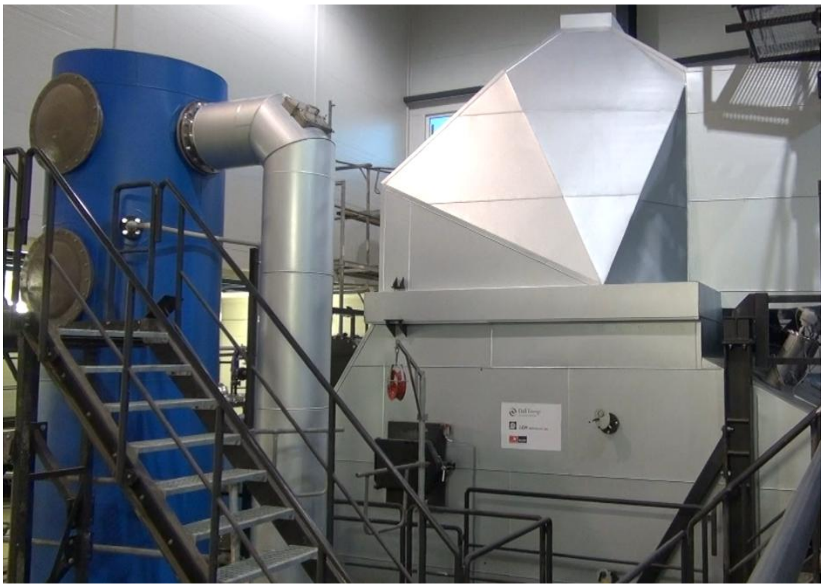
EUDP

Multi brændselsovn

Demonstrationsprojekt

Slutrapport

Juni 2012



Emission	***Luftvejled-ningen***	***Nuværende markeds standard***	***Dall Energy***
Støv	*100* *(i skorsten)*	*500-1000* *ud af ovn*	*50-70* *ud af ovn*
NOx	*300*	*200-400*	*175-200*
CO *100% last* *40% last* *20% last*	 *625* *625* *625*	 *100-200* *300-600* *Drift ikke mulig.*	 *<2* *<2* *<2*
Aske *Brændværdi*		*1%*	0,015 %

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Udgivelsesdato 6. Juni 2012

Udarbejdet JDB
Kontrolleret BT

Indholdsfortegnelse

1 Indledning

Biomasse teknologier er under udvikling til det voksende globale marked for miljøvenlig og CO2 neutral energi.

Modstrømsforgasningsteknologien, har vist sig at være en særdeles robust teknologi til omdannelse af træflis til gas. Modstrømsforgasning udmærker sig blandt andet ved meget høj udbrænding af kulstof og nem og hurtig at regulere.

En række danske virksomheder benytter sig således i dag af modstrømsteknologien, herunder Vølund, Stirling Danmark og Gasification Denmark.

Dall Energy har udviklet og patenteret en biomasse forbrændingsovn der kombinerer modstrømsforgasningsteknologien med gas-forbrænding i en integreret ovn.

Målsætningen med designet af ovnen var at opnå følgende egenskaber.

- Brændselsflexibilitet
- Lave emissioner
- Høj udbrænding af kulstof
- Høj Regulerbarhed

EUDP har støttet opførsel af pilot-ovn og verifikationen af forbrændingsprocessen. (EUDP projekt nr. 64009-0005).

Nærværende EUDP projekt nr. 64010-0007 omhandler

- langtidstidstest med pilotovn
- Design, etablering og indkøring af demonstrationsovn.

Projektet er udarbejdet i samarbejde mellem Dall Energy og SEM stålindustri.

Bogense Fjernvarme har været anlægsvært for demonstrationsovnen. Weiss har været ansvarlig for den samlede maskinleverance af biomasse anlæggettil Bogense Fjernvarme.

2 Langtidstest med pilotovn

I 2010 blev der kørt en række test med 2 MW pilot ovnen hos SEM stålindustri.

Formålene med disse test, var at give Dall Energy og SEM stålindustri tilstrækkelig erfaring med teknologien og fremvise pilot-ovnen til potentielle anlægsværter under drift, således at projektparterne og anlægsværten ville være trygge ved etableringen af et demonstrationsanlæg.

Dall Energy og SEM stålindustri gennemførte tests med pilot-anlægget i ugerne 24, 31, 35 og 38 i 2010.

Figur 2.1 Pilot-anlægget hos SEM stålindustri

2.1 Kørsler med pilot ovnen

2.1.1 Uge 24, 2010

Kørslen i uge 24 havde først og fremmest det formål, at fremvise anlægget til medlemmer af Dansk Fjernvarmes ERFA grupper vedrørende halm- og flis fyring.

Halm og flis gruppen havde fælles møde i Odense d. 16.-17. Juni, og det blev arrangeret, at dem der havde lyst, kunne komme til SEM stålindustri og se pilot ovnen i funktion.

Fremvisningen gik fint. Der var mellem 30-50 gæster, som fik et godt indtryk af pilotovnen og processen..

Figur 2.2 Foto fra besøg af halm og flis ERFA grupperne d.17. juni 2010. En film fra besøget kan ses her:http://www.youtube.com/watch?v=SSTh_elzNA0

2.1.2 Uge 31, 35 og 38, 2010

Efter fremvisningen i uge 24 skulle transportbåndet der havde forsynet anlægget med flis leveres tilbage.

SEM stålindustri lavede herefter en transport-snegl, som kunne forsyne anlægget.

Der blev planlagt en test række, med det primære formål at overbevise driftslederen for Thyborøn Fjernvarme om at driften er stabil.

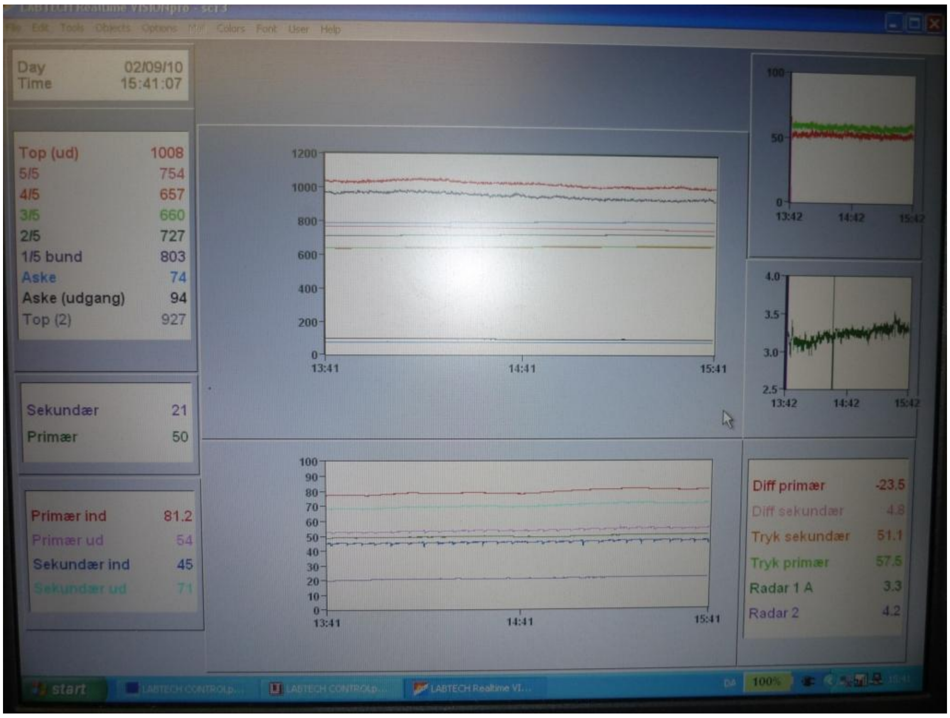
Under de første test var der problemer med styring og datalogningen idet der opstod støj. Dette blev afhjulpet og især kørslen i uge 38 forløb rigtigt godt.

Under de første to tests blev der også opserveret en aske-skorpe på bedden efter anlægget var lukket ned. Det var uklart om denne aske-skorpe var noget der var opstået under drift eller under nedlukning.

Det blev derfor besluttet at man under testen i uge 38 ville aske bedden ud i forlængelse af testen.

Testen varede en 4 dage og askeudmadningen forløb rigtigt fint, så det kunne konkluderes at de aske-skorper der tidligere var set på toppen af bedden efter nedlukning skyldes udbrænding på toppen efter brændselsindfødningen var stoppet.

Figur 2.3 Pilotanlægget om morgenen under test i uge 35, 2010.



Figur 2.4 Billede af datalogger under test i uge 35, 2010.

Figur 2.5 Pilotanlæg under askeudmadning efter test i uge 38, 2010.

På basis af forsøgene valgte Thyborøn Fjernvarme at starte forberedelserne af et projekt med en Dall Energy biomasse system (Dall Energy ovn + Dall Energy skrubbersystem).
Fornyelsesfonden blev ansøgt om støtte i marts 2011, som blev opnået i juni 2011.

I efteråret 2011 havde Dall Energy og Thyborøn fjernvarme en indgående dialog omkring projektet.

Thyborøns Fjernvarmes bestyrelse var på besøg i Bogense i starten af September og det blev her aftalt at Dall Energy skulle udarbejde et skitseprojekt.

Projektet blev dog vanskelig gjort ved at Thyborøns rådgiver mente at der skulle laves et traditionelt udbud og ved at udbedring af af mangler i Bogense tog lang tid. Thyborøn Fjernvarme blev herved nervøse omkring projektet Thyborøn gav Dall Energy lov til at finde en anden anlægsvært til demonstrationsprojektet.

Projektet med demonstration af Dall Energy biomase system (Dall Energy ovn + Dall Energy skrubbersystem) fortsættes hos Danish Malting Group (DMG).

3 Demonstrationsprojektet

3.1 Aftale med Bogense Fjernvarme

Inden projektets start havde flere potentielle anlægsværter udtrykt interesse via ”Letter of Intent” til EUDP ansøgningen, for at blive anlægsværter for demonstrationsprojektet:

1. Hjortebjerg Gartneri (2 MW)
2. Foulum (2 MW)
3. Egedal kommune (2 MW)
4. SEAS-NVE (4,6 MW)
5. Bogense Fjernvarme (8 MW)

Budgettet for demonstrationsprojektet var baseret på etablering af et 2 MW demonstrationsanlæg, og der var 3 mulige anlægsværter der havde behov for et 2 MW anlæg.

Men Bogense Fjernvarme var meget interesserede i at blive anlægsværter og SEM stålindustri var meget interesserede i at få Bogense Fjernvarme som kunde, så der var en meget indgående dialog mellem SEM stålindustri og Bogense Fjernvarme om demonstrationsprojektet i det tidlige forår 2010.

Dialogen ledte frem til en princip-aftale allerede i april måned 2010.

På grund af projektets størrelse og eftersom SEM-stålindustri ikke havde biomasse referencer, blev i stedet aftalt mellem parterne og med EUDP, at SEM´s søsterselskab Weiss A/S kunne indgå kontrakten med Bogense Fjernvarme.

For at afdække Weiss´s, SEM´s og Bogense risiko, blev det endvidere aftalt med Dall Energy, Bogense og EUDP at alle øvrige komponenter end ovnen skulle være ”Weiss Standard” og at Weiss skulle stå for alt den øvrige engineering og indkøring af anlægget.

Jævnfør EUDP ansøgningen var det ellers hensigten at demonstrationsprojektet også skulle omfatte Dall Energy´s patenterede løsninger (WO 2007/036236 A1, WO 2010/149173) omkring

- Røggasskrubber (højere virkningsgrad)
- Partikelfjernelse via quench
- Kondensat rens (keramisk filter)

Tidsplanen for projektet var ambitiøs:

Der skulle være koldtest uge 48 og opstart på flis uge 49, 2010. Dvs 7 måneder efter efter kontraktens indgåelse

3.2 Design af ovn (Dall Energy)

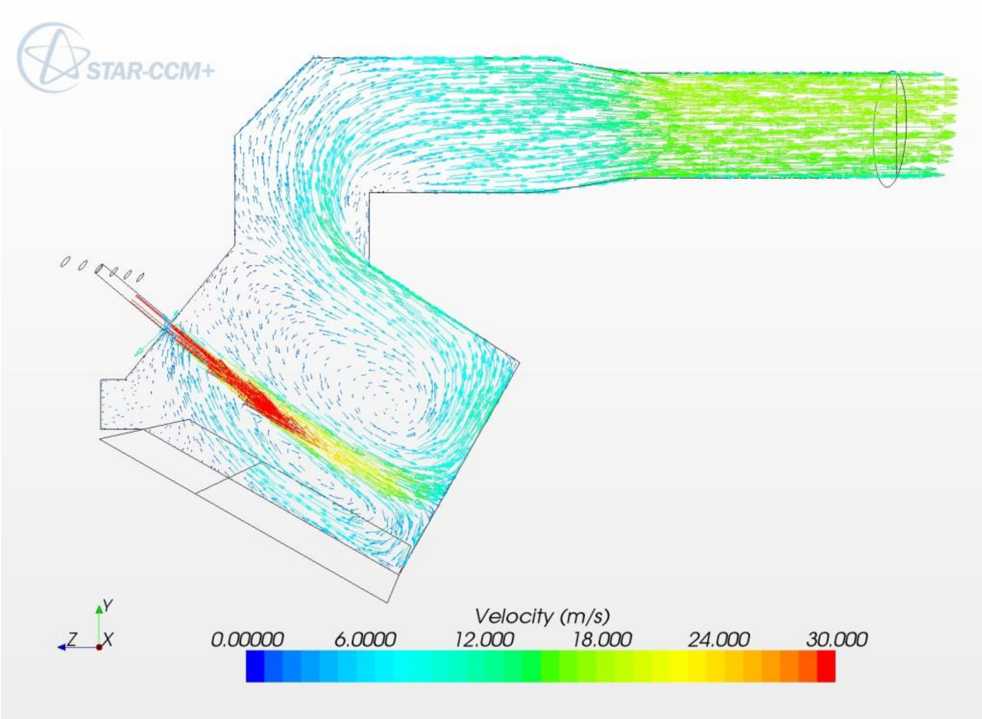
Pga. den ambitiøse tidsplan gik Dall Energy allerede i gang med designet af ovnen mens kontrakt forhandlinger mellem Weiss og Bogense Fjernvarme stod på.

Dall Energy havde en markant designmæssig og teknologisk udfordring idet ovnen til Bogense var 4 gange større end pilot-ovnen, som der på det tidspunkt (maj 2010) kun var begrænset erfaring med.

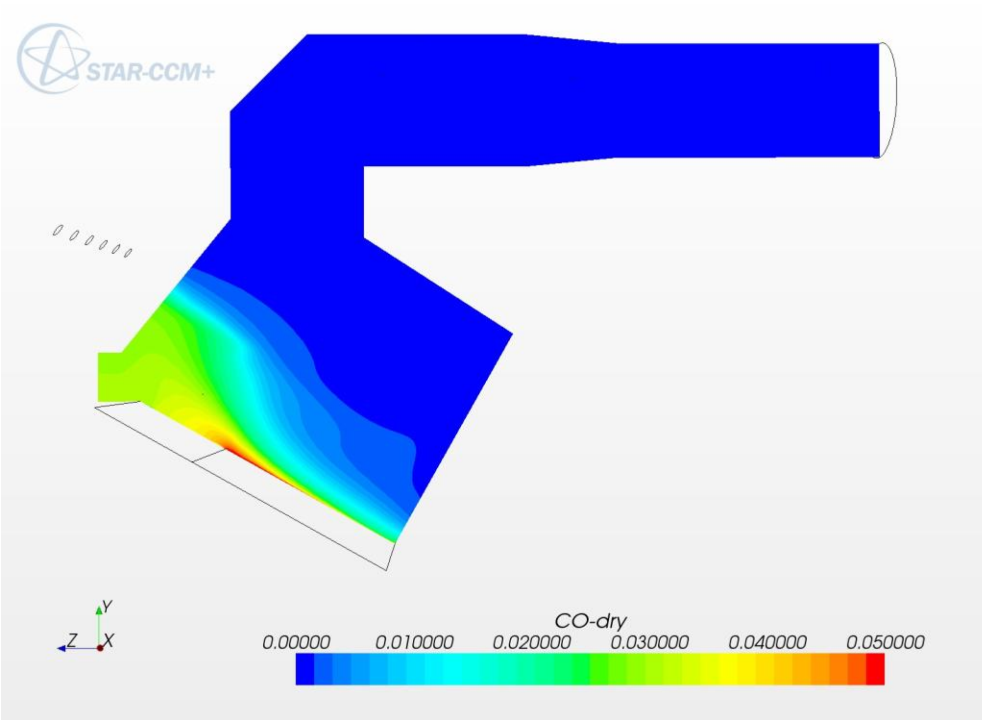
I design fasen stod det tidligt klart, at et helt nyt system for tilsætning af forgasningsluft skulle udvikles: Luften i pilotovnen blev tilsat fra siden, mens luften til Bogense ovnen skulle tilsættes fra bunden for at der kunne opnås tilstrækkelig god fordeling af luften.

Det principielle design af ovnen var færdigt i løbet af maj måned og CFD beregninger kunne allerede i juni bekræfte at det valgte design ville give god udbrænding = lave CO emissioner, ved såvel fuld last som ved dellast.

I juli måned blev tegninger af ovnen og specifikationer til udmuring leveret til SEM stålindustri.



Figur 3.1 CFD simulering af hastighed af gasstrømninger ved fuld last.



Figur 3.2 CFD simulering af CO emission ved 20% last

3.3 Etablering af ovn (SEM stålindustri)

Ovnen blev produceret på SEM stålindustris fabrik i Søndersø på Fyn i løbet af efteråret 2010.

Der blev indgået aftale med Smidth & Danielsen omkring udmuring af ovnen.

Den ambitiøse tidsplan, med opstart på flis i uge 48, kunne imidlertid ikke overholdes, og eftersom oven blev installeret i Bogense i vintermånederne, blev udmuringsarbejdet vanskeligt, idet støbemassen ikke må være kold under påføring, tørring og hærdning.

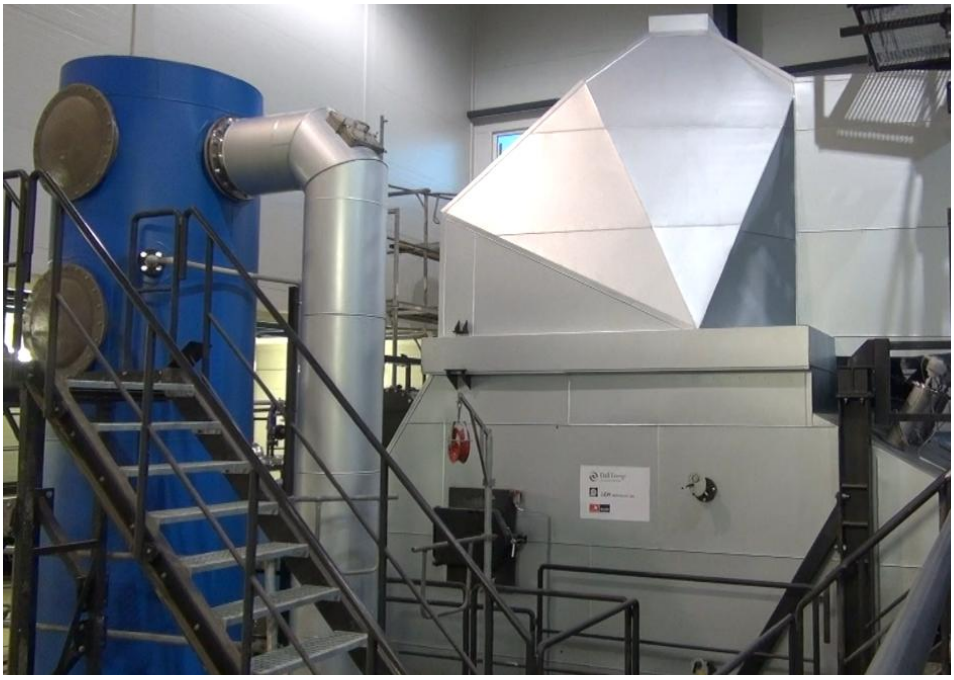
Ovnen stod klar til opstart på flis i uge 13, 2011.

Figur 3.3 Produktion af midtersektion, SEM stålindustri efterår 2010.

Figur 3.4 Transport af midtersektion til Bogense Fjervarme, December 2010.

Figur 3.5 Inspektion af udmuring. Februar 2011.

Figur 3.6 Ovn og kedel (Fabrikat Danstoker) Februar 2011.



Figur 3.7 Luft befugter og ovn med inddækning april 2011.

3.4 Indkøring af ovn (Weiss A/S)

Den første opstart af ovnen var i Marts måned 2011.

De mekaniske funktioner virkede fint, og anlægget producerede energi, men det stod hurtigt klart at en række ting skulle justeres, herunder:

- Temperatur-føler til røggassen ud af ovnen manglede.
  Føleren skal styre vanddoseringen som styrer temperaturen i ovnen.
- Vandpumpe til vanddoseringssystem til ovn manglede.
  Separat pumpe er nødvendig, så dyserne kan få det nødvendige tryk.
- Termofølere i askelaget manglede.
  Askesystemet styres via temperatur følere i asken.
- Kedelshunt manglede.
  Kedelshunt er nødvendig for at undgå korrosion af kedlen
- Kritisk grænse for temperatur for indløb til skrubber skulle ændres.
  Der kom en fejl når temperaturen af røgen ind i skrubberen bliver 75C.
- Ovn skal køre ved lavt ilt-overskud (4% tør basis)
  Weiss kørte ovnen ved 7-8% O_2 hvilket giver anledning til forbrænding og slaggedannelse på toppen af flislaget, samt høj støvbelastning med askepartikler.
- Vandrør til luftbefugter var for små.
  Befugtning af primær luft er nødvendig af hensyn til forgasningsprocessen.
- Justering af askesneglene.
- *Det er vigtigt af hensyn til forgasningsprocessen at askesneglene udmader i et jævnt lag.*

I løbet af sommeren og efteråret 2011 blev der kørt med anlægget mens de fleste af ovenstående fejl og mangler blev lavet.

Det var kun justering af sneglene der ikke blev lavet. Som alternativ løsning blev der lagt nogle plader over den forreste del af askesneglene, idet det var i den forreste del af ovnen det var konstateret at der opstod ”hul i bedden”

I takt med at fejl- og mangler blev udbedret blev driften af ovnen bedre og bedre.

Ved årsskiftet 2011/2012 var der dog fortsat udfordringer med askeudmadningen, idet asken i bunden af ovnen var vådt. Det var meningen at asken skulle holdes tør via varmeledning fra glødelaget.

I stedet blev det valgt valgt at lave tør aske ved at udtørre og overhede den befugtede luft der tilsættes askelaget. I samme omgang blev der installeret chokblaster system i asken.

Efter disse to tiltag var indført kørte ovnen godt, og det blev besluttet at afslutte EUDP projektet ved at lave et måleprogram der dokumenterer ovnens egenskaber, selvom det samlede anlæg ikke var færdigt og klar til aflevering.

En af de tekniske problemstillinger i foråret 2012 var, at der ind i mellem var problemer med for skrubberen, idet pladevarmeveksleren var indkøbt som en type ”GEA NX” som er for helt partikel frie væsker.

Frem for at udskifte veksleren til en type ”Weiss standard”, blev det besluttet at fjerne partikler via Quench jf. Dall Energys patent WO 2010/149173).

Dette løste problemet med NX pladevarmeveksleren. Dall Energy forventer at øvrige fejl og mangler laves i løbet af sommeren 2012.

3.5 Resultater fra ovn.

FORCE Technologies gennemførte i marts 2012 et omfattende måleprogram omkring ovnens egenskaber.

Nøgleresultater for målingerne ses i tabellen herunder:

Tabel 1. Measurements in flue gas outlet from furnace

Parameter	Unit	Average	Average
Load	%	100	20
Date	dd-mm-yy	20-03-2012	20-03-2012
Measuring period	hh:mm	11:12 - 14:22	16:44 - 20:00
Temperature	°C	958	845
O_2	Vol % (dry)	4.88	5.25
H_2O	Vol %	38.0	32.4
CO	mg/m³(ref)	< 2	< 2
NO_X	mg/m³(s,d)	300	200
NO_X	mg/m³(ref)	200	140
Particles *	mg/m³(s,d)	100	92
Particles *	mg/m³(ref)	69	64
Condensable in rinse and condensate	mg/m³(s,d)	73	97
Condensable in rinse and condensate	mg/m³(ref)	50	68

(s,d) indicates dry gas at standard conditions (0°C, 101,3 kPa)
(ref) indicates dry gas at standard conditions (0°C, 101,3 kPa) at 10 % O2
* means "not included in accreditation no. 51"

Den samlede målerapporten ses i bilag 1

4 Videre forløb

4.1 Forberedelser til eksport af teknologien

Dall Energy´s målsætning er at eksportere Dall Energy teknologierne, ved licensaftaler som også inkluderer leverancer af (nøgle) komponenter.

Forberedelserne til eksport sker ved danske referencer (som har været støttet af EUDP) og ved at forberede og etablere referencer i udlandet.

Foreløbigt er den grundlæggende forbrændings-teknologien blevet eftervist. I kommende anlæg skal det samlede Dall Energy system demonstreres.

4.2 Kommende danske demonstrations anlæg

Bogense projektet har (som beskrevet i kapitel 3) været en kombination af et Dall Energy anlæg (ovn) og et Weiss anlæg (skrubber og kondensat behandling). Denne kombination har på flere punkter ikke været hensigtsmæssig, idet de forskellige løsninger i det samlede anlæg bør hænge bedre sammen.

Dall Energy forbereder nu to projekter med Dall Energy system-løsninger:

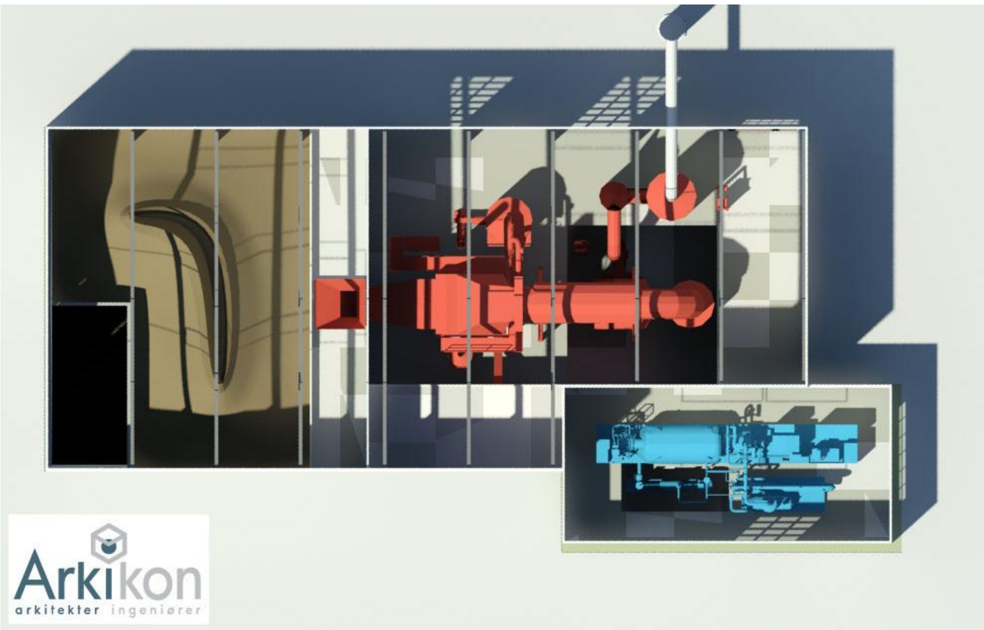
1. Heat only anlæg på industri anlæg (Danish Malting Group)

2. Kraftvarme anlæg på varmeværk (SEAS-NVE)

Ovnene til SEAS-NVE og Danish Malting Group vil bygge videre på de erfaringer der er opnået med ovnen i Bogense. Designet af disse ovne er ved at være afsluttet.

Dall Energy har udviklet et forbedret luftdoseringssystem og et forbedret askeudmadersystem, således at udfordringer der har været i Bogense med utætheder i luft-systemet og ujævn aske udmadninger er løst.

CFD beregninger bekræfter at de nye ovne også vil have lave emissioner. Det er ambitionen med det nye design at NOx bliver væsentligt lavere, mens øvrige egenskaber (brændselsflexibilitet, lav CO, lav O2, lav uforbrændt i aske) bibeholdes.



Figur 4.1 Layout af Dall Energy kraftvarmeanlægget i Sorø Kraftvarme-projektet støttes af EUDP.

4.3 Licensaftaler i udlandet

Dall Energy har fået de første erfaringer med licensaftaler i udlandet.

4.3.1 Warwick Mills, USA

Den amerikanske virksomhed Warwick Mills http://www.warwickmills.com/ har indgået en licensaftale med Dall Energy om at få opført et 2MW anlæg.

Anledningen til at Warwick Mills henvendte sig til Dall Energy var, at de amerikanske ovne ikke kunne overholde de skærpede amerikanske emissions krav.

Warwick Mills har nu fået alle tilladelser til anlægget og det forventes at anlægget kan indkøres i vinteren 2012/13.

4.3.2 Biomasse Innovation, Australien

Australien har indført en ny lovgivning der giver incitament til produktion af strøm fra biomasse.

Biomasse Innovation er et nyt Australsk firma der har til formål at blive førende leverandør af biomasse anlæg til det Australske marked, og Biomasse Innovation har indgået licensaftale med Dall Energy for det Australske marked.

5 Formidling og priser

5.1 Formidling

EUDP projektet er blevet formidlet ved flere lejligheder herunder:

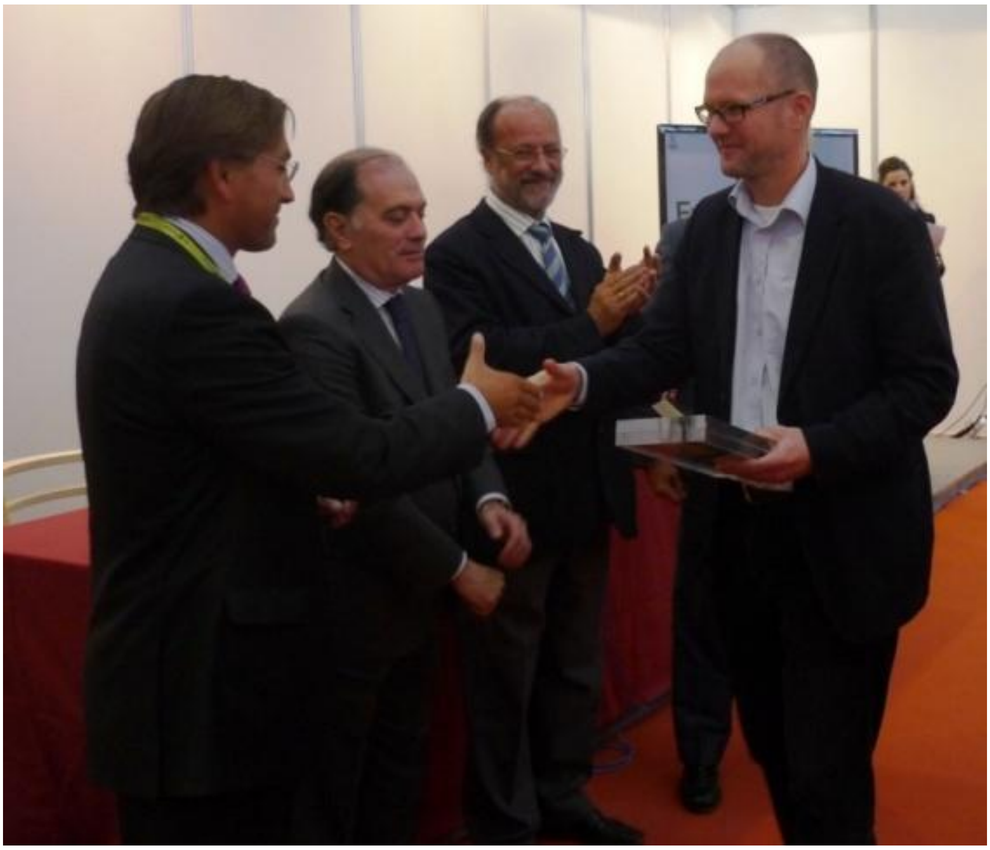
Formidlingsaktivitet	*Link*
2010	
17. September. Holzenergie-Symposium i Zurick	http://www.holzenergie-symposium.ch/programm10.html
6. Oktober. ”Mere viden skal i arbejde”. GTS seminar i IDA	
26. Oktober. Artikel i ”Fjernvarmen” med Bogense projektet.	http://www.fjernvarmen.dk/Fanebla de/FJERNVARMEN.aspx
27-29. Oktober. Biomasse konference i Valadolid (del af Dansk Stand stand)	http://www.energysuply.dk/article/v iew.html?id=55715
28-29 Oktober. Fjernvarmens årsmøde i Århus.	
24. November. Artikel i GTS avis.	http://www.teknologisk.dk/5374,4
23. November. Artikel i Ingeniøren	http://ing.dk/artikel/114170-ny-ovn-forgasser-biomassen-inden-den-braendes-af
30. November. Artikel i Børsen	
2011	
Januar: DBDH årsrapport (artikel side 19)	http://www.e-pages.dk/dbdh/18/
Januar: Biomassekonference i Graz, Østrig	
Marts. Energistyrelsens nyhedsbrev	http://www.ens.dk/da-dk/info/nyheder/nyhedsarkiv/2011/sider/20110318opfinderafbiomasseovnnomineret.aspx
April: Artikel i Biopress	http://www.biopress.dk/PDF/FiB%20nr.%2035-2010_10%20%20DK.pdf

Maj: Artikel i Politikken	
Maj: Artikel i Berlinske Tidende	
Maj: Artikel i Financial Times	
Maj: Artikel i Erhversbladet	
Maj: Artikel i Rudersdal avis	
Juni. Artikel i Hot-cool	http://www.e-pages.dk/dbdh/21/6

5.2 Priser

Dall Energy ovnen har opnået såvel national som international anerkendelse ved flere lejligheder:

5.2.1 Innovationspris 2010



Figur 5.1 Dall Energy modtager innovationspris på biomasse conference I Spanien (Valadolid), Oktober 2010.

5.2.2 Europæisk patent pris 2011

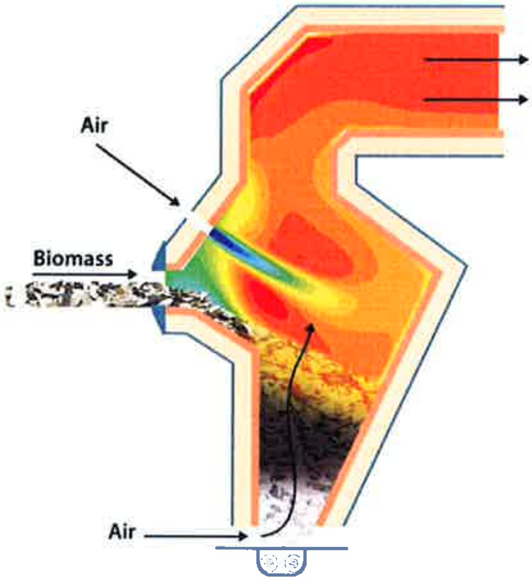
Figur 5.2 Jens Dall Bentzen modtager det Europæiske Pantentkontors opfinderpris i Budapest, maj 2011.
Patentmyndighedens film om ovnen i Bogense kan ses her:
http://www.youtube.com/watch?feature=player_embedded&v=LjKjM5FOXB8

5.2.3 Miljøestyrelsens Clean Tech pris 2012

Figur 5.3 Dall Energy modtager miljøstyrelsens Clean Tech pris I Herning, oktober 2011.

Bilag: FORCE målerappport

Dall Energy ApS
8 MW Dall Energy Biomass Furnace at Bogense Fjernvarme
Emission of particles, CO and NO_X



Accredited report no.: 5052-01
Project nr.: 111-32505
Measurement date: 20-21 March 2012

Contact
Project Manager: Ole Schleicher
Phone: +45 43 26 75 40
Cell phone: +45 22 69 75 40
E-mail: osc@force.dk
Web: www.force.dk
Park Allé 345, 2605 Brøndby

Main results

The main results from measurement in the outlet from the furnace as average of three one hour samples are shown i the table below.

Measurements in flue gas outlet from furnace

Parameter	Unit	Average	Average
Load	%	100	20
Date	dd-mm-yy	20-03-2012	20-03-2012
Measuring period	hh:mm	11:12 - 14:22	16:44 - 20:00
Temperature	°C	958	845
O_2	Vol % (dry)	4.88	5.25
H_2O	Vol %	38.0	32.4
CO	mg/m³(ref)	< 2	< 2
NO_x	mg/m³(s,d)	300	200
NO_x	mg/m³(ref)	200	140
Particles *	mg/m³(s,d)	100	92
Particles *	mg/m³(ref)	69	64
Condensable in rinse and condensate	mg/m³(s,d)	73	97
Condensable in rinse and condensate	mg/m³(ref)	50	68

(s,d) indicates dry gas at standard conditions (0°C, 101,3 kPa)
(ref) indicates dry gas at standard conditions (0°C, 101,3 kPa) at 10 % O2
* means "not included in accreditation no. 51"

Average concentrations of CO and NO_x in the different operation modes

Load	Time		CO emission	NO_x emission
%	From	To	mg/m³(ref)	mg/m³(ref)
100	8:30 AM	15:00 PM	< 2	200
100 → 20	15:00 PM	16:30 PM	3.4	160
20	16:30 PM	20:15 PM	< 2	135
20 → 60	20:15 PM	21:10 PM	2.3	200
60	21:10 PM	7:00 AM	< 2	200
60 → 100	7:00 AM	7:45 AM	< 2	230
100	7:45 AM	10:00 AM	< 2	240

Analysis of a wood chips samples showed a content of water of 34 % and content of ash and nitrogen of 1.5 % and 0.33 % on dry sample respectively.
The residual heat value in the ash sample was 0.27 MJ/kg, which calculated in relation to the heat value of dry wood, and the ash content in the wood chips equals app. 0.015 % of the input heat value.

FORCE Technology
23 May 2012

Steen Meldorf
Signatory

Ole Schleicher
Project Manager

Content

1 Summary

FORCE Technology has measured the concentration of particles, CO and NOx in the flue gas at the outlet from the furnace, to verify the claimed low concentrations and stable operation at low and high load as well as during load changes. Additionally a sample of wood chips was analysed for water, ash and N content, and an ash sample was analysed for water content and residual heat value.

The measurement was performed on the 20 and 21 of March 2012 at the newly constructed 8 MW Dall Energy Furnace at:

Andelsselskabet Bogense Fjernvarme
Fynsvej 5
5400 Bogense
Denmark

The measurement was ordered by:

Dall Energy
Venlighedsvej 2
2970 Hørsholm
Denmark
Phone: +45 29 87 22 22
Contact: Jens Dall Bentzen
E-mail: info@dallenergy.com

Measurement team was Steen Meldorf and Ole Schleicher, and author of the report is Ole Schleicher.

Sampling and analysis are performed according to FORCE Technology's accreditation No. 51 and accreditation No. 65 from The Danish Accreditation and Metrology Fund (DANAK).

Some parameters and information are not included in the accreditation:

- Description of the plant, operational conditions, wood fuel type and consumption
- Data from the plant SRO system
- Comments and evaluations of the measurement results

Results of the testing are valid only for the particular plant, and plant operation during the testing period.

2 Plant and test program

The Dall Energy furnace is a newly invented combustion design, which in one special designed unit combines the well known updraft gasification technology with a gas combustion section above the gasification.

The technology can only work as an integrated part of a biomass combustion plant, consisting of a fuel feeding system, a system to utilize heat and a chimney. To achieve the highest energy efficiency the heat utilizing system includes a wet condensation system. Several other units, e.g. blowers, instrumentation and a process control system are necessary to operate the plant. All these surrounding equipment can be selected among different technologies and suppliers.

The Dall Energy biomass furnace was tested for its ability to keep the emission of particles, CO and NO_x low during stable operation at both high and low load, as well as during load changes.

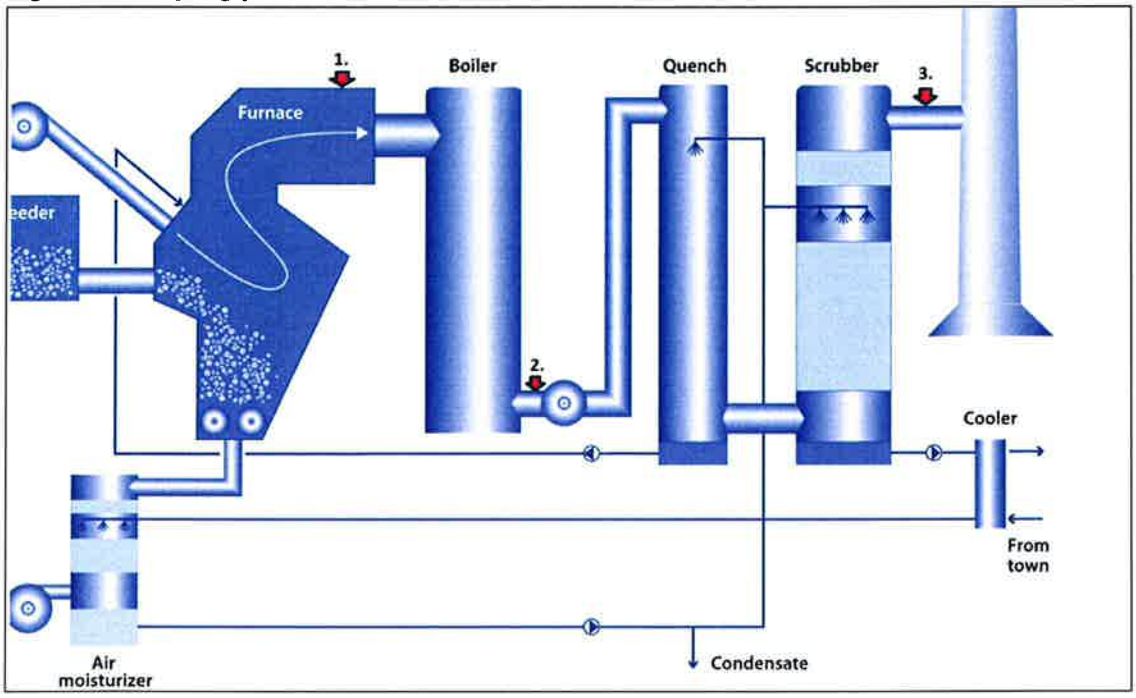
The main test parameters were the concentrations of particles, CO and NO_X but also the concentration of O_2, CO_2 and water and the flue gas temperature and flow was measured, to normalize the measured value to the reference conditions, and to verify the operational conditions during the test. Additionally a sample of wood chips was analysed for water, ash and N content, and an ash sample was analysed for water content and residual heat value.

2.1 Sampling sites

The accessible sampling points in the plant are showed in Figure 1. The sampling points are:

1. Outlet furnace
2. After the boiler
3. Stack

Figure 1. Sampling points marked with red arrow



The flue gas temperature at the outlet from the furnace, sampling point 1, is between 800 °C and 950 °C, and the concentration of particles at such high temperature, is not the same as if measured after the boiler, where the temperature is between 120 °C and 150 °C. This difference in particle concentration is due to condensable, which is salts and organic compounds on vapour form at high temperature, which condenses to form particles at lower temperature. To verify the load of particles from the furnace to the heat recovery system, the concentration of condensable is also measured and presented besides the concentration of particles.

2.2 Sampling program

The concentration of particles and condensable was measured manually, by isokinetic sampling of flue gas, and subsequent analysis. Because of the very high flue gas temperature, special sampling equipment med of quarts glass was needed, and also adjustments of the sampling procedure described in Appendix A was necessary, because the method is not intended for high temperature sampling. The sampling was consequently not precisely following the standard, and the reported values are not covered by the accreditation, but all standard procedures for accredited sampling was followed.

Continuous measurement was performed for the parameters O_2, CO, NO_X and flue gas temperature in sample point 2 after the boiler where the flue gas temperature is more suitable for the measurement.

During the test several operating parameters was measured and logged by the test team, and some additional parameters was delivered from the plant instrumentation and monitoring system in a data file covering the whole test period. Several of the plant data are used in this report, especially data for the thermal load, produced energy and furnace temperature.

2.3 Sampling methods and uncertainty

A list of sampling methods and the associated uncertainties are attached in Appendix A.

The testing consists of two types of measurements: Continuous and manual measurements.

See appendix 3 for a short description of the applied accredited measurement methods, limits of detection, references and uncertainty. The design of the sampling site has an influence on the measurement uncertainty.

The sampling point at the outlet from the boiler, are not within the normal demands for suitable sampling points, regarding especially the length of straight duct before and after the sampling point. Together with the very high temperature, the measurement uncertainty is increased, without knowing the magnitude.

2.4 Operation conditions

The test was carried out during two days, with different loads and during load changes, according to this program:

1. Stable operation at 100 % load.
2. Changing load from 100 % to 20 % load.
3. Stable operation 20 % load.
4. Changing load from 20 % to 60 %
5. Changing load from 60 % to 100 %
6. Stable operation at 100 % load

The continuously measurement of O_2, CO, NO_X and flue gas temperature was running during the whole test period, while sampling of particle was performed by three one-hour samples for each of the two first periods with stable load (point 1 and 3).

3 Test results

The measured concentrations as hourly averages for particles, CO and NO_X from the three sampling hours at high and low load are presented in Table 1 and Table 2.

Table 1. Measurements in flue gas outlet from furnace at 100 % load.

Parameter	Unit	Sample 1	Sample 2	Sample 3	Average	ELVs *
Date	dd-mm-yy	20-03-2012	20-03-2012	20-03-2012	20-03-2012	-
Measuring period	hh:mm	11:12 - 12:12	12:15 - 13:15	13:22 - 14:22	11:12 - 14:22	-
Operating parameters						
Temperature	°C	957	960	957	958	-
O_2	Vol % (dry)	4.95	4.75	4.93	4.88	-
CO_2	Vol % (dry)	15.4	15.6	15.4	15.5	-
H_2O	Vol %	38.0	38.2	37.7	38.0	-
Concentrations						
CO	mg/m³(s,d)	< 2	< 2	< 2	< 2	-
CO	mg/m³(ref)	< 2	< 2	< 2	< 2	625
NO_X	mg/m³(s,d)	300	290	300	300	-
NO_X	mg/m³(ref)	210	200	210	200	300
Particles *	mg/m³(s,d)	100	100	97	100	-
Particles *	mg/m³(ref)	70	69	66	69	100
Condensable in rinse and condensate	mg/m³(s,d)	73	73	73	73	
Condensable in rinse and condensate	mg/m³(ref)	50	49	50	50	

(s,d) indicates dry gas at standard conditions (0°C, 101,3 kPa)
(ref) indicates dry gas at standard conditions (0°C, 101,3 kPa) at 10 % O2
* means "not included in accreditation no. 51"
ELVs are the Danish Guideline values for wood fired boilers from 5 to 50 MW

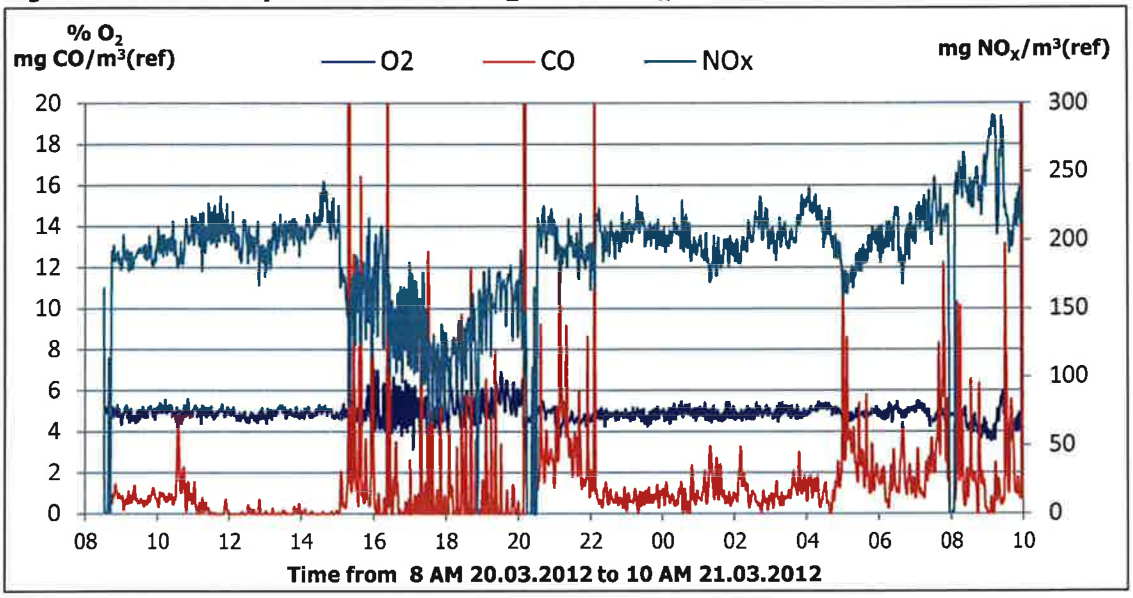
Table 2. Measurements in flue gas outlet from furnace at 20 % load.

Parameter	Unit	Sample 1	Sample 2	Sample 3	Average	ELVs *
Date	dd-mm-yy	20-03-2012	20-03-2012	20-03-2012	20-03-2012	-
Measuring period	hh:mm	16:44 - 17:44	17:50 - 18:55	19:00 - 20:00	16:44 - 20:00	-
Operating parameters						
Temperature	°C	858	841	836	845	-
O_2	Vol % (dry)	4.97	5.19	5.58	5.25	-
CO_2	Vol % (dry)	15.4	15.2	14.8	15.1	-
H_2O	Vol %	32.1	32.4	32.7	32.4	-
Concentrations						
CO	mg/m³(s,d)	< 2	< 2	< 2	< 2	-
CO	mg/m³(ref)	< 2	< 2	< 2	< 2	625
NO_X	mg/m³(s,d)	190	170	220	200	-
NO_X	mg/m³(ref)	130	120	160	140	300
Particles *	mg/m³(s,d)	100	90	87	92	-
Particles *	mg/m³(ref)	69	63	62	64	100
Condensable in rinse and condensate	mg/m³(s,d)	97	97	97	97	-
Condensable rinse and condensate	mg/m³(ref)	67	68	69	68	-

(s,d) indicates dry gas at standard conditions (0°C, 101,3 kPa)
(ref) indicates dry gas at standard conditions (0°C, 101,3 kPa) at 10 % O2
* means "not included in accreditation no. 51"
ELVs are the Danish Guideline values for wood fired boilers from 5 to 50 MW

A diagram with the measured concentrations of O_2, CO and NO_X for the whole measuring period are showed in Figure 2.

Figure 2. Continuously measurement of O_2, CO and NO_X



The measured concentrations of CO and NO_X for all the different load periods are showed in Table 3.

Table 3. Emission of CO and NO_X in the different load periods

Load	Time		CO emission [mg/m³(ref)]			NO_X emission [mg/m³(ref)]		
%	From	To	Average	Max.	Min.	Average	Max.	Min.
100	8:30 AM	15:00 PM	< 2	3	< 2	200	243	167
100 → 20	15:00 PM	16:30 PM	3.4	98	< 2	160	223	80
20	16:30 PM	20:15 PM	< 2	118	< 2	135	192	65
20 → 60	20:15 PM	21:10 PM	2.3	8	< 2	200	225	165
60	21:10 PM	7:00 AM	< 2	14	< 2	200	238	159
60 → 100	7:00 AM	7:45 AM	< 2	9	< 2	230	290	190
100	7:45 AM	10:00 AM	< 2	9	< 2	240	291	190

3.1 Wood chips and ash samples

A combined sample of the wood chips was analysed, and the results are showed in the table below.

Table 4. Wood chips analysis

Parameter	Unit	Dry sample	Wet sample
Water	%	-	34.0
Ash	%	1.5	1,0
Nitrogen, N	%	0.33	0.22

An ash sample, collected as described in section 3.4 was analysed for the parameters in the next table.

Table 5. Ash sample analysis

Parameter	Unit	Dry sample	Wet sample
Water	%	-	24.9
Residual heat value	MJ/kg	0.27	0.20

3.2 Comments to the results

The overall impression of the furnace is a stable operations and efficient combustion with hardly any CO emission, even during load changes and at such low load as 20 %.

The NO_X emission seems also relatively low for at boiler burning fresh chopped forest wood, but it is not as evidently low, as seen for the CO emission.

Normally condensate from wood combustion has a characteristic bad smell from different combustion by products, but here the condensate from any of the sampling has no detectable smell, indicating a very efficient combustion.

The test was started Tuesday the 20th of March, but measurement equipment was installed on Monday the 19th. The continuously operated emission measurement was running from Tuesday 8:30 until Wednesday at 10 AM.

The furnace and also the whole plant were operated without any problems during the whole test period. Time and periods for the thermal loads and changes of the load is listed in Table 6.

Table 6. Time and periods for the target and the actual thermal loads for the test period.

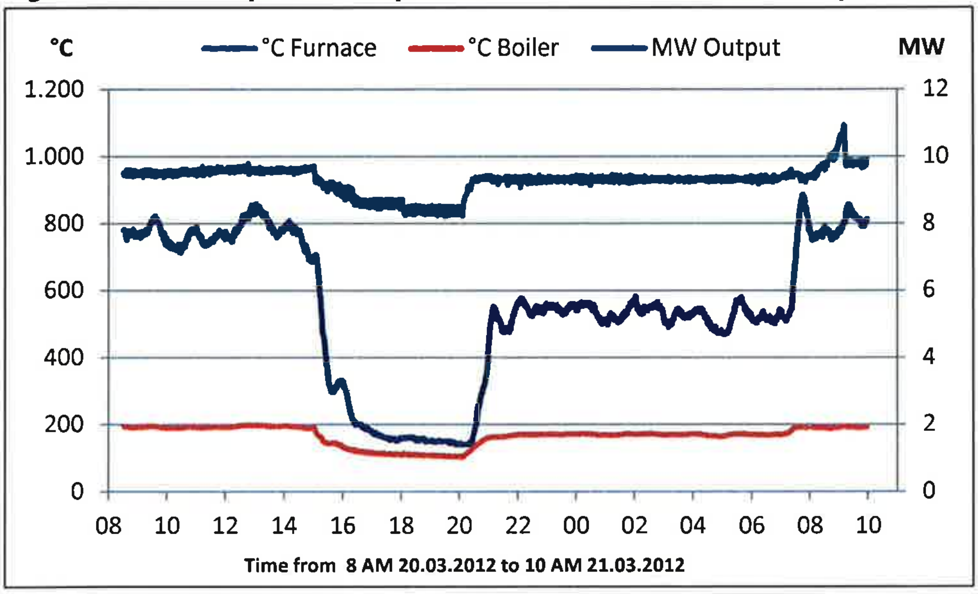
Period		Load			Comments
From	To	Target %	Actual average MW	Actual %	
8:30 AM	15:00 PM	100	7,7	96	Sampling period
15:00 PM	16:30 PM	100 → 20	3,7	-	Load change
16:30 PM	20:15 PM	20	1,6	20	Sampling period
20:15 PM	21:10 PM	20 → 60	2,9	-	Load change
21:10 PM	7:00 AM	App. 60	5,3	66	Night operation
7:00 AM	7:45 AM	60 → 100	6,3	-	Load change
7:45 AM	10:00 AM	100	8	100	

The load changed by changing fuel feed rate and the amount of primary air. When the fuel feed rate is changed the production rate of pyrolysis gases changes, and when the amount of primary air is changed the amount of gasification gas is changed. The SRO system will automatically adjust the set points for the regulation of some other parameters, e.g. the concentration of O_2, which is maintained by the feed of secondary air. The bed height of the fuel is maintained by regulating the fuel feed and the temperature in the combustion zone is maintained by the injection of water.

The flue gas temperature in the furnace and in the boiler is shown together with the thermal load in Figure 3.

The blue line in the figure is the thermal output from the furnace, which is calculated from the heat recovered in the boiler part and in the scrubber/condenser.

Figure 3. Thermal input and temperatures in furnace and boiler from plant instruments



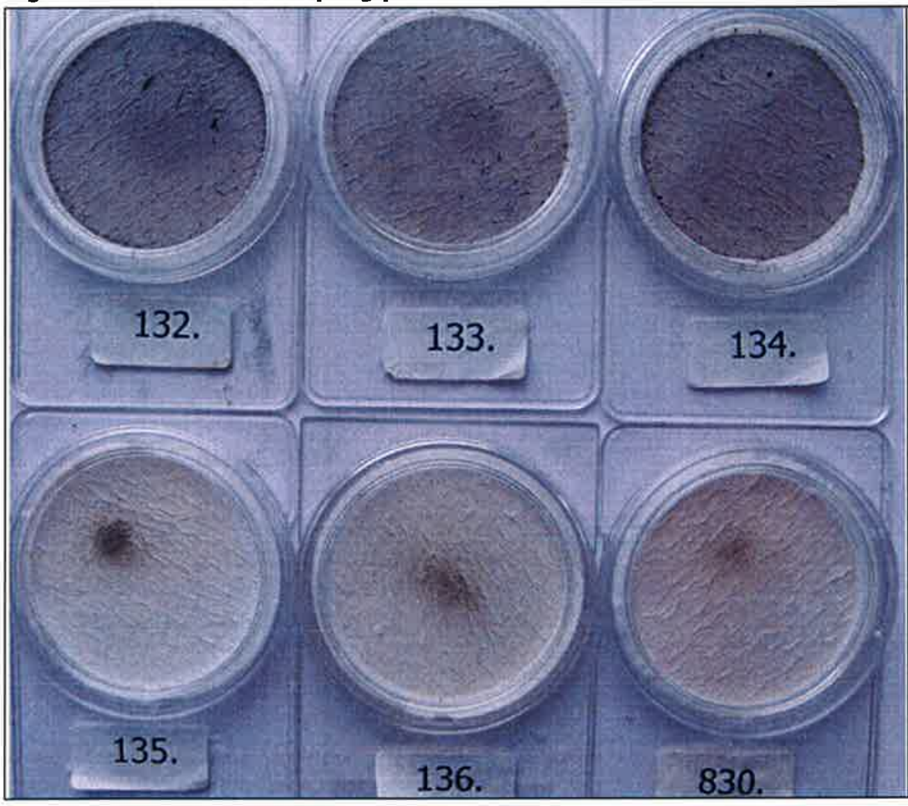
The furnace temperature is regulated by the injection of water into the combustion zone. The operator select a set point for the temperature and the water sprinkler system adjust the temperature automatically. At 100% load and at 60% load the set point is higher than at 20 % load. At 100 % load the average furnace temperature was just around 960 °C, but at 20% load the temperature drops to between 860 and 835 °C, because of the change of set point.

The emission of CO was on average below the detection limit of 2 mg/m^3(ref). In short periods the concentration was above the detection limit, especially when the load was changed, but apparently also once in a while when operation at low load. See the plot in Figure 2. The two peaks above the scale at the beginning and end of the 20 % load period is one-minute average peaks reaching app. 140 mg/m^3(ref).

The NO_X emission depends not only on the furnace conditions, but also on the nitrogen content in the fuel. The NO_X emission is clearly somewhat lower in the 20 % load period, which is related to the furnace conditions, e.g. retention time, as the nitrogen content in the fuel is anticipated to be constant. The NO_X concentration fluctuates, but it seems to be among pretty constant values, depending on the actual load.

Figure 4 and Figure 5 is photos of the filters from sampling particles.

Figure 4. Filters from sampling particles at the furnace outlet.



Filters 132–134	100 % load Sampling volume around 205 l
Filters 135, 136, 830	20 % load Sampling volume around 140 l

There is a significant visual difference in particle appearance comparing the filters: At 100 % load black particles are appearing and at the 20 % load there is no particles. As the black particles are unburned carbon, it is assumed that the difference derives from the flue gas velocity. With a reduced velocity (at 20 % load) and turbulence in the flue gas stream less particles (from the wood and ash filled gasification part in the bottom of the furnace) are carried with the flue gas.

The unburned particles can be seen more clearly in figure 5. The particles from 100 % load seem to be very different from the particles at 20 % load. The colour is darker, and there seems to be some lighter particles at the edge of the filter, where the particles at 20 % load are brownish, and they are mainly collected in a small area around the middle of the filter.

Figure 5. Close up pictures of filters with particles from furnace outlet

100 % load	20 % load

Unburned carbon has a low density, and despite the colorization of the filter, the weight share of these unburned particles is probably very low. It is assumed, that the main part of the particles are condensed salts from the combustion, and that the emissions are fairly the same at both 100 % and 20 % load.

The particles on the filters indicate a considerable difference in the combustion conditions and behaviour, since the particle size, colour and distribution on the filters are very different. Some differences could also be caused by differences in the sampling conditions, where the lower temperature in the furnace, and the reduced sampling flow at the 20 % furnace load, means that the sampled flue gas will cool down faster, but there is no knowledge or evidence for such effects. However, the considerable lower temperature in the furnace at 20 % load (100 to 125 °C lower) could mean different combustion properties and consequently the light brownish colour could be some residual combustion by products. Despite the differences in particle appearances and colour, the emissions are the same within the uncertainty of the measurement.

3.3 Wood chips

The wood chips burned in the furnace during the measurement campaign were wood chips from freshly felled and chopped wood. The wood chips are delivered by:

Skovdyrkerforeningen Fyn
Lombjergevej 1, 5750 Ringe
Phone: +45 6262 4747

The origin of the wood is not known by the plant. They have an agreement with the company to deliver the wood, and it is not important for them to know anything about the origin of the wood, which wood sort it is, or the content of leaves, needles and fines, as long as the furnace can burn it without problems. As mentioned earlier, the water content is also not important, because more water will automatically be added in the furnace if the wood contains less water. The wood chips used are freshly felled and chopped wood, from forest areas on Fyn, probably in the vicinity of Bogense to minimize transportation.

The next two figures are pictures of the actual wood fuel delivered in the test period. It seems to be a mixture of different size of branches and sort of wood, but the content of needles indicates a high proportion of spruce. The content of fines seems to be low.

Figure 6. Pictures showing the fresh wood chips burned in the furnace

3.4 Wood chips and ash samples

A combined sample of the ash, from the ash screw conveyers was taken when the last sampling at 20 % load was running. From the screw conveyers the ash is humidified, by transporting it to an ash container through water filled conveyer. To avoid loss of water soluble components to the water, the samples were taken between the screw conveyers with a steel pipe through 2" pipes installed at the end of each screw conveyer.

The ash sampling point is not very suitable for representative sampling, but there were no better sampling points available. Because of the sampling point, the ash samples may be different from the ash transported in the screw conveyers.

Figure 7. Sampling ash

The ash samples were pretty moist, which is caused by the water saturated primary air added to the bottom of the gasification part of the furnace.

The ash has a grey/brownish colour, with visible unburned particles

Figure 8. Ash sample

The measured heat value is just above the analytical detection limit of 0.2 MJ/kg for dry sample. The heat value of dry wood is app. 20 MJ/kg, and assuming that the wood used consist of 1.5 % ash as measured, the residual heat value in the ash is 0.2*100/20*1.5/100=0.015 % of the heat value of the wood.

Appendix A. Measuring methods and uncertainties

In the following a short description of the applied measurement methods, limits of detection, references and uncertainty are given. The design of the sampling site has an influence on the measurement uncertainty.

The testing consists of two types of measurements: Continuous and manual measurements.

Continuous emission monitoring (monitors, thermo couples etc.):

The limit of detection is given as the normal achievable at emission measurements. For monitors it is three times the average of monitor drift in the span point at repeated field measurements. Lower limits of detection can be achieved by optimized choice of calibration gas and higher frequency in the calibrations.

The uncertainty is based on measurements performed in a homogeneous gas stream as described in EN 15259. The uncertainty is given in % of the measured value (95 % confidence level). At low concentrations between 5 and 1 time the limit of detection, the uncertainty will increase from the stated %-value (at 5 times the limit of detection) up to 100 % of the measured value at the limit of detection.

Gas temperature:

The gas temperature is measured with a NiCr/NiAl-thermocouple connected to a data logger.

Range: -40 - 600 °C
Uncertainty: 4 °C (absolute)
FORCE Technology method: EM-03-01
Reference/standard: VDI 3511 bl. 1-5, IEC 584-2, IEC 584-2 amd. 1

CO_2-concentration: In a dry partial flow of flue gas free of particles the CO_2-concentration is determined by a nondispersive infrared (NDIR) monitor.
Range: 0 - 20 Vol. %
Limit of detection: 0.5 Vol. %
Uncertainty: 5 % of measured value (95% confidence interval).
FORCE Technology method: EM-05-01
Reference/standard: USEPA M.3A, ISO 12039

O_2-concentration: In a dry partial flow of the flue gas free of particles the O2-concentration is determined by means of a paramagnetic pilot cell.
Range: 0 - 25 Vol %
Limit of detection: 1 Vol %
Uncertainty: 5 % of measured value (95% confidence interval).
FORCE Technology method: EM-06-03
Reference/standard: EN 14789

CO-concentration: In a dry partial flow of flue gas free of particles the CO-concentration is determined by a non-dispersive infra red (NDIR) monitor.
Range: 0 - 1000 ppm
Limit of detection: 1 ppm
Uncertainty: 5 % of measured value (95% confidence interval).
FORCE Technology method: EM-07-01
Reference/standard: EN 15058

NO_X-concentration: In a dry partial flow of flue gas free of particles the NO_X-concentration is determined by a chemiluminescence monitor.
Ranges: 0 - 100, 0 - 1000, 0 - 10000, 0 - 100000 ppm
Limit of detection: 1 ppm
Uncertainty: 5 % of measured value (95% confidence interval).
FORCE Technology method: EM-10-01
Reference/standard: EN 14792

Manual methods

The limit of detection is stated as the normal achievable at 60 minutes sampling time, normal suction level and accredited analysis. In some cases the limit of detection can be either lower or higher than the stated value. The limit of detection can be improved by higher suction flow and longer sampling time. The limit of detection is defined as the average of repeated blank values plus three times the standard deviation of the same blank values.

The uncertainty is based on measurements performed in a sampling site that meets the requirements in EN 15259 for grid measurements. When the demands in EN 15259 are not fulfilled, the uncertainty rises to an unknown level. The uncertainty is given in % of the measured value (95 % confidence level). At low concentrations between 5 and 1 time the limit of detection, the uncertainty will increase from the stated %-value (at 5 times the limit of detection) up to 50-100 % of the measured value at the limit of detection.

Flow:

The gas velocity is measured by means of a pitot tube connected to an inclined tube manometer or a micro manometer, reading the dynamic pressure. The velocity is measured in a number of points in the cross section of the duct. From the velocity and the cross section area, the flow is calculated.

Range: 0 - 40 m/s
Limit of detection: 2.3 m/s
Uncertainty: 10 % of measured value (95% confidence interval).
FORCE Technology method: EM-02-01
Reference/standard: ISO 10780

Particles:

A partial gas stream is aspirated isokinetic through a planar filter and a drying column. The gas flow is aspirated by means of a pump unit consisting of a gas tight pump, a calibrated gas meter and a flow meter. Sampling can be either in-stack or out-stack (the filter in the stack at stack temperature or the filter outside the stack in an oven).

Range: 0 - 50 mg/m^3(n,t)
Limit of detection: 0,05 mg/m^3(n,t)
Uncertainty: 10 % of measured value (95% confidence interval).
FORCE Technology method: EM-01-05
Reference/standard: EN 13284-1

The method for sampling particle is modified to make the sampling in a 1000°C hot flue gas, and to include sampling of condensable, according to the US EPA Method 202[1] by means of:

1. The nozzle and probe will be made of quarts glass, which can tolerate the high temperature.
2. A cooling system with air will be adapted to the probe, to cool the flue gas down to between 120 and 180 °C where it enters the filter.
3. After the filter a condensation system to collect condensable according to US EPA Method 202 will be applied.

This modified particle and condensable measuring system are combining methods from well known and international accepted standards, which guarantee the applicability and quality. The only parts which are not according to any standard are the system to cool the flue gas, but this part is only critical for the results if particles are deposited in the probe. To include these possible depositions in the measurements, the probe will be washed with ultra pure water after the sampling, and the content of particles and condensable in the wash water will be measured by evaporating the water, and weighing the residue. The weight will be distributed to the samples in proportion to their sampling volume.

At the first interrupted sampling in November 2011 four samples was collected with final condensation in impinger bottles in an ice bath but only a very small volume of condensate was collected, and the content of condensable was below the limit of detection of 2 mg/sample for each sample. After sampling the glass equipment being in contact with the flue gas, was washed with ultra pure water, and the content of particles and

[1] US EPA Method 202. Dry impinger method for determining condensable particulate emissions from stationary sources.

condensable was measured by weighing the residual after evaporation of the water. A considerable amount of condensable was found her.

Based on these facts, and the risk with handling the heavy glass equipment, it was decided to skip the impinger bottles and the ice bath at the next samplings, because the water cooling appears to be efficient enough to condense all condensable.

Furthermore it was decided to measure the condensable in the condensate in combined sample for each of the two loads (100 % and 20 %), to increase the possibilities to measure something above the limit of detection. The results was measurable, where analysing each sample would on average give the result below the detection limit of 2 mg/sample for the 20 % load samples, and just above the 2 mg/sample for the three 100 % load samples (7.6 mg in combined sample = 2.5 mg/sample).

The used sampling equipment without impinger bottles are showed in Figure 9

Figure 9. Equipment used for sampling particles and condensable in the flue gas outlet from furnace.