, gathering the standards for solid biomass.

- TC 335 WG 1: Terminology, Definitions and Descriptions
- TC 335 WG 2: Fuel Specifications, classes an quality assurance
- TC 335 WG 3: Sampling and Sample Reduction
- TC 335 WG 4: Physical/Mechanical Tests
- TC 335 WG 5: Chemical Tests

These working groups developed plenty of technical specifications in the recent years. These technical standards will be adapted and published as EN standards in the forthcoming future.

The establishment of an uniform European standard defining the requirements for heating boilers was important for the development of combustion systems. Therefore the secretary CEN/TC 57/WG 1 “Combustion plants for solid fuels” worked out the EN 303-5, published in 1999. This standard is the basis for type testing of boilers in Europe and refers to all further relevant standards.

The European standardisation is carried out in CEN. 30 member states conclude the publishment of a new standard. The member states have committed to implement EN standards as national standards. If an EN is worked out or published national standards won't be created, which is caused by the standstill agreement, as well as already established standards are retrieved caused by the withdrawal commitment.

Essential elements of the European standardisation:

- neutral team work
- comprehensive consensus
- rules of procedure:
- commitment of inactivity
- weighted acclamation
- commitment of acceptance
- withdrawal commitment

Boiler tests in task 5.3 were done on the basis of 303-5. Measuring of gaseous emissions (CO, OGC, NO_X) and efficiency were satisfying according this standard. Concerning dust measurement focus was on the number of necessary replication of dust sampling by calculation of the coefficient of variation (relative standard deviation) in between the samples within received measurement periods.. The number of replications of dust sampling was between two and six.

Results show that coefficient of variation is the higher the lower the average of the dust emissions is (within one measurement period). Due to the expected low thresholds for dust emissions (e.g. Germany: 20 mg/Nm³ 13 % O_2 from 2014, Austria: 35 mg/MJ from 2015) the project consortium agreed to recommend in the best practice guideline 6 replications of dust sampling during testing period.

In the course of testing the creation and accumulation of slag and the abrasion due to corrosion was tried to be analysed. Slagging occasionally occurred, especially with the fuel straw. During the testing no breakdown due to slagging was caused. An evaluation of the intensity of slag formation was not possible because of the absence of regulations.

Checking of corrosion was not possible after the short time testing. For the analyses of corrosion long time tests or field surveys are required.

Following requirements from EN 303-5 on testing procedures have been identified:

- To determine the heat output, boiler efficiency and emission properties, the boiler is operated throughout the tests within the heat output range. At nominal heat output the boiler is to be operated in such a way that continuous service is possible.
- Before the start of the test the boiler is brought to operating temperature using the appropriate quantity of fuel; the necessary basic fire bed is established.
- Test duration at nominal heat output shall be at least 6 hours, test duration at minimum heat output shall be at least 6 hours.

- The amount of useful heat transmitted to the heat carrier (water) is measured. It can be determined directly in the boiler circuit or indirectly by means of a heat exchanger.
- The efficiency is determined on the basis of the net calorific value. The direct method is to be used. The indirect method allows an additional check of test accuracy of the test rig to be made by means of a heat balance. From this the values of other losses will also be determined.
- The average CO_2 or O_2 CO, OGC (and NO_X where appropriate) contents are determined over the entire test period at nominal heat output.

For dust determination following requirement was defined additionally:

- To determine the dust content the test period is divided into at minimum 6 equal time sections. The measurements begin in each case at the start of the sections, with the first measurement taken when the test begins. The suction time per filter is limited to 30 min. The average dust content is determined from the 6 half-hour values at minimum.

Test fuel classes diverge from fuel classes in EN 303-5 and are defined as follows:

- Fuel of commercial quality is used for testing heating boilers and characteristics of the type of fuel as declared by the manufacturer according table 3 and table 4 of best practice guideline (see Annex). These test fuels can be all kinds of chemically untreated non wood solid biomass (all classes of CEN/TS 14961 except classes 1; 2.2.2; 3; 4).
- Used test fuels have to be described in the testing report concerning their belonging to ash classes and nitrogen classes according table 4 and 5 of best practice guideline (e.g. A 1-3/N 1-1). Moreover, the test fuel has to be specified according to CEN/TS 14961 Table 1. Species and origin of test fuels have to be declared. This applies in particular to fuel blends, including a declaration of the share of each component used. Fuel mixtures are explicitly excluded as testing fuel.

Task 5.5 was done by preparation a so called “Best practice guideline - Heating boilers for solid biogenic fuels automatically stoked, nominal heat output of up to 400 kW - Terminology, requirements, testing and marking”.

This guideline shall be a proposal for an international standard for testing requirements of automatically stoked small-scale boilers used for non wood solid biomass fuels up to 400 kW.

For this guideline the European Standard EN 303-5 is used as basis. Conforming chapters are declared. In order to ensure a wide-spread acceptance of this guideline changes and amendments to the existing EN 303-5 were kept as low as possible. The work has focussed on derivation and evaluation of measurement principles and procedures. The consortium of the ERA-NET project “Development of test methods for non wood small-scale combustion plants” strongly recommends the establishment of a European standard regulating the requirements for furnaces (e.g. emissions and efficiency, construction requirements like wall thickness,...).

This guideline applies to automatically stoked heating boilers up to a heating output of 400 kW which are designed for the burning of non-wood solid biomass and are operated according to the instructions of the manufacturer either with negative pressure or with positive pressure in the combustion chamber.

5.6 WP6 – Identification of further R&D required and preparatory work for a round robin tests (responsible VTT)

5.6.1 Methods and data

Task 6.1 – 6.3 was to prepare a round robin test on the basis of the prepared Guideline. It was done by asking laboratories regarding their interest joining the round robin test, common definition of frame conditions, like boiler size and fuels as well as a calculation of the costs.

In task 6.4 identification of further R&D required was done by experts' workshop within two project meetings. That was in the final project meeting on March 10th, 11th, 2008 at TFZ in Straubing and on June 4th 2008 in Valencia. The aim of the workshops was to clearly identify further R&D needed to provide the scientific basis for the development of a European standard for testing of small scale non wood biomass boilers.

5.6.2 Results

Six testing institutes have been contacted and asked their willingness to participate in the round-robin testing. They all are (or will be in near future) accredited laboratories to carry out boiler tests according to the existing standard EN 303-5 including the adaptations of the guideline. They all expressed their interests in participating in round-robin testing.

The idea is to choose one boiler and two fuels for tests. One from the "safe" side which is known to be quite easy to burn. This is miscanthus in the form of pellets or briquettes. The other fuel will be more difficult, for example wheat straw. It will also be in the form of pellets or briquettes to make delivery easier. Manufacturers of these fuels will be chosen in the actual round-robin testing project.

Assuming six laboratories will participate in the round-robin testing project, estimated costs are about 122.000 € of which it assumed that at least 50% would come from a suitable European Union financing scheme. Each partner should have their own financing about 10.000 €. This action must be a new project and will be decided among the project partners.

Further R&D is required in form of a round robin test project according the proposed test procedure. Preparatory work of round robin test is advanced. As a result of WP6 that project could start immediately. Within the round robin test proposed test procedure should be evaluated and enhanced if necessary with focus on dust measurement methods again.

Test measurement methods regarding dust measurements have to be evaluated again and experience of participating laboratories have to be unified to common European wide dust measurement method.

Research activities regarding corrosion of heat exchanger and refractory materials by combusting non wood fuels have to be done by performing long term combustion tests.

6 Conclusions

The aim of the ERA-net project "Development of test methods for non wood small scale combustion plants" was to identify European regulations concerning testing rules, general conditions of the energetic use of non wood biomass, state of the boiler technology, applicable measurement methods, development of adequate test procedures and identification of further R&D required. The results of the project can be summarized as follows:

- There is a wide range of biomass sources which is relevant for the application in small-scale combustion plants and which is classified in the European pre-directive CEN/TS 14961.
- In the partner countries in general there are potentials for energy crops and several residues, especially straw from grain production. A potential increase can be expected for energy crops.
- Most interesting biomasses for use in smale-scale combustion units are straw-pellets as well as pellets from miscanthus or reed canary grass. The demand on energy grain will depend very much on market prices for grain.
- To meet an increased use of non-wood fuels, there is a need of technical development and of increased knowledge to improve the performance. Development is needed of fuel and load flexibility to avoid sintering, fouling, corrosion and high emissions.
- The granting of a license for the fuels is handled differently in the partner countries. Regulations reach from no licence for non-wood fuels over a dependence to the plant size up to no licence necessary.
- Boiler testing is orientated on EN 303-5 in the partner countries, but there is no valid regulation concerning boilers for non-wood fuels in most cases. Some voluntary labelling systems are implemented.
- Depending on future emission limits in the different countries, fuel specific emissions will need primary and/or secondary means to be reduced.
- Beside combustion and emission performance, it is important that future technique will meet also the users demands for convenience.
- Regarding dust measurements numerous sources of error and a high number of influencing factors and interactions (filter treatment, filter preparation, type of equipment, isokinetics, sampling positions in the exhaust pipe, volume flow determination, unsymmetrical dust distribution, etc.) are given. An isolated

consideration of a single influence is difficult, particularly as the repeatability of dust determinations is generally relatively low. Further R&D must attach importance on that topic.

- For the best practice guideline the European Standard EN 303-5 was used as basis. In order to ensure a wide-spread acceptance of this guideline changes and amendments to the existing EN 303-5 were kept as low as possible. The work has focused on derivation and evaluation of measurement principles and procedures.
- Six laboratories would participate in a following round-robin testing project. Two fuels will be chosen (e.g. miscanthus pellets/briquettes and wheat straw pellets/briquettes) and combusted in a 100 kW boiler according to the new guideline. Further necessary adaptations of the guideline will be done on the basis of the round robin results.

7 Recommendations

Derived from the results of the project following recommendations can be drawn:

- A continuation of the successfully started ERA-net activities through further joint calls of the ERA-net partners is highly recommended by the ERA-net consortium.
- Started research work on measurement methods for non wood small scale combustion plants should be continued categorically. Next step is to start a round robin project within the ERA-net programme or in another appropriate programme to evaluate compiled results and enhance the best practice guideline.
- The consortium of the ERA-net project "Development of test methods for non wood small-scale combustion plants" strongly recommends the establishment of a European standard regulating the requirements for testing small scale furnaces for biogenic fuels.

Best practice Guideline

Heating boilers for solid biogenic fuels automatically stoked, nominal heat output of up to 400 kW

Terminology, requirements, testing and marking

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Foreword

This Best practice guideline has been prepared by the project group working on the ERA-NET project “Development of test methods for non wood small-scale combustion plants”.

This guideline shall be a proposal for an international standard for testing requirements of automatically stoked small-scale boilers used for non wood solid biomass fuels up to 400 kW.

For this guideline the European Standard EN 303-5 is used as basis. Conforming chapters are declared. In order to ensure a wide-spread acceptance of this guideline changes and amendments to the existing EN 303-5 were kept as low as possible. The work has focussed on derivation and evaluation of measurement principles and procedures. Anyhow, the consortium of the ERA-NET project “Development of test methods for non wood small-scale combustion plants” strongly recommends the establishment of a European standard regulating the requirements for furnaces (e.g. emissions and efficiency, construction requirements like wall thickness,…).

1 Scope

This guideline applies to automatically stoked heating boilers up to a heating output of 400 kW which are designed for the burning of non-wood solid biomass and are operated according to the instructions of the manufacturer either with negative pressure or with positive pressure in the combustion chamber.

Categories of fuels according to this guideline are:

classes regarding ash content (A)								**classes regarding nitrogen content (N)**					
naturally fluent or compressed (1)				chopped (2)				naturally fluent or compressed (1)			chopped (2)		
code													
A1-1	A1-3	A1-6	A1-10	A2-1	A2-3	A2-6	A2-10	N1-0,5	N1-1	N1-2	N2-0,5	N2-1	N2-2

Table 1: Fuel classes (for description and details see chapter 5.3 Test fuels, Table 3 and Table 4)

The fuels can be all kinds of chemically untreated non wood solid biomass (all classes of CEN/TS 14961 except classes 1; 2.2.2; 3.2.2; 4).

The boilers can be used with natural draught or forced draught.

The stoking is automatic.

The ash removal is automatic.

The proposals of this guideline apply to heating boilers which are to be tested on accredited boiler test stands.

Heating boilers in accordance with this guideline are designed for central heating installations whose heat carrier is water and whose maximum allowable operating temperature is 100°C and which can operate at a maximum allowable operating pressure of 6 bar.

This guideline does not apply to

- hand stoked central heating systems,
- heating appliances which are designed for the direct heating of the place of installation,
- cooking appliances,
- the design and construction of automatic stoking devices.

2 Normative references

EN 267:1999

Forced draught oil burners – Definitions, requirements, testing, marking

EN 303-5:1999

Heating boilers for solid fuels, hand and automatically stoked, nominal heat output of up to 300 kW – Terminology, requirements, testing and marking

EN 304:2005

Heating boilers – Test code for heating boilers for atomizing oil boilers

(EN 304:1992 + A1:2000 + A2:2003

EN 13284-1:2002

Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual gravimetric method

EN 15270:2008

Pellet burners for small heating boilers — Definitions, requirements, testing, marking

EN 15486:2006

Heating boilers - Electrical power consumption for heat generators – System bounds - Measurements

CEN / TS 14774-2:2004

Solid biofuels - Methods for the determination of moisture content - Oven dry method - Part 2: Total moisture - Simplified method

CEN / TS 14775

Solid biofuels - Method for the determination of ash content

CEN / TS 14961:2004

Solid biofuels – Fuel specifications and classes

CEN / TS 15103:2005

Solid biofuels - Methods for the determination of bulk density

CEN / TS 15104:2005

Solid biofuels - Determination of total content of carbon, hydrogen and nitrogen - Instrumental methods

CEN / TS 15289:2006

Solid biofuels - Determination of total content of sulphur and chlorine

CEN / TS 15290:2006

Solid biofuels – Determination of major elements

3 Definitions

See EN 303-5:1999, Chapter 3 “Definitions”, page 6-8.

4 Requirements

See EN 303-5:1999, Chapter 4 “Requirements”.

BUT: The requirements of EN 303-5, chapter 4, do not necessarily apply for the fuels considered in this guideline. The definition of the required deviations has not been subject to the project within which this guideline has been derived.

5 Test

5.1 Test base

See EN 303-5:1999, Chapter 5.1 “Test base”, page 30-31.

5.2 Measurement uncertainties

Table 2 shows maximum uncertainties for relevant measuring parameters in combustion tests

Table 2: Maximum uncertainties for relevant measuring parameters

Parameter	Maximum uncertainty [a, b]	Comment
Boiler heat output	± 1,5 % of measured value	The uncertainties of the specified measured variables (mass flow of water temperature) difference contain all uncertainties of the particular instruments. These could be: - linearity - temperature influence - barometric pressure influence - drift - resolution - uncertainty of calibration reference - repeatability
Boiler efficiency (direct calculations)	± 3 % points (absolute)	The uncertainties of the specified measured variables (fuel mass input, net calorific value of the fuel at given moisture, boiler output (including mass flow of water and temperature difference, test time)) difference contain all uncertainties of the particular instruments. These could be: - linearity - temperature influence - barometric pressure influence - drift - resolution - uncertainty of calibration reference - repeatability

Dust [e,f]	± 15 % of measured value, but min. 8 mg/Nm^3 [i, j]	The applied instruments must fulfill the uncertainty requirements as specified in EN 13284[h], Part 1, Annex F, except for isokinetic sampling.[a] The determination of dust measuring uncertainties is performed according to EN 13284 [h], Part 1 chapter 12 by the method of successive parallel sampling tests with two identical sampling systems.
CO_2-content [c]	± 0,4 Vol %	The uncertainties of the specified measured variables difference contain all uncertainties of the particular instruments. - linearity - temperature influence - gas or barometric pressure influence - drift - sample gas flow influence - cross sensitivity - resolution - adjustment gas - repeatability - water vapor content
O_2-content [c]	± 0,4 Vol %	
CO-content [c,f]	± 10 % of measured value but min. 10 ppm at range 500 ppm ± 45 ppm at range 3000 ppm	
NO_x-content [c,f]	± 5 % of measured value but min. 15 ppm	
OGC-content [e,f]	± 5 % of order of magnitude [d], but min. 10 mg/Nm^3 [j]	
Pressure in the boiler combustion chamber	± 5 % of measured value [g]	If applicable
Pressure in the flue gas draught	± 1 Pa	If applicable
Electrical energy supplied	± 0,1 % of measured value [g]	

[a] See annex calculation.

[b] The uncertainties are given for single values not for average values.

[c] Calibration of the instrument should comprise the complete system from probe to analyzer including gas treatment and A/D-conversion of signals.

[d] The order of magnitude is defined as the highest decimal power of measured value, e.g for measured values up to 100 ppm measurement uncertainty is 5 % of 100, for measured values of 101 ppm up to 1000 ppm measurement uncertainty is 5 % of 1000 etc.

[e] Sampling errors are not included; measures for their reduction shall generally be applied.

[f] Not related to specific oxygen level. The calculation to specific oxygen values causes additionally uncertainties.

[g] Source: EN 15270:2008– Pellet burners for small heating boilers — Definitions, requirements, testing, marking.

[h] DIN EN 13284-1: Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual gravimetric method (April 2002).

[i] Further research (i.e. proposed Round Robin and other) needs to work out a practical value of this minimum value of the uncertainties for measuring dust. **Moreover, standardization work on dust measurements for residential boilers is required in the future.**

[j] at measured O_2 level.

5.3 Test fuel

Fuel of commercial quality is used for testing heating boilers and characteristics of the type of fuel as declared by the manufacturer according table 4 and table 5. These test fuels can be all kinds of chemically untreated non wood solid biomass (all classes of CEN/TS 14961 except classes 1; 2.2.2; 3; 4).

Used test fuels have to be described in the testing report concerning their belonging to ash classes and nitrogen classes according table 3 and 4 (E.g. A 1-3/N 1-1). Moreover, the test fuel has to be specified according to CEN/TS 14961 Table 1. Species and origin of test fuels have to be declared. This applies in particular to fuel blends, including a declaration of the share of each component used. Fuel mixtures are explicitly excluded as testing fuel.

Testing with a fuel of higher ash and nitrogen class replaces testing with a fuel with lower ash and nitrogen class. E.g. A 1-3/N 1-0,5 replaces: A 1-1/N 1-0,1; A 1-1/N 1-0,5; A 1-3/N 1-0,1.

Testing with naturally fluent or compressed fuels does not replace testing with chipped fuels, testing with chipped fuels does not replace testing with naturally fluent or compressed fuels.

The values of bulk density, ash content, nitrogen content and moisture content have to be determined.

Table 3: Test fuel classes regarding ash content

	classes regarding ash content (A)							
	naturally fluent or compressed (1)				chopped (2)			
bulk density (as delivered)	>300 kg/m³ (BD 300+)				≤300 kg/m³ (BD 300)			
classes[2]	A 1-1	A 1-3	A 1-6	A 1-10	A 2-1	A 2-3	A 2-6	A 2-10
moisture content	compressed and naturally fluent M < 20 % chopped M < 35 %							
ash content (db)	> 1 %	> 3 %	> 6 %	> 10 %	> 1 %	> 3 %	> 6 %	> 10 %
Cl content (db)	no restrictions	> 0,1 %			no restrictions	> 0,1 %		
K content (db) [A]	no restrictions	> 0,3 %	> 0,5 %		no restrictions	> 0,3 %	> 0,5 %	
additives[3, 4]	no restrictions	no additives allowed			no restrictions	no additives allowed		
pretreatment	no restrictions	not allowed			no restrictions	not allowed		
size/length	according to manufacturer's instruction							

[A] The K content is used here twofold. Firstly it indicates the necessity for a parameter describing the slagging tendency of a fuel, which is subject to ongoing and future research. As an outcome of research another parameter might be introduced for slagging tendency here respectively. Secondly, K is one of the most relevant elements for aerosol formation. As such it remains relevant anyhow.

[2] Classes are adapted to the proposed classes of CEN/TS 14961:2004 Solid biofuels — Fuel specifications and classes
[3] The term „additives“ refers to substances, which might be use to support the combustion process (e.g. slagging inhibitor). It does not include materials used in pellets production (eg. binding agents, such as starch,...).
[4] Moreover, see the regulations from prEN 14961-1:2007-12-01

Table 4: Test fuel classes regarding nitrogen content

	classes regarding nitrogen content (N)					
	naturally fluent or compressed (1)			chopped (2)		
bulk density (as delivered)	>300 kg/m³ (BD 300+)			≤300 kg/m³ (BD 300)		
classes[5]	N 1-0,5	N 1-1	N 1-2	N 2-0,5	N 2-1	N 2-2
moisture content	compressed and naturally fluent M < 20 % chopped M < 35 %					
nitrogen content (db)	> 0,5 %	> 1 %	> 2 %	> 0,5 %	> 1 %	> 2 %
size/length	according to manufacturer's instruction					

[5] Classes are adapted to the proposed classes of CEN/TS 14961:2004 Solid biofuels — Fuel specifications and classes

5.4 Pressure test for boilers of sheet or sheet metal of non-ferrous metal

See EN 303-5:1999, Chapter 5.4 “Pressure test for boilers of sheet or sheet metal of non-ferrous metal”, page 33.

5.5 Pressure test for boilers of cast iron or non-ferrous metal

See EN 303-5:1999, Chapter 5.5 “Pressure test for boilers of cast iron or non-ferrous metal”, page 33-34.

5.6 Test for gas soundness

See EN 303-5:1999, Chapter 5.6 “Test for gas soundness”, page 34.

5.7 Conducting the boiler performance test

See EN 303-5:1999, Chapter 5.7 “Conducting the boiler performance test”, page 34-36, except:

5.7.1 Measured quantities

One-off measurement:

- bulk density of the fuel;
- water content of the fuel;
- ash content of the fuel;
- nitrogen content of the fuel;
- potassium content of the fuel;
- chlorine content of the fuel;
- fuel mass added;
- surface temperatures (at nominal heat output in a typical operating condition).

Continuous measurement:

- heat output;
- flow temperature;
- return temperature;
- temperature of the entering cold water according to EN 304, figure A.2;
- ambient temperature;

- exhaust temperature; - draught;
- oxygen 0_2 or carbon dioxide CO_2 content;
- carbon monoxide CO content;
- nitrogen monoxide NO and nitrogen dioxide NO2 content;
- organic gaseous substances OGC (shown as organically bound carbon);
- dust content (intermittent measurement).

Emissions in the form of dust and nitrogen oxides are determined at nominal heat output only.

All the measured quantities to be determined continuously are at maximum intervals of 20 s and recorded as mean values at maximum intervals of 1 min. The time intervals are to be chosen in such a way that fluctuations in the measured values are recorded with sufficient accuracy.

The recorded mean values are the basis for making the mean value for the test period.

5.8 Determination of the heat output and the efficiency of the boiler

See EN 303-5:1999, Chapter 5.8 “Determination of the heat output and the efficiency of the boiler”, page 36-37.

5.9 Determination of the emission values

5.9.1 Determination of the emissions at nominal heat output

The average CO_2 or O_2 CO, OGC (and NO_X where appropriate) contents are determined over the entire test period at nominal heat output.

To determine the dust content the test period is divided into at minimum 6 equal time sections. The measurements begin in each case at the start of the sections, with the first measurement taken when the test begins. The suction time per filter is limited to 30 min. The average dust content is determined from the 6 half-hour values at minimum.

5.9.2 Determination of the emissions at minimum heat output

The average CO_2 or O_2 CO and OGC contents are determined over the entire test period.

5.10 Determination of the auxiliary energy consumption

See EN 15486:2006 - Heating boilers - Electrical power consumption for heat generators – System boundaries - Measurements

5.11 Calculation

See EN 303-5:1999, Chapter 5.10 “Calculation”, page 38.

5.12 Determination of the water resistance

See EN 303-5:1999, Chapter 5.11 “Determination of the water resistance”, page 39.

5.13 Surface temperature

See EN 303-5:1999, Chapter 5.12 “Surface temperature”, page 39.

5.14 Function check of the temperature controller and safety temperature limiter

See EN 303-5:1999, Chapter 5.13 “Function check of the temperature controller and safety temperature limiter”, page 39.

5.15 Function test on the device for dissipating excess heat

See EN 303-5:1999, Chapter 5.14 “Function test on the device for dissipating excess heat”, page 39.

6 Test report and other documents

See EN 303-5:1999, Chapter 6 “Test report and other documents”, page 39.

7 Designation

See EN 303-5:1999, Chapter 6 “Designation”, page 40.

8 Technical documentation

See EN 303-5:1999, Chapter 8 “Technical documentation”, page 40-41.

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ANNEX A: Proposal for calculation methods for measurement uncertainties

The uncertainties are calculated according to the calculation method “type B” as described in GUM [1] and DIN V ENV 13005 [2]. The results are given as the expanded uncertainty for a confidence interval of 95 % (k = 2).

The following description applies to test facilities with commonly used measuring equipment. However, for differing methods other sources for uncertainty may have to be considered. Therefore the here given procedure should be seen as an example of a widely applicable calculation.

1. Gas analysis

Uncertainties of gas analyses can be differentiated into uncertainties for analysers and – if applicable - uncertainties for moisture content determination in flue gas as required for relating the measured values to dry basis. Not covered here are uncertainties due to the sampling equipment (e.g. leakages, adsorption, condensation). These errors shall be avoided by general quality assurance measures.

1.1 Expanded uncertainty for gas analysers (as measured)

$$U(k=2) = 2 \times \sqrt{\sum_{i=1}^{N} \left[\left(\frac{\partial F}{\partial x_i} \right) \times u(x_i) \right]^2}$$ (valid only for uncorrelated quantities)

$$U(k=2) = 2 \times \sqrt{u^2_{analyser}(k=1) + u^2_{repeatability}(k=1) + u^2_{adjustment\ gas}(k=1)}$$

with

$u_{repeatability}$ and $u_{adjustment\ gas}$: Uncertainties as declared by the equipment manufacturer or gas distributor. ($u_{repeatability}$ may be included in the $u_{analyser}$, depending on manufacturer declaration

$u_{analyser}$: The uncertainty of the analyser is either fully or partially reported by the manufacturer or it is calculated according to the following formula.

$$u_{analyzer} = \sqrt{\begin{aligned}&\left(\frac{E_{linearity}}{f_i}\right)^2 + \left(\frac{E_{temperature\ influence}}{f_i}\right)^2 + \left(\frac{E_{gas\ or\ barometric\ pressure\ influence}}{f_i}\right)^2 + \left(\frac{E_{drift}}{f_i}\right)^2 \\ &+ \left(\frac{E_{sample\ gas\ flow\ influence}}{f_i}\right)^2 + \left(\frac{E_{cross\ sensitivity}}{f_i}\right)^2 + \left(\frac{E_{resolution}}{f_i}\right)^2 + \left(\frac{E_{gas\ outlet\ dew\ point\ of\ cooler}}{f_i}\right)^2 + \left(\frac{E_{data\ tranfer}}{f_i}\right)^2\end{aligned}}$$

E: Error limit according to the technical specification of the equipment manufacturer. Some error limits, like temperature influence, gas or barometric pressure influence, drift and sample gas flow influence are depending on the operational conditions of the test stand.

f_i: Factor to calculate the standard uncertainty (k = 1)
It depends on the declaration of the respective error limit.
For example:

$f_i = \sqrt{3}$: uniform or rectangular probability distribution

$f_i = \sqrt{6}$: triangular probability distribution

$f_i = k$: if coverage factor is given by manufacturer

1.2 Expanded uncertainty for emission at dry condition

This is only necessary if the gas component is directly measured in hot and wet condition.

$$\frac{U_{E_d}}{E_d}(k=2) = 2 \times \sqrt{\left(\frac{u_{E_w}(k=1)}{E_w}\right)^2 + \left(\frac{u_{C_{H_2O}}(k=1)}{100 - C_{H_2O}}\right)^2}$$

$\frac{U_{E_d}}{E_d}$: expanded uncertainty related to emission at dry condition

u_{E_w} : uncertainty of emission at wet condition (as measured)

E_w : emission at wet condition (as measured)

$u_{C_{H_2O}}$: uncertainty of vapor content at wet condition (as measured or calculated from fuel composition)

C_{H_2O} : water vapor content of flue gas in Vol.-% (as measured or calculated from fuel composition)

2. Expanded uncertainty for boiler efficiency and boiler heating power

General formula for calculation of uncertainties of results (e.g. boiler heating power, efficiency) which are calculated by combining different measuring parameters (e.g. mass flow, temperature differences).

$$U(k=2) = 2 \times \sqrt{\sum_{i=1}^{N}\left[\left(\frac{\partial F}{\partial x_i}\right) \times u(x_i)\right]^2}$$ Valid only for uncorrelated quantities

The expanded uncertainty for boiler efficiency related to boiler efficiency is calculated according to:

$$\frac{U_\eta}{\eta}(k=2) = 2 \times \sqrt{\left(\frac{u_{\dot{m}_F}}{\dot{m}_F}\right)^2 + \left(\frac{u_{q_{p,net,m}}}{q_{p,net,m}}\right)^2 + \left(\frac{u_{P_B}}{P_B}\right)^2}$$

$\frac{U_\eta}{\eta}$: expanded uncertainty related to boiler efficiency

$\frac{u_{\dot{m}_F}}{\dot{m}_F}$: uncertainty related to fuel mass input

$\frac{u_{q_{p,net,m}}}{q_{p,net,m}}$: uncertainty related to net calorific value at constant pressure of the biofuel at given moisture content (as given in CEN/TC 335, or laboratory)

$\frac{u_{P_B}}{P_B}$: uncertainty related to boiler heating power

with

$$\frac{u_{P_B}}{P_B} = \sqrt{\left(\frac{u_{\dot{m}_W}}{\dot{m}_W}\right)^2 + \left(\frac{u_{\Delta T}}{\Delta T}\right)^2}$$

$\frac{u_{P_B}}{P_B}$: uncertainty related to boiler heating power

$\frac{u_{\dot{m}_W}}{\dot{m}_W}$: uncertainty related to mass flow of water

$\frac{u_{\Delta T}}{\Delta T}$: uncertainty related to temperature difference of water

3. Dust

All measuring instruments for the dust measurement (e.g. balance, gas meter, etc.) must correspond to annex F in EN 13284, Part 1 [3]. Except for the isokinetic rate, for which the requirement is reduced to be between 90% and 200 % over the complete sampling period.

The uncertainties for dust measurement are calculated according to the calculation method “type A” as described in GUM [1] or DIN V ENV 13005 [2].
This method is not directly comparable to the measuring uncertainties as described in Chapter 1 and 2 of this annex. This is due to the fact that a reference to any “true value” can not be made due to the lack of the possibility for calibration. Therefore the here applied determination of the dust measuring uncertainty has to be based on internal laboratory test series of parallel measurements using identical equipment. This test series shall be performed following EN 13284, Part 1, Chapter 12 [3]. The parallel sampling tests are performed by the same measuring team. It is suggested to conduct a series of 20 parallel determinations.

This (internal) measuring uncertainty calculated by (see EN 13284, Part 1 [3]):

$$U(k=2) = t_{0,95;\ n-1} \times s_D$$

with

$$s_D = \sqrt{\frac{\sum_{i=1}^{n}(x_{i,1} - x_{i,2})^2}{2 \times n}}$$

x_1, x_2:	paired value
n:	number of sample pairs x_1 und x_2
s_D:	standard deviation of the paired values
$t_{0,95;\ n-1}$:	student factor for a 95 % confidence an the degrees of freedom n-1

4. References

[1] GUM, ISO/BIPM-Guide: Guide to the expression of uncertainty in measurement
[2] DIN V ENV 13005: 06 – 1999: Leitfaden zur Angabe der Unsicherheit beim Messen, Deutsche Fassung ENV 13005: 1999
[3] EN 13284-1: Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual gravimetric method (April 2002)